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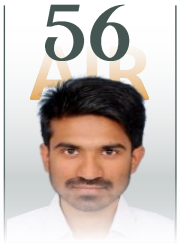
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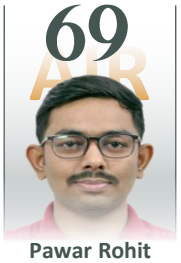
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Reference resources



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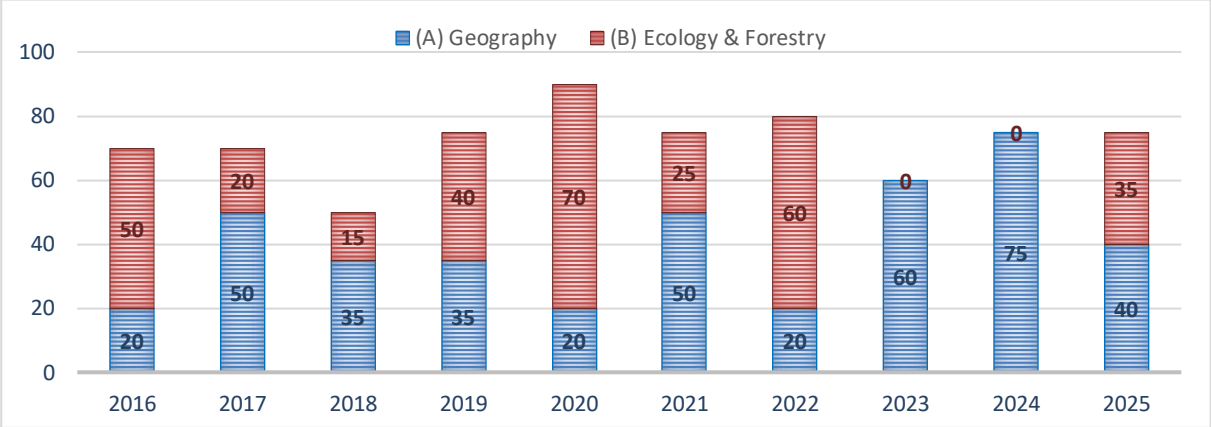
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Marks distribution

Year	2016	2017	2018	2019	2020	2021	2022	2023	2024	2025	Total
No. of Qs	6	6	4	6	7	6	6	5	6	6	
Marks	70	70	50	75	90	75	80	60	75	75	
(A) Geography	20	50	35	35	20	50	20	60	75	40	**56%**
(B) Ecology & Forestry	50	20	15	40	70	25	60	–	–	35	**44%**

Counted by content, from all question slots: Geography (A) mostly from Q4; Ecology–Forestry (B) from Q2, Q4 and Q5. Biogas (2024 Q5a) is counted here; it is cross-referenced in Science & Technology.



Chapter-wise distribution

#	Chapter / Theme	Qs	Marks	Years asked
URBANISATION, POPULATION & HUMAN GEOGRAPHY · 13 Qs · 155 marks				
1	**Urbanisation & Urban Environment (UHI, corridors)**	**3**	45	2023, 2024, 2025
2	**Population, Settlement & Human Geography**	**5**	55	2016, 2019, 2020 (×2), 2021
3	**Tourism & Carrying Capacity**	**3**	30	2016, 2023, 2024
4	Industry & Strategic Regions	2	25	2018, 2019
RESOURCES — ENERGY, MINERALS, WATER & SOIL · 11 Qs · 135 marks				
5	**Energy Resources — Renewable & Non-renewable**	**4**	50	2018, 2021, 2023, 2024
6	Mineral Resources	2	20	2023, 2024
7	Water Resources — Rivers & Groundwater	2	25	2022, 2025
8	**Soil Erosion, Land Degradation & Problem Soils**	**3**	40	2017, 2018, 2021
CLIMATOLOGY, DISASTERS & PHYSICAL GEOGRAPHY · 10 Qs · 115 marks				
9	**Monsoon, Cyclones & Extreme Weather**	**5**	60	2021, 2022, 2023, 2024 (×2)
10	**Geo-hazards — Flash Floods & Landslides**	**3**	35	2017 (×2), 2025
11	Physiography & Landforms	2	20	2017, 2019
	TOTAL	**34**	**405**	**2016–2025**

आवश्यक सूचना

This study material has been prepared with the assistance of Artificial Intelligence (AI), drawing upon 20+ reference books, online resources, and previous-year questions (PYQs) from UPSC and various State PSC examinations.

This is the **first edition**, which has **undergone only basic proofreading**. **Six additional stages of proofreading, detailed fact-checking, and content rewriting are still pending**. Therefore, factual, conceptual, technical, and typographical errors may remain. A fully revised and updated edition is currently under preparation.

Students are advised to use this material strictly as a supplementary reference and verify important information from standard textbooks and official sources.

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CHAPTER 1

INDIA — LOCATION, EXTENT & PHYSIOGRAPHIC OVERVIEW

CHAPTER AT A GLANCE

- India lies between 8°4′N–37°6′N latitude and 68°7′E–97°25′E longitude; 7th-largest country (3.28 million sq km).
- The Tropic of Cancer (23°30′N) bisects India through 8 states; Standard Meridian at 82°30′E gives IST = GMT + 5:30.
- India qualifies as a subcontinent due to tectonic isolation, a distinct monsoonal climate regime, physiographic uniqueness and a vast cultural mosaic.
- Six physiographic divisions — Himalayas, Northern Plains, Peninsular Plateau, Thar Desert, Coastal Plains, Islands — are products of one India–Eurasia plate collision.
- The Peninsular Plateau is an Archaean remnant of Gondwanaland; its Gondwana sedimentary rocks host ~98% of India's coal.
- Geomorphological resources (minerals, fertile plains, harbours, groundwater) and hazards (landslides, earthquakes, floods) are two sides of the same earth-surface process.
- Key current-affairs links: National Geospatial Policy 2022, SVAMITVA scheme, PM GatiShakti, revised coastline (11,098.81 km).

1.1 INDIA'S LOCATION & LATITUDINAL EXTENT

India is situated entirely in the **Northern and Eastern Hemispheres**, forming the southern extremity of Asia and jutting into the Indian Ocean. Its **latitudinal span of approximately 30°** — from the tropical south to the near-temperate north — is the primary driver of India's extraordinary climatic diversity. This single geographic fact explains why the country simultaneously hosts **tropical rainforests, hot deserts, alpine tundra and temperate forests** within its borders.

EXTREME POINTS OF INDIA

Direction	Named Point	Location	Coordinates
Northernmost	Indira Col	Ladakh (Siachen area)	~37°6′N
Southernmost — Mainland	Kanniyakumari	Tamil Nadu	~8°4′N
Southernmost — Territory	Indira Point (Pygmalion Point)	Great Nicobar Island	~6°45′N
Easternmost	Kibithu (near Walong)	Arunachal Pradesh	~97°25′E
Westernmost	Guhar Moti	Kutch, Gujarat	~68°7′E

The **north–south extent is approximately 3,214 km** and the **east–west extent approximately 2,933 km**. Despite the near-equal dimensions, the longitudinal range of ~29° creates a **solar time difference of nearly 2 hours** between Arunachal Pradesh and Gujarat — the practical justification for establishing a uniform Standard Meridian.

TROPIC OF CANCER — 8 STATES (WEST TO EAST)

The Tropic of Cancer (23°30′N) traverses India through precisely **eight states** in the following west-to-east order:

- **Gujarat → Rajasthan → Madhya Pradesh → Chhattisgarh → Jharkhand → West Bengal → Tripura → Mizoram**

Mnemonic : **"Guj-Raj-MP-Chhatt-Jhark-WB-Tri-Mizo"**. The Tropic effectively demarcates **tropical India (south)** from **sub-tropical/warm-temperate India (north)**, influencing solar radiation receipt, day-length variation and temperature regimes.

STANDARD MERIDIAN — "82°30'E"

India's Standard Meridian is fixed at **82°30'E**, which passes through **Mirzapur, Uttar Pradesh** and gives **Indian Standard Time (IST) = UTC + 5:30**.

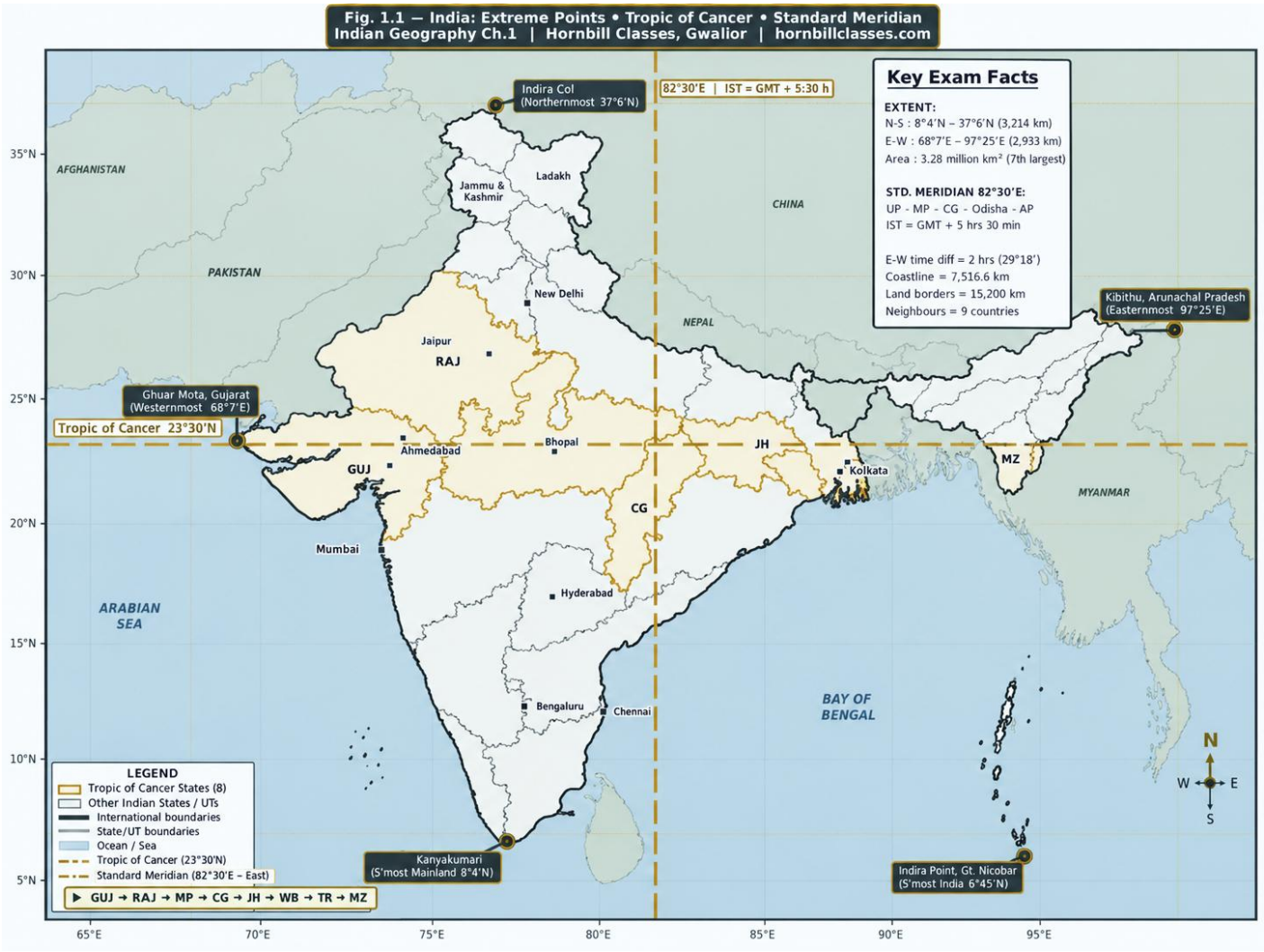
- It passes through five states: **Uttar Pradesh, Madhya Pradesh, Chhattisgarh, Odisha, Andhra Pradesh.**
- Chosen because it lies near the **longitudinal centre** of India and is a convenient **multiple of 7.5°**, yielding a whole/half-hour offset from UTC.
- The ~29° longitudinal spread would otherwise create a ~2-hour sunrise difference between the extreme east and west — managed by a single IST.

KEY FACTS

Debate on a Second Time Zone : Scientists at CSIR-NPL have argued that the Northeast (where sunrise is ~2 hours earlier than in Gujarat) would benefit from a separate time zone (e.g., UTC+6) to reduce wasted daylight, lower energy consumption and improve worker productivity. This remains a recurring prelims and essay topic.

EFFECT OF LATITUDINAL EXTENT ON CLIMATE DIVERSITY

The ~30° latitudinal range produces an unparalleled climatic gradient within a single country. The **far south (Indira Point, ~6°45'N)** experiences near-equatorial conditions — high humidity, low diurnal variation and bimodal rainfall — while the **high Himalaya (37°N+)** records sub-zero temperatures and periglacial processes. When combined with altitudinal zonation, the **rain-shadow effect** of the Western Ghats and Himalayas, and the **monsoonal pressure gradient**, this latitudinal span generates virtually every major Köppen climate type within Indian territory.



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1.2 INDIA AS A SUBCONTINENT — WHY?

The term **'subcontinent'** denotes a **large, physiographically and culturally distinct landmass** that — while geographically part of a continent — is **set apart by prominent natural barriers** and possesses a coherent internal identity. India unambiguously satisfies this definition through four converging arguments.

THE FOUR-PILLAR FRAMEWORK

Pillar I — Tectonic Isolation : India rides a **distinct lithospheric plate — the Indian Plate**. Its northward collision with the Eurasian Plate raised the **Himalayan arc** along with the Hindu Kush, Karakoram and Sulaiman–Kirthar ranges in the northwest, forming a **near-continuous mountain wall** of 2,500+ km. Combined with the **Thar Desert** to the west and the **Indian Ocean, Arabian Sea and Bay of Bengal** on three sides, the subcontinent is enclosed in a formidable physiographic compartment — historically insulating it from Central Asian and East Asian landmasses.

Pillar II — Distinct Monsoonal Climate Regime : The **South-West (Summer) Monsoon and North-East (Winter) Monsoon** constitute a **self-contained, internally consistent climatic system** unique to the Indian subcontinent and adjoining Monsoon Asia. This system — driven by the **differential heating of the landmass vs the Indian Ocean**, modulated by the Himalayan barrier and the ITCZ — is neither shared with Central Asia's continental climate nor with East Asia's Pacific-influenced regimes. The monsoon is therefore a **climatic identity marker** of the subcontinent.

Pillar III — Physiographic Uniqueness : Few regions on Earth juxtapose **the world's youngest and highest fold mountains (Himalayas, ~50 Ma)** with **one of its oldest stable shields (Peninsular Plateau, Archaean, ~3.5 Ga)** and **one of the world's largest alluvial plains (Indo-Gangetic Plain)** — all within a single geographical unit. This tripartite physiographic architecture is unique in its scale and geological contrast.

Pillar IV — Continental-Scale Cultural Mosaic : At **3,287,263 sq km**, India is the **7th-largest country on Earth (~2.4% of global land area)**. Within this space it contains extraordinary **linguistic diversity** (Indo-Aryan, Dravidian, Sino-Tibetan, Austroasiatic language families), **religious plurality** (origin/seat of Hinduism, Buddhism, Jainism, Sikhism; plus Islam, Christianity, Zoroastrianism), and **ethnic heterogeneity** — a diversity comparable to Europe as a whole, reinforcing its status as a distinct cultural world.

UPSC CIVIL

"Why is India considered as a subcontinent? Elaborate your answer." [UPSC Civil (Mains) 2021 | GS-1 | 150W | 10M]

Use the four-pillar framework above. Keywords the evaluator looks for: tectonic isolation, monsoonal climate regime, cultural mosaic, physiographic uniqueness, Indian Plate. See the Model Answer at the end of this chapter.

1.3 POLITICAL & ADMINISTRATIVE BOUNDARIES

India's boundary framework spans **land borders with seven countries**, an extensive coastline, and maritime zones that extend far into the Indian Ocean — endowing it with both **strategic depth** and **considerable resource potential**.

LAND BOUNDARIES

Neighbour	*Boundary Length (km)*	*Remark*
Bangladesh	4,096.7	India's longest land border
China	3,488	Disputed; along the Line of Actual Control (LAC)
Pakistan	3,323	Includes International Boundary + ~1,225 km LoC
Nepal	1,751	Open border; no visa required
Myanmar	1,643	—

Bhutan	699	—
Afghanistan	106	India's shortest land border (along PoK/Wakhan strip)
TOTAL	~15,106.7	Source: Dept. of Border Management, MHA

COASTLINE

India's coastline — spanning the Arabian Sea (west), Indian Ocean (south) and Bay of Bengal (east) — is one of its most strategically and economically significant assets.

- **Classic figure: 7,516.6 km** (mainland ~6,100 km + Andaman & Nicobar + Lakshadweep Island groups) — the long-standard Survey of India/India Yearbook figure.
- **Revised figure: ~11,098.81 km (2023–24)** per the National Hydrographic Office / Survey of India (MHA). The ~47% increase reflects **finer-resolution digital measurement** of creeks, estuaries and tidal indentations — known as the **'coastline paradox'** (measured length grows as the scale of measurement becomes finer). No territory was added.
- **For competitive exams:** cite both figures and explain the revision — this demonstrates analytical depth.

MARITIME ZONES (MARITIME ZONES ACT, 1976)

Zone	*Limit from Baseline*	*India's Rights*
Territorial Waters	0–12 nautical miles	Full sovereignty (equivalent to land territory)
Contiguous Zone	12–24 nm	Enforcement rights (customs, immigration, sanitation, security)
Exclusive Economic Zone (EEZ)	0–200 nm	Sovereign rights over living & non-living resources; ~2.37 million sq km
Extended Continental Shelf (ECS)	Beyond 200 nm (up to 350 nm)	Seabed / subsoil rights only; India filed CLCS claim in 2009

KEY NOTE **EEZ ≠ ECS:** The EEZ (200 nm) covers water column + seabed resources. The Extended Continental Shelf claim concerns seabed/subsoil rights beyond 200 nm — do not conflate the two. This distinction appears in GS-2 (international law) and Geography Optional questions.

1.4 PHYSIOGRAPHIC DIVISIONS — OVERVIEW

India's relief is organised into **six major physiographic divisions** (NCERT framework). These are not independent units — they are genetically linked by a **single tectonic event: the India–Eurasia collision**. Understanding this linkage is essential for both Prelims fact-based questions and Mains analytical answers.

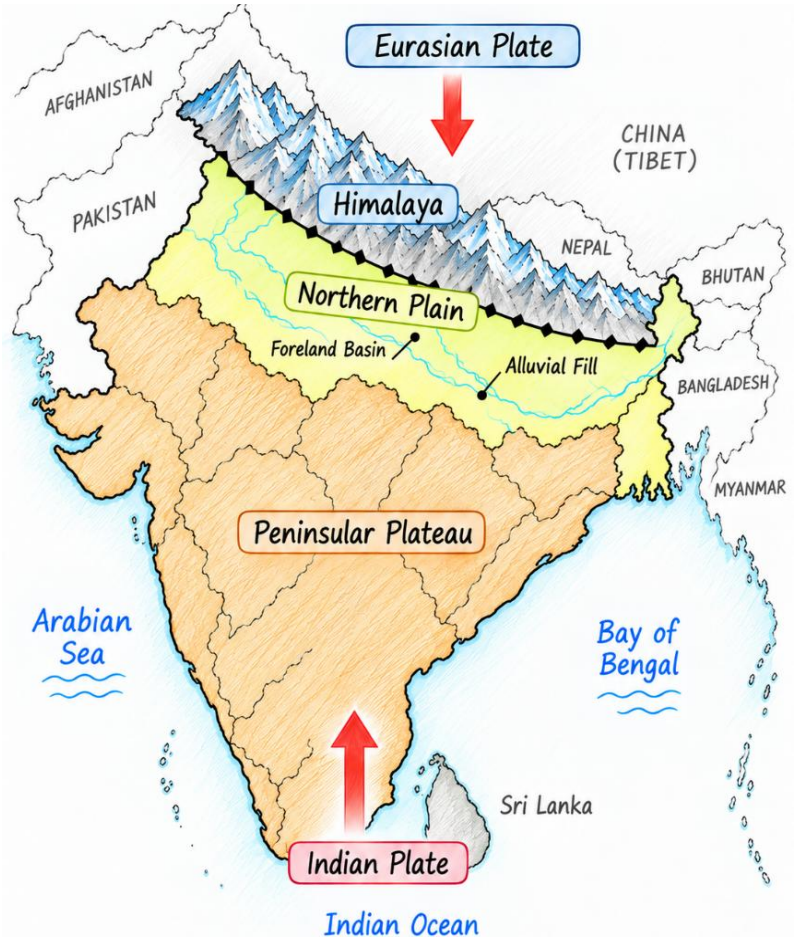
Division	*Elevation*	*Rock / Material*	*Geol. Age*	*Economic Significance*
Northern & NE Mountains (Himalayas)	1,000–8,000+ m; young fold mountains	Sedimentary & metamorphic; folded Tethyan rocks	Cenozoic (youngest, ~50 Ma)	Rivers/HEP, forests, tourism, strategic defence
Northern Plains (Indo-Gangetic-Brahmaputra)	<300 m; flat, expansive	Quaternary alluvium (khadar & bhangar)	Quaternary	Most fertile agri. belt; demographic core
Peninsular Plateau	300–900 m; ancient tablelands	Archaean gneiss / granite, Gondwana sediments, Deccan Trap basalt	Archaean/Precambrian (oldest, ~3.5 Ga)	Metallic minerals, coal, black cotton soil (Deccan Trap)
The Indian (Thar) Desert	150–300 m; arid, sandy	Aeolian sand, alluvium	Recent	Wind & solar energy; limited dryland agriculture

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Coastal Plains	Sea level; E. coast wide/deltaic; W. coast narrow	Marine & fluvial/alluvial deposits	Recent	Ports, fisheries, rice, lagoons (Chilika, Vembanad)
The Islands	Low–moderate elevation	A&N: tectonic/volcanic; Lakshadweep: coral atolls	Varies	Strategic location, biodiversity, fisheries, tourism

GEOMORPHOLOGICAL LINKAGE — ONE COLLISION, SIX DIVISIONS

The **Peninsular Plateau** is the ancient, rigid craton that drifted north on the Indian Plate and collided with Eurasia. This collision:



- **Raised the Himalayas** from the crumpled sediments of the Tethys Sea.
- **Downwarped a foredeep (foreland basin)** immediately south of the rising Himalayas.
- **Filled the foredeep with alluvium** eroded from the Himalayas and the Peninsula — creating the vast **Northern Plains**.
- The **Thar Desert** is a product of rain-shadow aridity and aeolian (wind) deposition west of the Aravallis.
- The **Coastal Plains** are shaped by the erosion of the Western and Eastern Ghats and subsequent marine/fluvial deposition.
- The **Andaman & Nicobar Islands** are a northward extension of the Indonesian island arc system; **Lakshadweep** comprises coral atolls on a submarine ridge.

1.5 GEOLOGICAL HISTORY — GONDWANALAND TO PRESENT

India's geological biography is one of the most dramatic on Earth — a journey from the interior of a supercontinent, across an ancient ocean, to a collision that built the world's highest mountain range. This narrative connects **mineral resources, seismic hazards, river systems and climate** in a single explanatory thread.

GONDWANALAND AND THE BREAKUP

Gondwanaland was the southern portion of the Pangaean supercontinent, comprising present-day South America, Africa, Antarctica, Australia and India. It **began fragmenting in the Jurassic (~180–140 Ma)**; the Indian block rifted away and commenced a rapid northward drift across the **Tethys Sea** — a vast, warm, shallow ocean that once separated Gondwana from the Eurasian landmass (Laurasia).

- The Indian Plate moved **north-northeast at ~5 cm/year** (among the fastest tectonic movements recorded).

- **Gondwana sediments** deposited in river basins on the drifting plate now form the **coal-bearing Gondwana rock system** of Peninsular India — the geological foundation of India's coal wealth.
- The **Deccan Plateau basalts (Deccan Trap, ~66 Ma)** erupted as the Indian Plate passed over the Réunion hotspot — one of Earth's largest flood-volcanic events.

TETHYS CLOSURE & HIMALAYAN UPLIFT

As the Indian Plate approached Eurasia, the Tethys Sea was **progressively subducted**. The **India–Eurasia collision began approximately 50–55 Ma (early Eocene)**. The collision crumpled Tethyan sediments — transforming ocean-floor limestone and shale — into the **Himalayas, Karakoram and Hindu Kush**. Critically, the Himalayas are **still rising today** (by a few millimetres per year) as India continues to underthrust beneath Eurasia — a process that simultaneously generates high seismic hazard and replenishes the river systems fed by glacial melt.

PENINSULAR PLATEAU — ANCIENT ARCHAEAN SHIELD

The Peninsular Plateau is one of Earth's **oldest geological formations (Archaean/Precambrian, ~3.5 billion years old)** — a stable **craton (rigid shield)** composed of ancient gneisses, granites and schists. Unlike the tectonically active Himalayas, it experiences minimal deformation.

IFoS FOCUS

IFoS / UPSC Civil Angle — Gondwanaland & India's Mineral Wealth :

- ~98% of India's coal reserves are hosted in Gondwana-age sedimentary rocks of the Damodar, Mahanadi, Godavari and Son valley basins.
- Iron ore, manganese, gold, copper and bauxite are concentrated in the Archaean–Dharwar–Cuddapah rock systems of the NE Peninsular shield (Jharkhand–Odisha–Chhattisgarh mineral belt).
- The Deccan Trap basalt forms the parent material for the highly fertile black cotton soil (Regur) of the Deccan Plateau.

UPSC CIVIL

" Despite India being one of the countries of the Gondwanaland, its mining industry contributes much less to GDP in percentage. Discuss." [UPSC Civil (Mains) 2021 | GS-1 | 10M]

Key argument: Geological endowment ≠ GDP contribution. Factors limiting mining's GDP share: (i) dominance of services sector; (ii) environmental-clearance and land-acquisition constraints; (iii) under-investment in deep-seated deposit exploration; (iv) tribal/forest-area regulatory overlap; (v) raw-ore export rather than processed value-addition; (vi) critical mineral import dependence (lithium, cobalt). Pair with geological reason why the wealth exists (Gondwana + Archaean shield).

1.6 GEOMORPHOLOGICAL RESOURCES & HAZARDS

Geomorphological resources are the **economically and ecologically useful attributes derived from landforms and the processes that shape them**. **Geomorphological hazards** are the **damaging events arising from the very same earth-surface processes**. The critical insight — and the analytical heart of this IFoS-favourite topic — is that **resources and hazards are two expressions of the same process, inseparable in space and time**.

TYPES OF GEOMORPHOLOGICAL RESOURCES

- **Mineral resources** tied to rock structure: coal in Gondwana basins; iron/manganese in Archaean shields; placer gold/ton in alluvial/coastal sands.
- **Fertile alluvial plains** (Indo-Gangetic-Brahmaputra Plain) — created by fluvial deposition from the Himalayas — constitute India's primary agricultural zone.
- **Natural harbours & port sites**: controlled by coastal geomorphology (e.g., the ria/estuarine configuration of Goa's coast; the sheltered bay of Visakhapatnam).
- **Groundwater aquifers**: alluvial aquifers of the Northern Plains; weathered/fractured-rock aquifers of the Peninsular plateau.

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- **Soils**: regur (black cotton soil) on Deccan Trap; laterite soils; construction aggregates.
- **Scenic & tourism resources**: glaciers, waterfalls, beaches, caves — geomorphically created landscapes.

TYPES OF GEOMORPHOLOGICAL HAZARDS

- **Earthquakes**: Himalayan collision belt and Kutch (seismically active); India's seismic zonation map (Zone II–V) reflects underlying tectonics.
- **Landslides**: Himalayan region (steep, young, poorly consolidated slopes + heavy rainfall + seismic shaking) and Western Ghats (laterite overburden on steep scarps).
- **Floods**: Brahmaputra–Ganga Plains (recurrent); flash floods in Himalayan valleys (Dharali, Kedarnath-type events).
- **GLOFs (Glacial Lake Outburst Floods)**: accelerating with Himalayan glacier retreat — high hazard for Uttarakhand, Himachal Pradesh, Sikkim.
- **Coastal erosion & storm surge**: low-lying delta coasts (Odisha, Andhra Pradesh, West Bengal) vulnerable to cyclonic surge.
- **Desertification/land degradation**: Thar margins and dry Deccan — aeolian processes expanding aridity.

THE RESOURCE–HAZARD NEXUS

The **same process that creates the resource also generates the hazard**. Himalayan uplift yields hydropower sites and metallic-mineral belts **and** produces earthquakes and landslides. Fluvial deposition builds fertile alluvial plains **and** creates recurrent flood risk. Coastal geomorphology creates fisheries and port sites **and** drives coastal erosion and storm surge. This dual character means that **resource exploitation and hazard management must be co-planned** — e.g., dam siting in seismically active Himalayan zones, or port development on erosion-prone coasts. This integrated approach is the foundation of **applied geomorphology, sustainable land use planning and disaster-risk reduction (DRR)** — all high-priority themes for IFoS and UPSC.

IFoS FOCUS

"What are geomorphological resources? How are geomorphological resources linked with geomorphological hazards?" [IFoS 2017 | GS | 150W | 10M]

Use the resource–hazard nexus argument above as your analytical anchor. Clearly state that they arise from the same earth-surface processes and that integrated management is therefore essential.

1.7 CURRENT AFFAIRS HOOKS (2021–2025)

CURRENT AFFAIRS

1. **National Geospatial Policy (NGP) 2022 — released 28 December 2022, Department of Science & Technology (DST)**
   A civilian-focused policy to make India a global leader in geospatial technology. Key objectives: develop a high-resolution national DEM and digital twin of cities/towns; build a Geospatial Knowledge Infrastructure (GKI); grow the geospatial economy and domestic start-up ecosystem. Preceded by the Geospatial Data Liberalisation Guidelines (Feb 2021) which removed prior-approval requirements for Indian entities acquiring/producing geospatial data.
2. **SVAMITVA Scheme (Survey of Villages and Mapping with Improvised Technology in Village Areas)**
   Launched: 24 April 2020 (National Panchayati Raj Day); national rollout from 24 April 2021. Ministry of Panchayati Raj, with Survey of India as technology partner. Uses drone surveys + Continuously Operating Reference Stations (CORS) to map rural abadi land and issue Property Cards — converting informal rural property into a bankable asset and enabling accurate land records.
3. **PM GatiShakti National Master Plan — launched 13 October 2021**
   A GIS-based digital platform (built on BISAG-N, MeitY) integrating data layers from 16+ central ministries and state governments for coordinated multi-modal infrastructure planning (roads, railways, ports, airports, logistics). Demonstrates how geospatial data directly drives national

planning — a powerful value-addition for answers on transport, industrialisation and regional development.

4. **Revised Coastline Figure (~11,098.81 km, 2023–24)**
The National Hydrographic Office / Survey of India revised India's coastline upward from the classic 7,516.6 km to ~11,098.81 km. The increase reflects finer digital measurement of estuaries, creeks and tidal indentations (the coastline paradox) — not any territorial addition. Use this to demonstrate awareness of evolving data standards.

1.8 PYQ ANALYSIS — CHAPTER 1 (2010–2025)

The following questions from UPSC Civil Services Mains and IFoS GS directly test themes covered in this chapter:

Source	Year	Marks	Question
UPSC Civil	2021	10M	"Why is India considered as a subcontinent? Elaborate your answer."
UPSC Civil	2021	10M	"Despite India being one of the countries of the Gondwanaland, its mining industry contributes much less to its GDP in percentage. Discuss."
IFoS GS	2017	10M	"What are geomorphological resources? How are geomorphological resources linked with geomorphological hazards?"
UPSC Civil	2019	10M	"Explain the topographical and structural characteristics of the Western Ghats."
UPSC Civil	2010	12M	"Differentiate the Western Ghats and Eastern Ghats in terms of physical characteristics."
UPSC Civil	2014	10M	"Why are the world's fold mountain systems located along the margins of continents? Bring out the association between global distribution of fold mountains and earthquakes and volcanoes."
UPSC Civil	2013	5M	"What do you understand by the theory of continental drift? Discuss the prominent evidences in its support."

KEY NOTE

Frequency pattern: The "subcontinent" argument and Gondwanaland-geology questions have appeared multiple times in GS-1 and Geography Optional. Plate tectonics and geomorphological resources are recurring in IFoS. The Western Ghats physiography is a perennial Prelims and Mains topic. Prioritise these three clusters.

1.9 MODEL QUESTION

Why is India considered as a subcontinent? Elaborate your answer.

UPSC Civil (Mains) 2021 | GS-1 | 10 Marks | 150 Words

India, though geographically part of Asia, is designated a **subcontinent** — a large, physiographically distinct and climatically self-contained landmass set apart from the rest of a continent by formidable natural barriers.

FOUR REASONS

(i) Tectonic Isolation: India rides a **distinct lithospheric plate (the Indian Plate)**. The resultant **Himalayan arc** — with the Hindu Kush and Thar Desert — physically insulates the region from Central Asia.

(ii) Distinct Monsoonal Climate Regime: The **South-West and North-East monsoon system** is a self-contained climatic identity unique to this landmass, unshared by Central or East Asia.

(iii) Physiographic Uniqueness: The coexistence of the **world's youngest fold mountains (Himalayas, ~50 Ma)**, the **oldest shields (Peninsular Plateau, ~3.5 Ga)** and vast **alluvial plains** is unparalleled in scale.

(iv) Cultural Mosaic: At **3.28 million sq km** (7th-largest country), India contains extraordinary linguistic, religious and ethnic diversity — comparable in scale and plurality to a continent.

India's **tectonic isolation, distinct monsoonal climate regime, physiographic uniqueness** and **vast cultural mosaic** together justify its recognition as a subcontinent rather than a mere country.

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CHAPTER 2

THE HIMALAYAN MOUNTAINS

CHAPTER AT A GLANCE

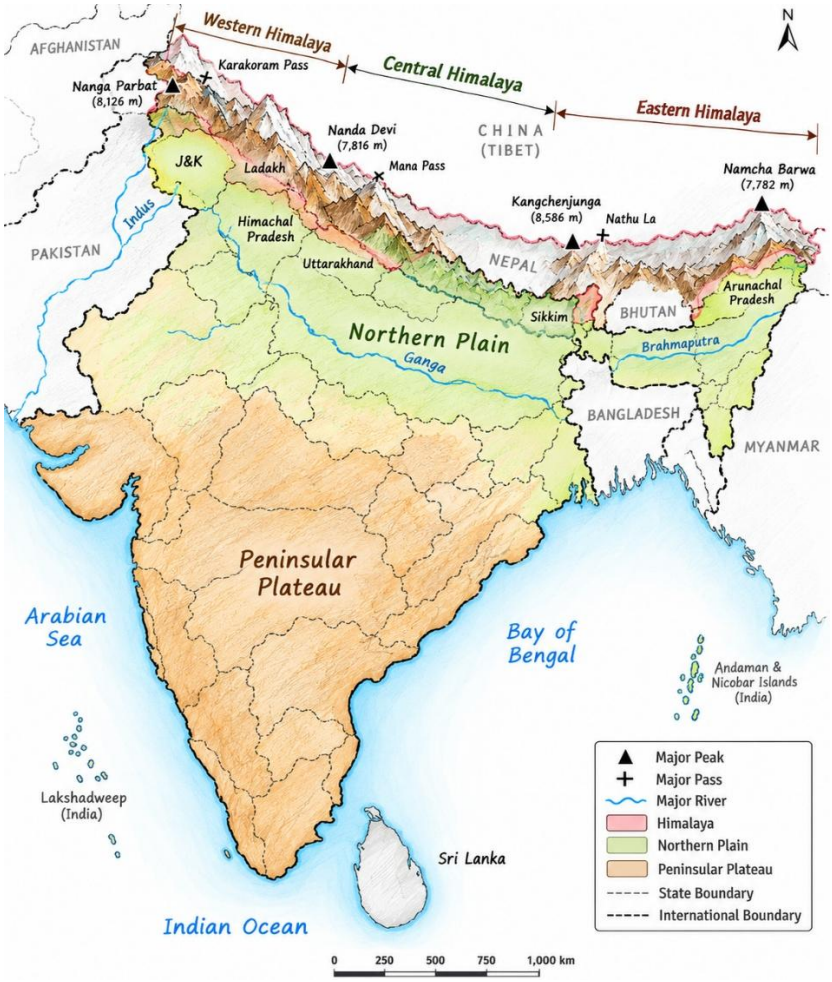
- The Himalaya stretches ~2,500 km from Nanga Parbat (west) to Namcha Barwa (east); width 150–400 km; highest peak Kangchenjunga (8,586 m) within India.
- Formed by India–Eurasia plate collision (~50 Ma); still rising ~5 mm/year; no associated volcanoes (continental collision, not oceanic subduction).
- Four longitudinal tectonic belts separated by major thrusts: Trans-Himalaya → Greater Himalaya (MCT) → Lesser Himalaya (MBT) → Shiwalik (HFF).
- Rivers are antecedent (older than mountains) — Indus, Ganga & Brahmaputra systems form the water backbone of the subcontinent.
- Acts as climatic barrier (blocks cold winds), orographic rain-bringer, and water tower of Asia; Trans-Himalayan areas become cold deserts in the rain shadow.
- Vertical vegetation zones: Tropical → Subtropical → Temperate (coniferous) → Alpine (bugyals) → Nival (lichens). Eastern Himalaya far more biodiverse than Western.
- Major hazards: landslides (unconsolidated Shiwalik + seismicity + rainfall), GLOFs (Chamoli 2021, South Lhonak 2023, Kedarnath 2013), seismic Zones IV–V.
- Strategic significance: LoC (~740 km), LAC (~3,488 km), passes (Nathu La, Zoji La, Sela), Atal Tunnel (2020), Sela Tunnel (March 2024).

2.1 INTRODUCTION — THE HIMALAYA AS A GEOGRAPHICAL PHENOMENON

The Himalaya — from the Sanskrit *hima* (snow) and *alaya* (abode) — is the world's youngest, highest and most tectonically active mountain system. It arcs across India's northern and north-eastern frontier for approximately **2,500 km** from the **Indus gorge near Nanga Parbat (8,126 m)** in the west to the **Brahmaputra gorge near Namcha Barwa (7,782 m)** in the east — the two **syntaxial bends** that anchor the arc. The system's width narrows from about **400 km in Kashmir** to **150 km in Arunachal Pradesh**. Within Indian territory, **Kangchenjunga (8,586 m)** — on the Sikkim–Nepal border — is India's highest peak; Mount Everest (8,848.86 m, Nepal–Tibet) crowns the global system.

The Himalaya functions as the structural and functional **'backbone'** of the Indian subcontinent across five dimensions:

- **Hydrological:** feeds the perennial Indus, Ganga and Brahmaputra river systems through glacier and snowmelt — sustaining hundreds of millions.
- **Climatic:** blocks frigid Central Asian winds and forces the South-West monsoon to precipitate, making the subcontinent anomalously warm and well-watered.
- **Ecological:** provides an altitudinal gradient from tropical to nival zones; the Eastern Himalaya is a global biodiversity hotspot.
- **Strategic:** forms a formidable physical frontier; its passes govern invasion, trade and military logistics.
- **Cultural & economic:** pilgrimages (Char Dham), adventure tourism, hydropower potential and mountain agriculture.



2.2 ORIGIN & FORMATION — PLATE TECTONIC EXPLANATION

The Himalaya is the canonical example of a **collision-type (Alpine) fold mountain system** — formed not at an oceanic-continental margin but at a **continent–continent convergent boundary**. Its evolutionary sequence follows directly from the breakup of Gondwanaland described in Chapter 1.

STAGE-BY-STAGE FORMATION

Stage 1 — Gondwanaland Breakup & Indian Plate Drift : From the **Jurassic period (~180 Ma)**, Gondwanaland fragmented. The Indian Plate broke away and began a rapid northward drift across the **Tethys Sea** — a vast, shallow, warm-water geosyncline accumulating thick sedimentary sequences that separated the Gondwana fragments from the Eurasian (Laurasian/Angaraland) landmass. The Indian Plate moved at approximately **5 cm/year** — among the fastest plate motions on record.

Stage 2 — Tethys Closure & Collision (~50 Ma) : As India moved north, the Tethys ocean floor was **progressively subducted** beneath Eurasia. The **India–Eurasia collision commenced approximately 50 million years ago** (early Eocene). When the two continental masses met, the buoyant Tethyan **sedimentary sequences were compressed, folded and thrust upward** — transforming ocean-floor limestone, shale and sandstone into the towering Himalayan peaks. The presence of **marine fossils (ammonites — locally called Shaligrams)** and fossiliferous sedimentary rocks at high elevations is the most cited field evidence for this tectonic history.

Stage 3 — Continuing Uplift & Seismicity : Convergence continues today; the Indian Plate still underthrusts Eurasia, causing the Himalaya to **rise at ~5 mm/year**. Simultaneously, **isostatic rebound** — the uplift of less-dense crustal material as erosion strips mass from peaks — supplements tectonic uplift. The accumulated strain along locked thrust faults is periodically released as **great thrust-fault earthquakes** (e.g., 1905 Kangra, 1934 Bihar-Nepal, 2005 Kashmir, 2015 Gorkha-Nepal), placing the Himalayan belt in seismic Zones IV–V.

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UPSC CIVIL

"Why are the world's fold mountain systems located along the margins of continents? Bring out the association between global distribution of fold mountains and earthquakes and volcanoes." [UPSC CSM 2014 | GS-1]

Key answer point : The Himalaya is a fold mountain at a continent–continent convergent margin. Unlike subduction-zone mountains (Andes, Cascades), it has **NO active volcanoes** — continental crust is too buoyant to subduct to magma-generating depths. But it does generate intense seismicity along MCT/MBT/HFF thrust faults. This distinction separates Himalayan-type from Andean-type fold mountains.

2.3 GEOLOGICAL STRUCTURE & ROCK TYPES

The Himalaya is divided into **four longitudinal tectonic belts**, each bounded by a major crustal-scale thrust fault. Understanding this structure is essential for answering questions on seismicity, rock types, landslide hazard and physiographic zonation.

Tectonic Belt	*Position*	*Rock Types*	*Character*
Trans-Himalaya / Tethyan	North of Greater Himalaya	Fossiliferous Tethyan sedimentary rocks (limestone, shale)	Cold desert; Ladakh, Zaskar, Karakoram; marine fossils at altitude
Greater Himalaya (Himadri)	Axial crystalline zone	Ancient crystalline: gneiss, schist, granite	Highest peaks; perennially snow-covered; major glaciers
Lesser Himalaya (Himachal)	Between MCT and MBT	Folded sedimentary & metamorphic: slate, limestone, quartzite	Hill stations; valleys (Kashmir, Kangra, Doon); important passes
Outer Himalaya (Shiwalik)	South of MBT / HFF	Soft, unconsolidated Tertiary fluvial sediments: sandstone, conglomerate, clay	Youngest; Duns & Duars; most landslide-prone

MAJOR THRUST FAULTS (NORTH TO SOUTH)

- **Main Central Thrust (MCT):** separates the Greater Himalaya from the Lesser Himalaya. A major zone of ductile shearing.
- **Main Boundary Thrust (MBT):** separates the Lesser Himalaya from the Shiwalik. Site of repeated thrust earthquakes.
- **Himalayan Frontal Fault (HFF) / Main Frontal Thrust (MFT):** the active deformation front; separates the Shiwalik from the Indo-Gangetic Plain. Youngest and most seismically active.

KEY NOTE

Why thrusts explain the seismic hazard pattern : These are low-angle reverse faults along which the Indian Plate underthrusts the Himalaya. Locked fault segments accumulate strain over decades and release it suddenly as great earthquakes — which is why seismic hazard is highest along the MBT–HFF belt (Zones IV–V). The Shiwalik zone, with its soft unconsolidated sediments, amplifies seismic shaking and is the most hazardous zone for construction.

2.4 PHYSIOGRAPHIC DIVISIONS OF THE HIMALAYA

(a) WESTERN HIMALAYAS

Comprising the **Kashmir, Himachal and Kumaon Himalaya** (J&K/Ladakh UT, Himachal Pradesh, Uttarakhand), the Western Himalayas are **broader, with well-developed parallel ranges** — Karakoram, Ladakh, Zaskar, Pir Panjal and Dhauladhar. The region is drier in the north (Ladakh, Spiti as **cold deserts in the rain shadow**) but supports famous hill stations (Shimla, Mussoorie, Nainital) and fertile valleys (Kashmir, Kangra, Kullu, Doon). Western Disturbances bring winter snowfall crucial for the *rabi* crop.

(b) EASTERN HIMALAYAS

Covering Sikkim, Darjeeling (WB) and Arunachal Pradesh, the Eastern Himalaya is **narrower, steeper and far wetter** — the South-West monsoon strikes directly, delivering among the world's highest rainfall. This produces **exceptionally dense and biodiverse forests**: rhododendrons, orchids, bamboos, temperate broadleaf cover. The Eastern Himalaya forms a **global biodiversity hotspot** with far greater species richness and endemism than the west.

(c) PURVANCHAL (NORTH-EASTERN HILLS)

The Himalaya bends southward into NE India as the **Purvanchal** — comprising the Patkai Bum, Naga Hills, Manipur Hills and Mizo (Lushai) Hills. These are lower ranges (peaks rarely exceed 3,000 m), covered in dense tropical and sub-tropical forests, receiving very heavy rainfall, and forming a natural boundary with Myanmar.

STRATEGIC PASSES

Pass	*State/UT*	*Altitude (approx.)*	*Strategic Significance*
Zoji La	J&K/Ladakh	~3,528 m	Srinagar–Leh route; only road link before tunnel; closed in winter
Shipki La	Himachal Pradesh	~5,639 m	Sutlej river enters India; trade route to Tibet
Rohtang Pass	Himachal Pradesh	~3,978 m	Manali–Lahaul/Leh corridor; now bypassed by Atal Tunnel (2020)
Nathu La	Sikkim	~4,310 m	India–China border; reopened for trade 2006
Bomdi La	Arunachal Pradesh	~2,415 m	Tawang sector approach; Chinese advance route in 1962 war
Diphu Pass	Arunachal Pradesh	~4,587 m	India–China–Myanmar tri-junction; strategic eastern flank

KEY PEAKS WITHIN INDIAN TERRITORY

- **Kangchenjunga (8,586 m):** world's 3rd highest; on Sikkim–Nepal border; India's highest peak.
- **Nanda Devi (7,816 m):** Uttarakhand; highest peak *entirely* within India.
- **Namcha Barwa (7,782 m):** eastern syntaxial anchor; Arunachal Pradesh (near Arunachal–Tibet border).
- **Kamet (7,756 m):** Uttarakhand, near Tibet border; 2nd highest in India.
- **K2 / Godwin Austen (8,611 m):** world's 2nd highest; in Karakoram (Trans-Himalaya, PoK); **not** within Indian-administered territory.

2.5 HIMALAYAN RANGES — KEY REFERENCE FACTS

Range	*Elevation*	*Geological character*	*Key features*
Greater Himalaya (Himadri)	6,000–8,848 m	Ancient crystalline: gneiss, schist, granite; perennially snow-covered	Gangotri, Zemu, Siachen glaciers; Everest, Kangchenjunga, Nanda Devi
Lesser Himalaya (Himachal)	1,000–4,500 m	Folded sedimentary & metamorphic; slate, limestone, quartzite	Pir Panjal, Dhauladhar, Mahabharat; Shimla, Darjeeling; Kangra, Kullu, Doon valleys
Outer Himalaya (Shiwalik)	600–1,500 m	Soft unconsolidated Tertiary sediments: sandstone, conglomerate	Duns (W) & Duars (E); most landslide-prone; geologically youngest
Trans-Himalaya	3,000–8,611 m	Cold desert; Tethyan sediments + Karakoram crystalline	Ladakh, Zaskar, Karakoram; K2; Siachen Glacier; cold desert conditions

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KEY NOTE

Duns vs Duars : Longitudinal valleys between the Shiwalik and Lesser Himalaya are called **Duns** in the west (Dehra Dun, Patli Dun, Kothri Dun — Uttarakhand) and **Duars** in the east (West Bengal/Assam). These fertile, flat-bottomed valleys are formed by synclinal folding of Shiwalik sediments and are agriculturally and strategically important.

2.6 HIMALAYAN RIVERS — ANTECEDENT DRAINAGE

Many major Himalayan rivers are **older than the mountains themselves** — a phenomenon called **antecedent drainage**. These rivers originated as consequent streams flowing north-to-south on the Tibetan plateau *before* the Himalayan uplift. As the mountains rose, the rivers **maintained their courses by down-cutting at a rate matching tectonic uplift**, carving spectacular **transverse gorges** across the grain of the mountains. The **Indus, Sutlej and Brahmaputra (Tsangpo)** — all of which rise *beyond* the Greater Himalaya in Tibet — are the classic examples.

THREE MASTER DRAINAGE SYSTEMS

- **Indus System:** Indus and its five Punjab tributaries — Jhelum, Chenab, Ravi, Beas, Sutlej. Drains the Western Himalaya and much of Pakistan.
- **Ganga System:** Ganga with Yamuna, Ghaghara, Gandak, Kosi and others. The most populated river basin on Earth.
- **Brahmaputra System:** Brahmaputra (Tsangpo) with Dibang, Lohit, Subansiri and others. Drains the Eastern Himalaya and North-East India.

KEY NOTE

Perennial vs Seasonal : Himalayan rivers are **perennial** — fed by both monsoon rain AND glacier/snowmelt, ensuring year-round flow. In contrast, Peninsular rivers are **seasonal** (rain-fed only). This distinction has major implications for agriculture, water security and irrigation planning — frequently tested in GS-1.

Note: Detailed treatment of river systems — tributaries, drainage patterns, interstate water disputes and interlinking — is covered in **Chapter 8 (Himalayan Rivers)** and **Chapter 9 (Peninsular Rivers)**.

2.7 CLIMATE INFLUENCE OF THE HIMALAYAS

The Himalaya does not merely record climate — it **creates** climate. Its five primary climatic functions are among the most frequently examined topics in physical geography.

1. **Barrier to Cold Continental Winds**
   The Himalayan wall blocks frigid **Central Asian and Siberian anticyclonic winds** from sweeping into the subcontinent during winter. As a result, **North India is anomalously warm** compared to the same latitudes in Central Asia and the Middle East. Without the Himalaya, cities like Delhi (~28°N) would experience Siberia-like winters.
2. **Orographic Rainfall**
   The moisture-laden **South-West monsoon winds are forced to rise** along the southern Himalayan slopes, cooling adiabatically and precipitating as heavy rainfall on the **windward (southern) slopes**. The Eastern Himalaya and adjacent Meghalaya plateau (Mawsynram, Cherrapunji) receive among the **world's highest rainfall** — Mawsynram holds the record at ~11,871 mm/year.
3. **Rain Shadow Effect — Cold Deserts**
   Beyond the Greater Himalaya, the **Trans-Himalayan areas (Ladakh, Spiti, Lahaul)** lie in a profound rain shadow. The monsoon is exhausted before it can cross the ranges, leaving these regions as **cold, high-altitude deserts** — with annual rainfall often below 100 mm, despite being at altitudes of 3,000–5,000 m.

4. **Water Tower of Asia**

   Himalayan glaciers and permanent snowfields are the **perennial source of Asia's great rivers**. They act as natural reservoirs, releasing meltwater during the summer dry spells when monsoon rainfall is insufficient. This "water tower" function is increasingly threatened by **glacier retreat due to climate change** — a major concern for water security across South and South-East Asia.

5. **Western Disturbances — Winter Rainfall**

   Extra-tropical cyclonic storms originating over the Mediterranean travel eastward as **Western Disturbances (WDs)**, bringing valuable **winter rain and snowfall to Punjab, Haryana, Himachal Pradesh and J&K**. This winter precipitation is critical for the *rabi* (wheat) crop and for replenishing snowpack. The Himalayan barrier channels WDs' precipitation onto the north-western subcontinent.

IFoS FOCUS

IFoS angle : The Himalaya's role as "water tower of Asia" is directly relevant to IFoS questions on hydrology, watershed management and climate change. Pair this with discussions of glacier retreat, GLOF risk, and downstream water security — demonstrating the linkage between physical geography and forest/environmental management.

2.8 VERTICAL ZONATION OF VEGETATION

IFoS FOCUS

"Write on the vertical distribution of natural vegetation of Himalayas." [IFoS 2018 | GS | 15M]
This is a direct, high-mark IFoS question. Memorise the five zones with altitudes, dominant species and the East–West contrast. A diagram showing the altitudinal belt sequence adds significant value.

The Himalaya's extraordinary **altitudinal gradient** compresses the equivalent of a journey from the tropics to the Arctic into a vertical span of ~5,000 m. Five distinct vegetation belts are recognised on the southern Himalayan slopes:

Zone	*Altitude Range*	*Key Species*	*Character*
Tropical	Below ~1,000 m	Sal (Shorea robusta), Teak, Bamboo, Evergreen species	Dense moist deciduous/evergreen forests; Terai & Bhabar transition zone
Subtropical	~1,000–2,000 m	Chir Pine (Pinus roxburghii), Oak, Rhododendron	Pine forests dominant in W; oak-rhododendron in E; moderate rainfall
Temperate	~2,000–3,500 m	Deodar (Cedrus deodara), Oak, Chestnut, Silver Fir, Blue Pine, Spruce	Moist temperate coniferous belt; "cedar zone"; rich in biodiversity
Alpine	~3,500–5,000 m	Junipers, Birch (Betula), dwarf Rhododendron, Alpine meadows (Bugyals/Payars)	Tree line ends; open alpine grasslands; seasonal grazing by pastoral communities
Glacial / Nival	Above ~5,000 m	Lichens, Mosses only; sparse vascular plants	Permanent snow/ice; virtually no vegetation; specialised cryophytes

EASTERN VS WESTERN HIMALAYA — VEGETATION CONTRAST

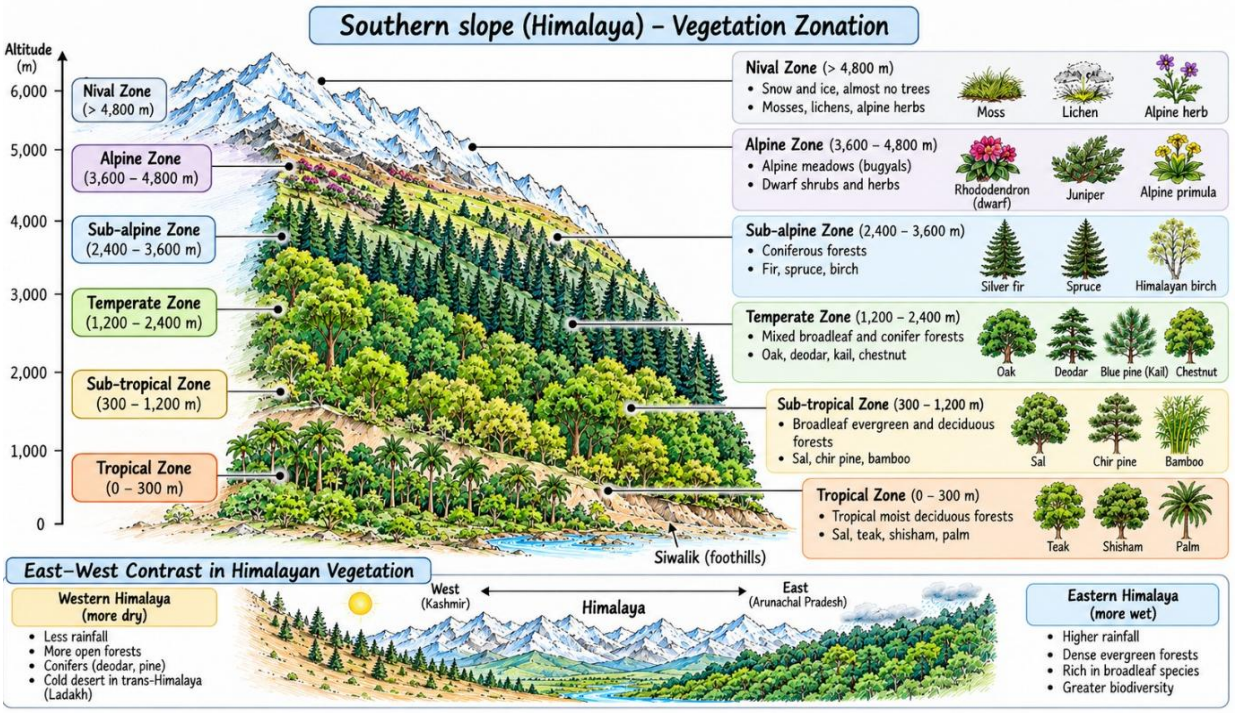
Parameter	*Western Himalaya*	*Eastern Himalaya*
Annual rainfall	Lower (100–2,000 mm; drier in NW)	Very high (2,000–10,000+ mm)
Dominant vegetation	Chir Pine, Deodar; conifer-dominated	Broadleaf, rhododendrons, orchids, bamboo
Biodiversity	Moderate	Exceptionally high; global biodiversity hotspot

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Tree line altitude	Lower (~3,500 m)	Higher (~4,000 m) due to warmer, wetter conditions
Endemism	Lower	Very high; many endemic orchids, birds, mammals

KEY NOTE

Bugyals : High-altitude alpine meadows of Uttarakhand (locally called *bugyals*, e.g., Bedni Bugyal, Ali Bugyal) are ecologically fragile grasslands above the tree line. They serve as seasonal grazing grounds and are under increasing pressure from tourism and climate change — a relevant IFoS conservation topic.



2.9 HIMALAYAN BIODIVERSITY & ECOSYSTEM

The Himalaya — particularly its eastern sector — is one of the world's **36 recognised biodiversity hotspots** (Conservation International). India hosts **four biodiversity hotspots**: the Himalaya, Western Ghats–Sri Lanka, Indo-Burma and Sundaland (Nicobar Islands). The Eastern Himalaya stands out for extraordinary **species richness, endemism and ecological complexity** arising from the convergence of Paleo-Arctic, Indo-Malayan and Sino-Japanese biogeographical zones.

FLAGSHIP & ENDEMIC FAUNA

- **Snow leopard (Panthera uncia):** the apex predator of high-altitude Himalayan terrain (3,000–5,000 m); endangered; the flagship species of Project Snow Leopard.
- **Red panda (Ailurus fulgens):** temperate bamboo forests of the Eastern Himalaya; vulnerable; arboreal and highly specialised.
- **Hangul / Kashmir stag (Cervus hanglu hanglu):** critically endangered; restricted to Dachigam National Park, J&K.
- **Himalayan brown bear, Musk deer, Snow partridge:** key high-altitude endemic fauna.

KEY FLORA

- **Brahma Kamal (Saussurea obvallata):** the state flower of Uttarakhand; iconic high-alpine bloom; considered sacred in Hindu tradition.
- **Rhododendron arboreum:** state tree of Uttarakhand; Sikkim's emblematic flora; indicator of healthy temperate forests.
- **Orchids:** The Eastern Himalaya hosts over 600 orchid species — many endemic.

CONSERVATION MILESTONES

- **Project Snow Leopard (2009):** landscape-level conservation initiative across the five Himalayan states/UTs — Ladakh/J&K, HP, Uttarakhand, Sikkim, Arunachal Pradesh.
- **Nanda Devi Biosphere Reserve:** UNESCO Man and the Biosphere (MAB) reserve; Nanda Devi & Valley of Flowers National Parks designated UNESCO World Heritage Site (1988, extended 2005).
- **Khangchendzonga National Park, Sikkim:** India's first **'Mixed' (natural + cultural)** UNESCO World Heritage Site (2016); also a Biosphere Reserve.

IFoS FOCUS

IFoS Exam Tip : Pair ecological services (carbon sink, watershed protection, biodiversity repository) with specific conservation schemes and protected areas. The examiner expects you to go beyond listing species — demonstrate understanding of **ecosystem function and conservation governance**. For example: how does the Himalayan tree line shift affect pastoralism, carbon storage and downstream hydrology simultaneously?

2.10 HAZARDS — LANDSLIDES, EARTHQUAKES & GLOFS

The Himalaya is among the world's most hazard-prone mountain systems — a product of its **young, unstable geology, steep terrain, high seismicity, heavy rainfall** and, increasingly, **climate-driven glacier retreat**. The three primary natural hazard types — landslides, earthquakes and GLOFs — are not independent but **deeply interconnected**, often cascading from one to another.

WHY THE HIMALAYA IS HAZARD-PRONE

- **Unconsolidated lithology:** soft Shiwalik sediments (sandstone, conglomerate, clay) are poorly cemented and fail readily on steep slopes.
- **Seismically active zones IV–V:** thrust earthquakes along MCT, MBT and HFF destabilise slopes and trigger mass movements.
- **Orographic rainfall & cloudbursts:** intense, localised precipitation rapidly saturates slopes and triggers debris flows.
- **Steep gradients:** antecedent rivers have cut deep, oversteepened valley walls highly susceptible to failure.
- **Anthropogenic pressure:** road and hydropower construction blasts, deforestation, unregulated construction and mass tourism exacerbate instability.
- **Climate change:** permafrost thaw, glacier retreat and the growth of glacial lakes amplify GLOF and mass-movement risk.

HIMALAYAN VS WESTERN GHATS LANDSLIDES — COMPARATIVE ANALYSIS

UPSC CIVIL

: "Differentiate the causes of landslides in the Himalayan region and the Western Ghats." [UPSC CSM 2021 | GS-1 | 10M]
This is a direct comparison question. Use the table below as your answer framework.

Factor	*Himalayan Region*	*Western Ghats*
Tectonics	Active; seismic Zones IV–V; thrust earthquakes trigger slides	Stable Peninsular shield; NO seismic trigger
Lithology	Unconsolidated Shiwalik sediments; sheared/fractured rock at thrust zones	Laterite overburden on Deccan basalt; weathered material
Rainfall trigger	Heavy orographic monsoon + cloudbursts; rapid saturation	Very heavy SW monsoon; prolonged saturation
Human factors	Road/hydropower blasting, construction in fragile zones, pilgrimage/tourism	Deforestation (plantation crops), quarrying, urban sprawl

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GLOF/glacier link	Yes — glacier retreat and GLOF amplify hazard	No glacial component
Seasonality	Monsoon + post-earthquake events	Monsoon-season only

GLOFS — GLACIAL LAKE OUTBURST FLOODS

As Himalayan glaciers retreat under climate warming, meltwater accumulates in lakes held back by **unstable moraine dams or ice dams**. Failure — triggered by a slope failure/avalanche into the lake, earthquake, overtopping or internal piping — releases a catastrophic **debris-laden flood wave** downstream. GLOFs are increasing in frequency and magnitude as glaciers retreat faster.

HAZARD ALERT

GLOF Case Studies — Three Major Events:

- **South Lhonak Lake GLOF, Sikkim — 3–4 October 2023:** A slope failure into South Lhonak glacial lake (following prolonged rainfall and moraine weakening) triggered a massive outburst that surged down the Teesta River. The 1,200 MW Chungthang Dam (Teesta Stage III) was breached. 40+ confirmed dead; ~100 dead/missing overall. Largest recent Himalayan GLOF.
- **Chamoli Disaster, Uttarakhand — 7 February 2021:** A massive rock-and-ice avalanche detached from Ronti Peak and crashed into the Rishiganga valley, generating a debris-laden flash flood. Destroyed the Rishiganga HEP (13.2 MW) and severely damaged NTPC's Tapovan-Vishnugad project (520 MW). ~204 dead/missing.
- **Kedarnath Disaster, Uttarakhand — 16–17 June 2013:** Extreme cloudburst + breach of Chorabari glacial lake above Kedarnath; wall of water, mud and boulders down the Mandakini. Over 5,000 presumed dead — India's deadliest post-Independence natural disaster.

MITIGATION MEASURES

- **Early warning systems:** ISRO/NRSC satellite monitoring of glacial lakes; automated lake-level and weather sensors.
- **Land-use regulation:** restricting construction and hydropower projects in high-risk Shiwalik and valley zones.
- **NDMA guidelines:** updated protocols on GLOF risk assessment, landslide zonation and slope drainage.
- **Bio-engineering:** combining vegetative cover (deep-rooted grasses, shrubs) with structural slope-stabilisation measures.
- **GSI hazard zonation mapping:** Geological Survey of India landslide susceptibility maps for all hill districts.
- **Afforestation and slope drainage:** reducing surface runoff and enhancing slope cohesion through forest cover.

2.11 STRATEGIC & ECONOMIC IMPORTANCE

DEFENCE & STRATEGIC FRONTIER

The Himalaya forms India's primary land-frontier barrier, encompassing the **Line of Control (LoC) with Pakistan (~740 km in J&K)** and the **Line of Actual Control (LAC) with China (~3,488 km across Western, Middle and Eastern sectors)**. Mountain passes are strategic corridors — both for historical invasion routes and modern military logistics. The **1962 Sino-Indian war** demonstrated the critical importance of Himalayan passes (notably Bomdi La) and all-weather connectivity to forward areas.

HYDROPOWER POTENTIAL

Himalayan rivers hold a substantial share of India's assessed hydropower potential. Key projects currently operational or under construction:

- **Tehri Dam (Bhagirathi, Uttarakhand):** India's tallest dam at 260.5 m; the Tehri complex (including Koteshwar and pumped storage) totals ~2,400 MW.
- **Koldam (Sutlej, HP):** 800 MW (NTPC).

- **Subansiri Lower (Assam–Arunachal border):** 2,000 MW (NHPC); India's largest HEP project under construction.

TOURISM

- **Char Dham Yatra:** Yamunotri, Gangotri, Kedarnath, Badrinath — pilgrimage circuit of national significance; also driving the Char Dham all-weather road project.
- **Adventure tourism:** mountaineering, trekking, skiing (Auli, Uttarakhand; Gulmarg, J&K).

BORDER INFRASTRUCTURE — BRO

- **Atal Tunnel, Rohtang (HP) — inaugurated 3 October 2020:** 9.02 km; world's longest highway tunnel above 10,000 ft; provides all-weather Manali–Lahaul/Leh connectivity, bypassing the snowbound Rohtang Pass.
- **Sela Tunnel, Arunachal Pradesh — inaugurated 9 March 2024:** twin-tube design (~1,555 m + ~980 m tubes) at ~13,000 ft; provides all-weather access to Tawang near the LAC — strategic significance for border defence.
- **DSDBO Road (Darbuk–Shyok–Daulat Beg Oldie):** strategic road connecting eastern Ladakh to the high-altitude Depsang plains near the LAC.

2.12 CURRENT AFFAIRS HOOKS (2021–2025)

CURRENT AFFAIRS

Chamoli rock-avalanche/GLOF (7 February 2021) : debris flow down Rishiganga / Dhauliganga valleys, Uttarakhand; 204 dead/missing; hydropower projects destroyed; highlighted dangers of HEP development in fragile Himalayan valleys.

South Lhonak Lake GLOF (3–4 October 2023): Largest recent Himalayan GLOF; Teesta River flooding; breach of 1,200 MW Chungthang Dam (Sikkim); ~100 dead/missing. Published in *Science* journal (2024); cited in COP28 cryosphere discussions.

Sela Tunnel inauguration (9 March 2024): All-weather connectivity to Tawang, Arunachal Pradesh; significant for forward-area logistics along the China LAC.

Atal Tunnel (3 October 2020): World's longest highway tunnel above 10,000 ft; Manali–Leh all-weather axis operational.

ISRO/GSI Glacier Reports (2023): Studies documenting accelerating Himalayan glacier retreat and growing number of high-hazard glacial lakes — directly relevant to GLOF risk and water security.

COP28 (Dubai, December 2023): Himalayan cryosphere and glacier retreat highlighted as a frontier climate-change risk; India pushed for mountain-specific climate-finance mechanisms.

China's LAC Border Villages: Dual-use civilian settlements (xiaokang villages) being constructed near LAC by China — strategic geography dimension of the Himalayan frontier.

Ladakh UT Status (31 October 2019 — ongoing salience): J&K reorganisation (Article 370 abrogation) continues to shape the administrative and strategic geography of the western Himalayan frontier.

2.13 PYQ ANALYSIS — CHAPTER 2 (2010–2025)

All questions from UPSC Civil Mains GS-1 and IFoS GS that directly test themes covered in this chapter:

Source	Year	Marks	Question
UPSC Civil	2016	12M	"The Himalayas are highly prone to landslides. Discuss the causes and suggest suitable measures of mitigation."
UPSC Civil	2021	10M	"Differentiate the causes of landslides in the Himalayan region and the Western Ghats."
UPSC Civil	2013	5M	"Bring out the causes for more frequent landslides in the Himalayas than in Western Ghats."
UPSC Civil	2012	12M	"Explain the formation of the Himalayas and their significance to India's climate."

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UPSC Civil	2014	10M	"Why are the world's fold mountain systems located along the margins of continents? Bring out the association between global distribution of fold mountains, earthquakes and volcanoes."
UPSC Civil	2020	15M	"How will the melting of Himalayan glaciers have a far-reaching impact on the water resources of India?"
IFoS GS	2018	15M	"Write on the vertical distribution of natural vegetation of Himalayas."
UPSC Civil	2019	10M	"Explain the topographical and structural characteristics of the Western Ghats." (compare Eastern vs Western)
IFoS GS	2017	10M	"What are geomorphological resources? How are geomorphological resources linked with geomorphological hazards?"
IFoS GS	2023	15M	"Differentiate between Cyclone and Anti-cyclone. How are tropical cyclones being affected globally by climate change?" (includes Himalayan cryosphere link)
IFoS GS	2025	10M	"Causes of flash floods are both natural and human-made. Comment in context of flash floods in Dharali, Uttarkashi, August 2025."

KEY NOTE

Frequency pattern: Himalayan landslides appear in GS-1 almost every 2–3 years (2012, 2013, 2016, 2021). Glacier/climate questions appear in GS-1 and GS-3 cycles. Vertical vegetation zonation is a recurring IFoS question. The tectonic formation question (fold mountains + earthquakes vs volcanoes) is a GS-1 staple. Prioritise: landslides, GLOF events, vertical zonation and tectonic origin.

2.14 MODEL QUESTION

The Himalayas are highly prone to landslides. Discuss the causes and suggest suitable measures of mitigation.

UPSC Civil (Mains) 2016 | GS-1 | 12.5 Marks | 200 Words

The Himalaya — the world's youngest fold mountains — combines fragile geology, steep terrain and intense rainfall with high seismicity and growing anthropogenic pressure, making it one of Earth's most landslide-prone regions.

CAUSES — NATURAL

- **Unconsolidated lithology :** soft Shiwalik sediments (sandstone, conglomerate, clay) lack cohesion and fail readily on slopes.
- **Seismically active zone (IV–V) :** thrust earthquakes along MCT/MBT/HFF faults destabilise slopes and trigger mass movements.
- **Orographic rainfall & cloudbursts :** intense precipitation rapidly saturates slopes; Kedarnath (2013) exemplifies this cascading trigger.
- **Steep antecedent gorges :** oversteepened valley walls left by river incision are inherently unstable.
- **Causes — Anthropogenic :**
- **Anthropogenic pressure :** unplanned road-cutting, hydropower tunnelling and construction activity in fragile hill zones undercut slope support.
- **Deforestation & tourism pressure :** loss of root cohesion and increased surface runoff accelerate failure.

MITIGATION

- **Early warning systems :** ISRO/NRSC satellite monitoring of vulnerable slopes; automated sensors.
- **Bio-engineering :** deep-rooted vegetation combined with gabion walls and slope drainage structures.
- **NDMA guidelines :** land-use regulation and prohibition of construction in Shiwalik/seismic Zone V corridors.
- **Afforestation and slope drainage :** reducing runoff and improving root cohesion.

A science-led, ecologically sensitive development model — integrating hazard zonation, bio-engineering and early warning — is essential for disaster-resilient mountain infrastructure.

CHAPTER 3

THE NORTHERN PLAINS

CHAPTER AT A GLANCE

- Northern Plains: ~7 lakh sq km, ~2,400 km long, 240–320 km wide; stretches from Punjab in the west to Assam in the east.
- Formed by Quaternary alluvial filling of the Himalayan foredeep (1,000–2,000 m deep alluvium); purely sedimentary — no hard rock.
- Four latitudinal belts (N→S): Bhabar (porous, rivers vanish) → Terai (waterlogged, biodiverse) → Bhangar (old alluvium, kankar) → Khadar (new alluvium, most fertile).
- Three longitudinal divisions (W→E): Punjab-Haryana Plain (wheat bowl, doabs) → Ganga Plain (Upper/Middle/Lower; Sundarbans delta) → Brahmaputra Plain (tea, rhinoceros, bils).
- Alluvial soils: rich in potash/lime, deficient in N/P/humus; problem soils include usar/reh (saline-alkaline) and waterlogged soils in canal commands.
- Green Revolution concentrated in Punjab-Haryana-W. UP; bypassed eastern India due to irrigation deficit, fragmented holdings, poor infrastructure — key UPSC 2014 theme.
- Key environmental crises: groundwater depletion (NW India losing ~4 cm/yr, GRACE data), Kosi floods (Bihar), Brahmaputra-Assam flooding, Ganga/Yamuna pollution, IGP air quality.
- Major schemes: Namami Gange (2014, ₹20,000 cr), NW-1/Jal Marg Vikas (1,620 km), PMKSY, Punjab Subsoil Water Act 2009, CAQM Act 2021, Jal Jeevan Mission 2019.

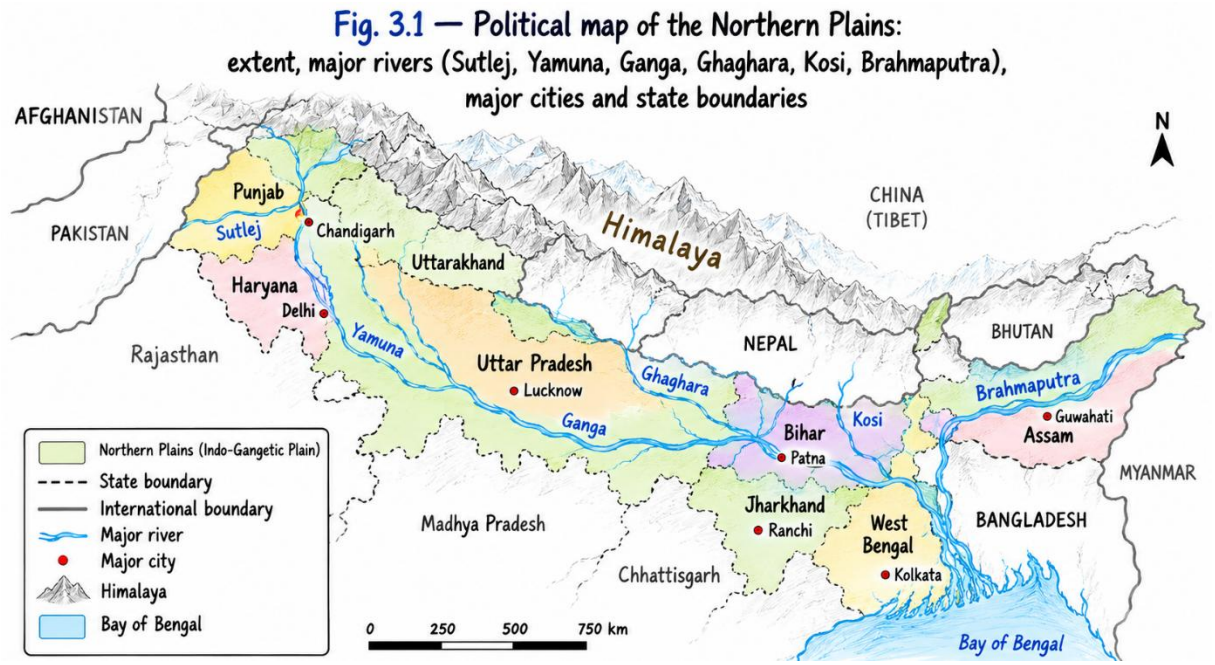
3.1 INTRODUCTION — THE GREAT PLAINS AS A CIVILISATIONAL CRADLE

The Northern Plains of India constitute one of the world's most remarkable landforms — a vast, near-featureless expanse of **deep Himalayan alluvium** stretching approximately **2,400 km from the Punjab plains in the west to the Brahmaputra valley in the east**, and **240–320 km from north to south**. Covering about **7 lakh sq km (~700,000 sq km)**, they form India's agricultural heartland, its demographic core and the cradle of its great civilisations. In one geological sentence: **they are an aggradational landform — the alluvial fill of the Himalayan foredeep, a crustal trough formed by the India-Eurasia plate collision and progressively filled by Himalayan River sediments over the Quaternary period.**

The Plains are the **"food bowl"** of the nation for five interlocking reasons:

- **Fertile deep alluvial soils** (Khadar and Bhangar) renewed by Himalayan rivers — the basis of intensive multi-crop agriculture.
- **Perennial Himalayan rivers** (Indus system, Ganga system, Brahmaputra) providing year-round irrigation.
- **Level terrain** easing mechanisation, canal construction and settlement.
- **Long frost-free growing season** supporting two to three crops per year.
- **Dense agrarian population** providing agricultural labour — the highest rural densities in India.

Historically, the Plains nurtured the **Harappan/Indus civilisation** in the west, the **Vedic culture** in the Ganga-Yamuna doab, and successive imperial capitals — Pataliputra (modern Patna), Kannauj, Delhi, Agra and Lucknow. The Ganga remains the sacred axis of Indian civilisation and the geographic spine of the country's most populated states.



3.2 FORMATION & GEOLOGICAL ORIGIN

The Northern Plains are a product of the same tectonic event that built the Himalayas. When the **Indian Plate (a Gondwanaland fragment) collided with the Eurasian Plate** beginning ~50 million years ago (Chapter 2), the **leading edge of the Indian crust was flexed downward** under the enormous load of the rising mountain belt. This linear depression between the **rising Himalayas to the north and the rigid Peninsular Shield to the south** is the **Himalayan foredeep (foreland basin)** — a classic peripheral foreland basin formed by lithospheric flexure.

HOW THE FOREDEEP FILLED

Over the **Quaternary period (last ~2 million years)**, vigorous Himalayan rivers carrying enormous sediment loads progressively **filled this trough with alluvium** — sands, silts and clays eroded from the rising mountains. The **alluvium ranges from 1,000 to 2,000 m in thickness** in the Ganga plains. This infilling continues today — the Plains are a geomorphological **"work in progress"** still being actively built by river aggradation, which is why river channels shift, meander and occasionally avulse (change course dramatically).

WHY NO HARD ROCK

Unlike the Peninsular Plateau with its Archaean gneiss and granite, the Northern Plains have **purely sedimentary/alluvial material at and near the surface**. The underlying Peninsular basement rock (the "buried ridge") lies thousands of metres below. This explains the **absence of rocky outcrops, the uniformity of terrain, the ease with which rivers shift course**, and the susceptibility to major floods — there is no hard rock to anchor channels.

KEY NOTE

Tectonic chain to memorise : Gondwanaland breakup → Indian Plate drift → India-Eurasia collision (~50 Ma) → Himalayan uplift + crustal flexure → Himalayan foredeep → Quaternary alluvial infilling → The Northern Plains. This is the same chain as Chapter 1 (Gondwana) and Chapter 2 (Himalayan formation) — demonstrating that the three major physiographic divisions are products of a single tectonic event.

3.3 PHYSIOGRAPHIC DIVISIONS — THE NORTH-TO-SOUTH BELT SEQUENCE

The most exam-critical section of this chapter is the **four-fold latitudinal division** of the Plains — from the Shiwalik foothills southward. Each belt is distinct in **alluvium age, texture, drainage behaviour, fertility and land use**. Master the comparison table at the end of this section.

BHABAR BELT

Immediately south of the Shiwalik Hills lies the **Bhabar** — a **narrow belt of 8–16 km width** running from the Indus in the west to the Tista in the east. Where fast-flowing Himalayan rivers debouch onto the plains and abruptly lose velocity, they deposit **coarse, unsorted material — gravel, pebbles and boulders**. These deposits are highly **porous and permeable**, causing streams to **disappear underground (become subterranean)** as soon as they enter the Bhabar. The surface is therefore **dry and uneven** — unsuitable for agriculture, largely forested, and sparsely settled.

TERAI BELT

South of the Bhabar, the **Terai** is a **15–30 km wide belt** where the underground streams of the Bhabar **re-emerge as surface streams and springs**. The fine alluvium here retains water, producing a **waterlogged, marshy, ill-drained zone** of exceptional ecological richness.

- Originally covered by **dense subtropical moist forests and tall elephant-grass (Saccharum spontaneum) meadows** — the habitat of tiger, elephant, swamp deer (barasingha), rhinoceros and python.
- Historically a **malarial "fever belt"** — sparsely settled until the mid-20th-century **DDT campaign and post-Partition forest-clearance** converted large areas to agriculture.
- Major **wildlife reserves** of India lie in the Terai-Duar forest-grassland belt: Jim Corbett NP (Uttarakhand), Dudhwa NP (UP), Valmiki NP (Bihar), and in the eastern continuation, Kaziranga NP (Assam).

IFoS FOCUS

IFoS Focus — Terai Conservation : The Terai-Bhabar-Duar forest-grassland mosaic is India's richest lowland biodiversity zone. Its conversion to agriculture (post-independence) is a major habitat-fragmentation case study. Kaziranga, Dudhwa and Corbett collectively hold critical populations of tiger, elephant, one-horned rhino and swamp deer. IFoS answers should link the Terai's biodiversity to the re-emergence of underground Bhabar streams — showing understanding of the hydrology-ecology connection.

BHANGAR (OLD ALLUVIAL PLAINS)

The **Bhangar** is the zone of **older alluvium** — deposits laid down in older phases of aggradation that now form **slightly elevated terraces above the active floodplain**. It is distinguished by the presence of **kankar** — calcareous (calcium carbonate) concretionary nodules in its sub-soil — formed by the upward movement of lime in the soil column over long periods.

- Comparatively **less fertile** than Khadar (older, more leached, oxidised).
- Sits **above flood level** — making it the preferred site of **ancient and stable settlements** (many historic towns sit on Bhangar terraces).
- **Kankar** is used locally as a road-building material and has also limited agricultural productivity in some tracts.

KHADAR (NEW ALLUVIAL PLAINS)

The **Khadar** is the zone of **newer alluvium** deposited in the **active floodplains** of the rivers. Fresh silt is added **almost every monsoon season** during river flooding, continuously renewing the soil's fertility. Khadar soils are **the most productive agricultural land in India** — fine-textured, moisture-retentive and nutrient-rich — but they are also the most **flood-prone** lands.

OTHER LOCAL FEATURES

- **Bils / Beels (Assam-Bengal):** ox-bow lakes, backwaters and wetlands formed by meander cut-offs and abandoned channels of the Brahmaputra and Ganga systems. Ecologically important as fish nurseries and bird habitats
- **Chars (Brahmaputra plain):** shifting mid-channel sand-silt islands within the braided Brahmaputra, seasonally inundated, inhabited by vulnerable communities.

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- **Chos (Punjab-Himachal foothills):** seasonal erosional torrents/gullies that bring flash floods of coarse debris onto the plains from the Shiwalik foothills — a severe **soil conservation problem.**
- **Mauns / Mauris (Bihar plains):** ox-bow lakes left by meander cut-offs of the Ganga and its tributaries; important wetland habitats.
- **Bhur (UP-Bihar):** aeolian sand ridges along the Ganga-Yamuna doab; low fertility; distinctive micro-habitat.

MASTER COMPARISON TABLE — BHABAR VS TERAI VS BHANGAR VS KHADAR

Feature	*Bhabar*	*Terai*	*Bhangar*	*Khadar*
Position (N→S)	Northernmost; foot of Shiwaliks	South of Bhabar	Above floodplains; older uplands	Active floodplains; lowest
Width	8–16 km	15–30 km	Extensive uplands	Along active rivers
Alluvium age	Recent, coarsest	Recent, finer	Old alluvium	New alluvium
Texture / material	Gravel, pebbles, boulders (porous)	Fine silt/clay; waterlogged	Clayey; contains kankar	Fine silt; renewed yearly
Drainage	Streams disappear underground	Streams re-emerge; marshy	Above flood level; well-drained	Annually flooded
Fertility / land use	Low; forested, little farming	Reclaimed farmland; forest/grassland	Less fertile; stable settlements	Most fertile; intensive farming
Key hazard / note	Surface water scarcity	Historically malarial; rich biodiversity	Flood-safe; kankar limits fertility	Flood-prone

UPSC CIVIL

UPSC Prelims Exam Tip : The discriminators are: (1) **drainage behaviour** — Bhabar (sinks underground) vs Terai (re-emerges); (2) **alluvium age + kankar + flood relationship** — Bhangar (old, kankar, above floods) vs Khadar (new, no kankar, flooded). These four terms appear as options in MCQs almost every cycle. Khadar = most fertile = most flood-prone; Bhangar = kankar = ancient settlement sites.

3.4 REGIONAL (LONGITUDINAL) DIVISIONS OF THE NORTHERN PLAINS

PUNJAB-HARYANA PLAIN

Built by the **Indus and its five major tributaries (Jhelum, Chenab, Ravi, Beas, Sutlej)**, the Punjab-Haryana Plain is India's most intensively farmed region. It is characterised by **doabs** — fertile interfluvial tracts between two rivers. Key doabs:

- **Bist Doab:** between Beas and Sutlej — the main doab in Indian Punjab.
- **Bari Doab:** between Beas/Sutlej and Ravi.
- **Rachna Doab:** between Ravi and Chenab (largely in Pakistan).
- **Chaj Doab:** between Chenab and Jhelum (largely in Pakistan).
- **Sindh Sagar Doab:** between Jhelum/Chenab and Indus (Pakistan).

Served by the **Bhakra-Nangal and Indira Gandhi (Rajasthan) canal systems** and intensive **tube-well irrigation**, this is India's **wheat bowl** — also producing rice (despite water concerns), cotton and oilseeds. Local features include **chos** along the Shiwalik fringe and **bet lands** (Khadar strips) along active river channels.

GANGA PLAIN

The largest unit, sloping gently eastward at an almost imperceptible gradient. Conventionally divided into three sub-units:

Upper Ganga Plain

Western Uttar Pradesh up to Prayagraj; includes the celebrated **Ganga-Yamuna doab**. Relatively higher, intensively irrigated by canal and tube-well systems. Wheat-sugarcane-potato belt; densely settled.

Middle Ganga Plain

Eastern UP and Bihar; lower gradient, lower elevation; more flood-prone as several major tributaries (**Ghaghara, Gandak, Kosi**) join the Ganga from the north, carrying heavy sediment loads from Nepal. Major city: Patna (Ganga).

Lower Ganga Plain

West Bengal; the Ganga here becomes the **Hugli (Hooghly)** and debouches into the Bay of Bengal through the **Sundarbans delta — the world's largest delta**, shared with Bangladesh (~10,000 sq km on the Indian side). The Sundarbans hosts the **Royal Bengal tiger, Irrawaddy dolphin** and the largest mangrove ecosystem in the world — a **UNESCO World Heritage Site and Ramsar Wetland**.

BRAHMAPUTRA PLAIN (ASSAM VALLEY)

A long, narrow, hemmed-in valley enclosed by hills — the Himalayas and Arunachal foothills to the north and the Meghalaya-Nagaland hills to the south. The **braided Brahmaputra** creates numerous **char islands (shifting sand-silt bars)** and **bils (ox-bow lakes/wetlands)**. The valley is **annually and severely flooded** during the monsoon, and is the global stronghold of the **one-horned Indian rhinoceros (Rhinoceros unicornis) in Kaziranga National Park** — a UNESCO World Heritage Site (**IFoS flagship species**). The economy is anchored by **tea gardens** on the higher, well-drained piedmont and **rice** on the valley floor.

3.5 SOILS OF THE NORTHERN PLAINS

Alluvial soils blanket the Northern Plains and are India's most extensive and agriculturally productive soil group. Being transported (azonal) soils, their properties vary with proximity to the river source and the age of the deposit.

GENERAL PROPERTIES OF ALLUVIAL SOILS

- **Texture:** ranges from sandy loam (near rivers, coarser) to clay loam (inter-fluvial tracts).
- **Nutrient profile:** generally **rich in potash and lime**, but **deficient in nitrogen (N), phosphorus (P) and humus (organic matter)** — hence the heavy reliance on chemical fertilisers, especially urea.
- **Depth:** very deep profile (thousands of metres) — no impediment to deep-rooted crops.
- **Workability:** easy to till; responds well to irrigation.

Aspect	*Khadar (New Alluvium)*	*Bhangar (Old Alluvium)*
Deposition	Annual fresh silt — renewed each monsoon	Older deposits; not annually renewed
Texture / colour	Finer, lighter coloured	Darker, more clayey
Kankar	Absent or rare	Present (calcareous nodules)
Fertility	Higher — continuously renewed	Lower — older, leached
Flood risk	Flood-prone (active floodplain)	Above flood level
Agricultural use	Intensive; most productive	Moderately productive; stable

PROBLEM SOILS — SALINE/ALKALINE (USAR/REH/KALLAR)

In canal-irrigated tracts of **Punjab, Haryana and western UP**, over-irrigation without adequate sub-surface drainage has **raised water tables**. Capillary action draws salts to the surface — especially **sodium carbonate and sodium sulphate (reh)** — creating **saline-alkaline** patches locally called **usar (UP), reh/kallar (Punjab-Haryana)**. These soils reduce or destroy crop productivity.

Reclamation of Saline-Alkaline Soils

- **Gypsum application:** calcium from gypsum displaces sodium in the soil exchange complex — the principal chemical amendment.
- **Leaching with drainage:** flushing salts below the root zone through controlled surface irrigation plus sub-surface tile/mole drains.

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- **Improving sub-surface drainage:** lowering the water table to prevent capillary salt rise.
- **Salt-tolerant crops:** barley, dhaincha (green manure), rice in initial reclamation phases.
- **Bio-reclamation:** planting salt-tolerant tree species (*Prosopis juliflora, Eucalyptus*) to lower water tables through transpiration (IFoS angle).

3.6 RIVERS OF THE NORTHERN PLAINS

The Northern Plains exist **because** of rivers — and are simultaneously threatened by them. The same processes of **aggradation (deposition) that built the plains** also raise river beds, reduce channel capacity and **increase flood hazard**.

PLAIN-BUILDING — AGGRADATION

As Himalayan rivers enter the nearly flat plains and dramatically lose velocity, they **drop their sediment load (aggradation)**. This raises river beds progressively above the surrounding plain, building **natural levees** that confine the river — until a flood overtops or breaches the levee, causing avulsion (sudden channel change) to a lower course.

FLUVIAL LANDFORMS

- **Meanders:** on the low-gradient middle and lower courses, rivers swing in wide meander loops; cut-offs create **ox-bow lakes** — *mauns/mauris* in Bihar, *bils* in Assam.
- **Braiding:** the heavily silt-laden Brahmaputra forms a **wide, shallow, multi-channel braided pattern** with numerous shifting char islands — characteristic of very high sediment load relative to water discharge.
- **Doabs:** the fertile, flat interfluves of the Punjab plain (detailed in Section 3.4.1).

THE KOSI — "SORROW OF BIHAR"

The Kosi rises in the Himalaya (Tibet/Nepal) and carries one of the **world's highest sediment loads**. As it enters the plains and deposits this sediment, its channel **aggrads (raises) progressively, forcing the river outward**. Over approximately **200–250 years, the Kosi has migrated ~120–133 km westward**, building a vast alluvial **megafan** in north Bihar. This propensity for sudden course changes (avulsions), combined with embankment breaches, produces **catastrophic flooding** — most infamously the **August 2008 Kusaha breach (Nepal)** that inundated large parts of Supaul, Saharsa, Madhepura, Araria and Purnia districts, affecting millions.

KEY NOTE

Saraswati / Ghaggar-Hakra Debate: The seasonal Ghaggar-Hakra channel is widely identified with the legendary Vedic **Saraswati River**, which is hypothesised to have once been a perennial glacier-fed Himalayan River flowing across Haryana and Rajasthan to the Rann of Kachchh. A dense cluster of Harappan sites along its palaeo-channel supports this thesis; the Haryana government has pursued revival works. However, the river's perennial-glacial origin remains scientifically debated — present as a hypothesis, not settled fact.

3.7 AGRICULTURE & LAND USE

The Northern Plains produce **the majority of India's wheat, a dominant share of its rice, sugarcane and cotton**, and sustain the country's most intensive agricultural economy. The convergence of deep fertile alluvium, perennial rivers, flat terrain, extensive irrigation and dense agrarian labour makes this India's **food bowl**.

CROPS BY SUB-REGION

Sub-Region	*Major Crops*	*Key Feature*
Punjab-Haryana	Wheat, Rice (paddy), Cotton, Oilseeds	Highest agricultural productivity; mechanised; MSP/mandi-driven
Upper Uttar Pradesh	Wheat, Sugarcane, Potato	India's leading sugarcane producer

Bihar / Middle Ganga	Maize, Pulses, Paddy, Makhana, Litchi	Low irrigation; flood-prone; fragmented holdings
West Bengal (Lower Ganga)	Rice (multiple cropping), Jute, Vegetables	Highest rice diversity; jute in delta
Assam (Brahmaputra)	Tea (world-class), Rice	Tea on higher well-drained piedmont

THE GREEN REVOLUTION & REGIONAL DISPARITY

The Green Revolution (mid-1960s onward — HYV seeds + chemical fertilisers + assured irrigation + mechanisation) transformed Indian food security but **concentrated its gains in Punjab, Haryana and western UP**, creating a lasting east-west productivity divide.

UPSC CIVIL

"Why did the Green Revolution in India virtually bypass the eastern region despite fertile soil and good availability of water?" [UPSC Civil (Mains) 2014 | GS-1 | 10M]

Six reasons (use as Mains bullet list):

- **Lack of assured irrigation:** dependence on unreliable monsoon and flood-disrupted canal systems.
- **Poor rural infrastructure:** weak road/mandi connectivity; limited extension services.
- **Fragmented landholdings:** sub-divided, absentee-landlord-dominated tenancy — HYV packages are scale-sensitive.
- **Institutional credit gap:** cooperative banking and input-credit systems far weaker than in NW India.
- **Delayed HYV diffusion:** seed-fertiliser packages reached eastern India a decade or more later.
- **Flood damage:** recurrent Kosi/Gandak/Ghaghara floods destroy standing crops — disincentivising input investment.

IRRIGATION SYSTEMS

- **Canal irrigation:** dominant in Punjab-Haryana doabs (Bhakra-Nangal, Sirhind, Indira Gandhi Canal systems); structured, assured supply.
- **Tube-well irrigation:** dominant in UP and Bihar; exploits the high-water table of the alluvial aquifer — but has driven the groundwater crisis.
- **Tanks:** largely **absent** in the Northern Plains — the porous alluvium and high-water table make wells far more practical than surface-water impoundment (unlike the Peninsular India tank belt).

The eastern Green Revolution / BGREI: Recognising the underperformance of eastern India despite natural potential, the government launched **Bringing Green Revolution to Eastern India (BGREI, 2010)** focusing on paddy productivity in Bihar, eastern UP, West Bengal, Odisha, Jharkhand and Chhattisgarh — the second-generation food-security imperative.

3.8 POPULATION & URBANISATION

The Northern Plains are the **most densely populated physiographic region of India** — the product of millennia of agrarian settlement on fertile alluvium. Among the plain's states, **Bihar recorded the highest population density in India at 1,106 persons/sq km (Census 2011)**, followed by West Bengal (1,028/sq km) and Uttar Pradesh (829/sq km), against a national average of 382/sq km.

CITIES AND THEIR RIVERS

City	*River*	*Economic/Historical Significance*
Delhi	Yamuna	National capital; seat of power since medieval era
Prayagraj (Allahabad)	Ganga-Yamuna confluence (Sangam)	Sacred; Kumbh Mela; judiciary hub

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Varanasi (Kashi)	Ganga	One of world's oldest continuously inhabited cities; Hindu pilgrimage
Kanpur	Ganga	Industrial city; leather/tannery cluster (major Ganga polluter)
Lucknow	Gomti	State capital UP; Nawabi heritage
Patna	Ganga	Bihar capital; ancient Pataliputra
Kolkata	Hugli (Hooghly)	Former colonial capital; port city; jute/trade

The **Bihar–eastern UP–West Bengal corridor** is India's largest source region of **inter-state rural-to-urban out-migration** — driven by the agrarian productivity gap, fragmented landholdings, recurrent floods and limited non-farm employment. Migrants flow to Delhi, Punjab, Maharashtra and Gujarat, making the plains simultaneously the most densely populated *rural* zone and a major origin of urban migrants.

3.9 ENVIRONMENTAL ISSUES

The Northern Plains face a **converging environmental crisis** — a paradox of the world's most productive agricultural region simultaneously suffering groundwater collapse, recurrent floods, severe river pollution and chronic air pollution. These crises share a common root: **the ecological carrying capacity of the plains is being systematically exceeded.**

GROUNDWATER DEPLETION — THE NORTHWEST CRISIS

Paddy cultivation in **Punjab and Haryana** — sustained by subsidised electricity driving tube-well pumping — consumes **far more groundwater than monsoon recharge can replenish**. Water tables are falling at **0.5–1 m per year** in over-exploited blocks.

ENV ALERT

GRACE Satellite Evidence: The landmark Rodell, Velicogna & Famiglietti study (*Nature*, 20 August 2009) found groundwater in Rajasthan, Punjab and Haryana declining at **4.0 ± 1.0 cm/yr of equivalent water height — a net loss of 109 km³ over August 2002–October 2008**. Monitoring continues via GRACE-FO (launched May 2018), a joint NASA–GFZ Potsdam mission. Recent (2022–23) studies continue to confirm sustained Indo-Gangetic groundwater mass loss.

WATERLOGGING & SOIL SALINITY

Canal over-irrigation **without sub-surface drainage** raises water tables, causing **waterlogging**. Capillary rise then deposits salts (*reh*) at the surface, creating **usar/kallar saline-alkaline patches** — a productivity-destroying paradox alongside groundwater mining just a few districts away.

RIVER POLLUTION

- **Ganga:** heavily polluted by **tannery effluents (chromium) from Kanpur**, untreated municipal sewage from Varanasi, Prayagraj, Patna and other riverside cities, and industrial discharge.
- **Yamuna:** the **Delhi–Agra stretch** is among India's most polluted river reaches — extremely low dry-season dilution flow, massive sewage input, foamy surface (phosphate detergents).
- **Gangetic dolphin (*Platanista gangetica*)**: India's national aquatic animal; critically sensitive to river pollution, sand mining and barrages — a **flagship conservation species (IFoS flag)**.

FLOOD VULNERABILITY

- **Kosi / Gandak / Ghaghara (Bihar):** recurrent channel avulsion and embankment breaches cause severe north-Bihar flooding almost every year. The 2008 Kusaha breach was catastrophic.
- **Brahmaputra / Barak (Assam):** annual valley-wide flooding inundates **Kaziranga National Park** — rhinos and other wildlife attempt to flee to uplands along NH-37, facing vehicle strikes. The 2022 and 2023 floods were particularly severe (**IFoS flag**).

SAND MINING & RIVERBED DEGRADATION

Illegal in-stream **sand and gravel extraction** from the Ganga, Yamuna and Sone rivers **deepens channels, destabilises banks, fragments riparian habitat** and threatens the Gangetic dolphin and gharial. It also undermines bridge foundations — posing infrastructure and safety risks.

AIR POLLUTION — THE IGP AIRSHED

The Indo-Gangetic Plain is **one of the world's most air-polluted regions**. Delhi and many plains cities routinely record extreme PM2.5 levels in winter. The principal drivers:

- **Post-kharif paddy stubble (parali) burning:** massive October-November plumes from Punjab and Haryana fields.
- **Vehicular, industrial and biomass emissions:** year-round base load.
- **Winter temperature inversions:** the Himalayan wall to the north prevents northward dispersal of pollutants, trapping them in the basin. Cold, stable winter air masses suppress vertical mixing — pollutant concentrations spike.

3.10 CONSERVATION & GOVERNMENT INITIATIVES

Namami Gange Programme

Launched **June 2014** as India's flagship river-cleaning initiative; initial outlay **₹20,000 crore (2015–2020)**, extended to 2026 (₹22,500 crore additionally). Implemented by the **National Mission for Clean Ganga (NMCG)** under the National Ganga Council. Five pillars: sewage-treatment infrastructure, riverfront/ghat development, afforestation, biodiversity conservation (dolphin, turtles) and industrial-effluent monitoring.

National Waterway-1 (NW-1) / Jal Marg Vikas Project

The **Ganga–Bhagirathi–Hooghly stretch from Prayagraj to Haldia (1,620 km)** — India's longest national waterway. Developed through the **Jal Marg Vikas Project (₹5,369 crore, World Bank-aided, IWAI)** with multimodal terminals at Varanasi, Sahibganj and Haldia. Aims to shift freight off overburdened roads and railways — reducing logistics costs and emissions.

PM Krishi Sinchayee Yojana (PMKSY, 2015)

Mottos **"Har Khet Ko Pani"** (piped irrigation to every field) and **"Per Drop More Crop"** (micro-irrigation efficiency). Targets irrigation deficit in eastern India while simultaneously reducing water wastage in the northwest through drip and sprinkler adoption.

Punjab Preservation of Subsoil Water Act, 2009

A landmark demand-side groundwater law: **bars paddy nursery-sowing and transplanting before a state-notified date** (aligned to monsoon onset, typically mid-June), preventing pre-monsoon groundwater depletion. Haryana enacted a parallel law. This reduced groundwater extraction by millions of cubic metres but its implementation faces enforcement challenges.

Commission for Air Quality Management (CAQM, 2021)

Established as a **statutory authority under the CAQM Act, 2021** — replacing the ad-hoc EPCA. Covers NCR and adjoining areas; issues annual directions on **stubble-burning control (farm machinery, bio-decomposer, Happy Seeder subsidies)**, GRAP (Graded Response Action Plan) enforcement, industrial compliance and vehicular standards.

Jal Jeevan Mission (JJM, 2019)

Aims to provide **piped tap water to every rural household by 2024**. The plains states — UP (largest absolute target), Bihar, West Bengal — showed significant progress in coverage; Bihar and West Bengal lagged the national average. **Reducing dependence on contaminated groundwater** is the key public health outcome in the arsenic- and fluoride-affected plains districts.

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3.11 CURRENT AFFAIRS HOOKS (2021–2025)

CURRENT AFFAIRS	**Namami Gange 2023–24 progress:** continued commissioning of sewage-treatment capacity and river-front development; Dolphin Census 2022 recorded a modest rise in Gangetic dolphin numbers (confirm exact figures with NMCG). NMCG extended to 2026 with additional budget. **GRACE-FO groundwater studies (2022–23):** continued satellite confirmation of sustained Indo-Gangetic groundwater mass loss; peer-reviewed papers in Science/Nature Geoscience consistently flag the NW India crisis. Use with the 2009 Rodell et al. baseline figure. **Assam floods 2022 & 2023:** severe Brahmaputra-Barak valley flooding affecting millions across 30+ districts; annual Kaziranga inundation causes wildlife mortality and vehicle strikes on NH-37. A powerful IFoS answer example. **Bihar floods 2022–2024:** recurrent Kosi, Gandak and Bagmati flooding; 2024 saw high Kosi discharges from Birpur barrage. Reinforces the embankment-vs-floodplain debate. **Eastern Dedicated Freight Corridor (EDFC):** Ludhiana (Sahnewal)–Sonnagar core commissioned by 2023–24 (DFCCIL); transforms logistics across the plains. Use in GS-3 (infrastructure, economic geography) answers. **CAQM stubble-burning orders (2023–24):** strengthened enforcement of in-situ residue management; Happy Seeder and bio-decomposer adoption tracked; real-time fire-count monitoring via satellite (ISRO/NASA FIRMS). **Jal Jeevan Mission (progress 2024):** approaching national coverage targets; north-Indian plains states show mixed progress (verify on ejalshakti.gov.in). **Saraswati river revival (Haryana):** Adi Badri water-release project and canal works; channel excavation in Haryana continues the geo-archaeological debate.

3.12 PYQ ANALYSIS — CHAPTER 3 (2010–2025)

Questions from UPSC Civil Mains GS-1/GS-3 and IFoS GS directly testing themes of this chapter:

Source	Year	Marks	Question
UPSC Civil	2025	15M	"Discuss distribution and density of population in the Ganga River Basin with special reference to land, soil and water resources."
UPSC Civil	2014	10M	"Why did the Green Revolution in India virtually bypass the eastern region despite fertile soil and good availability of water?"
UPSC Civil	2010	12M	"Describe the Green Revolution and its impact on regional disparities in India."
UPSC Civil	2024	15M	"The groundwater potential of the Gangetic valley is on a serious decline. How may it affect the food security of India?"
UPSC Civil	2019	15M	"What is water stress? How and why does it differ regionally in India?"
UPSC Civil	2018	15M	"The ideal solution of depleting ground water resources in India is water harvesting system. How can it be made effective in urban areas?"
UPSC Civil	2015	12M	"India is well endowed with fresh water resources. Critically examine why it still suffers from water scarcity."
UPSC Civil	2020	15M	"The interlinking of rivers can provide viable solutions to the multi-dimensional problems of droughts, floods and navigation. Critically examine."
UPSC Civil	2011	12M	"Discuss the problems and prospects of inter-linking of rivers in India."
UPSC Civil	2016	12M	"Major cities of India are becoming vulnerable to flood conditions. Discuss."
IFoS GS	2014	12M	"What are wetlands? Discuss their importance."
IFoS GS	2020	10M	"Briefly explain the physiological, agricultural and population densities of India. How are they different from each other?"

KEY NOTE

Frequency pattern: The Ganga/groundwater/water-stress cluster is the most frequently examined in GS-1 and GS-3 combined. Green Revolution and eastern disparity recur every 3–4 years. Wetlands and biodiversity are IFoS favourites. Floods (Kosi, Brahmaputra) and the interlinking debate appear in both. Prioritise: Green Revolution disparity, groundwater depletion (with GRACE data) and the Bhabar-Terai-Bhangar-Khadar descriptive framework.

3.13 MODEL QUESTION

Discuss the distribution and density of population in the Ganga River Basin with special reference to land, soil and water resources.

UPSC Civil (Mains) 2025 | GS-1 | 15 Marks | 200 Words

The Ganga River Basin — the heart of the Indo-Gangetic Plain — supports the **highest population densities in India**: Bihar (1,106/sq km), West Bengal (1,028/sq km) and UP (829/sq km) per Census 2011. This **demographic concentration** is a direct function of land, soil and water endowments.

LAND

- **Level, extensive terrain:** flat alluvial plain eases settlement, mechanised farming and transport — raising **agricultural carrying capacity** and rural density.

SOIL

- **Alluvial soil fertility:** Khadar (annually renewed) and Bhangar soils — rich in potash/lime — support intensive multi-cropping. The **Indo-Gangetic Plain** produces the majority of India's wheat and a large share of its rice.

WATER

- **Perennial rivers:** the Ganga, Yamuna, Ghaghara, Gandak and Kosi provide year-round irrigation via canals and recharge shallow alluvial aquifers — enabling **Green Revolution** productivity in the upper basin (Punjab, Haryana, W. UP) and sustaining dense agrarian populations eastward.
- **Eastward water paradox:** abundant water and fertile Khadar in Bihar coexist with **recurrent flooding (Kosi, Gandak)**, irrigation unreliability and poor infrastructure — producing high density but lower prosperity and high out-migration.

EMERGING STRESS

Severe **groundwater depletion** (NW India losing ~4 cm/yr, GRACE data), waterlogging/salinity and river pollution now threaten the basin's **agricultural carrying capacity** — demanding PMKSY, Namami Gange and the BGREI second Green Revolution as correctives.

Population density in the Ganga Basin mirrors the land–soil–water triad; sustaining it requires **efficient irrigation, groundwater governance and eastern agricultural transformation.**

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CHAPTER 4

THE PENINSULAR PLATEAU

CHAPTER AT A GLANCE

- Peninsular Plateau: ~16 lakh sq km, triangular, 600–900 m altitude; one of Earth's oldest Archaean cratons (~3.5 Ga); a Gondwanaland fragment.
- Three geological episodes: Archaean basement (metallic minerals) + Gondwana basins (~98% of India's coal) + Deccan Trap (~66 Ma basalt → Regur soil).
- Six physiographic divisions: Aravalli, Malwa/Bundelkhand/Vindhya/Satpura (Central Highlands), Chhota Nagpur Plateau, Deccan Plateau, Western Ghats, Eastern Ghats.
- Narmada & Tapi flow WEST (rift valleys/grabens) — anomalous among peninsular rivers; all others flow east due to the eastward tilt of the plateau.
- Chhota Nagpur = "Ruhr of India": Jharia coal, Singhbhum iron ore, DVC, Tata Steel/Jamshedpur; Gondwana coal-bearing rocks.
- Deccan Trap → black cotton soil (Regur, montmorillonite clay) → cotton, jowar, sugarcane; basalt aquifers, construction material.
- Western Ghats: UNESCO World Natural Heritage Site (2012); global biodiversity hotspot; Anamudi (2,695 m); shola forests; lion-tailed macaque, Nilgiri tahr, purple frog.
- Key conflicts: Western Ghats ESA (Kasturirangan Committee), Niyamgiri/Vedanta bauxite, Goa iron ore ban, J&K lithium (5.9 Mt, GSI 2023), Sukinda chromite pollution.

4.1 INTRODUCTION — THE ANCIENT SHIELD

The Peninsular Plateau is the geological nucleus of the Indian landmass — a vast, ancient, stable **Archaean craton** that has remained tectonically inert for hundreds of millions of years while the Himalayas rose and the Northern Plains accumulated around it. It is one of **Earth's oldest stable shields (~3.5 Ga)**, composed dominantly of Precambrian gneiss, schist and granite, and it is a surviving fragment of the supercontinent **Gondwanaland**. In three defining characteristics: it is the **oldest landform** in India, the **richest mineral storehouse** of the country, and the creator of profound **rain-shadow effects** through its bounding mountain ranges.

The plateau covers approximately **16 lakh sq km (~1.6 million sq km)** in a broadly **triangular shape** — base along the Vindhya–Satpura system in the north, apex pointing southward toward Kanyakumari. Its general elevation ranges from **600–900 m above sea level**, sloping gently eastward — a tilt that controls the direction of its major rivers. The surface is an ancient **peneplain** — repeatedly worn flat by erosion — dotted with residual hills (monadnocks/inselbergs) of exceptionally hard Archaean rock.

KEY NOTE

Boundaries : West — Western Ghats (Sahyadri); East — Eastern Ghats; North — Vindhya–Satpura ranges and the Aravalli system (separating it from the Indo-Gangetic Plain); South — narrows to a point at Kanyakumari where Arabian Sea and Bay of Bengal meet.

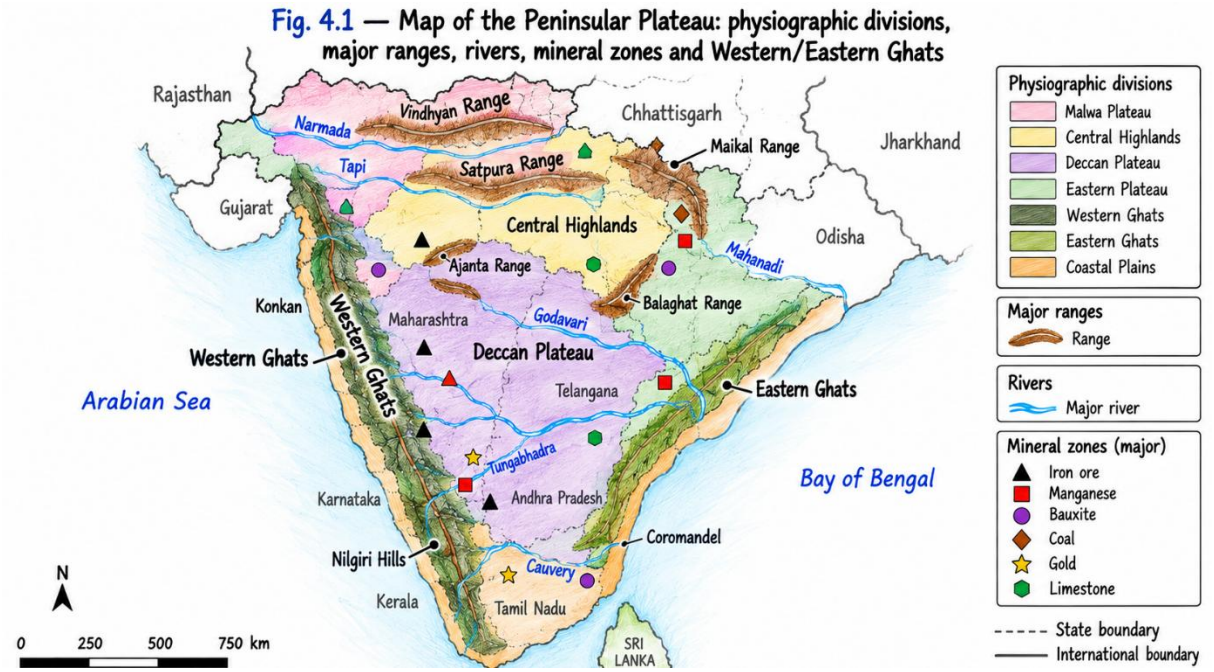


Fig. 4.1 — Map of the Peninsular Plateau: physiographic divisions, major ranges, rivers, mineral zones and Western/Eastern Ghats

4.2 GEOLOGICAL ORIGIN — GONDWANALAND'S LEGACY

The Peninsular Plateau's resource wealth and tectonic character are products of **three distinct geological episodes** spanning 3.5 billion years — together forming one of the most geologically layered terrains on Earth.

EPISODE 1 — ARCHAEAN CRATON (~3.5 GA): METALLIC MINERAL FOUNDATION

The foundation of the plateau is an ancient **Archaean craton composed of gneiss, schist and granite** — one of Earth's oldest stable crustal blocks. Once part of Gondwanaland, this block drifted north on the Indian Plate and ultimately collided with Eurasia to raise the Himalayas. The **Archaean and Dharwar–Cuddapah rock systems** host India's major metallic minerals — iron ore, manganese, copper, gold, bauxite and chromite — concentrated in the **north-eastern Peninsular shield (Jharkhand–Odisha–Chhattisgarh–Karnataka belt)**.

EPISODE 2 — GONDWANA ROCK SYSTEM (~300–150 MA): COAL WEALTH

During the Permo-Carboniferous to Jurassic period, thick **sedimentary sequences accumulated in fault-bounded river basins** on the drifting Indian plate. These **Gondwana sediments** now host approximately **98% of India's coal reserves**, concentrated in the **Damodar, Mahanadi, Godavari and Son river valleys** of Jharkhand, Chhattisgarh, Odisha and MP. Gondwana coal (Permian age) is superior in quality to India's limited Tertiary coal.

EPISODE 3 — DECCAN TRAP BASALT (~66 MA): AGRICULTURAL LEGACY

At the Cretaceous–Paleocene boundary (~66 Ma), as the Indian Plate traversed the **Réunion mantle hotspot**, vast fissure eruptions produced the **Deccan Traps — one of Earth's largest Large Igneous Provinces (LIPs)**. Basalt covers ~500,000 sq km today (original extent estimated >1.5 million sq km) across Maharashtra, Karnataka, MP and Gujarat. Weathering of this basalt in the tropical wet-dry climate produces **black cotton soil (Regur)** — the agricultural foundation of the Deccan.

UPSC CIVIL

"Despite India being one of the countries of the Gondwanaland, its mining industry contributes much less to its GDP in percentage. Discuss." [UPSC Civil (Mains) 2021 | GS-1 | 10M]

Analytical framework : Geological endowment ≠ economic output. Rich Gondwana + Archaean endowment, but: (i) dominance of services in GDP; (ii) environmental clearance and land-acquisition constraints; (iii) tribal/forest-area regulatory overlap; (iv) under-exploration of deep deposits; (v) raw-ore export vs value addition; (vi) critical mineral import dependence. The three geological episodes above explain **why the endowment exists**; the structural factors explain why it is underutilised.

INTRAPLATE SEISMICITY — THE LATUR EXCEPTION

While the craton is broadly stable, **intraplate earthquakes** can occur through reactivation of ancient buried faults under far-field tectonic stresses. The devastating **Latur (Killari) earthquake of 30 September 1993 in Maharashtra** (Mw 6.2, focal depth ~6.8 km) killed **7,928 people** and injured ~30,000 — shocking seismologists who had considered this region aseismic. It exemplifies the principle that **Stable Continental Regions (SCRs) are not immune to damaging earthquakes**, though they are less frequent than at active plate margins.

4.3 PHYSIOGRAPHIC DIVISIONS — OVERVIEW

Division	*Sub-units*	*Key Character*	*Economic Significance*
Central Highlands	Aravalli, Malwa, Bundelkhand, Baghelkhand, Vindhya, Satpura	Eroded plateaus, block mountains, rift valleys	Chambal ravines, Narmada-Tapi rivers, Pachmarhi forests
Chhota Nagpur Plateau	Jharkhand-Chhattisgarh-Odisha border	Archaean gneiss + Gondwana coal	"Ruhr of India" — coal, iron, DVC, Tata Steel
Deccan Plateau proper	Maharashtra, Karnataka, Telangana, Andhra plateaus	Deccan Trap basalt / Archaean granite	Cotton, jowar, sugarcane on Regur; coffee, silk
Western Ghats (Sahyadri)	N. Sahyadri, Nilgiris, Anamalai, Cardamom Hills	Continuous horst; highest escarpment of S. India	Biodiversity hotspot, HEP, spices, tourism
Eastern Ghats	Discontinuous ranges: Odisha to Tamil Nadu	Dissected by rivers; lower and older	Bauxite (contested), tribal forests
Aravalli Range	Gujarat to Delhi (800 km)	Oldest fold mountains; erosional remnants	Mineral pockets; rain shadow (Thar)

4.4 THE ARAVALLI RANGE

The Aravallis are the **oldest fold mountains in India** — Precambrian in age (conventionally cited at ~570 Ma; underlying crustal events may be much older). They trend **NE-SW for ~800 km from Gujarat through Rajasthan to Delhi**, making them a defining physiographic feature of north-west peninsular India.

- **Highest peak: Guru Shikhar (1,722 m)** on Mount Abu, Sirohi district, Rajasthan — the highest point in the Peninsular Plateau west of the Eastern Ghats.
- **Rain shadow effect:** the Aravallis intercept moisture from the Arabian Sea branch of the SW monsoon, leaving the Thar Desert to the west starved of rainfall — a direct Aravalli-Desert causal linkage.
- **Erosional remnants:** heavily eroded into monadnocks (inselbergs), residual hills and rocky ridges — a mature erosion landscape.
- **Watershed function:** divides the Ganga–Yamuna drainage (east) from the Indus–Luni drainage (west).
- **Historical significance:** natural barrier; seat of Rajput strongholds — Chittorgarh, Kumbhalgarh, Ranthambore.

KEY NOTE

Malwa & Chambal : South of the Aravallis lies the **Malwa Plateau** — drained northward by the Chambal, Betwa and Ken rivers (Yamuna tributaries). The Chambal ravines (badlands) are one of India's most severe land-degradation zones — formed by gully erosion of soft alluvial-plateau soils. East of this lies the **Bundelkhand Plateau** on ancient Archaean granite-gneiss, characterised by eroded relief.

4.5 THE VINDHYA & SATPURA RANGES

VINDHYA RANGE — THE GREAT DIVIDE

The Vindhya is a **block mountain (horst)** with a prominent **north-facing fault scarp**, trending E-W. It is the traditional physiographic and cultural boundary between **northern (Aryan) India and the Deccan**. The Vindhyas

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divides the Ganga basin from the Narmada-Deccan drainage. They are composed of sandstone and limestone (Vindhyan sedimentary system, ~1.4–0.6 Ga).

SATPURA RANGE

The Satpura lies between the **Narmada (north) and Tapi (south) rift valleys**, trending E-W parallel to them. **Dhupgarh (1,350 m)** near Pachmarhi is the highest point — both of the Satpura and of Madhya Pradesh. Pachmarhi (MP's only hill station) sits in a Satpura valley and hosts the **Pachmarhi Biosphere Reserve** — an important sal and mixed-forest conservation landscape (**IFoS flag**).

NARMADA & TAPI — THE RIFT VALLEY RIVERS (KEY UPSC TOPIC)

The **Narmada** and **Tapi (Tapti)** are the **two major west-flowing peninsular rivers** — anomalous among their eastward-flowing counterparts.

- **Why they flow WEST:** both follow E-W trending **rift valleys (grabens)** — down-faulted crustal blocks that slope westward — between uplifted horst blocks (Vindhya to the north; Satpura between them; Deccan Trap to the south). This rift/graben structure pre-determines a westward drainage direction, overriding the general eastward plateau tilt.
- **Narmada:** flows ~1,312 km through the rift valley between Vindhya (north) and Satpura (south); debouches into the Gulf of Khambhat; forms an estuary, NOT a delta.
- **Tapi:** ~724 km; flows through the rift between Satpura (north) and Ajanta-Satmala ranges (south); also debouches into the Gulf of Khambhat as an estuary.
- **No deltas:** both rivers are short relative to their catchment and reach the sea quickly, depositing in estuaries rather than building extensive deltas.

UPSC CIVIL

UPSC Prelims Tip : "Why does the Narmada flow westward?" is a perennial MCQ.
Answer : it flows along an E-W rift valley (graben) between the Vindhya and Satpura block mountains. Contrast with east-flowing Godavari/Krishna which follow the plateau's eastward tilt.

4.6 THE CHHOTA NAGPUR PLATEAU — "RUHR OF INDIA"

The Chhota Nagpur Plateau — straddling Jharkhand, Chhattisgarh and Odisha — is India's richest mineral belt. Its geology combines **ancient Archaean gneiss and granite** with **Gondwana coal-bearing sedimentary sequences**, producing an unmatched concentration of energy and metallic minerals. The dense industrial complex built upon this wealth — steel at Jamshedpur and Bokaro, coal at Jharia, power through the DVC — earned it the sobriquet **"Ruhr of India"** after Germany's industrial heartland.

MINERAL INVENTORY

Mineral	*Key Locations*	*Significance*
Coal (Gondwana)	Jharia, Bokaro, Giridih, Ramgarh (Jharkhand); Ib-valley (Odisha)	Jharia = India's largest coking-coal reserve; Jharia coal fires (century-old underground fires)
Iron Ore	Singhbhum (Jharkhand); Keonjhar-Sundargarh (Odisha)	High-grade haematite; feeds Tata Steel Jamshedpur and Bokaro Steel
Manganese	Bonai (Odisha); Balaghat (MP)	Steel alloy; ferro-manganese production
Mica	Hazaribagh, Koderma (Jharkhand)	Electrical insulation; historically one of world's largest producers
Copper	Singhbhum — Mosaboni, Rakha mines	Limited reserves; Hindustan Copper Ltd operations
Bauxite	Lohardaga, Gumla (Jharkhand)	Aluminium production; Nalco, Hindalco feedstock

DAMODAR VALLEY & DVC

The **Damodar Valley Corporation (DVC)** — established **1948**, India's first multipurpose river valley project — was modelled on the **Tennessee Valley Authority (TVA)** of the USA. It integrates **flood control, irrigation,**

hydropower and thermal power across the Damodar and Barakar rivers. The valley hosts thermal power stations at Bokaro, Chandrapura and Durgapur, and the **Jamshedpur steel complex (Tata Steel)** — India's first integrated steel plant — lies just south of the plateau.

IFoS FOCUS

IFoS Focus — Tribal Ecology & Forest Rights : The Chhota Nagpur Plateau is home to Santhal, Munda, Oraon and Ho tribal communities, many practising the Sarna nature-worship faith. Mining-driven displacement makes the **Forest Rights Act, 2006 (FRA)** and **Particularly Vulnerable Tribal Groups (PVTGs)** policy central issues. Saranda forest (West Singhbhum) — Asia's largest *Shorea robusta* (sal) forest — sits atop major iron-ore reserves, epitomising the mining-versus-forest-rights tension that IFoS exams repeatedly test.

4.7 THE DECCAN TRAP

At the **Cretaceous–Paleocene boundary (~66 million years ago)**, the Indian Plate's passage over the **Réunion mantle hotspot** triggered one of Earth's largest **Large Igneous Province (LIP)** flood-basalt events. Vast volumes of basaltic lava poured through fissures in sub-horizontal flows, building a **step-like (trap) landscape** — the word "trap" deriving from a Scandinavian term for "step" — visible in the staircase-like scarps of the Western Ghats.

Key Facts — Deccan Trap

- **Extent:** ~500,000 sq km exposed today across Maharashtra, Karnataka, MP, Gujarat (parts of Chhattisgarh and Andhra Pradesh); original extent estimated >1.5 million sq km before erosion.
- **Thickness:** basalt flows up to ~2,000 m thick near the Western Ghats; thins eastward.
- **K-Pg debate:** Deccan eruptions coincided with the end-Cretaceous mass extinction at ~66 Ma; their role alongside the Chicxulub asteroid impact is actively debated in science journals.

Weathering Chain → Black Cotton Soil (Regur)

In the tropical wet-dry climate, Deccan basalt weathers through the sequence:

- **Basalt → laterite** on upland surfaces (upland hilltops, high rainfall areas).
- **Basalt → Regur (black cotton soil)** in lower-lying basins and plains under seasonal wet-dry conditions.

Property	*Regur (Black Cotton Soil) Details*
Mineral composition	Montmorillonite clay (a 2:1 expanding lattice clay) — the defining mineral
Behaviour	Swells and becomes sticky/waterlogged when wet; develops deep cracks (self-mulching) when dry
Fertility	Naturally fertile; moisture-retentive; rich in calcium, magnesium, potash, lime but deficient in N and P
Best crops	Cotton (primary), Jowar (sorghum), Sugarcane, Wheat, Linseed
Region	Maharashtra Deccan, Marathwada, Vidarbha, Karnataka plateau, MP Malwa edge
Challenge	Difficult to till (sticky/cracking); waterlogging risk; Vidarbha cotton-farmer distress

RESOURCE POTENTIALS OF THE DECCAN TRAP

- **Agricultural:** Regur soil supports Maharashtra's cotton (Vidarbha), sugarcane (western Maharashtra) and jowar — the Deccan's agricultural identity is defined by this soil.
- **Construction material:** hard, durable basalt is extensively quarried for road metal, building stone and railway ballast.
- **Groundwater:** vesicular and fractured zones within the basalt serve as **phreatic aquifers**, providing groundwater storage in an otherwise semi-arid plateau — vital for drinking water and irrigation in Marathwada and Vidarbha.

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- **Tourism & scenic value:** the step-like Sahyadri scarps, waterfalls (Dudhsagar, Jog on the western slope) and hill stations generate eco-tourism.
- **Inter-trappean minerals:** zeolites and secondary silica/agate mineralisation in inter-trappean beds (between lava flows) have gem and industrial mineral value.

IFoS FOCUS

"Discuss the natural resource potentials of the 'Deccan Trap'." [UPSC Civil (Mains) 2022 | GS-1 | 10M]
— Use the five resource categories above (soil/agriculture, construction, groundwater, tourism, minerals). Open with the LIP formation context, close with Vidarbha distress as a contemporary challenge. See Model Answer in Section 4.14.

4.8 WESTERN GHATS (SAHYADRI)

The Western Ghats form a **near-continuous escarpment ~1,600 km long** running parallel to India's west coast from the Tapi mouth in the north to Kanyakumari in the south. Geologically, the Ghats are a **classic horst** — a crustal block uplifted along faults as the western margin of the Indian peninsula rifted when Madagascar/Seychelles separated in the Mesozoic. They are the **principal watershed of Peninsular India**: east-flowing rivers (Godavari, Krishna, Cauvery) rise on their eastern slopes, while short, steep west-flowing streams (Sharavathi, Periyar, Mandovi) descend rapidly to the Arabian Sea.

KEY PEAKS

Peak	*Height*	*Location*	*Note*
Anamudi	2,695 m	Idukki/Ernakulam, Kerala	Highest in Peninsular & South India
Doddabetta	2,637 m	Nilgiris, Tamil Nadu	Highest in Nilgiris
Mukurthi (Makurti)	~2,554 m	Nilgiris, Tamil Nadu	Nilgiri tahr habitat; Mukurthi NP
Kudremukh	~1,894 m	Chikkamagaluru, Karnataka	Iron ore deposits; National Park
Kalsubai	1,646 m	Ahmednagar, Maharashtra	Highest peak in Maharashtra Sahyadri

CLIMATE FUNCTIONS

- **Orographic rainfall:** the Western (windward) slopes receive **2,000–6,000+ mm annually** as the SW monsoon is forced to rise; Agumbe (Karnataka) and Mahabaleshwar (Maharashtra) are among India's rainiest stations.
- **Rain shadow:** the leeward eastern slopes and the Deccan interior receive significantly less rainfall (500–800 mm in parts of Karnataka-Telangana) — creating the semi-arid Deccan interior.
- **Palakkad (Pal Ghat) Gap:** a ~30 km wide low pass in the Ghats at ~300 m altitude in Kerala — the widest gap, funnelling monsoon winds and providing the primary transport corridor (road and rail) between Kerala and Tamil Nadu.

BIODIVERSITY — UNESCO WORLD NATURAL HERITAGE SITE (2012)

The Western Ghats are one of the world's **36 biodiversity hotspots** and were inscribed as a **UNESCO World Natural Heritage Site in 2012** comprising **39 serial properties** across six states (Gujarat, Maharashtra, Goa, Karnataka, Kerala, Tamil Nadu). The region's **exceptional endemism** — arising from its isolation as an ancient tropical refuge — makes it a global conservation priority.

- **Endemic fauna:** Lion-tailed macaque (*Macaca silenus*), Nilgiri tahr (*Nilgiritragus hylocrius*), Malabar large-spotted civet, Nilgiri langur, Indian gaur, **Purple frog** (*Nasikabatrachus sahyadrensis*) — a "living fossil" of a 70-Ma Gondwanan lineage; Kerala's state amphibian.
- **Endemic flora:** hundreds of orchid species; Myristica (nutmeg) swamps; dense evergreen forests.
- **Shola forests (IFoS flag):** montane tropical forest-grassland mosaic above ~1,500 m in the Nilgiris, Anamalai and Palani hills; ecologically fragile; increasingly fragmented by exotic plantation species (eucalyptus, acacia, wattle).

- **Protected areas:** Nilgiri Biosphere Reserve (India's first BR, 1986; UNESCO MAB, 2000); Periyar TR; Anamalai (Indira Gandhi) TR; Silent Valley NP; Kudremukh NP.

IFoS FOCUS

IFoS Biodiversity Tip : For any Western Ghats question pair: (1) biodiversity hotspot status + endemism figures, (2) shola fragmentation by exotic plantations, (3) ESA/Kasturirangan conflict. The Purple frog is a powerful exam-differentiating fact — a Gondwana relic discovered only in 2003, exemplifying why the Ghats are a living museum of ancient lineages.

4.9 EASTERN GHATS

The Eastern Ghats are a **discontinuous series of hills and ranges** running roughly NE-SW parallel to India's eastern coast from Odisha to Tamil Nadu — in stark contrast to the continuous Western Ghats. The key distinction and the most frequently tested fact is **why they are discontinuous: the major peninsular rivers — Mahanadi, Godavari, Krishna, Penner and Cauvery — cut transversely through them**, breaking their continuity into isolated hill ranges separated by river valleys.

Feature	*Western Ghats*	*Eastern Ghats*
Continuity	Near-continuous, ~1,600 km	Discontinuous — broken by rivers
Height	Higher; Anamudi 2,695 m	Lower; highest ~1,690 m
Origin	Horst (uplifted block along rift)	Eroded fold mountains (gneiss, khondalite)
Rainfall (windward)	2,000–6,000+ mm (west face)	Less orographic rainfall (Bay of Bengal side)
Biodiversity	Global hotspot; UNESCO WHS (2012)	Significant but not formally a hotspot
Key feature	Rain-shadow; shola forests; endemism	River gaps; bauxite deposits; tribal communities
Rivers	Short west-flowing streams (Sharavathi, Periyar)	Major peninsular rivers cut through (Godavari, Krishna)

The Eastern Ghats are home to **Kondhs, Saoras, Bondas and Gonds** — tribal communities with a distinctive forest-based culture and active forest-rights claims. The **Niyamgiri hills (Odisha)** — home to the Dongria Kondh — contain major bauxite deposits coveted by mining interests, making the **Niyamgiri/Vedanta case (2013 gram-sabha verdict)** a landmark precedent for **community forest rights under the FRA 2006**.

4.10 MAJOR RIVERS OF THE PENINSULAR PLATEAU

Peninsular rivers differ fundamentally from Himalayan rivers in **origin, behaviour and economic use**. They are **rain-fed and seasonal (non-perennial)**, flowing in fixed rocky channels that do not meander like plains rivers, and draining predominantly eastward.

Feature	*Himalayan Rivers*	*Peninsular Rivers*
Source	Glaciers + snow + rain (perennial)	Rainwater only (seasonal)
Course	Meanders on soft alluvial plains	Fixed; incised in hard rock; does not meander
Flow direction	Generally east (some west-Indus system)	Mostly EAST; exceptions: Narmada, Tapi (WEST)
Delta/Estuary	Large deltas (Ganga-Brahmaputra)	East-coast deltas (Godavari, Krishna); west-coast estuaries (Narmada, Tapi)
Flood pattern	Perennial risk; bed aggradation	Monsoon-season only; some flash flooding
Irrigation use	Perennial canal irrigation	Seasonal; tank/reservoir-dependent

WHY EAST-FLOWING RIVERS BUILD DELTAS — WHY WEST-FLOWING DO NOT

- **East-flowing (Mahanadi, Godavari, Krishna, Cauvery):** traverse the broad, gentle eastern slope; long

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journey deposits heavy sediment in the **shallow Bay of Bengal → wide, fertile deltas** (Krishna and Godavari deltas are major rice bowls).

- **West-flowing (Sharavathi, Periyar, Mandovi):** short, steep, high-velocity rivers descend rapidly; **no time/space to build deltas; form rias/estuaries** on the narrow west coast.
- **Narmada & Tapi (exceptions):** west-flowing rift-valley rivers; **form estuaries at the Gulf of Khambhat**, not deltas.

KEY NOTE

Key river facts for Prelims : Godavari = largest peninsular river (1,465 km); Cauvery = most litigated/regulated (TN-Karnataka dispute); Mahanadi = Odisha's "Sorrow" (before Hirakud Dam); Narmada = India's longest west-flowing river. Detailed coverage in Chapter 9.

4.11 NATURAL RESOURCES — THE MINERAL WEALTH

The Peninsular Plateau's three-episode geological history (Archaean + Gondwana + Deccan Trap) makes it India's **mineral treasure house**. The distribution of minerals closely follows the underlying geological map.

Category	*Mineral*	*Key Locations*	*Significance*
Ferrous	Iron Ore (haematite)	Singhbhum (Jh), Keonjhar-Sundargarh (Od), Bailadila/Dalli-Rajhara (CG), Bellary-Hospet (KA), N. Goa	India = 4th largest iron ore reserves globally
Ferrous	Manganese	Bonai (Od), Balaghat (MP), Nagpur district (MH)	Steel alloy; ferro-manganese production
Non-ferrous	Bauxite (aluminium ore)	Lohardaga-Gumla (Jh), Koraput-Kalahandi (Od), E. Ghats (AP)	Major Al production; Vedanta/Nalco nexus
Non-ferrous	Copper	Singhbhum (Jh) — Mosaboni, Rakha	Limited; Hindustan Copper Ltd
Non-ferrous	Gold	Kolar (KA) — Kolar Gold Fields	Largely exhausted; deepest mines in the world
Non-ferrous	Zinc-Lead	Zawar, Rajpura-Dariba (Rajasthan)	Hindustan Zinc Ltd (Vedanta)
Energy	Coal (Gondwana)	Jharia, Bokaro (Jh); Ib-valley (Od); Wardha (MH); Singrauli (MP)	~98% of India's coal; coking coal at Jharia
Critical	Lithium	Salal-Haimana, Reasi (J&K); Mandya (KA); Chhattisgarh	5.9 Mt inferred (GSI, Feb 2023); EV battery material
Critical	Chromite	Sukinda valley, Jajpur (Od); Boula-Nuasahi (Od)	Sukinda = among world's largest; hexavalent Cr pollution

IFoS FOCUS

IFoS 2024 — Chromite : Sukinda valley, Odisha holds the overwhelming majority (~98%) of India's chromite reserves and is among the world's largest deposits. Hexavalent chromium (Cr-VI) groundwater pollution from mining waste makes Sukinda a critical environmental hazard zone — water sources are contaminated, affecting local tribal communities. This links chromite resource value to ecological cost.

IFoS 2023 — Lithium : India's 5.9 Mt inferred lithium resource at Reasi, J&K (GSI, February 2023) is strategically critical for EV batteries. Mining lithium involves open-cast excavation in ecologically sensitive mountain terrain, high water use, toxic tailings and displacement of communities — the social-environmental cost framework IFoS examiners expect.

4.12 BIODIVERSITY & FORESTS

WESTERN GHATS CONSERVATION LANDSCAPE

- **Nilgiri Biosphere Reserve:** India's first biosphere reserve (1986) and first Indian site in UNESCO's MAB network (2000); ~5,520 sq km; includes Mudumalai, Nagarhole, Bandipur, Wayanad.
- **Periyar Tiger Reserve (Kerala):** famous for elephant population; Periyar lake ecosystem; ecotourism model.
- **Anamalai (Indira Gandhi) TR (Tamil Nadu):** lion-tailed macaque stronghold; rich biodiversity.
- **Silent Valley NP (Kerala):** saved from hydropower project in 1983 — India's early conservation success; last significant undisturbed tropical rainforest in the Western Ghats.

EASTERN GHATS & CHHOTA NAGPUR FORESTS

- **Simlipal (Odisha):** Tiger Reserve + Biosphere Reserve; sal forests; tribal communities (Santhals, Kolhs).
- **Saranda Forest (Jharkhand):** Asia's largest sal (*Shorea robusta*) forest; sits atop iron-ore reserves — the defining mining-vs-forest tension of the Chhota Nagpur Plateau (**IFoS flag**).
- **Nallamala Hills (AP-Telangana):** Nallama forests; Nagarjunasagar-Srisailam TR; Chenchu tribal community.

IFoS FOCUS

Shola Forests — IFoS Conservation Priority : Shola forests are fragile montane tropical forest-grassland mosaics above ~1,500 m in the Nilgiris-Anamalai-Palani hills. They are being fragmented by conversion to **exotic plantations (Eucalyptus, Acacia mearnsii/wattle)** which out-compete native vegetation, reduce water yields and eliminate shola-specialist fauna (Nilgiri tahr, Nilgiri pipit). This is a high-priority IFoS answer topic — always link shola fragmentation to **exotic species invasion and watershed degradation**.

4.13 ENVIRONMENTAL ISSUES

MINING-INDUCED DEFORESTATION & TRIBAL DISPLACEMENT

Open-cast coal and iron-ore mining in Jharkhand, Odisha and Chhattisgarh has caused **large-scale forest clearance and tribal displacement**. The Forest (Conservation) Act, the FRA and environmental impact assessments are routinely contested. CAMPA (Compensatory Afforestation Fund Management and Planning Authority) funds — collected from mining project developers — are meant to finance compensatory afforestation, but **compensatory plantations rarely match the ecological quality of natural forests cleared** (**IFoS flag**).

WESTERN GHATS LANDSLIDES

Steep slopes of laterite overburden on basalt, combined with **heavy concentrated monsoon rainfall** and human triggers (road-cutting, quarrying, plantation clearing), cause recurrent landslides. The **Wayanad (Mundakkai-Chooralmala) landslides of 30 July 2024** killed ~298 confirmed dead (many more missing), devastating a tea-estate region of Kerala and reigniting the **Western Ghats ESA notification debate**.

GOA IRON ORE MINING

The Supreme Court's **February 2018 ban on all iron-ore mining in Goa** — following the Goa Foundation case — halted the state's primary industry. Subsequent auctioning of mine blocks (2022–23) has sought to resume activity, but environmental compliance and carrying-capacity concerns persist.

NIYAMGIRI/VEDANTA — LANDMARK TRIBAL RIGHTS CASE

The **Dongria Kondh tribal community of Odisha's Niyamgiri hills** rejected bauxite mining by Vedanta Resources through a **series of gram sabha (village-assembly) votes in 2013** — upheld by the Supreme Court. This was the first time the **Forest Rights Act was operationalised to give tribal communities a veto over mining in their ancestral forest areas** — a landmark in the resource-extraction vs. rights-recognition debate.

VIDARBHA AGRARIAN DISTRESS

The Deccan Trap Regur zone of **Vidarbha (eastern Maharashtra)** is India's most distressed cotton-farming region. Farmer suicides driven by **debt, water variability (rain-shadow of the Eastern Ghats), high input costs and low**

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support prices have been documented since the early 2000s — making Regur soil's agricultural potential its **socio-economic vulnerability** in practice.

MARATHWADA WATER CRISIS

The semi-arid **Marathwada region** of Maharashtra depends on the Jayakwadi Dam on the Godavari. Repeated drought years (including 2023-24) have reduced reservoir levels to critically low levels, triggering water-tanker dependency, crop failures and **acute rural distress** — a consequence of the Deccan plateau's rain-shadow semi-aridity amplified by climate variability.

4.14 CURRENT AFFAIRS HOOKS (2021–2025)

CURRENT AFFAIRS	**Western Ghats ESA (Kasturirangan Committee):** The High-Level Working Group Report (April 2013) recommended ~37% of the Western Ghats (~59,940 sq km; 56,825 sq km natural landscape across 6 states) be declared an Ecologically Sensitive Area. Successive draft MoEFCC notifications (2014, 2015, 2017, 2018, 2022) have lapsed amid state objections. A fresh draft is expected post-Wayanad 2024. States want to exclude populated/cultivated zones; Centre wants to protect high-endemism areas. **J&K Lithium — GSI, February 2023:** GSI announced inferred (G3) resources of 5.9 million tonnes of lithium at Salal-Haimana, Reasi district, J&K — India's first significant lithium find. Auctions have faced technical-feasibility challenges. Also found: Karnataka (Mandya) and Chhattisgarh (Korba). KABIL (Khanij Bidesh India Limited) mandated to source lithium overseas (Argentina, Chile, Australia). **Sukinda Chromite & Pollution:** Sukinda valley, Jajpur (Odisha) — among world's largest chromite deposits. Hexavalent chromium (Cr-VI) contamination of groundwater and surface water is a chronic public health crisis for local communities. **Wayanad Landslides (30 July 2024):** Mundakkai-Chooralmala landslides in Wayanad, Kerala — ~298 confirmed dead; tea-estate workers among worst affected. Triggered Western Ghats ESA notification debate anew. **CAMPA Implementation:** CAMPA funds (collected from forestland diversion for mining/infrastructure) are being deployed in Jharkhand, Odisha and Chhattisgarh — debates about quality vs. quantity of compensatory plantations. **Deccan Drought (2023-24):** Deficient SW monsoon, low Jayakwadi reservoir (Marathwada) and widespread Vidarbha-Marathwada distress. Cotton yield impacts and agrarian crisis in the Regur zone.

4.15 PYQ ANALYSIS — CHAPTER 4 (2010–2025)

Questions from UPSC Civil Mains GS-1 and IFoS GS directly testing themes of this chapter:

Source	*Year*	*Marks*	*Question*
UPSC Civil	2022	10M	"Discuss the natural resource potentials of 'Deccan Trap'."
UPSC Civil	2021	10M	"Despite India being one of the countries of the Gondwanaland, its mining industry contributes much less to its GDP in percentage. Discuss."
UPSC Civil	2019	10M	"Explain the topographical and structural characteristics of the Western Ghats."
UPSC Civil	2010	12M	"Differentiate the Western Ghats and Eastern Ghats in terms of physical characteristics."
UPSC Civil	2021	10M	"Differentiate the causes of landslides in the Himalayan region and the Western Ghats."

UPSC Civil	2016	12M	"The Himalayas are highly prone to landslides. Discuss causes and suggest mitigation." (Western Ghats comparison angle)
UPSC Civil	2013	5M	"Bring out the causes for more frequent landslides in the Himalayas than in Western Ghats."
UPSC Civil	2020	10M	"The process of desertification does not have climate boundaries. Justify with examples." (Thar-Deccan margin)
UPSC Civil	2012	15M	"Examine the causes and extent of desertification in India and suggest remedial measures."
UPSC Civil	2011	12M	"Mention the major mineral resources of the Peninsular plateau and their economic importance."
IFoS GS	2024	10M	"Describe the distribution of chromite in India and discuss its socio-economic significance."
IFoS GS	2023	10M	"Explain the potential of lithium reserves in India and discuss the social and environmental problems associated with mining."
IFoS GS	2017	10M	"What are biogeographic zones of India?"
IFoS GS	2018	10M	"Account for the environmental problems of lagoon ecosystem for tourism development." (Western Ghats coast)

KEY NOTE

Frequency pattern: Western Ghats (comparison, landslides, biodiversity) and Deccan Trap/mineral resources recur in GS-1 every 2-3 years. Gondwanaland-mining GDP is an analytical favourite. IFoS examines critical minerals (lithium 2023, chromite 2024) annually. Shola forests, biogeographic zones and tribal-forest rights are recurring IFoS themes. Prioritise: Deccan Trap resource potential, Western vs Eastern Ghats comparison, Chhota Nagpur mineral map and the Western Ghats ESA current-affairs link.

4.16 MODEL QUESTION

Discuss the natural resource potentials of the "Deccan Trap".

UPSC Civil (Mains) 2022 | GS-1 | 10 Marks | 150 Words

The Deccan Trap — a **Cretaceous-Paleocene Large Igneous Province (~66 Ma)** formed as the Indian Plate crossed the Réunion hotspot — is not merely a volcanic relic but a multi-dimensional resource base underpinning the agrarian and industrial economy of western and central India.

1. **Soil — Agricultural Potential:** Basalt weathering yields **Regur (black cotton soil)** — a **montmorillonite clay** that is moisture-retentive and naturally fertile. It supports **cotton (Vidarbha), sugarcane (W. Maharashtra) and jowar** — defining the Deccan's agricultural identity.
2. **Construction Material:** Hard, durable **basalt** is widely quarried as **road metal, building stone and railway ballast** — a low-cost, locally abundant construction resource.
3. **Groundwater:** Vesicular and fractured basalt zones function as **phreatic aquifers**, providing critical groundwater in Marathwada and Vidarbha — a semi-arid region with limited surface water.
4. **Tourism:** The step-like Sahyadri scarps, waterfalls (Dudhsagar) and hill stations (Mahabaleshwar) offer **eco-tourism and scenic landscape** value.
5. **Minerals:** Inter-trappean beds host **zeolites, agate and silica**; laterite caps on Trap hills yield **bauxite**.

However, Vidarbha's **farmer suicides and Marathwada's water crisis** reveal the gap between the Trap's geological potential and equitable socio-economic realisation — demanding targeted irrigation, soil-health and market-support interventions.

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CHAPTER 5

THE INDIAN DESERT THE THAR

CHAPTER AT A GLANCE

- Thar Desert: ~2 lakh sq km; ~60% in Rajasthan; also Gujarat, SW Punjab, SW Haryana; world's most densely populated desert.
- Formation: subtropical high-pressure belt (Horse Latitudes) + Aravalli range oriented PARALLEL to the SW monsoon → no orographic rainfall interception.
- Physiographic features: erg (barchans, longitudinal, transverse dunes), reg, hamada, playas; Sambhar Lake (India's largest inland Salt Lake, Ramsar); Luni River (only significant river).
- Climate: 48–50°C summer, near-0°C winter; <150 mm rainfall; Loo winds; dust storms (andhi); Western Disturbances in winter.
- Vegetation: xerophytic — Khejri (State Tree), Rohida (State Flower), Phog, Sewan grass (endemic); Desert National Park (3,162 sq km).
- Great Indian Bustard (GIB): Critically Endangered; ~150 individuals; SC 2021 order → underground power lines; SC modified 21 March 2024.
- Water: Extreme scarcity; johad, khadin, tanka, kund (traditional systems); IGNP — 649 km canal from Harike barrage (transformation + waterlogging/salinity problems).
- Economy: Bhadla Solar Park (~2,245 MW); Mangala oilfield (Barmer, 2004); HRRL refinery; gypsum largest reserves in India; Sambhar salt.

5.1 INTRODUCTION — THE GREAT INDIAN DESERT

The **Great Indian Desert — the Thar** — is the largest desert of the Indian subcontinent and the world's 17th-largest desert by area. Stretching across approximately **2 lakh sq km (~200,000 sq km)**, it dominates the northwestern corner of India: roughly **60% lies in Rajasthan**, with extensions into **Gujarat (Kachchh), southern Punjab and southern Haryana**. Across the International Border, it merges seamlessly into the **Cholistan Desert of Pakistan** — a reminder that political boundaries are invisible to geomorphology.

Among the world's hot deserts, the Thar is genuinely **unique** in three respects. First, it is the **world's most densely populated desert** — sustaining tens of millions of people, dense livestock populations and an agro-pastoral economy that has thrived for millennia. Second, it carries an exceptionally **rich cultural heritage** — the legacy of Rajput kingdoms (Jaisalmer, Bikaner, Jodhpur), living folk-music traditions of the **Manganiyar and Langa** communities, and a thriving handicraft economy. Third, it experiences a **seasonal monsoon influence** absent in most subtropical deserts — a brief, erratic wet season that supports seasonal grasses, ephemeral wildflowers and rain-fed cultivation.

KEY NOTE

Three defining exam anchors : (1) **Formation cause** — subtropical high + Aravalli orientation; (2) **Resource paradox** — most solar-rich zone in India, yet extreme water poverty; (3) **Conservation conflict** — Great Indian Bustard vs. renewable energy infrastructure. Every question on the Thar turns on one of these three axes.

5.2 FORMATION & GEOLOGICAL ORIGIN

The aridity of the Thar is best understood as the **superimposition of a planetary cause on a regional cause** — together producing one of the world's largest hot deserts on the Indian subcontinent.

PLANETARY CAUSE — SUBTROPICAL HIGH-PRESSURE BELT

At latitudes of **25–35°N (and symmetrically S)** lies the **Subtropical High-Pressure Belt (Horse Latitudes)**. Here, air that rose near the Equator (ITCZ) and flowed poleward in the upper atmosphere **descends back to the surface**. As it descends, it undergoes **adiabatic compression and warming**, which **lowers relative humidity, suppresses cloud formation and inhibits rainfall**. The Thar lies squarely within this zone (~23–32°N).

REGIONAL CAUSE — THE ARAVALLI ORIENTATION PARADOX

The **Aravalli Range is oriented NE-SW — parallel to the moisture-bearing Arabian Sea branch of the SW monsoon**, not perpendicular to it. Because the monsoon winds travel *alongside* the ranges rather than being forced *over* them, the Aravallis **cannot generate the orographic lift needed to cause precipitation**. This is the **decisive geometrical contrast** with the **Western Ghats**, which stand **perpendicular** to the same monsoon current and wring out 2,000–6,000 mm on their windward slopes.

KEY NOTE

The key exam distinction : Western Ghats = PERPENDICULAR to SW monsoon = heavy orographic rainfall. Aravallis = PARALLEL to Arabian Sea branch = no barrier effect = Thar aridity. This single sentence answers half the questions asked about why the Thar is a desert.

WHY THE SW MONSOON LARGELY BYPASSES THE THAR

- **Arabian Sea branch:** strikes the Western Ghats, deposits most moisture on the windward side, and the rain-depleted descending air reaching Rajasthan cannot sustain significant rainfall.
- **Bay of Bengal branch:** curves northwest along the Gangetic plain; by the time it reaches the arid northwest it has lost most of its moisture over the plains.
- **Aravallis too low and discontinuous:** even where some perpendicular blocking might occur, the ranges are too eroded and fragmented to force significant lifting.

GEOLOGICAL HISTORY & PALAEOGEOGRAPHY

The Thar was **once far better-watered**. The **Saraswati / Ghaggar-Hakra** river system — a major Himalayan-fed perennial river — once drained the region and supported the **Harappan (Indus-Saraswati) civilisation**. Its progressive **desiccation through tectonic river capture** (Yamuna and Sutlej capturing the Saraswati's Himalayan sources) **accelerated the Thar's aridification**. Tectonically, the area sits on the old **Gondwana margin**, and the **Jaisalmer limestone bears marine fossils** — evidence that this now-arid interior was once a **shallow Tethys Sea floor**.

5.3 PHYSIOGRAPHIC FEATURES

SANDY DESERT (ERG) — DUNE TYPES

The **erg** (sand sea) covers the majority of the Thar. Dune morphology depends on **sand supply, wind velocity and direction consistency** — a frequent Prelims topic.

Dune Type	*Shape*	*Formation Condition*	*Movement*
Barchan	Crescent-shaped; HORNS POINT DOWNWIND	Limited sand supply; constant unimodal wind	Migrate with wind direction
Longitudinal (Seif)	Long ridges PARALLEL to wind direction	Moderate sand supply; strong steady wind	Extend in wind direction
Transverse	Ridges PERPENDICULAR to wind	Abundant sand supply; near fixed obstacles	Migrate perpendicular to their length
Star Dune	Pyramidal; multiple arms radiating from centre	Variable / multidirectional winds	Stationary or slow-moving

ROCKY AND STONY DESERTS

- **Reg / Serir :** bare rock or gravel surface stripped of finer material by deflation (wind removal); what remains after the sand has been carried away.
- **Hamada :** flat, bare rock plateau or pavement; the end-stage of wind erosion on resistant bedrock.

SALT LAKES (PLAYAS / DHANDS)

Internal drainage in the Thar produces **saline/salt lakes (playas)** where water collects and evaporates, leaving salt residues.

- **Sambhar Lake:** India's largest inland saltwater lake (~190–230 sq km at full water); **Ramsar Wetland of International Importance (1990)**; major salt production centre; vital flamingo and migratory shorebird habitat.
- **Didwana, Pachpadra, Lunkaransar:** other significant Rajasthan saline lakes — each a source of salt and mineral wealth.

DRAINAGE

- **Luni River:** the only significant river of the Thar; rises in the Aravallis near Ajmer (Pushkar valley); flows southwest ~500 km into the Rann of Kachchh without reaching the sea. Famous as the **"salt river"** — fresh in its upper reaches, increasingly saline downstream (derives from Sanskrit *lavanavari*, salt water).
- **Ghaggar-Hakra:** a seasonal channel marking the ancient bed of the lost Saraswati system; active only during heavy rains; carries water into the Pakistan desert as the Hakra.
- **Indira Gandhi Nahar Pariyojana (IGNP):** the great man-made water artery — detailed in Section 5.8.

5.4 CLIMATE OF THE THAR

The Thar's climate is a **hot, continental, arid climate (BWh in Köppen classification)** — defined by **extreme temperature ranges, very low and erratic rainfall**, and distinctive wind phenomena.

TEMPERATURE EXTREMES

- **Summer:** maxima of 48–50°C are regularly recorded at Phalodi, Churu and Barmer — among India's highest temperatures. High solar radiation + dry air + bare sand surfaces create extreme surface heating.
- **Winter:** minima near 0°C; Churu and Ganganagar (north Rajasthan) occasionally record sub-zero temperatures. Clear desert skies allow rapid radiative cooling at night.
- **Diurnal range:** 20–30°C daily temperature swing — a hallmark of **continental desert climate** driven by low atmospheric moisture and clear skies.

RAINFALL

- **Total:** most of the Thar receives <150 mm/year; western tracts receive <100 mm (Jaisalmer ~100 mm; Barmer ~150 mm).
- **Variability:** extremely erratic; a single cloudburst may deliver the entire annual total in one day, followed by years of near-zero rainfall.
- **Season:** what rain falls comes in June–September with the SW monsoon, highly localised.

CHARACTERISTIC WIND PHENOMENA

- **Loo:** hot, dry, dust-laden winds from the west/northwest in May–June; temperature 40–48°C; **can cause fatal heat strokes**. The Loo is the Thar's signature summer weather event.
- **Dust storms (Andhi / Aandhi):** convective storms in summer; reduce visibility, deposit sand and redistribute dunes.
- **Western Disturbances (winter):** extratropical cyclones bring fog, drizzle and cold waves to NW Rajasthan; crucial for the *rabi* wheat crop in irrigated areas.

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WHY HOT DESERTS FORM AT 20–30°N ON WESTERN CONTINENTAL MARGINS

This is the most repeatedly examined theoretical concept in the chapter (UPSC Civil 2013). Four mechanisms act together:

- **Subtropical High-Pressure Belt (Horse Latitudes, 25–35°N/S):** descending air undergoes **adiabatic warming**, which raises temperature and lowers relative humidity — suppressing cloud formation and precipitation.
- **Cold ocean currents on western continental margins** (Canary in Atlantic, California/Humboldt in Pacific): cool the overlying air below its dew point, creating **fog and dew but NO rainfall**; crucially, **cold air beneath warm air = thermal inversion = atmospheric stability = no convective rainfall**.
- **Offshore trade winds:** the Trade Winds blow from land to sea on western continental margins, so they **pick up no moisture** from the ocean.
- **Continentality:** reinforces aridity in interior locations by increasing temperature ranges and reducing moisture access.

UPSC CIVIL

"Major hot deserts in the Northern Hemisphere are located between 20–30° N and on the western side of the continents. Why?" [UPSC Civil (Mains) 2013 | GS-1 | 100W | 5M]
Examples to cite : Sahara (N Africa), Arabian Desert (SW Asia), Thar (NW India), Sonoran (North America) — all on western margins at 20–30°N. See full model answer in Section 5.13.

5.5 SOILS OF THE THAR

The Thar's soils are **arid and desert soils** — classified as **Entisols and Aridisols** in modern soil taxonomy. Their key characteristics make them simultaneously **an impediment and a potential asset** for agriculture.

Property	*Characteristic*	*Implication*
Texture	Sandy, coarse-grained	Low water-holding capacity; high permeability
Organic matter	Very low	Poor nutrient retention; low biological activity
Carbonate content	Calcareous — high lime ($CaCO_3$) nodules / hardpans	Restricts root penetration; high pH
Structure	Poorly developed; structureless	Highly erodible by wind (deflation)
Fertility potential	Moderate — deficient in N, P; adequate K	Responds well to irrigation + fertiliser input
Under irrigation	Risk of waterlogging and secondary salinisation	Capillary rise brings salts to surface

Despite their apparent poverty, Thar soils have demonstrated **high productive potential under irrigation** — the IGNP command area converted desert into wheat and cotton fields. However, **canal irrigation in arid soils without sub-surface drainage creates secondary salinisation** — the same paradox seen in Punjab and Haryana (Chapter 3). This is the **fundamental soil-management challenge of the Thar** and a recurrent exam topic.

5.6 VEGETATION & ECOLOGY

The Thar's flora has evolved a remarkable suite of **xerophytic adaptations** to survive extreme heat, minimal water and nutrient-poor sandy soils. These adaptations are a **high-priority IFoS topic** — always demonstrate understanding of the *mechanism* behind each adaptation, not just a list.

XEROPHYTIC ADAPTATION MECHANISMS

- **Deep root systems (phreatophytes):** roots penetrate to the water table (sometimes 30+ m) for perennial groundwater access — exemplified by **Khejri**.
- **Thorny/spiny stems:** reduce transpiration; deter herbivory; the photosynthetic stem compensates for reduced leaf surface.

- **Small, waxy or reduced leaves:** minimise evaporative surface area; waxy cuticle reduces cuticular transpiration.
- **Succulent tissues:** store water in stems or leaves (e.g., cacti analogues and euphorbs).
- **Geophytes:** underground bulbs/corms/rhizomes survive the dry season dormant and sprout rapidly after rain.
- **Annual ephemerals:** complete the entire life cycle (germination to seed dispersal) within the brief wet season — maximum genetic output from minimum water.

KEY PLANT SPECIES

Species	*Common Name*	*Significance*
Prosopis cineraria	Khejri	STATE TREE of Rajasthan; nitrogen-fixing; deep roots; fodder (pods = sangri), timber; sacred to Bishnoi — "King of the Desert"
Tecomella undulata	Rohida	STATE FLOWER of Rajasthan; "Desert Teak"; hard, durable timber; attractive orange flowers
Calligonum polygonoides	Phog	Sand binder; critical for dune stabilisation; deep-rooted shrub; edible flowers
Lasiurus sindicus	Sewan / Sevan grass	ENDEMIC to the Thar; key xerophytic grass; lifeline of livestock (camel, sheep, goat) in the desert
Acacia senegal	Khair/Kumta	Gum-arabic producing; nitrogen-fixing; soil binder

DESERT NATIONAL PARK

The **Desert National Park (DNP)** in **Jaisalmer and Barmer districts of Rajasthan** covers approximately **3,162 sqft km** — one of India's largest national parks. It protects a mosaic of **shifting and fixed sand dunes, rocky terrain, saline flats and scrubland** and is the **primary wild habitat of the Great Indian Bustard**. The park also harbours the blackbuck, chinkara, desert fox, spiny-tailed lizard and a rich reptile community.

IFoS FOCUS

Bishnoi Community — Ecological Guardians : The Bishnoi community of Rajasthan has a 500-year tradition of protecting khejri trees and wildlife, founded by **Guru Jambheshwar (Jambhoji)** in 1485. In **1730 CE**, **Amrita Devi Bishnoi and 363 followers were killed at Khejarli (near Jodhpur)** while embracing trees to prevent their felling for a royal palace. This is celebrated as a precursor of the **Chipko movement** and India's foundational community-conservation episode. The **Amrita Devi Bishnoi Award for Wildlife Conservation** is named in her honour.

5.7 WILDLIFE & BIODIVERSITY

GREAT INDIAN BUSTARD (GIB) — INDIA'S MOST ENDANGERED LARGE BIRD

The **Great Indian Bustard (***Ardeotis nigriceps***)** is India's **State Bird of Rajasthan**, **Critically Endangered (IUCN)**, listed under **Schedule I** of the Wildlife (Protection) Act, 1972, and **CMS Appendix I**. With only about **~150 individuals remaining in India**, it is one of the world's rarest large birds — and the Thar's most urgent conservation challenge.

- **Primary threats — Power line collision:** the GIB is a heavy, ground-dwelling bird that flies low and has limited frontal vision; it cannot detect overhead high-tension wires in time. **Power-line and wind-turbine blade collision** is the single largest documented cause of unnatural mortality — more critical than habitat loss alone.
- **Habitat loss:** rapid expansion of **solar and wind energy farms** across its grassland habitat is the second-largest threat; large solar parks fragment the open landscape the GIB requires for foraging and nesting.
- **Agricultural intensification:** conversion of grassland to cropland reduces foraging and nesting areas; pesticide use reduces insect prey.

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ENV ALERT

Supreme Court Litigation — M.K. Ranjitsinh & Ors v. Union of India:

- **2021 order (19 April 2021) :** SC directed that ALL overhead power lines in priority and potential GIB habitat in Rajasthan and Gujarat be laid **underground**, with bird-diverters installed on existing lines in the interim.
- **21 March 2024 modification :** SC **modified** the blanket undergrounding order, acknowledging the genuine conflict with India's solar/wind energy and climate commitments, and **constituted an expert committee** to assess feasibility of overhead vs underground lines and other conservation measures. The 2024 judgment also articulated a **"right against adverse effects of climate change"** under Articles 14 and 21 of the Constitution — a landmark in Indian environmental jurisprudence.

OTHER CHARACTERISTIC FAUNA

- **Blackbuck (*Antilope cervicapra*):** protected by the Bishnoi community; **Tal Chhapar Wildlife Sanctuary (Churu)** is a prime habitat.
- **Chinkara (Indian gazelle, *Gazella bennettii*):** the most common antelope of the Thar; remarkably heat-adapted.
- **Indian wild ass (*Equus hemionus khur*):** not in the Thar proper but in the **Little Rann of Kachchh (Wild Ass Sanctuary), Gujarat** — a closely related arid habitat.
- **Desert fox, Desert cat, Spiny-tailed lizard (*Uromastyx hardwickii*):** characteristic reptile of the Thar grasslands; armour-plated against the heat.

MIGRATORY & WETLAND BIRDS

- **Demoiselle crane (*Anthropoides virgo*) — "Koonj":** winters in the Thar in spectacular numbers; the congregation at **Khichan village, Jodhpur district** (where the Marwari community feeds them daily) is one of India's most celebrated wildlife spectacles.
- **Sambhar Lake — Ramsar Wetland (1990):** India's largest inland saltwater lake; flamingo breeding and migratory shorebird habitat of international importance; also a major **salt production** centre.

5.8 WATER RESOURCES — CRISIS & INNOVATION

Water is the defining constraint of life in the Thar. Most groundwater in the desert is **saline and unfit for drinking**; freshwater aquifers are rare and over-exploited. The **CGWB classifies major blocks in Jaisalmer, Barmer and Bikaner as over-exploited**. Yet the Thar has produced **some of India's most ingenious water-harvesting traditions** — a testament to millennia of human adaptation to scarcity.

TRADITIONAL WATER-HARVESTING SYSTEMS

(High-priority IFoS section — exam answers should demonstrate mechanism, not just name)

System	Mechanism	Location / Community	Key Point
Johad	Earthen check dam/pond captures monsoon runoff; impounded water percolates to recharge groundwater	Alwar, eastern Rajasthan; revived by Tarun Bharat Sangh (Rajendra Singh)	Demonstrated perennial river revival through johad networks
Tanka / Kund	Underground cylindrical cistern collects rooftop and courtyard runoff; covered to prevent evaporation	Jaisalmer and Barmer; individual families	Provides pure, cool drinking water in sand-dune terrain where wells are saline
Kundi / Beri	Covered underground well tapping freshwater lens above saline groundwater in sandy terrain	Western Thar	Exploits the freshwater-saline interface unique to aeolian sand deposits

Khadin (Dhora)	Stone/earthen bund across a gentle slope traps runoff AND silt; moisture-conserving crop cultivation on the impounded bed	Jaisalmer region; Paliwal Brahmin community	Uniquely integrates water HARVESTING + FLOOD IRRIGATION + SOIL CONSERVATION in one structure
Baoli / Vav (Stepwell)	Descending staircase to reach water table; communal access; evaporation-minimising architecture	All Rajasthan; Chand Baori (Abhaneri), Adalaj (Gujarat)	Architectural heritage; seasonal water access; cooling microclimate

INDIRA GANDHI NAHAR PARIYOJANA (IGNP) / RAJASTHAN CANAL

The IGNP is the most transformative infrastructure project in the history of Rajasthan — a **649 km main canal** that carries water from the **Harike barrage (Sutlej-Beas confluence, Punjab)** through the desert to **Mohangarh (Jaisalmer district)**. The main canal comprises the **Rajasthan Feeder (~204 km)** and the **Main Canal (~445 km)**; the total distribution network with branches and distributaries extends to roughly **~9,060 km**.

Benefits

- **Agricultural transformation:** converted desert into productive wheat-cotton-mustard cropland across Ganganagar, Hanumangarh, Bikaner, Jaisalmer and Barmer districts.
- **Food and livelihood security:** enabled large-scale settlement of previously uninhabitable desert.
- **Drinking water:** provided potable water to desert towns and villages previously dependent on saline groundwater.

Problems Created

- **Waterlogging:** poor sub-surface drainage in arid soils has led to water table rise in parts of the command area.
- **Secondary soil salinity:** evaporation of canal water in the hot, arid climate deposits salts on the soil surface — the classic canal-irrigation paradox in arid zones.
- **Ecosystem disruption:** conversion of desert grassland to irrigated farmland has destroyed GIB and blackbuck habitat.
- **Displacement of pastoral communities:** nomadic herders who depended on desert commons lost grazing lands to irrigated agriculture.

IFoS FOCUS

IFoS Exam Tip — Rajendra Singh (Waterman of India) : Rajendra Singh of Tarun Bharat Sangh (TBS) won the **Ramon Magsaysay Award (2001)** and the **Stockholm Water Prize (2015)** for reviving johads in the Alwar region of Rajasthan. Five rivers — Arvari, Ruparel, Sarsa, Bhagani and Jahajwali — that had run dry were revived through community johad construction. This is the premier Indian example of **community-led traditional water harvesting restoring river ecology** — cite it in any question on watershed management, community conservation or traditional knowledge.

5.9 DESERTIFICATION — CAUSES, EXTENT & MITIGATION

Desertification is defined by the UNCCD as **"land degradation in arid, semi-arid and dry sub-humid areas resulting from climatic variations and human activities."** The phrase **"arid, semi-arid and dry sub-humid"** — and not "hot deserts" — is analytically crucial: it explains why the 2020 UPSC question argues that **"desertification does not have climate boundaries."**

INDIA'S DESERTIFICATION — SCALE

The **Desertification and Land Degradation Atlas of India (SAC/ISRO, 2021 edition)** found that approximately **97.85 million hectares (~30% of India's total geographical area)** is undergoing desertification or land

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degradation. **Rajasthan is among the most severely affected states in absolute area**, alongside Gujarat, Maharashtra, Haryana and Punjab.

CAUSES OF DESERTIFICATION

- **Overgrazing:** the most widespread cause in the Thar; reduction of plant cover triggers soil compaction, surface-crust formation and wind/water erosion.
- **Deforestation:** removal of khejri and other native trees exposes sandy soils to deflation (wind removal).
- **Agricultural practices:** over-irrigation → salinisation; mono-cropping → loss of protective cover; land-use conversion of grassland.
- **Mining:** sand mining and stone quarrying destabilise desert terrain, exposing fresh sand to wind.
- **Climate change:** rising temperatures, erratic rainfall and prolonged drought episodes accelerate aridification.

UPSC CIVIL

"The process of desertification does not have climate boundaries. Justify with examples." [UPSC Civil (Mains) 2020 | GS-1 | 10M]

Key argument : desertification (land degradation in drylands) can affect **semi-arid and dry sub-humid zones** — not just hot deserts. Examples: the Indo-Gangetic plain margins (Punjab-Haryana through over-irrigation → salinity); the Deccan (soil erosion in semi-arid tracts); even **the Sahel (sub-Saharan Africa)** — degradation through overgrazing in a sub-humid zone. Desertification is a process of **soil-productivity collapse**, not a product of climate aridity alone. India: use Rajasthan (arid), Gujarat semi-arid margins, and over-irrigated Haryana as a dry sub-humid case.

MITIGATION MEASURES

- **Shelterbelts and windbreaks:** rows of Prosopis, Acacia and Eucalyptus along field margins break wind velocity and reduce deflation.
- **Sand dune stabilisation:** Phog and Sewan grass planted on dune slopes; mechanical micro-windbreaks of dry brushwood or stone barriers fix migrating dunes.
- **MGNREGA:** watershed development, check-dam construction, afforestation and sand-stabilisation works in desert districts.
- **Community-based soil and water conservation:** johad construction, khadin restoration, community pasture (oran/gauchar) protection.
- **National Action Programme to Combat Desertification (NAPCD):** India's policy framework under the UNCCD; committed to restoring **26 million hectares of degraded land by 2030** (announced at UNCCD COP14, Greater Noida, September 2019).

5.10 STRATEGIC & ECONOMIC IMPORTANCE

DEFENCE & STRATEGIC BORDER

The **Rajasthan sector of the India-Pakistan International Border** runs through the Thar Desert — a frontier of strategic significance in both the **1965 and 1971 wars**. The **Battle of Longewala (4–5 December 1971)** — fought in the Rajasthan desert with a small BSF and Army force halting a Pakistani armoured advance — is iconic in Indian military history. Today, **BSF operations, border fencing, sensors and surveillance infrastructure** define this frontier zone.

OIL & NATURAL GAS

- **Barmer-Sanchore basin:** the **Mangala oilfield** (discovered 2004 by Cairn India, now Vedanta) is Rajasthan's largest oilfield. Rajasthan supplies a significant share of India's domestic onshore crude production.
- **Jaisalmer basin:** natural gas reserves operated by GAIL and ONGC.
- **HRRL Refinery (Pachpadra, Barmer):** the **HPCL-Rajasthan Refinery Limited (74% HPCL / 26% GoR)** — a 9

MMTPA refinery-cum-petrochemical complex under construction/commissioning at Pachpadra, Barmer; set to add major value to Rajasthan's crude production.

SOLAR ENERGY — RAJASTHAN AS INDIA'S SOLAR CAPITAL

Rajasthan receives **India's highest solar insolation** — the Jaisalmer-Jodhpur belt records **~5.5–6.5 kWh/sq m/day**. This makes the Thar the natural home of India's solar energy future.

- **Bhadla Solar Park (Jodhpur district): ~2,245 MW installed capacity** over ~14,000 acres; **among the world's largest solar parks**. Rajasthan is a **lead state for India's 500 GW non-fossil capacity target by 2030**.
- **PM-KUSUM scheme:** solar pumps for desert farmers, cutting diesel-irrigation costs and enabling off-grid water pumping.
- **Conservation conflict:** rapid solar park expansion directly threatens **GIB and blackbuck habitat** — the defining policy tension in the Thar today.

WIND ENERGY

- **Jaisalmer wind cluster:** among India's oldest and largest wind farm zones; but **wind turbine blades and towers directly kill GIBs** — making every wind turbine in the desert a conservation hazard.

MINERALS

Mineral	*Location*	*Significance*
Gypsum	Nagaur, Bikaner (Rajasthan)	India's LARGEST reserves; used for cement, plaster, ammonium sulphate fertiliser
Feldspar	Ajmer area	Used in glass and ceramics industry
Limestone / Sandstone	Jaisalmer (famous yellow stone)	Jaisalmer Fort and Parliament-area construction; building material
Salt	Sambhar Lake, Didwana, Pachpadra	Rajasthan = major salt producer; Sambhar alone contributes ~8.7% of India's salt production

5.11 CURRENT AFFAIRS HOOKS (2021–2025)

UPSC CIVIL

GIB vs Renewable Energy — SC Order Evolution: 19 April 2021: SC ordered underground power lines in all GIB priority habitat in Rajasthan-Gujarat. 21 March 2024: SC modified order, constituted expert committee given solar/wind energy investment conflict. This is the leading ongoing conservation-vs-development case in India — essential for any wildlife or energy answer about Rajasthan.

Bhadla Solar Park Expansion: Continued capacity addition; Rajasthan on track to be India's largest renewable energy state. ~2,245 MW at Bhadla alone; multiple other solar parks in pipeline across Jodhpur and Jaisalmer.

HRRL Refinery (Barmer): HPCL-Rajasthan Refinery Limited 9 MMTPA project at Pachpadra nearing commissioning; will be a game-changer for Rajasthan's energy economy. Verify operational status before exam.

UNCCD COP14 (India, 2019): India hosted UNCCD COP14 in Greater Noida (September 2019) — NOT COP15. India committed to restoring 26 million hectares by 2030 under Land Degradation Neutrality. COP15 was held in Abidjan, Côte d'Ivoire (2022). Do not confuse.

PM-KUSUM Scheme: Pradhan Mantri Kisan Urja Suraksha evam Utthaan Mahabhiyan — solar pumps for farmers; reducing diesel dependency in desert; feeder-level solarisation of agriculture.

Groundwater Crisis (CGWB data): Jaisalmer, Barmer, Bikaner blocks classified over-exploited/critical for groundwater; annual decline accelerating with expanding irrigated area under IGNP. Water-table monitoring by CGWB shows consistent drop.

5.12 PYQ ANALYSIS — CHAPTER 5 (2010–2025)

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Questions from UPSC Civil Mains GS and IFoS GS directly testing themes of this chapter:

Source	Year	Marks	Question
UPSC Civil	2013	5M	"Major hot deserts in the Northern Hemisphere are located between 20–30° N and on the western side of the continents. Why?"
UPSC Civil	2012	15M	"Examine the causes and extent of desertification in India and suggest remedial measures."
UPSC Civil	2020	10M	"The process of desertification does not have climate boundaries. Justify with examples."
UPSC Civil	2016	12M	"The effective management of land and water resources will drastically reduce human miseries. Explain."
UPSC Civil	2019	15M	"What is water stress? How and why does it differ regionally in India?"
UPSC Civil	2018	15M	"The ideal solution of depleting groundwater resources in India is water harvesting system. How can it be made effective in urban areas?"
UPSC Civil	2022	10M	"India has immense potential of solar energy though there are regional variations in its development. Elaborate."
IFoS GS	2015	15M	"The droughts and its outcomes in India are the result of both the physical and the human factors. Discuss."
IFoS GS	2021	10M	"Energy transition is considered the best measure to achieve the goal of carbon neutrality. Explain."
UPSC Civil	2017	10M	"Mention advantages of cultivation of pulses." (dryland/arid zone agriculture link)

KEY NOTE

Frequency pattern : Hot-desert location theory (2013) and desertification (2012, 2020) are the two highest-frequency themes — master these first. Traditional water harvesting and water stress are recurring favourites in both exams. Solar energy (Bhadla) is a growing current-affairs angle in GS-3. For IFoS, always pair any Thar vegetation answer with xerophytic adaptations + Bishnoi community + GIB conservation.

5.13 MODEL QUESTION

Major hot deserts in the Northern Hemisphere are located between 20–30° north and on the western side of the continents. Why?

UPSC Civil (Mains) 2013 | GS-1 | 5 Marks | 100 Words

FOUR MECHANISMS ACT TOGETHER

1. **Subtropical High-Pressure Belt (Horse Latitudes, 25–35°N):** Descending air undergoes **adiabatic compression and warming**, which suppresses relative humidity, cloud formation and precipitation — a **thermal / subtropical anticyclone** condition.
2. **Cold Ocean Currents on western margins** (Canary, California/Humboldt): cool overlying air below dew point → fog but NO rain; create a **thermal inversion** that stabilises the atmosphere and prevents convective rainfall.
3. **Offshore Trade Winds:** blow from land toward the ocean on western margins, picking up NO moisture from the sea.
4. **Continentality:** amplifies aridity in interior locations.

Examples: Sahara (N. Africa), **Arabian Desert** (SW Asia), **Thar** (NW India), **Sonoran** (North America) — all lie at 20–30°N on western continental margins. Keywords: subtropical anticyclone, thermal inversion, adiabatic warming, cold current, offshore trade winds, continentality.

CHAPTER 6

COASTAL PLAINS

CHAPTER AT A GLANCE

- Coastline: 7,516.6 km (classic) vs 11,098.81 km (revised 2023-24, NHO/SoI) — coastline paradox; 1,382 islands; 9 coastal states.
- West coast: narrow, faulted (horst origin), estuaries/rias, backwaters — NO major deltas. East coast: wide, depositional, great deltas, lagoons.
- Western sub-divisions (N→S): Gujarat → Konkan → Kanara → Malabar (Kayals/backwaters); Eastern: Utkal → Northern Circars → Coromandel → Tamil Nadu.
- Lagoons: Chilika (India's largest coastal lagoon, first Ramsar 1981); Pulicat (2nd largest brackish); Vembanad, Ashtamudi (Ramsar) on west.
- Islands: A&N = tectonic/volcanic (Arakan Yoma extension; Barren Island = active volcano); Lakshadweep = coral atolls (Laccadive-Maldive ridge) — most tested distinction.
- A&N strategic: Andaman & Nicobar Command (tri-service, 2001); Malacca Strait approaches; Great Nicobar development project controversy (Rs 72,000 crore).
- EEZ: ~2.37 million sq km; Blue Economy; MISHTI (mangroves, Budget 2023); Sagarmala; Deep Ocean Mission (₹4,077 cr, 2021); CRZ 2019.
- Hazards: Bay of Bengal more cyclone-prone (funnel shape, warm waters, low coasts); 2004 tsunami; ~33.6% of coast eroding (NCCR); Lakshadweep SLR threat.

6.1 INTRODUCTION — INDIA'S VAST COASTLINE

India is a peninsula surrounded by the **Arabian Sea to the west**, the **Bay of Bengal to the east** and the **Indian Ocean to the south** — a maritime exposure unique among large Asian nations. Its coastline is one of the world's longest and most strategically positioned. The figure long cited in the *India Yearbook* and Survey of India materials is **7,516.6 km** (roughly 6,100 km of mainland + island coastlines). In 2023-24, the **National Hydrographic Office (NHO) together with the Survey of India** released a revised figure of **11,098.81 km**.

This near-50% increase is NOT a territorial change — it is a demonstration of the **"coastline paradox"**: the finer the scale of measurement, the more creeks, estuaries, tidal inlets and indentations are captured, and the **longer the measured length becomes**. Earlier maps smoothed over fine-scale coastal detail; high-resolution digital charts and finer measurement scales capture the fractal nature of the shore.

KEY NOTE

For exams : Cite BOTH figures and explain WHY they differ — this demonstrates analytical depth over rote recall. The classic 7,516.6 km = coarser Survey of India measurement; 11,098.81 km = finer NHO/SoI digital measurement (2023-24). The territory is the same; the measuring technique improved.

STRATEGIC SIGNIFICANCE OF INDIA'S COASTLINE

- **9 coastal states** and several island/coastal Union Territories (Daman & Diu, Puducherry, Lakshadweep, Andaman & Nicobar).
- **1,382 islands** (official count), of which 572 in A&N and 36 in Lakshadweep.
- **~95% of trade by volume** and roughly 65-68% by value moves through sea ports.
- **Blue Economy** potential: fisheries, hydrocarbons, deep-sea minerals, coastal tourism, tidal energy.
- **Maritime security:** the A&N Islands command the western approaches to the Malacca Strait.

6.2 FORMATION OF THE COASTAL PLAINS

The fundamental difference between India's two coasts — narrow rocky west vs wide deltaic east — is explained entirely by their **different modes of formation**. This is the single most important conceptual point in the chapter.

WESTERN COAST — TECTONIC / FAULT ORIGIN

The Western Ghats are interpreted as a **horst** — a crustal block uplifted along a rift/fault system — created when the Indian peninsula rifted away from Madagascar/Gondwanaland in the Mesozoic. The narrow coastal strip west of the Ghats is a **low-lying plain trapped between the fault escarpment and the sea**. Rivers descending the steep western face are **short, swift and carry insufficient sediment to build deltas** — they form **estuaries and rias** instead. The west coast is broadly a **submergent, fault-origin coast**.

EASTERN COAST — DEPOSITIONAL / DELTAIC ORIGIN

The east coast is largely **aggradational and depositional**. The peninsula's gentle eastward slope allows the great east-flowing rivers (Mahanadi, Godavari, Krishna, Cauvery) to lose velocity and **spread sediment over a broad area, building extensive deltas**. The coast is broadly **emergent and prograding** — it is growing seaward as rivers add more material.

UPSC CIVIL

UPSC Prelims/Mains Tip : The question "why are there no major deltas on the west coast?" is answered by the formation story: short steep rivers + narrow shelf + strong longshore currents = no delta building. The question "why is the east coast wider?" is answered by depositional origin + gentle slope. Linking origin to landforms earns analytical marks.

6.3 WESTERN COASTAL PLAINS

SUB-DIVISIONS (NORTH TO SOUTH)

Gujarat Coast (Rann of Kachchh & Gulf of Khambhat)

The Gujarat coast is **unlike any other in India** — it includes the vast **tidal flats of the Rann of Kachchh** (seasonally flooded saline plain), the **Gulf of Khambhat (Cambay)** into which the Narmada and Tapi discharge, and the **Gulf of Kutch** with its **coral reefs and Marine National Park** — India's only reef system in a semi-arid coastal zone. Mangroves, the Wild Ass Sanctuary and India's major salt production dominate this coast.

Konkan Coast (Maharashtra + Goa)

Approximately **500 km long, ~50 km wide**; composed of **rocky, cliffed coastline with laterite plateaus** descending to the sea. Small pocket beaches, Mumbai's natural harbour, and Goa's beaches dominate. **Mumbai (JNPT/Nhava Sheva)** — India's largest container port — anchors this coast economically. The **Konkan Railway** (running along the coast through tunnels and bridges) connects Mumbai to Mangaluru.

Karnataka (Kanara) Coast

Approximately **320 km**; rocky, with abundant **cashew, coconut and areca nut cultivation** on the laterite coastal slopes. **New Mangalore port** handles iron ore, fertilisers and petroleum products.

Malabar Coast (Kerala)

Approximately **560 km**; the most ecologically distinctive section of the west coast, renowned for its **network of backwaters (kayals)**, **Vembanad Lake** (Kerala's largest lake and India's longest lake), rich fishing grounds and houseboat tourism. The **Palakkad Gap** in the Western Ghats channels monsoon winds and rail/road connectivity into Kerala.

BACKWATERS (KAYALS) — IFOS PRIORITY SECTION

The Kerala backwaters are one of India's most iconic ecosystems — a **labyrinth of interconnected canals, rivers, lakes and inlets** lying behind long sandy barrier spits that separate them from the Arabian Sea.

- **Formation:** longshore drift builds sand bars/spits parallel to the coast; rivers discharge into the protected water body behind the barrier, creating a **brackish-water lagoonal zone**.
- **Inland navigation: National Waterway 3** (West Coast Canal, Kottapuram to Kollam, ~205 km) — one of India's busiest inland waterways.
- **Fisheries and livelihoods:** the backwaters are one of Kerala's most productive fishing zones; prawn aquaculture is also significant.
- **Tourism:** houseboat (kettuvallam) cruises are Kerala's premier tourism product.
- **Kuttanad — "Rice Bowl of Kerala":** farming **below sea level** on reclaimed backwater polders — one of the world's few below-sea-level agricultural systems; paddy grown on inundated fields by controlling sluice gates.

Backwater / Lake	*Type*	*Ramsar Status*	*Key Feature*
Vembanad Lake	Brackish lagoon / Kerala's longest lake	Ramsar site (2002)	Kuttanad farming below sea level; houseboat tourism hub
Ashtamudi Lake	Estuary-lagoon	Ramsar site (2002)	Kollam; cashew export point; mangroves
Sasthamkotta Lake	Freshwater lake	Ramsar site (2002)	Kerala's only freshwater Ramsar lake; drinking water source

IFoS FOCUS

IFoS Exam Tip — Backwaters : Any IFoS question on lagoon or estuarine ecology should mention: (1) formation by longshore-drift sand bars, (2) brackish water = high productivity (estuarine effect), (3) fish nursery function, (4) threats: eutrophication from aquaculture/agriculture runoff, water hyacinth invasion, siltation of the sea mouth, tourism pollution. Kuttanad's below-sea-level farming adds a unique angle on the resource potential of coastal wetlands.

WHY NO MAJOR DELTAS ON THE WEST COAST

- **Short, steep rivers** (Mandovi, Zuari, Sharavathi, Periyar) have high velocity and drop most sediment before reaching the sea.
- Rivers form **estuaries and rias** — drowned river mouths — rather than building out into the sea.
- **Narrow continental shelf** provides minimal space for delta accumulation.
- **Strong longshore currents** of the Arabian Sea sweep sediment away from river mouths northward or southward.

MAJOR WESTERN COAST PORTS

Port	*State*	*Key Cargo/Note*
Mumbai Port	Maharashtra	General cargo; passenger; container (smaller role)
JNPT (Nhava Sheva)	Maharashtra	India's LARGEST container port; handles ~50% of India's containerised trade
Mormugao	Goa	Iron ore export; one of India's oldest ports
New Mangalore	Karnataka	Iron ore, fertilisers, petroleum; deep-water port
Kochi (Cochin)	Kerala	Natural harbour; container transhipment; bunkering; naval base

6.4 EASTERN COASTAL PLAINS

SUB-DIVISIONS (NORTH TO SOUTH)

Utkal/Mahanadi Coast (Odisha)

The Mahanadi delta and adjoining coastal zone; **Chilika Lake** — India's largest coastal lagoon and first Ramsar site; **Gahirmatha beach** — the world's largest known olive ridley turtle mass-nesting site.

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Northern Circars (Northern Andhra Pradesh)

The Godavari and Krishna river deltas create a **wide, fertile rice-cultivation zone**. The coastal plain here is flat and deltaic with active delta growth.

Coromandel Coast (Southern AP + Tamil Nadu)

Uniquely, the Coromandel Coast receives most of its annual rainfall from the **retreating/north-east monsoon (October–December)** — the **reverse of the rest of India**, which relies on the SW monsoon. This happens because the NE monsoon winds pick up moisture while crossing the Bay of Bengal and deposit it on the Coromandel coast. The Krishna and Cauvery deltas feed a **fertile rice bowl**.

Tamil Nadu Coast

Cauvery delta (major rice); Palk Strait (shallow; separates India from Sri Lanka); Gulf of Mannar (coral reefs, dugong, biosphere reserve); **Thoothukudi (Tuticorin)** port handles cargo and fishing.

LAGOONS AND COASTAL LAKES

Lake / Lagoon	*Location*	*Type*	*Area (approx.)*	*Ramsar / Key Feature*
Chilika Lake	Odisha	Coastal lagoon (brackish)	~900-1,165 sq km (seasonal)	INDIA'S FIRST RAMSAR SITE (1981); flamingo, grey pelican, Irrawaddy dolphin; fisheries
Pulicat Lake	AP-TN border	Brackish water lagoon	~461 sq km (varies)	Pulicat Bird Sanctuary; flamingo; Sriharikota spit separates from Bay of Bengal
Kolleru Lake	Andhra Pradesh	Freshwater lake	~245 sq km	Ramsar site; between Godavari-Krishna deltas; migratory birds
Vembanad Lake	Kerala	Brackish backwater lagoon	~200 sq km	Ramsar; Kuttanad below-sea-level farming; houseboat tourism

IFoS FOCUS

IFoS 2016 PYQ — Environmental Problems of Lagoon Ecosystem for Tourism

- **Physical:** siltation of the lagoon mouth (reduces water exchange); water hyacinth invasion; narrowing of the inlet.
- **Chemical:** eutrophication from aquaculture/agricultural runoff; algal blooms; oxygen depletion.
- **Biological:** invasive species; loss of native fish species; disruption of migratory bird nesting.
- **Tourism-specific:** boat-fuel/oil pollution; noise disruption of birds; solid-waste dumping; coastal construction encroachment.

Example: Chilika Lake experienced ecological collapse in the 1990s from siltation (closing the mouth), encroachment and aquaculture. Restoration through mouth re-opening (Operation Chilika) and CRZ regulation revived the ecosystem — a textbook IFoS case study.

MAJOR EASTERN COAST PORTS

Port	*State*	*Key Cargo/Note*
Kolkata / Haldia	West Bengal	Riverine port (Hugli); major container; Haldia handles petroleum and chemicals
Paradip	Odisha	India's newest major port; iron ore, coal, fertilisers
Visakhapatnam	Andhra Pradesh	DEEPEST NATURAL HARBOUR in India; steel, crude oil, general cargo; major naval base
Chennai	Tamil Nadu	Major container and automobile port; second largest by capacity
Kamarajar (Ennore)	Tamil Nadu	Coal, LNG, automobiles; India's first corporatised port
Thoothukudi (Tuticorin)	Tamil Nadu	Container, copper, salt, fishing

6.5 WESTERN VS EASTERN COASTAL PLAINS — MASTER COMPARISON

Feature	*Western Coastal Plain*	*Eastern Coastal Plain*
Origin	Tectonic / faulted — horst / rift (submergent)	Depositional / deltaic (emergent, prograding)
Width	Narrow (50–80 km)	Wide (100–130 km)
Drainage	Short, steep rivers; estuaries / rias	Large, slow rivers; extensive deltas
Coastal landforms	Cliffs, rocky beaches, backwaters, lagoons, rias	Deltas, coastal lagoons, straight beaches, spits
Rainfall timing	SW monsoon (Jun–Sept)	Coromandel: NE / retreating monsoon (Oct–Dec)
Major resources	Fishing, spices, coconut, cashew, ports, tourism	Rice, aquaculture, deltaic agriculture
Notable lagoons	Vembanad, Ashtamudi, Sasthamkotta (Kerala)	Chilika, Pulicat, Kolleru (eastern states)
Delta formation	ABSENT — estuaries/rias only	Present — Mahanadi, Godavari, Krishna, Cauvery
Continental shelf	Narrow	Wide (rich fishing grounds, offshore potential)
Key ports	JNPT, Mumbai, Mormugao, New Mangalore, Kochi	Visakhapatnam, Chennai, Paradip, Haldia, Tuticorin

6.6 THE ISLANDS — ANDAMAN & NICOBAR

BASIC FACTS

Parameter	*Detail*
Location	Bay of Bengal; ~1,400 km from Indian mainland; 8°4'N to 13°34'N
Extent	~800 km N-S archipelago
Total islands	572 (official); ~38 inhabited
Capital	Port Blair — renamed Sri Vijaya Puram (September 2024)
Administrative status	Union Territory (since 1956)
Southernmost point	Indira Point (Pygmalion Point), Great Nicobar — ~6°45'N; India's southernmost tip
Highest peak	Saddle Peak, North Andaman (732 m)

GEOLOGICAL ORIGIN — TECTONIC/VOLCANIC (IFOS + CIVIL KEY POINT)

The Andaman & Nicobar Islands are a **submerged extension of the Arakan Yoma mountains of Myanmar** — part of the great Himalayan fold-mountain arc that bends southward through Myanmar before disappearing beneath the Indian Ocean and re-emerging as these islands. They are **tectonic/volcanic in origin — NOT coral atolls**, and sit on the **Sunda subduction zone**, making them highly seismically active.

- **Barren Island:** India's **only confirmed active volcano** — the most northerly active volcano in the Indian Ocean; renewed activity 2017-18.
- **Narcondam Island:** India's only **dormant volcano** — a near-perfect volcanic cone.
- The 2004 tsunami originated from a rupture on the **Sunda megathrust** just west of the A&N islands — direct evidence of their tectonic setting.

KEY NOTE

The Most-Tested Island Distinction : A&N Islands = TECTONIC/VOLCANIC (Arakan Yoma fold extension; Barren Island active volcano; seismically active). Lakshadweep = CORAL ATOLLS (coral polyp accretion on Laccadive-Maldive submarine ridge; geologically stable). This distinction appears in Prelims MCQs almost every year.

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BIODIVERSITY (IFOS PRIORITY)

- **Forest cover:** dense tropical evergreen rainforests similar to Southeast Asian forests; high species diversity.
- **Key fauna:** Andaman wild pig, **Nicobar pigeon** (the ancestor of the domestic pigeon, found only in A&N and surrounding islands), Andaman Sea eagle, **saltwater crocodile** (*Crocodylus porosus*), Andaman monitor lizard, hawksbill and **leatherback turtles** (nesting on Great Nicobar — one of the key leatherback nesting sites in the Indian Ocean).
- **Key flora: Andaman padauk (***Pterocarpus dalbergioides***)** — the "island teak"; Gurjan timber trees; mangroves.
- **Marine biodiversity:** coral reefs, dugong, dolphins, whale sharks.

STRATEGIC IMPORTANCE (CIVIL MAINS CRITICAL)

The A&N Islands are India's most strategically located territories — they sit astride the **western approaches to the Strait of Malacca**, the world's busiest shipping lane (~90,000+ vessel transits annually, carrying an estimated ~25-30% of global trade and about 40% of India's own trade).

- **Andaman & Nicobar Command (ANC):** India's **first and only tri-service (unified theatre) command** — integrating Army, Navy and Air Force — established in 2001; headquartered at Port Blair/Sri Vijaya Puram.
- **Great Nicobar:** closest to Sumatra (~150 km); site of the proposed megaport/logistics hub; strategically crucial for interdicting the Malacca approach.
- **QUAD and Maritime Domain Awareness:** the islands are central to India's IOR surveillance and QUAD maritime cooperation in the Bay of Bengal.

TRIBAL COMMUNITIES (HIGHLY PROTECTED)

Tribe	*Island*	*Population (approx.)*	*Status*
Great Andamanese	Strait Island (settled)	Fewer than 60 individuals	Nearly extinct; smallest indigenous group
Onge	Little Andaman	~100 individuals	Vulnerable; Onge Biosphere Reserve
Sentinelese	North Sentinel Island	Unknown; estimated 50-400	UNCONTACTED; hostile to outsiders; no entry permitted
Shompen	Great Nicobar	~200-250 individuals	Forest nomads; highly vulnerable to development
Nicobarese	Nicobar group	Thousands	Largest indigenous group; partial mainstream contact

IFoS FOCUS

IFoS Conservation Tip — Tribal Protection : The Sentinelese are protected under the Andaman & Nicobar Islands (Protection of Aboriginal Tribes) Regulation, 1956. No contact is permitted. The Great Nicobar Development Project (below) threatens both the Shompen and the leatherback turtle nesting site at Galathea Bay — a direct wildlife-tribal rights-development conflict.

ENV ALERT

Great Nicobar Island Development Project — NITI Aayog

- **Scale:** ~Rs 72,000 crore; International Container Transshipment Terminal at Galathea Bay, international airport, township and power plant.
- **Ecological controversy:** Galathea Bay is one of the Indian Ocean's most important leatherback turtle nesting sites; the project requires large-scale forest clearance of pristine tropical rainforest; threatens the Shompen; coral reefs at risk from port dredging.
- **Status:** Forest Advisory Committee and National Board for Wildlife clearances granted (controversially); active litigation before NGT and courts; project in early execution amid sustained opposition.

6.7 THE ISLANDS — LAKSHADWEEP

BASIC FACTS

Parameter	*Detail*
Location	Arabian Sea; ~200–440 km west of Kerala; 8°N to 12°N
Total	36 islands, 12 atolls, 3 reefs, 5 submerged banks; ONLY 10 inhabited
Capital	Kavaratti
Area	~32 sq km — India's SMALLEST UT by land area
Population	~64,473 (2011 Census); predominantly Sunni Muslim (~96%)
Economy	Coconut (major cash crop), fishing (tuna), growing tourism
Distance	Minicoy (southernmost) ~280 km from Kerala; nearest island ~200 km

GEOLOGICAL ORIGIN — CORAL ATOLLS (KEY EXAM POINT)

Lakshadweep consists of **coral atolls built by coral polyp (scleractinian) accretion on the Laccadive-Maldive submarine volcanic ridge**. The islands themselves are **coral — NOT volcanic** in character. The underlying ridge is volcanic; the islands are biological constructs. They are classic **atolls** — ring-shaped reef structures enclosing a shallow **lagoon** — formed as coral grew upward to sea level on submerged volcanic seamounts that had subsided over geological time.

CORAL REEF ECOSYSTEM (IFOS PRIORITY)

Lakshadweep's reef systems are among India's **healthiest coral ecosystems**, supporting exceptional marine biodiversity including clownfish, parrotfish, reef sharks, green and hawksbill turtles, and the critically endangered **dugong (***Dugong dugon***)** — India's only sea cow, which grazes on seagrass meadows around the atolls.

- **Reef-building corals:** families *Acropora*, *Porites*, *Favites* — different growth forms (branching, massive, encrusting).
- **Major threats:**
  - **Coral bleaching:** mass bleaching events occurred in 1998, 2010, 2016 and 2020; **renewed mass bleaching reported in 2024** amid record Indian Ocean sea surface temperatures. Bleaching occurs when thermal stress causes corals to expel their symbiotic zooxanthellae algae — the corals turn white and may die if stress persists.
  - **Ocean acidification:** rising CO_2 reduces carbonate ion availability, weakening coral skeletons.
  - **Anchor damage and overfishing:** physical damage to reef structures.
  - **Tourism pressure:** inadequate waste management; direct physical contact with corals.

IFoS FOCUS

IFoS Coral Bleaching Framework : Always link coral bleaching to the MECHANISM: thermal stress (SST rising >1°C above mean max for 4+ weeks) → zooxanthellae expulsion → bleaching → death if stress persists. Then connect to CAUSE (climate change, ENSO El Niño warming) and IMPACT (loss of reef structure, loss of fish biodiversity, reduced coastal protection, damage to Blue Economy/tourism). The 2024 mass bleaching event is the latest in a pattern of increasing frequency and severity.

6.8 INDIA'S MARITIME ZONES & EEZ

Zone	*Limit from Baseline*	*India's Rights*
Territorial Waters	0–12 nautical miles	Full sovereignty (equivalent to land territory); foreign ships: innocent passage only
Contiguous Zone	12–24 nm	Limited enforcement: customs, fiscal, immigration, sanitary laws

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Exclusive Economic Zone (EEZ)	0–200 nm	Sovereign rights over living and non-living resources; ~2.37 million sq km
Extended Continental Shelf (ECS)	Beyond 200 nm (up to 350 nm)	Seabed/subsoil rights only; India's 2009 CLCS submission (Arabian Sea + Bay of Bengal)

Blue Economy — the sustainable use of ocean resources for economic growth, improved livelihoods and ocean health — is India's overarching maritime-development framework. The **Draft Blue Economy Policy (2021)** aims to expand the marine sector's GDP contribution through fisheries, aquaculture, offshore hydrocarbons, deep-sea mining (polymetallic nodules), coastal tourism and ocean energy.

UPSC CIVIL

"Comment on the resource potentials of the long coastline of India and highlight the status of natural hazard preparedness in these areas." [UPSC Civil (Mains) 2023 | GS-1 | 15M]
answer must cover EEZ resources (fisheries, oil-gas, placer minerals, polymetallic nodules), ports/trade, coastal tourism, Blue Economy, AND hazard preparedness (IMD cyclone warning, INCOIS tsunami warning, NDMA, Odisha model, MISHTI mangroves). See full model answer in Section 6.13.

6.9 COASTAL ECOSYSTEMS & BIODIVERSITY

MANGROVES

Mangrove System	*State*	*Area / Feature*	*Conservation Status*
Sundarbans	West Bengal (+ Bangladesh)	World's largest mangrove delta; Royal Bengal tiger; Gangetic & Irrawaddy dolphin	UNESCO World Heritage Site; Tiger Reserve; Ramsar site
Bhitarkanika	Odisha	India's 2nd-largest mangrove; saltwater crocodile stronghold	Ramsar site; National Park
Pichavaram	Tamil Nadu	Large mangrove between Vellar & Kollidam rivers	No formal Ramsar; important biodiversity
Gulf of Kutch	Gujarat	Arid-zone mangroves; unique in semi-arid coastal setting	Marine National Park nearby
Chorao Island (Mandovi)	Goa	Small but well-studied mangrove; Salim Ali Bird Sanctuary	State-level conservation

IFoS FOCUS

Mangrove Ecological Services (IFoS must-know) : (1) **Coastal protection** — wave attenuation/storm-surge buffering (Bhitarkanika reduced cyclone damage significantly). (2) **Blue carbon** — mangroves sequester carbon 3-5× faster per unit area than tropical forests. (3) **Fish nurseries** — ~80% of tropical marine fish species use mangroves as juvenile habitat. (4) **Livelihoods** — coastal fishing communities depend on mangrove fish/crab harvest. (5) **Habitat** — mudskippers, fiddler crabs, proboscis monkeys, and mangrove-specific bird species.

CORAL REEFS

- **Lakshadweep:** most extensive healthy reefs in India; among India's best-preserved.
- **Gulf of Mannar Biosphere Reserve (Tamil Nadu):** 21 islands; dugong habitat; 3,600+ plant and animal species; India's first marine biosphere reserve (1989); also a Marine National Park.
- **Andaman & Nicobar:** diverse reefs; some damaged by the 2004 tsunami.
- **Gulf of Kutch Marine National Park (Gujarat):** unique arid-zone coral in northwest India.

OLIVE RIDLEY SEA TURTLES — GAHIRMATHA

Gahirmatha beach (Odisha) is the **world's largest known mass-nesting (arribada) site** for **olive ridley sea turtles**

(*Lepidochelys olivacea*). Tens of thousands of females come ashore simultaneously to lay eggs in a synchronised event. Rushikulya (Odisha) is the second mass-nesting site. Primary threat: **entanglement in fishing nets (bycatch)**; **Turtle Excluder Devices (TEDs)** are legally mandated on trawlers but enforcement remains weak.

DUGONG — INDIA'S SEA COW

The **dugong (***Dugong dugon***)** is India's only species of sea cow — a large, slow, herbivorous marine mammal that grazes on seagrass beds. It is **Schedule I (WPA), CITES Appendix I** and **Critically Endangered nationally**. Small populations persist in the **Gulf of Mannar (Tamil Nadu)** and the **Andaman & Nicobar Islands**. Loss of seagrass beds through coastal pollution, dredging and boat propeller strikes is the primary threat.

6.10 HAZARDS & ENVIRONMENTAL ISSUES

CYCLONES — WHY BAY OF BENGAL IS MORE PRONE

The Bay of Bengal accounts for approximately **6-7% of global tropical cyclone activity** but contributes disproportionately to casualties — driven by **four structural reasons** that recur as UPSC PYQs (2014, 2022, 2024):

- **Funnel shape:** the enclosed Bay amplifies storm surges as cyclones move northward into its narrowing head — water has nowhere to escape and piles up against the low-lying Odisha-West Bengal coast.
- **Persistently warm sea surface temperatures:** Bay waters cool more slowly than the Arabian Sea (which cools through upwelling of the Somali current); sustained warmth fuels stronger and longer-lasting cyclones.
- **No cold-water upwelling:** Arabian Sea upwelling (Somali current) stabilises the atmosphere and inhibits cyclone formation; no equivalent upwelling occurs in the Bay.
- **Low-lying deltaic coasts:** the Bengal-Odisha coast is flat, low and densely populated — storm surges of 3-5 m inundate vast areas.

UPSC CIVIL

Arabian Sea Cyclones Rising : Historically rare, Arabian Sea cyclones are increasing with ocean warming. Cyclone Tauktae (May 2021) and Cyclone Biparjoy (June 2023, landfall near Jakhau, Kutch) are recent examples — cite these for the "climate change → cyclone intensification" argument.

COASTAL EROSION

Per the **National Centre for Coastal Research (NCCR), Ministry of Earth Sciences**: of India's ~6,907 km of assessed mainland coast (1990-2018), **33.6% is under erosion, 26.9% is accreting and 39.6% is stable**. **West Bengal has the highest erosion rate (~60.5% of its coast)**.

- **Causes:** sea-level rise (mean SLR ~1.2-1.7 mm/year along Indian coasts; INCOIS), mangrove loss, sand mining from beaches and river beds, breakwaters/sea walls disrupting longshore sediment transport, dredging.
- **Most affected:** Odisha, West Bengal, Kerala and Tamil Nadu coasts.

2004 INDIAN OCEAN TSUNAMI

The **26 December 2004 Sumatra-Andaman earthquake (Mw 9.1-9.3)** generated the deadliest tsunami in recorded history. In India, per NDMA, **~10,749 dead and 5,640 missing (~16,389 total)** — across Tamil Nadu, Andhra Pradesh, Kerala, Puducherry and the A&N Islands. **A&N Islands accounted for ~3,513 of the dead/missing**; Indira Point area was submerged; some islands changed shape. This event directly led to India establishing the **Indian National Centre for Ocean Information Services (INCOIS) tsunami early-warning system in 2007**.

SEA-LEVEL RISE — ISLAND AND DELTA THREATS

- **Sundarbans:** dozens of low-lying islands shrinking; Ghoramara island has lost much of its area; New Moore/South Talpatti island (disputed India-Bangladesh shoal) has submerged.
- **Lakshadweep:** atolls rarely rise above 3 m — **sea-level rise poses an existential threat** to these islands within decades.

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6.11 GOVERNMENT INITIATIVES

MISHTI – Mangrove Initiative for Shoreline Habitats & Tangible Incomes

Announced in the **Union Budget 2023-24**; mangrove plantation and restoration along India's coastline through **MGNREGS and CAMPA** convergence. Aims to increase mangrove cover while providing livelihood income to coastal communities. One of the most important conservation-livelihood integration schemes of recent years.

SAGARMALA Programme (2015)

Port-led development: **port modernisation, port connectivity, port-linked industrialisation and coastal community development**. Aims to reduce logistics costs and boost coastal employment. Over 800 projects identified worth ~Rs 6 lakh crore.

Coastal Regulation Zone (CRZ) Notification 2019

Replaced CRZ 2011; recalibrated no-development zones and setback distances. Allowed construction closer to tidal water lines in some categories — **controversial** among environmentalists for easing coastal protection norms.

Deep Ocean Mission (2021)

Approved by Union Cabinet in June 2021; **₹4,077 crore for 2021-26** (₹2,823.4 crore for Phase I); Ministry of Earth Sciences. Six components: **Samudrayaan** (manned deep-sea submersible to 6,000 m), deep-sea mining technology (polymetallic nodules in Central Indian Ocean), ocean biodiversity, climate-change advisory, coastal-tourism support, and ocean energy/freshwater systems.

INCOIS Tsunami Early Warning System

Established **2007** at the **Indian National Centre for Ocean Information Services (INCOIS)**, Hyderabad; operates 24/7; uses seismic data + deep-ocean buoys (DART/OMNI) + tide gauges to detect tsunamigenic earthquakes and issue alerts within minutes.

Project Sea Turtle

MoEFCC programme for sea-turtle conservation; includes Gahirmatha Marine Sanctuary management, TED enforcement, and community-based conservation.

6.12 CURRENT AFFAIRS HOOKS (2021–2025)

CURRENT AFFAIRS	**Revised coastline 11,098.81 km (2023-24):** NHO/SoI revision; coastline paradox (fractal geometry); no territorial change. Classic 7,516.6 km remains valid in older sources. **MISHTI (Budget 2023-24):** Mangrove restoration via MGNREGS+CAMPA; live implementation along multiple state coastlines. **2024 Mass Coral Bleaching:** Record Indian Ocean sea surface temperatures triggered mass bleaching in Lakshadweep and Gulf of Mannar — part of the 2024 global fourth mass-bleaching event (NOAA classification). Especially severe in Indian waters. **Cyclone Remal (26-27 May 2024):** Bay of Bengal; landfall near West Bengal-Bangladesh coast; widespread flooding in Bangladesh and NE India (Mizoram, Tripura, Assam). A reminder of Bengal coast cyclone vulnerability. **Cyclone Biparjoy (15 June 2023):** Rare Arabian Sea cyclone; landfall near Jakhau, Kutch, Gujarat. Large-scale evacuation; demonstrated rising Arabian Sea cyclone risk. **Great Nicobar Mega-Project (Rs 72,000 crore):** NITI Aayog project for megaport, airport, township on Great Nicobar; clearances granted controversially; litigation ongoing; leatherback turtle, Shompen tribal and coral reef concerns. **Port Blair renamed Sri Vijaya Puram (2024):** Capital of A&N UT renamed; cite both names in exam answers.

Lakshadweep development controversy (2021): Draft regulations on land, licensing and alcohol seen as threatening island ecology and way of life; protests by island community and opposition.

6.13 PYQ ANALYSIS — CHAPTER 6 (2010–2025)

Questions from UPSC Civil Mains GS-1/GS-3 and IFoS GS directly testing themes of this chapter:

Source	Year	Marks	Question
UPSC Civil	2023	15M	"Comment on the resource potentials of the long coastline of India and highlight the status of natural hazard preparedness in these areas."
IFoS GS	2018	10M	"Examine the economic and strategic importance of the Island regions of India."
IFoS GS	2016	10M	"Account for the environmental problems of lagoon ecosystem for tourism development."
UPSC Civil	2014	10M	"Tropical cyclones are largely confined to the South China Sea, Bay of Bengal and Gulf of Mexico. Why?"
UPSC Civil	2022	10M	"Discuss the meaning of colour-coded weather warnings for cyclone-prone areas given by India Meteorological Department."
UPSC Civil	2024	10M	"What is sea surface temperature rise? How does it affect the formation of tropical cyclones?"
IFoS GS	2023	15M	"Differentiate between Cyclone and Anti-cyclone. How are tropical cyclones being affected globally by climate change?"
UPSC Civil	2022	15M	"Mention the significance of straits and isthmus in international trade."
UPSC Civil	2025	15M	"Explain briefly the ecological and economic benefits of solar energy generation in India." (Lakshadweep solar potential angle)
IFoS GS	2022	10M	"Write a note on tropical cyclones. Discuss genesis and impact of Cyclone Amphan on India."

KEY NOTE

Frequency pattern : Cyclones (Bay of Bengal, SST, climate change) form the most frequently examined cluster — appearing in GS-1, GS-3 and IFoS. Coastal resource potential + hazard preparedness (Civil 2023) is a new consolidated question type. Lagoon ecology, mangroves, coral bleaching and island strategic importance are recurring IFoS themes. Prioritise: (1) cyclone mechanism/Bay of Bengal factors, (2) W vs E coast comparison, (3) A&N vs Lakshadweep geology, (4) Blue Economy + EEZ, (5) MISHTI/Sagarmala/Deep Ocean Mission.

6.14 MODEL QUESTION

Comment on the resource potentials of the long coastline of India and highlight the status of natural hazard preparedness in these areas.

UPSC Civil (Mains) 2023 | GS-1 | 15 Marks | 200 Words

India's 11,098.81 km coastline and an EEZ of ~2.37 million sq km constitute a vast resource frontier — the engine of India's **Blue Economy**.

RESOURCE POTENTIALS

- **Living resources:** Marine fisheries support ~14 million fishers; India's marine fish production ~4.5 million tonnes annually. The EEZ's fishery resource is significantly underexploited.
- **Hydrocarbons:** Offshore Mumbai High (crude oil); Krishna-Godavari basin (gas); western shelf reserves sustain energy security.

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- **Mineral sands:** Kerala-Tamil Nadu coast: ilmenite, garnet, zircon, **monazite (thorium)** — strategic for India's thorium-based nuclear programme.
- **Salt and chemicals:** Gujarat coast — India's largest salt producer; coastal brine for chemicals.
- **Ports and trade:** ~95% of trade by volume; 12 major ports; SAGARMALA building port-led industrial zones.
- **Tourism and Deep Sea:** backwaters (Kerala), beaches, islands; Deep Ocean Mission targets polymetallic nodules in the Central Indian Ocean.

HAZARD PREPAREDNESS

- **Cyclones:** IMD Doppler-radar early warning; NDMA-NDRF framework; Odisha's zero-casualty model of mass cyclone evacuation.
- **Tsunami:** INCOIS warning system (since 2007); deep-ocean DART buoys; community awareness.
- **Coastal erosion/SLR:** MISHTI mangrove restoration (Budget 2023); CRZ 2019 setback regulation; NCCR coastal monitoring.

Realising coastal resource potential sustainably demands integrating Blue Economy growth with climate-resilient hazard infrastructure — through ecological corridors, community-based management and international maritime cooperation.

CHAPTER 7

ISLANDS OF INDIA

Andaman & Nicobar | Lakshadweep | Maritime Zones

CHAPTER AT A GLANCE

- India has ~1,382 islands: Andaman & Nicobar (Bay of Bengal; ~572 islands) + Lakshadweep (Arabian Sea; 36 islands, 11 inhabited) + others (Majuli, Pamban, Sriharikota, Diu etc.).
- A&N Islands: union territory; volcanic + coral origin; extension of Arakan Yoma fold mountains of Myanmar; Port Blair (capital); Indira Point (southernmost point of India; submerged in 2004 tsunami; on Great Nicobar).
- Tribal communities of A&N: Andamanese, Onge, Jarwa (Strait Island), Sentinelese (North Sentinel — most isolated tribe on Earth; contact prohibited under law), Shompen, Nicobarese; 5 Particularly Vulnerable Tribal Groups (PVTGs).
- Great Nicobar Development Project (2023): Rs.72,000 crore; transshipment port + international airport + township + 450 MW power plant; near Malacca Strait; MAJOR controversy — leatherback sea turtle nesting beach, Shompen tribe, pristine tropical evergreen forest, biosphere reserve.
- Lakshadweep: coral atolls (not volcanic); 36 islands; 11 inhabited; Kavaratti (capital); Agatti (airport); Minicoy (southernmost; Maldivian culture). Highest forest cover UT (~91.33% ISFR 2023). 2024 coral bleaching crisis.
- PM Modi Lakshadweep visit (Jan 2024) + Maldives diplomatic row: India-Maldives tension over Maldives PM Muizzu's pro-China stance; Modi's visit promoted Lakshadweep tourism as India alternative to Maldives.
- EEZ: India's Exclusive Economic Zone = 2.37 million sq km (larger than India's land area of 3.29 million sq km). Islands extend EEZ enormously; A&N Islands give India strategic presence near Malacca Strait (80% of global oil trade passes through it).
- Blue Economy: deep-sea mining (Samudrayaan Mission; MATSYA 6000 submersible); polymetallic nodules; fish resources; seabed minerals; India signed ISA (International Seabed Authority) contracts for exploration blocks.

7.1 INTRODUCTION — INDIA'S ISLAND TERRITORIES

India's island territories are among its most strategically valuable and ecologically precious assets — yet they remain among the least-known and least-visited parts of the country. Scattered across two entirely different seas, India's islands have profoundly different origins, ecologies, cultures and geopolitical significance:

- **Andaman & Nicobar Islands (Bay of Bengal):** a **volcanic and sedimentary arc** stretching ~794 km from north to south; geologically an extension of the **Arakan Yoma fold mountain system** of Myanmar; home to some of India's most biodiverse tropical evergreen forests; site of **North Sentinel Island** — home to the world's most isolated tribe; and the location of India's strategic **Andaman and Nicobar Command (ANC)** — the country's only tri-services (army+navy+air force) operational command.
- **Lakshadweep Islands (Arabian Sea):** a chain of **coral atolls** (not volcanic) ~200-400 km west of Kerala; the smallest union territory of India by area (~32 sq km of land); overwhelmingly Muslim population; uniquely dependent on the sea, coconuts and tourism; an ecologically critical coral reef ecosystem under severe stress from climate change-induced bleaching.

India's islands are not merely beautiful vacation spots — they are **strategic outposts that define India's maritime boundaries and Exclusive Economic Zone (EEZ).** The two archipelagos together add roughly **2 million sq km to India's EEZ** — an area larger than India's land territory — making them indispensable to India's Blue Economy, maritime security and climate negotiations.

KEY ISLAND STATISTICS AT A GLANCE

Parameter	*Andaman & Nicobar Islands*	*Lakshadweep*

Location	Bay of Bengal (east coast; ~1,200 km from Chennai; ~150 km from Myanmar/Sumatra)	Arabian Sea (west coast; ~200-400 km from Kerala coast)
Total islands	~572 (some sources cite 836 counting all rocks/islets); 38 inhabited	36 islands, 5 coral reefs, 3 submerged banks; 11 inhabited
Total land area	~8,249 sq km (largest island UT by area)	~32 sq km (smallest UT by area)
Capital	Port Blair (South Andaman Island)	Kavaratti
Geological origin	Volcanic (Barren Island) + uplifted sedimentary / coral; extension of Myanmar's Arakan Yoma fold mountains	Coral atolls (ring-shaped coral reefs enclosing a lagoon); no volcanic origin
Population (Census 2011)	380,581	64,473
Literacy (2011)	86.27% (above national average)	91.85% (3rd highest in India)
Forest cover (ISFR 2023)	~81.62% of geographic area	~91.33% of geographic area (HIGHEST among all UTs)
Administrative status	Union Territory (with legislature)	Union Territory (without legislature — Lakshadweep Regulation 1965; 2021 controversy)
Key strategic asset	Only tri-services Andaman and Nicobar Command (ANC); proximity to Malacca Strait	No military command; proximity to major shipping lanes; coral reef biodiversity

WHY ISLANDS MATTER — SIX DIMENSIONS

1. **Maritime Security:** A&N Islands sit at the junction of the Indian Ocean, Bay of Bengal and Pacific approaches — enabling India to monitor the **Malacca Strait** (through which ~80% of global oil trade and ~60% of world's container traffic passes). The Andaman and Nicobar Command (ANC) — India's only tri-services command, at Port Blair — is designed to project power across this critical chokepoint.
2. **Exclusive Economic Zone (EEZ):** Under UNCLOS 1982, every island gives a state a 200 nautical mile EEZ of exclusive resource rights. India's islands extend its EEZ to **2.37 million sq km** — rich in fish, polymetallic nodules, oil/gas potential and other seabed resources.
3. **Ecological Wealth:** A&N Islands host one of the world's finest tropical evergreen forest ecosystems (comparable to the Amazon for its species density and endemism); Lakshadweep's coral atolls are among the most biodiverse marine ecosystems in the Indian Ocean — both are globally threatened.
4. **Blue Economy:** India's deep-sea mining programme (Samudrayaan Mission; MATSYA 6000), offshore fisheries, seabed oil/gas exploration and future hydrogen/offshore wind ambitions all depend on India's maritime territories — defined by its islands.
5. **Tribal Preservation:** A&N's five PVTGs (Particularly Vulnerable Tribal Groups) — especially the Sentinelese — represent some of the last pre-Neolithic human communities on Earth; their protection is both a legal obligation and a moral imperative under the UN Declaration on the Rights of Indigenous Peoples.
6. **Tourism and Soft Power:** Havelock (Swaraj Dweep) and Neil (Shaheed Dweep) in A&N, and the pristine lagoons of Lakshadweep, are world-class tourism assets; in 2024, India leveraged Lakshadweep to project an alternative to Maldives tourism amid a diplomatic row.

7.2 ANDAMAN AND NICOBAR ISLANDS — DETAILED GEOGRAPHY

The Andaman and Nicobar Islands form India's most remote Union Territory — a **794-km long archipelago** stretching from **Landfall Island (northernmost)** to **Indira Point on Great Nicobar Island (southernmost)** across the Bay of Bengal. The total land area of ~8,249 sq km is spread across hundreds of islands, with only 38

permanently inhabited. The islands are separated from each other by straits, channels and sounds — many of which are named after British colonial explorers.

PHYSICAL DIVISIONS

Division	*Key Islands*	*Area/Note*
NORTH ANDAMAN GROUP	Landfall Island (northernmost), Interview Island, North Andaman Island	Largely uninhabited; Interview Island = Wildlife Sanctuary (feral elephants — released from logging operations); dense tropical forests
MIDDLE ANDAMAN GROUP	Middle Andaman Island (Mayabunder, Rangat taluks)	Tribals (Karen people — descendants of Burmese settlers brought by British); timber forests; largely undeveloped
SOUTH ANDAMAN GROUP	South Andaman (contains Port Blair), Rutland Island, Havelock Island (Swaraj Dweep), Neil Island (Shaheed Dweep), Ross Island (Netaji Subhas Chandra Bose Island)	Most populated group; Port Blair = capital and main port; Havelock = most famous tourism island (Radhanagar Beach — rated one of Asia's best); Ross Island = British colonial capital
LITTLE ANDAMAN	Little Andaman Island	Onge tribe territory; largely restricted to outsiders; national park
CAR NICOBAR GROUP	Car Nicobar Island (northernmost Nicobar)	Air force base (INS Baaz); strategic; damaged in 2004 tsunami; Nicobarese tribe
CENTRAL NICOBAR GROUP	Camorta, Nancowry, Katchal	Nancowry Harbour — excellent natural harbour; Katchal = damaged badly by 2004 tsunami
SOUTHERN NICOBAR GROUP / GREAT NICOBAR	Great Nicobar (southernmost; ~910 sq km); Indira Point; Pygmalion Point area	India's southernmost point (Indira Point, 6°45'N); near Indonesian Sumatra (only ~150 km); biosphere reserve; leatherback sea turtle nesting; Shompen tribe; centre of Great Nicobar Development controversy
BARREN ISLAND	~135 km NE of Port Blair	India's ONLY ACTIVE VOLCANO; South Asia's only confirmed active volcano; last erupted 2017-18; basaltic lava flows; no permanent inhabitants; visited by scientists
NARCONDAM ISLAND	~150 km NE of Port Blair	Dormant volcano; Narcondam Hornbill (Aceros narcondami) — endemic to this single island; restricted entry; bird endemic

GEOLOGICAL ORIGIN

The Andaman and Nicobar Islands are geologically an **extension of the Arakan Yoma fold mountains of Myanmar** — the westernmost sub-range of the Indo-Burman Ranges. When the Indian tectonic plate subducted under the Eurasian/Burmese plate at the **Andaman Trench** (one of the deepest oceanic trenches in the Indian Ocean, ~4,500 m deep), the resulting volcanic and fold-mountain arc emerged above sea level as the Andaman and Nicobar Islands.

Geological Zone	*Islands*	*Formation Process*
Volcanic Arc	Barren Island (active), Narcondam Island (dormant)	Classic subduction zone volcanism; Indian plate subducting → magma rising → volcanic islands; same process as Indonesian Java-Bali arc

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Uplifted Sedimentary/Flysch	Main Andaman Islands (North, Middle, South Andaman)	Flysch (alternating sandstone-shale); uplifted and folded by tectonic compression; similar rocks to the Arakan Yoma of Myanmar
Coral / Fringing Reefs	Fringing reefs around most islands; atoll reefs on some low islands	Coral growth on shallow volcanic/sedimentary platforms; extensive fringing and barrier reefs
Ophiolites	Ophiolitic sequences exposed on some islands	Ancient oceanic crust emplaced; geologically significant for understanding subduction

KEY NOTE

Andaman Trench — Exam Point: The Andaman Trench (also called the Sunda Trench extension in the Bay of Bengal) — the subduction zone between the Indian plate and the Burmese microplate — was the epicentre of the **December 26, 2004 Indian Ocean Tsunami (Mw 9.1-9.3 — one of the strongest earthquakes in recorded history)**. The earthquake (off the coast of northern Sumatra) generated a massive tsunami that devastated the Andaman and Nicobar Islands (especially Car Nicobar, Katchal and Indira Point), Sri Lanka, Thailand, India's Tamil Nadu/Andhra coast, and 14 countries. Indira Point was partially submerged. An estimated 10,000+ people died in the A&N Islands alone.

CLIMATE

The A&N Islands have a **tropical rainforest climate (Af type in Koppen classification)** — hot and humid throughout the year with very high rainfall. Unlike mainland India where monsoon is seasonal, the islands receive rainfall from **both the SW monsoon (May-October)** and the **NE monsoon (November-December)** plus inter-monsoon periods, resulting in rainfall throughout the year.

Climate Parameter	*Detail*
Temperature	Mean temperature: 23-30°C throughout year; very small annual range (~3-4°C); no winter; humidity 70-85%
Rainfall	~3,000-4,000 mm/year (North Andaman receives most; some areas >4,000 mm); more or less year-round
Monsoon	SW monsoon reaches A&N very early (mid-May, 2-3 weeks before mainland India); NE monsoon also brings rain (Oct-Dec); inter-monsoon rain common
Cyclones	Bay of Bengal is one of the world's most active cyclone basins; A&N Islands face cyclone risk; Cyclone Warning Centre at Port Blair
Sea surface temperature	Warm year-round (27-30°C); warming due to climate change causing coral bleaching; sea-level rise threatens low-lying islands

NATURAL VEGETATION — TROPICAL EVERGREEN AND ALLIED TYPES

The Andaman and Nicobar Islands support India's finest tropical evergreen forests — with a **forest cover of ~81.62% of geographical area (ISFR 2023)** — the 2nd highest among India's UTs and states after Lakshadweep. The forest types include:

Forest Type	*Location / Extent*	*Key Species / Notes*
Tropical Wet Evergreen (Type 1A)	Main Andaman group and most of Nicobar; >200 cm rainfall; predominant type	Padauk (Pterocarpus dalbergioides — State Tree of A&N; beautiful red-gold timber, used in ship-building and furniture), Gurjan (Dipterocarpus grandiflorus — one of India's tallest timber trees; plywood), Kokko (Albizia lebbeck), Canes, Bamboo
Andaman Tropical Moist Deciduous	Some areas of South Andaman; secondary growth on disturbed areas	Semi-evergreen character; Teak, Tun (Toona ciliata), Terminalia species

Tropical Semi-Evergreen	Transitional areas; disturbed habitats	Mixed deciduous and evergreen; common near settlements
Littoral / Mangrove Forests (Champion & Seth Type 4)	All tidal mudflat and creek areas; most extensive along low-lying coasts	Rhizophora, Avicennia, Bruguiera, Sonneratia; rich mangrove diversity; many species unique to A&N
Nicobar Tropical Wet Evergreen	Nicobar Islands; floristically distinct from Andaman (closer to SE Asian flora)	Nicobar Pandanus (screw pine), Melaleuca (paper bark), giant Dipterocarpus; orchids; SE Asian affinities
Sub-montane Forests	Higher elevations in Nicobar (Saddle Peak highest at 732 m)	Mossy forests; pitcher plants; unique microhabitats

IFoS FOCUS

IFOS — ANDAMAN TIMBER AND CONSERVATION: Andaman Padauk (Pterocarpus dalbergioides) — the Andaman State Tree — is a premium timber used historically for furniture and ship-building. Logging of Padauk and Gurjan in the Andaman forests was extensive under British rule and continued post-independence through the Andaman and Nicobar Islands Forest Plantation and Development Corporation (ANFPDC). The Supreme Court's 2002 order in TN Godavarman vs Union of India significantly restricted logging and ordered halt to clear-felling. Today timber extraction is largely stopped; conservation focus has increased. However, the Great Nicobar Development Project (2023) would require felling of ~8.27 lakh trees — reigniting the conservation debate. Key IFoS point: Andaman Padauk + Gurjan + Canes + Bamboo = major commercial species of this unique island forest ecosystem.

WILDLIFE OF ANDAMAN AND NICOBAR ISLANDS

The A&N Islands' isolation over millions of years has produced a **remarkable level of endemism — species found nowhere else on Earth.** The islands also serve as nesting grounds for globally threatened marine species and host unique subspecies of mainland Indian animals.

Category	*Species / Notes*
ENDEMIC MAMMALS	Andaman Wild Pig (Sus scrofa andamanensis); Andaman Spiny Shrew; Nicobar Treeshrew; Crab-eating Macaque (Macaca fascicularis — introduced by British); Dugong (Dugong dugon — sea cow; endangered; feeds on seagrass beds; protected under WPA 1972; A&N have significant population)
ENDEMIC BIRDS	Andaman Teal (Anas albogularis — rare dabbling duck); Andaman Serpent Eagle (Spilornis elgini); Andaman Woodpecker; Narcondam Hornbill (Aceros narcondami — found ONLY on Narcondam Island — one of world's rarest hornbills; ~300 individuals; island protected); Nicobar Pigeon (Caloenas nicobarica — most beautiful pigeon in the world; runs along ground; closest living relative of the extinct Dodo); Nicobar Megapode (Megapodius nicobariensis — mound-nesting bird; builds temperature-regulated incubation mounds); White-headed Starling
MARINE TURTLES	LEATHERBACK SEA TURTLE (Dermochelys coriacea — world's largest turtle; up to 900 kg; lays eggs on beaches of Great Nicobar — one of the last major leatherback nesting sites in the Indian Ocean; PRIMARY REASON FOR OPPOSITION TO GREAT NICOBAR DEVELOPMENT PROJECT); Green Turtle, Hawksbill Turtle, Olive Ridley Turtle — all nest on A&N beaches; all critically endangered or vulnerable
CROCODILES	Saltwater Crocodile (Crocodylus porosus — largest living reptile; up to 7 m; A&N Islands have significant population; attacks on humans recorded); Mugger Crocodile (freshwater; some areas)

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MARINE LIFE	Coral reef fish diversity (>600 species); Reef Shark; Manta Ray; Giant Grouper; Napoleon Wrasse; Hawksbill Turtle (as above); Dugong; Whale Shark (seasonal visitor); Irrawaddy Dolphin
REPTILES	Andaman Cobra (endemic); various Sea Snakes; Monitor Lizards; Reticulated Python
HERPETOFAUNA / ENDEMICS	Many endemic frogs, lizards, snakes; A&N = one of India's richest herpetofaunal zones; largely unstudied
INSECTS / INVERTEBRATES	Extremely high diversity; many endemics; Giant Robber Crab (Birgus latro — world's largest land invertebrate; coconut crab; up to 4 kg; threatened by habitat loss and hunting)

PROTECTED AREAS

Protected Area	*Type*	*Key Feature*
Mahatma Gandhi Marine National Park (Wandur)	Marine NP	One of India's most important marine protected areas; around Wandur, South Andaman; coral reefs, mangroves, seagrass; glass-bottom boat safaris
South Button Island Marine NP	Marine NP	Excellent coral reef; snorkeling/diving
Saddle Peak National Park	NP	Highest peak in A&N (732 m, North Andaman); montane forests; birds
Mount Harriet National Park	NP	Near Port Blair; hill forest; birds (Andaman Teal)
Narcondam Island Sanctuary	Wildlife Sanctuary	Narcondam Hornbill; access restricted; dormant volcanic island
Interview Island Sanctuary	Wildlife Sanctuary	Feral elephants (released by British logging teams; now wild); restricted access; North Andaman
Great Nicobar Biosphere Reserve	UNESCO Biosphere Reserve (1989)	Leatherback turtle nesting; Shompen tribe; pristine evergreen forest; biodiversity hotspot; under threat from development project
Galathea Bay Wildlife Sanctuary	Wildlife Sanctuary (within GN Biosphere Reserve)	Main leatherback nesting beach; PROPOSED TO BE DENOTIFIED for Great Nicobar Port — major controversy
Campbell Bay National Park	National Park (Great Nicobar)	Tropical wet evergreen; rich endemics; within the biosphere reserve

TRIBAL COMMUNITIES OF ANDAMAN AND NICOBAR

The A&N Islands are home to **six tribal groups** — five of which are designated as **Particularly Vulnerable Tribal Groups (PVTGs)** under the Ministry of Tribal Affairs. These communities are among the **most ancient surviving human populations on Earth,** with genetic studies suggesting the Andamanese and Nicobarese have inhabited these islands for 60,000-70,000 years — since the **"Out of Africa"** human migration.

Tribe	*Island(s)*	*Population (approx.)*	*Status / Key Note*
GREAT ANDAMANESE (Andamanese)	Strait Island (relocated)	~60 (critically low)	PVTG; once the most numerous A&N tribe (~5,000+ in 1850s); decimated by contact diseases (measles, influenza) introduced by British; language isolate (Andamanese language family — no relation to any known language); now living in government rehabilitation facility on Strait Island; critically endangered ethnically

ONGE	Little Andaman Island	~100-150 (VERY LOW; declining)	PVTG; semi-nomadic; hunter-gatherer; southern Little Andaman designated as Onge Tribal Reserve; 2/3 of Little Andaman opened to outsiders — created tensions; highly vulnerable to outside contact; alcoholism a significant concern
JARWA	South and Middle Andaman (Jarawa Reserve, Strait Island area)	~250-300 (stable / slightly growing)	PVTG; most discussed A&N tribe; lived in isolation for decades (hostile to outsiders — attacked logging roads, helicopters); first peaceful contact ~1998-1999; since then, some contact; JARAWA RESERVE = ~1,028 sq km; their main hunter-gatherer territory; controversy over "human safaris" (tourists driving through their territory — SC banned in 2011 orders; partly violated)
SENTINELESE	North Sentinel Island	~50-400 (estimated; uncertain)	PVTG; WORLD'S MOST ISOLATED TRIBE; no contact with outside world; attack any approaching vessels/aircraft; contact is PROHIBITED under Indian law (A&N Protection of Aboriginal Tribes Regulation 1956; IPC provisions); John Allen Chau (American missionary) killed November 2018 when he attempted contact; government has maintained strict no-contact policy; 3 km exclusion zone around North Sentinel Island; listed as one of the world's most intriguing isolated communities
SHOMPEN	Great Nicobar Island (interior)	~100-200 (declining)	PVTG; semi-nomadic; forest dwellers of Great Nicobar's interior; at GREATEST RISK from the Great Nicobar Development Project which would bring thousands of workers into their territory; National Commission for Scheduled Tribes has flagged serious risk
NICOBARESE	Nicobar group islands (Car Nicobar, Katchal, Camorta, Great Nicobar coast)	~25,000-30,000	NOT a PVTG; settled farming and fishing community; predominantly Christian (post-British missionary contact); speak Nicobarese languages (Mon-Khmer family — SE Asian linguistic affinity); most progressive and adaptive of A&N tribes; significantly affected by 2004 tsunami

ENV ALERT

Sentinelese — The Last Uncontacted Tribe

North Sentinel Island (~72 sq km; off the western coast of South Andaman) is home to the **Sentinelese** — the last people on Earth to have had no verified contact with the outside world. They have resisted all contact violently for centuries — shooting arrows at approaching ships and aircraft. The Indian government's official policy (under the A&N Protection of Aboriginal Tribes Regulation 1956) is **total non-contact and a 3-nautical-mile exclusion zone**. Their population is unknown (satellite images suggest 50-500 individuals). In November 2018, John Allen Chau, an American evangelical missionary, was killed when he attempted contact in violation of Indian law. The government declined to retrieve his body or take action against the Sentinelese — upholding the tribe's right to isolation. This case was globally prominent and reinforced India's non-contact policy as the only ethical approach to truly isolated peoples.

CELLULAR JAIL — KALA PANI

The **Cellular Jail (Kala Pani) at Port Blair** is India's most iconic colonial penal facility — a **National Memorial** and one of the most visited historical sites in India. Built by the British between 1896 and 1906, it was designed on a

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panopticon plan (seven wings radiating from a central watchtower; each prisoner isolated in individual cells — hence "Cellular") to house Indian political prisoners. Notable internees included **Vinayak Damodar Savarkar (Veer Savarkar)** (1911-21, two consecutive life terms), **Batukeshwar Dutt**, **Yogendra Shukla** and thousands of freedom fighters from the Revolt of 1857, the Ghadar movement and the Bengal Partition agitation. The Andaman Islands were also the site of India's **first provisional government (Netaji Subhas Chandra Bose, December 1943)** — when the Japanese-allied Indian National Army (INA) briefly controlled Port Blair.

IMPORTANT PLACES AND TOURISM

Place	*Island / Location*	*Significance*
Port Blair	South Andaman Island	Capital; main airport (Veer Savarkar International Airport); main port; Cellular Jail; Ross Island (Netaji Subhas Chandra Bose Island) nearby
Havelock Island (Swaraj Dweep)	38 km from Port Blair (ferry)	Most famous tourist island; Radhanagar Beach (Beach 7) — rated one of Asia's top beaches (Time Magazine 2004); scuba diving; snorkeling; coral reefs
Neil Island (Shaheed Dweep)	~40 km from Port Blair	Quieter tourism; natural bridge (rock arch); beaches; coral reefs; backpacker favourite
Ross Island (Netaji Subhas Chandra Bose Island)	~2 km from Port Blair	Former British colonial capital; ruins of colonial buildings (church, tennis courts, club); now managed by Indian Navy; deer roam freely
Barren Island	~135 km NE of Port Blair	India's only active volcano; last erupted 2017-18; accessible by boat; no landing permitted
North Bay Island	~8 km from Port Blair (boat)	Coral reef; glass-bottom boat rides; snorkeling; entry-level dive site; very popular
Jolly Buoy Island	Mahatma Gandhi Marine NP	Premier snorkeling/diving spot; only open in winter months (Oct-May); no permanent human settlement; very pristine reef
Diglipur (North Andaman)	North Andaman Island	Saddle Peak (highest point); Lamiya Bay coral; Mud Volcano (mud erupts periodically); sea turtles
Chidiya Tapu	South Andaman Island	Sunset Point; mangroves; birds (Andaman Teal, herons, kingfishers)
Car Nicobar	Northern Nicobar group	Air Force station; Nicobarese population; coconut; 2004 tsunami site
Great Nicobar / Indira Point	Southernmost point of India	India's southernmost point (6°45'N); lighthouse; near Indonesia (Sumatra ~150 km); Biosphere Reserve; leatherback turtle nesting

7.3 GREAT NICOBAR DEVELOPMENT PROJECT — INDIA'S MOST CONTROVERSIAL INFRASTRUCTURE DECISION

The **Great Nicobar Holistic Development Project** — approved by MoEFCC in January 2023 and estimated to cost **Rs.72,000 crore** — is the single most controversial environmental governance decision in recent Indian history. It proposes to transform the pristine southern tip of Great Nicobar Island (India's southernmost territory, near the Malacca Strait) into a major maritime-aviation-urban hub — an initiative hailed by proponents as strategic brilliance and condemned by ecologists as ecological catastrophe.

COMPONENTS OF THE PROJECT

Component	Details / Scale
Transshipment Port	A large-scale container transshipment port at Galathea Bay, Great Nicobar; capacity ~16 million TEUs (eventually comparable to Singapore's port); to capture transshipment traffic from Colombo and Singapore; near the critical Malacca Strait choke-point
International Airport	A new greenfield international airport on Great Nicobar Island; to serve the port + future township; allow strategic military use by Indian forces
Township	A township housing ~3,50,000 people (defence and civilian personnel, port workers, service workers) — currently the ENTIRE A&N Islands has only ~380,000 people
Power Plant	450 MW gas-based power plant to supply the new port + airport + township
Total project area	~166 sq km of Great Nicobar Island's southern tip
Implementing agency	ANIIDCO (Andaman and Nicobar Islands Integrated Development Corporation) + strategic coordination by NITI Aayog
Forest clearance	~130.75 sq km of dense tropical forest cleared; ~8.27 lakh trees felled; Stage-I clearance given by MoEFCC January 2023

STRATEGIC RATIONALE

- **Malacca Strait proximity:** Great Nicobar is only ~150 km from the northern tip of Sumatra; the Malacca Strait (through which ~80% of global oil trade passes) is within striking distance of A&N Command. A major port here would give India unprecedented maritime strategic presence — enabling monitoring, interdiction capability and power projection.
- **Transshipment revenue:** India currently loses ~75% of its container transshipment business to Colombo (Sri Lanka) and Singapore because Indian ports are too shallow. A deep-water port at Galathea Bay (natural depth 18+ m) could capture this business — generating revenue and reducing shipping costs for Indian exporters.
- **Dual-use (civil-military) infrastructure:** The airport and port would serve both commercial and strategic military purposes — enabling rapid deployment of Indian forces in the Andaman Sea/Indian Ocean.
- **Geopolitical competition with China:** China's "String of Pearls" strategy (network of ports in the Indian Ocean — Gwadar, Hambantota, Kyaukpyu) surrounds India. A Great Nicobar hub counters this by giving India its own eastern Indian Ocean base.

ENVIRONMENTAL CONCERNS — WHY ECOLOGISTS AND TRIBALS OPPOSE IT

Concern	Details
LEATHERBACK SEA TURTLE	Galathea Bay and its beaches are one of the last major nesting grounds for the Leatherback sea turtle (Dermochelys coriacea) in the Indian Ocean; Leatherbacks are critically endangered; they return to their birth beach to nest (natal homing); port lights + construction + vessel traffic would permanently destroy nesting; ~8.27 lakh trees to be cleared destroys coastal nesting habitat
DENOTIFICATION OF GALATHEA BAY WILDLIFE SANCTUARY	The proposed port area overlaps with the Galathea Bay Wildlife Sanctuary; NBWL (National Board for Wildlife) recommended denotification; critics argue denotifying a wildlife sanctuary for industrial use sets a dangerous precedent violating the Wildlife Protection Act
GREAT NICOBAR BIOSPHERE RESERVE / UNESCO	Great Nicobar is a UNESCO-designated Biosphere Reserve (1989); a World Heritage nomination was being considered; the development would compromise the biosphere reserve's integrity; internationally embarrassing given India's global climate and biodiversity commitments

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SHOMPEN TRIBE	The Shompen (PVTG; ~100-200 individuals) live in the interior forests of Great Nicobar; the township of 3.5 lakh people would dramatically overwhelm their territory; disease risk (no immunity to common illnesses); land alienation; National Commission for Scheduled Tribes raised "serious concerns"
TROPICAL FOREST LOSS	~8.27 lakh trees in a pristine tropical wet evergreen forest (rated among the finest in the Indian Ocean region) to be felled; irreversible loss; forest is home to the Nicobar Long-tailed Macaque (endemic), Giant Robber Crab and dozens of endemic species
SEISMIC AND TSUNAMI RISK	Great Nicobar is near the Andaman Trench (epicentre of 2004 tsunami); building a major port and 3.5 lakh-person township in a high tsunami-risk zone is a disaster-preparedness concern; the island already lost significant population and infrastructure in 2004
EIA PROCESS CONCERNS	The Environmental Impact Assessment (EIA) was challenged in the National Green Tribunal (NGT) for procedural violations; critics allege inadequate study of cumulative impact; Stage-I clearance given without complete data; independent scientists dispute MoEFCC's clearance rationale

UPSC CIVIL

Civil GS-3 / GS-2 — Great Nicobar : This project is one of the richest case studies in UPSC for simultaneous themes of: (1) National security vs ecology; (2) Tribal rights (Shompen PVTG + PESA + FRA conflict); (3) Environmental governance (EIA process; wildlife sanctuary denotification; biosphere reserve compromise); (4) Blue economy and transshipment port strategy; (5) India-China geopolitical competition in Indian Ocean. Mains 2024-25 almost certain to include a question on this.

7.4 LAKSHADWEEP — INDIA'S CORAL PARADISE

Lakshadweep (meaning "*a hundred thousand islands*" in Sanskrit/Malayalam, though there are only 36) is India's smallest Union Territory by area (~32 sq km of land, though its lagoon and EEZ cover a vastly larger area) and one of its most ecologically fragile. As **coral atolls built entirely on living and dead coral,** the Lakshadweep islands exist at a **fundamentally different ecological and geological baseline from the Andaman Islands** — their very existence depends on the health of coral reefs.

PHYSICAL GEOGRAPHY

Parameter	*Detail*
Location	10°N to 12°N latitude; 71°E to 74°E longitude; 200-400 km west of Kerala coast; in the Arabian Sea
Geological origin	CORAL ATOLLS — the islands are built on a submerged ridge called the Lakshadweep-Chagos Ridge (part of the Carlsberg Ridge system); coral grew on the submerged volcanic bases; as the volcanic base eroded, the coral remained as ring-shaped atolls
Island types	Atolls (ring reefs with lagoon; Kavaratti, Agatti, Bangaram etc.); Barrier reefs; Fringing reefs; Low-lying flat islands (max elevation 4-5 m above sea level); absolutely flat — no hills
Total islands	36 islands; 12 atolls; 3 coral reefs; 5 submerged banks (Chetlat Bank etc.); 11 inhabited islands
Largest island by area	Andrott Island (~4.9 sq km)
Capital	Kavaratti Island (administrative headquarters; only island with civil court, hospital, secretariat)
Airport	Agatti Island (only airport; connects to Kochi and other cities; very short runway — only ATR 42/72 and similar aircraft can land)

Southernmost island	Minicoy Island (Maliku; unique Maldivian Mahl culture; separate from other islands culturally; famous lighthouse built by British in 1885)
Sea level rise threat	With mean elevation only 1-2 m above sea level, Lakshadweep is AMONG THE WORLD'S MOST VULNERABLE TERRITORIES to sea-level rise; IPCC projections suggest some islands may be uninhabitable by 2100

PEOPLE, CULTURE AND LANGUAGE

Aspect	*Detail*
Population	~64,473 (Census 2011); ~70,000 estimated 2024; very small
Religion	~96% Muslim (highest % Muslim UT/state in India); Islamic culture deeply rooted; conservative society; matrilineal (Marumakkathayam) system prevalent — property passes through female line
Language	Malayalam (official and widely spoken); Mahl (spoken on Minicoy — a dialect of Dhivehi, the language of Maldives; reflecting shared Maldivian cultural heritage)
Literacy	91.85% (2011) — 3rd highest in India; reflects Kerala influence
Social structure	Matrilineal; women have significant property and social rights (unlike many mainlands Muslim communities); historically distinct from Kerala's legal system
Culture of Minicoy	Minicoy (southernmost; Maliku) has a distinct Maldivian cultural identity; Mahl language; laccadive dance (unique art form); lighthouse; separate from main Lakshadweep cultural tradition
Economy	Fishing (primary; tuna fishing — Lakshadweep is one of India's best tuna fishing grounds; skipjack and yellowfin tuna), coconut cultivation (copra), tourism (strictly regulated); no mining; limited industry

ECOLOGY OF LAKSHADWEEP — CORAL REEF SYSTEM

Lakshadweep's coral reefs are the **most ecologically productive ecosystems in Indian waters** — a fraction of the area of the A&N forests but of equal global biodiversity significance. The reefs serve as:

- **Fish nurseries:** >1,000 species of fish recorded in Lakshadweep waters; the reefs support India's most productive tuna fishing grounds and are critical to the food security of the island communities.
- **Coastal protection:** the ring of coral reefs dissipates wave energy before it reaches the low-lying atolls — without healthy reefs, storm waves would frequently inundate the islands. A dead reef = an exposed, wave-battered shoreline.
- **Biodiversity:** ~400 coral species; endangered Hawksbill and Green sea turtles; Spinner Dolphins (who'se synchronised spinning jumps are famous near Lakshadweep); Whale Shark; Reef Manta Ray; Giant Clam; Humphead Wrasse; various species of nudibranchs and invertebrates.
- **Blue carbon:** seagrass beds and mangroves in lagoons store significant blue carbon; coral carbonate structures sequester carbon over geological timescales.

Coral Bleaching — Lakshadweep's Existential Threat

Coral bleaching occurs when **sea surface temperature (SST) rises above the coral's thermal tolerance (typically >30-31°C for Indian Ocean corals) for prolonged periods,** causing corals to expel their symbiotic algae (zooxanthellae) — the source of their colour and 90% of their nutrition. Without zooxanthellae, corals turn white (bleach) and starve; if SST returns to normal quickly, corals can recover; if not, they die.

Bleaching Event	*Impact on Lakshadweep*
1998 (El Nino)	Worst bleaching event in Indian Ocean history; ~90% of Lakshadweep's coral bleached; ~70% coral mortality in some areas; major ecological shock

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2010 (ENSO)	Significant bleaching; partial recovery from 1998 ongoing
2016 (ENSO/Indian Ocean warming)	Global mass bleaching (3rd global bleaching event); Lakshadweep and Great Barrier Reef both severely affected
2020 (COVID-related SST rise as shipping reduced)	Some bleaching; partial events
2024 (UNPRECEDENTED — record SST)	Indian Ocean SSTs hit record levels in 2024 (ENSO + Indian Ocean warming); Mass bleaching reported across Lakshadweep; preliminary surveys show widespread bleaching event; monitoring ongoing; most severe 21st-century bleaching for Lakshadweep

ENV ALERT

Climate Change and Lakshadweep — Double Threat

Lakshadweep faces an existential **double threat from climate change**: (1) **Coral bleaching** from rising sea surface temperatures kills the reefs that protect the islands and sustain their fisheries; (2) **Sea-level rise** (IPCC projects 0.3-1.0 m rise by 2100; extreme projections up to 2 m) threatens to permanently submerge islands whose maximum elevation is only 4-5 m. If coral reefs die AND sea levels rise, Lakshadweep may be uninhabitable for a large fraction of its population by the end of this century. India raised this at the UNFCCC COP meetings as a **climate justice issue** — the islands contribute near-zero greenhouse gases but face the worst consequences of global warming.

THE 2021 LAKSHADWEEP CONTROVERSY

In 2021, the newly appointed Administrator of Lakshadweep (Praful Patel, formerly Administrator of Dadra & Nagar Haveli + Daman & Diu) proposed a series of regulations that triggered major controversy:

Proposed Regulation	*Concern Raised*
Lakshadweep Development Authority Regulation (LDAR)	New land use planning authority with power to acquire land; fear of outsider land acquisition; potential displacement of islanders for tourism development
Prevention of Slaughter and Preservation of Animals Regulation	Would have banned beef — a dietary staple of the predominantly Muslim population; perceived as culturally insensitive
Anti-Social Activities Prevention Regulation (LAAPAR)	Broad preventive detention powers; critics compared it to AFSPA/NSA; civil liberties concerns
Liquor Policy Amendment	Allow liquor in the islands for tourism; opposed by the predominantly Muslim population on religious grounds
Panchayat Regulation Amendment	Proposed that those with more than 2 children be disqualified from contesting Panchayat elections

The proposals led to **massive protests** from Lakshadweep's population, elected representatives and Kerala government (whose people have deep cultural and economic links with Lakshadweep). Several MLPs from across parties signed a petition. The Supreme Court declined to stay the regulations. **Most controversial regulations were withdrawn or diluted**, but the episode raised fundamental questions about the governance of Union Territories without legislatures, where elected representatives have limited authority and the Administrator wields near-total power.

PM MODI'S LAKSHADWEEP VISIT AND INDIA-MALDIVES ROW (JANUARY 2024)

CURRENT AFFAIRS

January 2024 — A Geopolitical Tourism Moment: PM Modi visited Lakshadweep in January 2024 and posted photographs on social media, urging Indians to visit Lakshadweep as a tourist destination. This came in the context of:

- **India-Maldives diplomatic tensions:** New Maldivian President Mohamed Muizzu (elected late 2023; closer to China) demanded removal of Indian military personnel from the Maldives; three Maldivian junior ministers made disparaging remarks about PM Modi and India on social media, triggering Indian public anger.
- **Boycott Maldives movement:** Indian social media launched a "Boycott Maldives" campaign; airlines reduced Maldives flights; Indian tourism to Maldives (a major revenue source for them) dropped sharply.
- **Lakshadweep as alternative:** Modi's Lakshadweep photos were widely seen as a deliberate signal: "Visit Lakshadweep instead of Maldives"; Indian tourism to Lakshadweep increased; new packages launched; GMAC (Lakshadweep tourism board) reported surge in bookings.

Ecological concern: Tourism ecologists warned that a surge in uncontrolled tourism to Lakshadweep's fragile coral reef ecosystem — without equivalent growth in waste management, eco-sensitive zoning and sustainable tourism infrastructure — could damage the very ecosystem that makes Lakshadweep attractive. Carrying capacity limits are essential for coral reef tourism.

7.5 OTHER IMPORTANT ISLANDS OF INDIA

MAJULI ISLAND (BRAHMAPUTRA, ASSAM)

Majuli (also spelled Majoli) is the **world's largest river island** (though disputed — Marajo in Brazil is larger; among the largest freshwater river islands) — located in the **Brahmaputra River in Assam**, between the Brahmaputra main channel and the Kherkata/Lohit branch. It is unique as the **centre of Assamese Vaishnav culture** — the great Vaishnav saint **Srimanta Sankaradeva (1449-1568 CE)** established the **Satra system (Vaishnav monasteries/cultural institutions)** here, and Majuli has 22 surviving Satras that are living centres of **Satriya dance, drama, music, mask-making and manuscript traditions.**

Parameter	*Detail*
Location	Brahmaputra River, Jorhat district (and partly Lakhimpur), Assam; ~350 km from Guwahati
Area (current)	~880 sq km (dramatically reduced from ~1,250 sq km in 1950 due to erosion; losing ~8 sq km per year to Brahmaputra's dynamic channel)
Population	~1.67 lakh (Census 2011); largely Mising tribe + Ahom + Bengali communities
Status	District (Majuli district created 2016 — India's first island district); UNESCO World Heritage tentative list (submitted 2004 for cultural landscapes); also nominated for Geographical Indication for Satras
Vaishnav Satras	22 Satras survive; Auniati Satra, Dakhinpat Satra, Garamur Satra most important; house Vaishnav manuscripts, masks, dance traditions; each has a distinct specialisation
Satriya Classical Dance	Satriya (classical Indian dance from Majuli/Assam) was recognised as India's 8th classical dance form by Sangeet Natak Akademi in 2000; Srimanta Sankaradeva created it as devotional art for temple use
MAJOR THREAT — EROSION	The Brahmaputra River channels shift dramatically; Majuli is being eroded from all sides; estimated to lose another 30% by 2030 if unchecked; some Satras have had to relocate; climate change-induced floods worsening erosion; the island may disappear within decades without intervention
Government response	National Erosion Prevention Mission (NMCG); IIT Guwahati studies; hard engineering (bunds, spurs) and bioengineering (bamboo plantations) being tried; UNESCO World Heritage nomination could bring international support

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IFoS FOCUS

IFOS — MAJULI AND RIVER BANK EROSION: Majuli is a textbook case of **river bank erosion by a braided river** — the Brahmaputra is one of the world's most dynamic (braided) rivers with extremely high sediment load. Bank erosion = bank undercutting + mass wasting + lateral channel migration. Majuli sits in the Brahmaputra's active flood plain; channel switching (avulsion) permanently removes land. Management: porcupine spurs (bamboo structures); stone revetments; bioengineering with Arundo donax (giant reed) and vetiver grass. The conflict between engineering fixes and natural river dynamics is the core IFoS lesson.

PAMBAN ISLAND (RAMESWARAM) AND RAM SETU

Aspect	*Detail*
Location	Gulf of Mannar; connects to mainland Tamil Nadu at Mandapam (by Pamban Bridge) and to Sri Lanka by a shallow sandbar (Adam's Bridge/Ram Setu)
Main city	Rameswaram — major Hindu pilgrimage centre; Ramanathaswamy Temple (12 Jyotirlinga site); Dr. APJ Abdul Kalam's birthplace and burial site
Pamban Bridge	India's first sea bridge (completed 1914; British; spans Pamban Channel); a new Pamban Bridge (India's first vertical-lift sea bridge) is under construction alongside the old one; will allow ships to pass beneath the raised section
Ram Setu / Adam's Bridge	Chain of limestone shoals and sand bars connecting Pamban Island to Mannar Island (Sri Lanka); 48 km long; reportedly bridged by Rama's vanara sena (monkey army) in the Ramayana; only 1-10 m deep; walkable at some points historically; SETHUSAMUDRAM CANAL CONTROVERSY (proposed ship canal through Ram Setu for shorter shipping route; opposed on religious grounds; SC involved; project stalled since 2007)
Ecology	Gulf of Mannar Biosphere Reserve; rich coral reef; seagrass; dugong habitat; marine National Park; one of India's biodiversity-richest marine zones

SRIHARIKOTA (ANDHRA PRADESH)

Sriharikota is a **barrier island (semi-island) in Pulicat Lake,** Nellore district, Andhra Pradesh — separated from the mainland by a backwater lagoon. It is internationally famous as the home of **ISRO's Satish Dhawan Space Centre (SDSC-SHAR),** India's primary satellite launch facility. Almost all Indian space missions launch from Sriharikota: PSLV, GSLV, and the LVM3 rockets all launch from here. The island's isolation (surrounded by water on most sides) ensures launch safety. **Chandrayaan-3 (launched July 14, 2023), Aditya-L1 (launched September 2, 2023)** and all ISRO commercial launches were from Sriharikota.

OTHER NOTABLE ISLANDS

Island	*Location*	*Significance*
Diu Island	Off the southern tip of Kathiawar, Gujarat; separated from mainland by Diu Channel; UT of Daman and Diu + Dadra & Nagar Haveli	Former Portuguese colony (1535-1961); liberated December 19, 1961 (Goa Liberation Day — same day); famous for Portuguese fort, beaches; tourism; distinct architecture; historically significant as Portuguese India's most strategic possession
Bet Dwarka (Beyt Dwarka)	Off the coast of Okha, Gujarat; in Arabian Sea	Major Hindu pilgrimage island; associated with Lord Krishna (Dwarkadhish Temple on this island; main Dwarka on mainland); ferry from Okha; Shankhodhara (sacred conch); rich in coral reefs and marine life
Pulicat Lake Islands (various islets)	Pulicat Lake, Nellore-Tiruvallur, AP-TN border	Flamingo habitat; migratory birds; Sriharikota adjacent

Elephanta Island (Gharapuri)	Mumbai Harbour	UNESCO World Heritage Site (1987); cave temples dedicated to Shiva (Trimurti — 3-headed Shiva); accessible by ferry from Mumbai Gateway of India; ~10 km from Mumbai; Portuguese named it "Island of Elephants" for a large stone elephant (now in CSMVS Museum, Mumbai)
Alibaug / Kolaba Island	Off Alibaug, Raigad, Maharashtra	Kulaba Fort (Maratha naval fort; Chatrapati Shivaji Maharaj used it as a naval base; accessible by foot at low tide)
Kuriyad / Willingdon Island	Kochi, Kerala	Artificial island created from dredged material; has Kochi Port, Cochin Airport (first scheduled flights in India), hotels; manmade island
St. Mary's Islands / Coconut Island	Off Malpe coast, Udupi, Karnataka	Basalt columns (columnar jointing — hexagonal basalt columns formed by rapid cooling of lava); Vasco da Gama landed here 1498; geological monument; popular tourist site

7.6 MARITIME ZONES, EEZ AND BLUE ECONOMY

UNCLOS MARITIME ZONES

India's maritime jurisdiction is defined by the **United Nations Convention on the Law of the Sea (UNCLOS 1982),** which India ratified in **1995.** UNCLOS creates a series of nested maritime zones extending from the baseline (normal low-water line of the coast):

Zone	*Distance from Baseline*	*India's Rights / Jurisdiction*	*Legal Basis*
Internal Waters	0 (inside baselines)	Full sovereignty; no right of innocent passage for foreign vessels	Equivalent to land territory
Territorial Sea	0-12 nautical miles (NM)	Full sovereignty; foreign vessels have right of innocent passage (cannot stop, fish, research or be hostile)	UNCLOS Art. 3; India's Territorial Waters, Continental Shelf etc. Act 1976
Contiguous Zone	12-24 NM	India can enforce customs, immigration, sanitation, fiscal laws; prevent violations	UNCLOS Art. 33
Exclusive Economic Zone (EEZ)	0-200 NM from baseline	India has sovereign rights for exploring, exploiting, conserving and managing all natural resources (fish, minerals, oil, gas); rights over scientific research; right to build artificial islands	UNCLOS Art. 55-75; India's EEZ = 2.37 million sq km
Continental Shelf	Natural prolongation of land territory (max 350 NM)	India has rights over seabed and subsoil resources (oil, gas, minerals) even beyond the EEZ if the shelf extends beyond 200 NM (India has claimed extended continental shelf in the Arabian Sea and Bay of Bengal)	UNCLOS Art. 76-85
High Seas / International Waters	Beyond 200 NM (or beyond Continental Shelf)	Freedom of navigation, overflight, fishing, research; no single state's sovereignty; governed by UNCLOS and ISA	UNCLOS Part VII

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KEY NOTE

India's EEZ = 2.37 million sq km : India's EEZ is larger than its land area (3.29 million sq km of land vs 2.37 million sq km EEZ; total maritime area including continental shelf is ~3.86 million sq km). The Andaman & Nicobar Islands are primarily responsible for this large EEZ — they extend India's EEZ deep into the Bay of Bengal and Andaman Sea. Without these islands, India's EEZ would be dramatically smaller. This makes island territories geopolitically invaluable.

BLUE ECONOMY — INDIA'S MARITIME ECONOMIC VISION

India's **"Blue Economy"** refers to the sustainable use of ocean resources for economic growth and improved livelihoods while preserving ocean ecosystem health. India's Blue Economy potential is enormous — covering fisheries, maritime shipping, offshore oil/gas, deep-sea minerals, coastal tourism, seawater desalination, marine biotechnology and renewable ocean energy.

Blue Economy Component	*India's Status / Potential*
Marine Fisheries	India = 3rd largest fish producer globally; ~8.57 million tonne annual production; ~1.28 million fishermen; Marine Products Export Development Authority (MPEDA, Kochi); Pradhan Mantri Matsya Sampada Yojana (PMMSY) — Rs.20,050 crore for fisheries development
Offshore Oil and Gas	Mumbai High (ONGC); KG Basin (Reliance); significant gas hydrate potential; Andaman and Andaman-Nicobar basins unexplored
Deep-Sea Mining	India has a Pioneer Investor status with the International Seabed Authority (ISA) for exploration of polymetallic nodules in the Central Indian Ocean Basin (CIOB); India's exploration block = ~75,000 sq km; nodules contain Ni, Cu, Co, Mn (critical minerals)
Samudrayaan Mission	India's deep-sea human manned mission; MATSYA 6000 submersible (can dive to 6,000 m); NIOT (National Institute of Ocean Technology, Chennai) developing; first manned dive target 2025-26
Seabed Minerals / Polymetallic Sulphides	India has been allocated a hydrothermal vent mineral block in the Indian Ocean; cobalt-rich crusts being surveyed
Marine Biotechnology	Marine bioactive compounds for pharmaceuticals, nutraceuticals, anti-fouling agents; CMFRI (Central Marine Fisheries Research Institute, Kochi) and ICAR-NCMRDF research
Offshore Wind	India has significant offshore wind potential (Gulf of Khambhat, Tamil Nadu coast); National Offshore Wind Energy Policy 2015; first tenders issued 2023; A&N Islands also proposed
Coastal Tourism	Lakshadweep, A&N Islands, Goa, Kerala; Rs.15,000+ crore annual revenue; ecotourism governance challenge

ANDAMAN AND NICOBAR COMMAND (ANC) — STRATEGIC SIGNIFICANCE

The **Andaman and Nicobar Command (ANC),** headquartered at **Port Blair,** is India's **only tri-services (Army + Navy + Air Force) integrated operational command** — India's other commands are service-specific. Established in **2001** under the recommendations of the Kargil Review Committee (1999) to enhance joint command and control in the critical **Indian Ocean-Bay of Bengal-Malacca Strait region.**

- **Strategic location:** The A&N Islands straddle the shipping lanes between the Indian Ocean and the Pacific; 80% of global oil trade and a majority of Chinese trade passes through the Malacca Strait (less than 700 km from Port Blair).
- **Naval assets:** INS Jarawa (Port Blair); IN Baaz (Car Nicobar) — India's southernmost air base; naval patrol aircraft; submarine support; surface warships.

- **Role in Indian Ocean Security:** Maritime domain awareness (MDA); anti-piracy; disaster relief (ANC responded in 2004 tsunami relief); counter China's naval presence; monitoring Malacca Strait.
- **Proposed upgrade:** India is developing maritime patrol infrastructure; expanding runway at Car Nicobar; developing Port Blair as a deeper-draft base; the Great Nicobar Project would add a major transshipment port + airport near the Malacca approaches.

7.7 CURRENT AFFAIRS HOOKS (2021–2025)

CURRENT AFFAIRS	**Great Nicobar Development Project (Jan 2023 — ongoing):** MoEFCC Stage-I environmental clearance (January 2023); Rs.72,000 crore; transshipment port + airport + township + power plant; Galathea Bay Wildlife Sanctuary denotification proposed; leatherback turtle, Shompen tribe and biosphere reserve at risk; NGT petitions; SC petitions; ongoing controversy as of 2025. **PM Modi Lakshadweep Visit + India-Maldives Row (January 2024):** Modi's social media posts promoting Lakshadweep coincided with India-Maldives diplomatic tension (Muizzu government); Indians boycotted Maldives; Lakshadweep tourism bookings surged; raised concerns about carrying capacity of fragile reef ecosystem. **Lakshadweep Coral Bleaching (2024):** Record Indian Ocean sea surface temperatures in 2024 caused mass coral bleaching across Lakshadweep; surveys showed widespread bleaching; impact assessment ongoing; raises questions about viability of coral ecosystem long-term. **Samudrayaan Mission / MATSYA 6000 (2023-25):** India's first manned deep-sea mission; MATSYA 6000 (6,000 m rated submersible) under development at NIOT Chennai; sea trials ongoing; target: first manned descent by 2025-26; polymetallic nodule exploration in CIOB (Central Indian Ocean Basin). **Vizhinjam Port Inauguration (July 2024):** Deep-water transshipment port at Thiruvananthapuram inaugurated; will reduce dependence on Colombo/Singapore for Indian container transshipment — linked to A&N Islands EEZ strategy and Blue Economy. **New Pamban Bridge (Railway Vertical Lift Bridge):** Under construction alongside the old Pamban Bridge; India's first vertical-lift railway sea bridge; will allow ships to pass; target completion 2024-25 (delayed). **North Sentinel Island Contact Incidents:** While no new major incidents since John Allen Chau's death (2018), the ongoing debate about India's no-contact policy continues; anthropologists and rights groups continue to support India's non-contact approach; government has maintained the 3-NM exclusion zone strictly.

7.8 PYQ ANALYSIS — CHAPTER 7 (2010–2025)

Source	Year	Marks	Question
UPSC Civil	2023	15M	"Critically examine the Great Nicobar Holistic Development Project in the context of India's strategic interests, environmental laws and tribal rights."
UPSC Civil	2021	12M	"Discuss the significance of India's Exclusive Economic Zone (EEZ) and the role of island territories in defining India's maritime boundaries."
UPSC Civil	2020	10M	"Explain the significance of the Andaman and Nicobar Islands for India's strategic position in the Indian Ocean region."
UPSC Civil	2019	12M	"What is the Blue Economy? Discuss the potential and challenges of India's Blue Economy with special reference to deep-sea resources."
UPSC Civil	2018	10M	"Discuss the vulnerability of Lakshadweep to climate change. What measures are needed to protect India's coral island territories?"

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UPSC Civil	2017	10M	"How does the Malacca Strait affect India's energy security? Discuss the strategic importance of the Andaman and Nicobar Islands in this context."
UPSC Civil	2015	10M	"Write a note on the major tribal communities of the Andaman and Nicobar Islands. What should be India's policy toward uncontacted tribes like the Sentinelese?"
IFOS GS	2024	15M	"Discuss the ecological significance of the Great Nicobar Biosphere Reserve. Examine the environmental impact of the proposed holistic development project on its biodiversity."
IFOS GS	2022	10M	"Explain the process of coral bleaching and its impact on the Lakshadweep coral reef ecosystem."
IFOS GS	2021	10M	"Write a note on the Leatherback sea turtle. Why is the Great Nicobar Island critical for its conservation in the Indian Ocean?"
IFOS GS	2020	10M	"What are the endemic species of the Andaman and Nicobar Islands? Discuss the conservation challenges faced by the Narcondam Hornbill."
IFOS GS	2019	10M	"Discuss the ecology and conservation status of mangroves in the Andaman and Nicobar Islands."
IFOS GS	2018	10M	"Discuss the ethnobotanical significance of the Nicobar Islands for the tribal communities. How should India balance development and tribal welfare?"

KEY NOTE

Frequency pattern: Great Nicobar Development Project (Civil 2023; IFoS 2024) — NOW THE HIGHEST FREQUENCY TOPIC for this chapter; Lakshadweep coral bleaching + climate change (Civil 2018; IFoS 2022); Sentinelese/tribal policy (Civil 2015; IFoS 2018); Blue Economy/EEZ (Civil 2019, 2021); Malacca Strait strategic angle (Civil 2017, 2020); Leatherback turtle (IFoS 2021); Narcondam Hornbill (IFoS 2020). For 2025-26: Great Nicobar project updates, Samudrayaan Mission, 2024 coral bleaching crisis, and PM Modi Lakshadweep-Maldives episode are the top current affairs.

7.9 MODEL BOOK

Critically examine the Great Nicobar Holistic Development Project in the context of India's strategic interests, environmental laws and tribal rights.

UPSC Civil (Mains) | 15 Marks | 200 Words

The Rs.72,000-crore Great Nicobar Holistic Development Project — comprising a transshipment port, international airport, township (3.5 lakh people) and 450 MW power plant at the southern tip of Great Nicobar Island — exemplifies the tension between India's strategic ambitions and its environmental and tribal obligations.

STRATEGIC CASE FOR

- **Malacca Strait leverage:** Great Nicobar is ~150 km from Sumatra; a major port here gives India monitoring capability over the Malacca Strait through which 80% of global oil trade flows — countering China's Indian Ocean footprint.
- **Transshipment revenue:** India loses ~75% of its container transshipment to Colombo and Singapore; a deep-water Galathea Bay port could capture this back, reducing shipping costs and generating revenue.
- **Dual-use infrastructure:** Airport + port can serve both commercial and Indian Navy/ANC strategic purposes.

ENVIRONMENTAL CASE AGAINST

- **Leatherback sea turtle:** Galathea Bay is one of the Indian Ocean's last leatherback nesting sites; port lights and vessel traffic would permanently eliminate nesting — pushing an already critically endangered species closer to extinction in the Indian Ocean.

- **Biosphere Reserve compromise:** Great Nicobar is a UNESCO Biosphere Reserve (1989); the project overlaps with the Galathea Bay Wildlife Sanctuary (proposed for denotification) — setting a dangerous precedent for using wildlife sanctuaries for industrial development.
- **8.27 lakh trees:** Felling of ~8.27 lakh trees in pristine tropical wet evergreen forest — one of the Indian Ocean's finest — is an irreversible ecological loss.

TRIBAL RIGHTS CASE AGAINST

- **Shompen PVTG at risk:** Introducing 3.5 lakh people into a 166 sq km zone of an island where only ~200 Shompen tribespeople live would overwhelm their territory, expose them to diseases and destroy their forest-dependent livelihood. The National Commission for STs has flagged serious concerns.

WAY FORWARD: A narrower strategic intervention — a smaller naval base + limited port for strategic use — could achieve India's security objectives without the full civilian-commercial township that drives most of the ecological destruction. Separation of strategic and commercial components, strict environmental safeguards and prior Shompen consent are essential.

Discuss the ecological significance of Lakshadweep's coral reef ecosystem. How is climate change threatening it, and what conservation measures are needed?

IFoS | 15 Marks | 200 Words

Lakshadweep's 36 coral atolls — built on the Lakshadweep-Chagos Ridge — host some of the Indian Ocean's most biodiverse marine ecosystems, yet these same reefs face an existential threat from climate change-driven bleaching and sea-level rise.

ECOLOGICAL SIGNIFICANCE:

- **BIODIVERSITY:** 400+ coral species, 1,000+ fish species, Hawksbill and Green sea turtles, Spinner Dolphins, Whale Sharks, Reef Manta Rays, Giant Clams. The reef supports extraordinary marine diversity in a geographically compact area.
- **FISH NURSERIES:** Coral reefs are nurseries for >80% of commercially important tropical marine fish; the islands' tuna fisheries (India's most productive) depend entirely on healthy reefs.
- **COASTAL PROTECTION:** Reef structures dissipate wave energy before it reaches the low-lying atolls (elevation 1-4 m); dead reefs = exposed shorelines vulnerable to wave erosion.
- **BLUE CARBON:** Seagrass beds and mangroves in lagoons store significant blue carbon.

CLIMATE CHANGE THREATS:

- **CORAL BLEACHING:** 1998 bleaching killed ~70% of Lakshadweep corals; 2016 and 2024 bleaching events further devastated recovering reefs; rising SSTs from 1.5°C global warming scenarios would make annual bleaching the norm by 2050.
- **SEA-LEVEL RISE:** IPCC projects 0.3-1.0 m rise by 2100; low-lying atolls face regular inundation; saltwater intrusion threatens freshwater lenses (the only source of freshwater); island habitation becomes untenable.

CONSERVATION MEASURES NEEDED:

1. **CLIMATE-RESILIENT CORALS:** identify and protect "super corals" (naturally heat-resistant varieties); assisted evolution research.
2. **MARINE PROTECTED AREAS (MPAS):** strengthen existing PAs; strictly regulate fishing and tourism in reef zones.
3. **CORAL TRANSPLANTATION:** ongoing ZSI-led coral gardening programs; transplant heat-tolerant corals to bleached areas.
4. **CARRYING CAPACITY TOURISM:** strictly regulate visitor numbers per reef; eco-certification for tourism operators.
5. **CLIMATE JUSTICE ADVOCACY:** India must raise Lakshadweep's plight in UNFCCC negotiations as a climate victim state equivalent — representing Small Island Developing States (SIDS) interests.

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PATCH 1 – CHAPTER 7 | Koppen Climate Classification for India

The **Koppen Climate Classification System** (devised by German climatologist Wladimir Koppen, 1918; modified by Geiger) is the world's most widely used climate classification. It uses **temperature and precipitation thresholds** to define climate types. India, despite its large size (~3.3 million sq km), spans **six Koppen climate types** — from the hot desert (BWh) of the Thar to the tropical monsoon (Am) of the Western Ghats to the alpine tundra (ET/H) of the Himalayas.

KOPPEN CODE SYSTEM — KEY LETTERS

Letter	*Meaning*	*Threshold*
A	Tropical (1st letter)	All months mean temp > 18°C; no winter
B	Dry (1st letter)	Potential evaporation exceeds precipitation
C	Temperate/Mesothermal (1st letter)	Warmest month > 10°C; coldest between 0°C and 18°C
E/H	Polar / Highland (1st letter)	Warmest month < 10°C (E); High altitude (H)
w	Dry winter (2nd letter)	Driest winter month < 1/10th of wettest summer month
m	Monsoon (2nd letter, for A)	Short dry season but heavy monsoon rain compensates
s	Dry summer (2nd letter)	Driest summer month < 40 mm (Mediterranean)
h	Hot (3rd letter, for B)	Mean annual temp > 18°C
W	Arid desert (2nd letter, for B)	Very low precipitation
S	Semi-arid steppe (2nd letter, for B)	More rain than desert, less than humid

INDIA'S SIX KOPPEN CLIMATE TYPES — COMPLETE TABLE

Koppen Type	*Full Name*	*Key Characteristics*	*Indian Regions*	*Key Cities*	*Crops / Vegetation*
Am	Tropical Monsoon	Short dry season (1-3 months); very heavy monsoon rain; total annual > 1500 mm; all months > 18°C; dry season compensated by heavy wet season	Western Ghats (Konkan + Malabar coast), NE India (Assam, Meghalaya, Tripura, Mizoram, Arunachal low areas), Andaman & Nicobar Islands	Mangalore, Kozhikode, Thrissur, Guwahati, Cherrapunji, Shillong foothills	Tropical rainforest / moist deciduous; rubber, coconut, paddy (3 crops/year), spices, tea (Assam)
Aw	Tropical Savanna	Well-defined dry winter (3+ months < 60 mm); rainy summer; all months > 18°C; annual rain 750-1500 mm; distinct wet-dry seasons	Peninsular India interior — Deccan Plateau, most of Maharashtra, Telangana, AP, Karnataka (except coast), Chhattisgarh, Jharkhand, eastern MP	Nagpur, Hyderabad, Pune, Aurangabad, Raipur, Ranchi, Bhopal	Tropical dry deciduous (teak, sal); cotton, jowar, bajra, tur dal; red/laterite soils; single kharif crop (rain-fed)
BSh	Hot Semi-Arid (Steppe)	Low, erratic rainfall (250-750 mm); potential evaporation exceeds precipitation; hot temperatures (> 18°C mean annual);	Rajasthan (eastern; Nagaur, Barmer, Bikaner margins), rain-shadow Deccan (parts of Karnataka, MH -- Marathwada,	Jodhpur, Jaisalmer margins, Solapur, Bidar,	Sparse dry deciduous scrub; drought-resistant millets (bajra, jowar), guar,

		transitional between desert and humid	Solapur), Gujarat (eastern)	Gulbarga, Bellary	moth bean; pastoralism
BWh	Hot Desert (Arid)	Very low rainfall (< 250 mm; Jaisalmer ~100 mm); high temperatures; very high potential evaporation; no or minimal vegetation	Thar Desert: western Rajasthan (Jaisalmer, Barmer, Bikaner, Ganganagar), Kachchh (Gujarat)	Jaisalmer, Barmer, Kachchh, Bikaner (drier areas)	Desert scrub; cactus; Khejri (Prosopis cineraria); guar, bajra; camel herding; minimal agriculture except under Indira Gandhi Canal irrigation
Cwa	Humid Subtropical (Dry Winter)	Dry winter (< 40 mm driest winter month); hot humid summer; warmest month > 22°C; coldest 0-18°C; moderate rainfall 600-1000 mm via monsoon	Northern Plains (IGP): Punjab, Haryana, Delhi, UP, Bihar, north MP, north WB (Kolkata area), north Odisha	Delhi, Lucknow, Patna, Allahabad, Kanpur, Varanasi, Kolkata, Jaipur	Wheat (rabi), paddy (kharif), mustard; alluvial soils; double-cropped; most important agricultural zone of India; transition of crops between tropical and temperate
H / ET	Highland / Alpine / Tundra	Temperature decreases with altitude; very cold winters; short cool summers; ET = warmest month < 10°C; H = high altitude with varied microclimates	Himalayas (high altitude): Ladakh, Lahaul-Spiti, upper Himachal Pradesh, Uttarakhand Himalayas > 3000 m, Sikkim Himalayas, high Arunachal	Leh (-3°C mean annual), Drass (coldest inhabited place in India; -60°C recorded), Kargil, Keylong, Munsiyari	Alpine meadows (bugyals), conifer forests (deodar, blue pine, silver fir below snow line); pastoral nomadism (Gaddi, Gujjar, Bakkarwal); cold desert crops: barley, buckwheat, lentils

KEY NOTE

Prelims Exam Traps — Koppen: (1) **Am vs Aw distinction:** Am = Monsoon type (NE India + west coast); Aw = Savanna (Deccan interior). Am has very heavy total rain despite a short dry season; Aw has a prolonged dry season. EXAM TRAP: "Which type gets dry season but still has heavy annual rainfall?" = Am. (2) **Cwa:** The entire Gangetic Plain (Delhi to Kolkata) is Cwa — NOT tropical. It has dry winters (WDs provide light rain but not enough for Koppen humid threshold). (3) **BSh vs BWh:** BSh = semi-arid steppe (eastern Rajasthan, rain-shadow Deccan); BWh = hot desert (western Rajasthan, Thar). The line separating them runs roughly through Bikaner-Jodhpur. (4) **No Cfb (Oceanic/Marine West Coast) in India:** Unlike Western Europe, India has no Cfb because its west coast receives dry-winter monsoon pattern (Am) not year-round rain. (5) **No Mediterranean (Csa/Csb):** India has no Cs type — there is no area with dry summers + wet winters (which Mediterranean climate requires). This is commonly asked as a negative.

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CHAPTER 8

HIMALAYAN RIVERS OF INDIA

CHAPTER AT A GLANCE

- Three master Himalayan systems: Indus (~3,180 km, basin 1.17 M sq km), Ganga (2,525 km, basin 8.6 lakh sq km — India's largest), Brahmaputra (~2,900 km).
- All are PERENNIAL: triple source — glacier melt + snowmelt + monsoon rain. Antecedent drainage explains deep gorges (Indus at Nanga Parbat, Sutlej at Shipki La, Tsangpo at Namcha Barwa).
- Indus Waters Treaty (IWT, 1960): Eastern rivers (Ravi, Beas, Sutlej) → India; Western rivers (Indus, Jhelum, Chenab) → Pakistan. PLACED IN ABEYANCE by India on April 23, 2025 (post-Pahalgam attack).
- Ganga: Bhagirathi + Alaknanda at Devprayag; 5 Prayags; left-bank tributaries (Ghaghara, Gandak, Kosi); right-bank (Yamuna, Son, Damodar); Farakka Barrage; Sundarbans — world's largest delta.
- Brahmaputra: Yarlung Tsangpo (Tibet) → Siang (Arunachal) → Brahmaputra (Assam); widest river in India (up to 18 km); Majuli — world's largest river island; annual Assam flooding.
- China factor: ~60,000 MW Medog mega-dam on Tsangpo planned; no India-China water treaty; India is lower riparian with no treaty protection.
- ILR: National Perspective Plan (1980) — 30 links; Ken-Betwa Link Project (first ILR, ₹44,605 cr) under construction; Panna Tiger Reserve controversy.
- Key disasters: Kosi breach (2008), Chamoli GLOF (Feb 2021, 200+ dead), South Lhonak GLOF Sikkim (Oct 2023, Chungthang Dam breach).

8.1 INTRODUCTION — INDIA'S RIVER SYSTEMS: AN OVERVIEW

Rivers are the **lifelines of Indian civilisation** — sustaining agriculture, drinking water, spiritual identity and ecological balance across the subcontinent. The **Harappan/Indus Valley Civilisation** (c. 2600–1900 BCE) grew on the Indus; the **Vedic-Gangetic civilisation** defined itself by the Ganga; and today, the **water security of over 600 million people** depends on the flows of three Himalayan river systems.

India's rivers are divided into **two broad categories**:

Feature	*Himalayan Rivers*	*Peninsular Rivers*
Origin	Glaciers/snowfields of the Himalaya and Tibet	Plateau uplands (Western Ghats, Vindhya-Satpura, Amarkantak)
Flow regime	PERENNIAL — glacier melt + snowmelt + monsoon rain	SEASONAL — rain-fed only (monsoon); dry in summer
Geological age	Antecedent in origin; cut gorges as Himalaya rose	Old, mature, largely graded; flowing in ancient valleys
Valley	Deep V-gorges in mountains; wide meandering plains	Shallow, broad, graded; controlled by hard rock
Sediment load	Very heavy — active erosion, rapid deposition	Lighter — near base level; less active erosion
River course	Long, meandering, shifting; ox-bow lakes common	Relatively fixed; hard-rock banks resist migration
Mouth / terminus	Large DELTAS (Ganga-Brahmaputra, Indus)	East: deltas (Godavari, Krishna, Cauvery); West: ESTUARIES (Narmada, Tapi)

Economic value	Perennial irrigation, large HEP, navigation, large populations	Seasonal irrigation, HEP (Deccan), less navigation

KEY NOTE **Why Himalayan rivers are perennial — the TRIPLE SOURCE : (1) Glacier melt** (summer peak — June-August); **(2) Snowmelt** (spring — March-May); **(3) Monsoon rainfall** (June-September). These three staggered contributions ensure year-round flow even during dry winter months.

INDIA'S RIVER BASIN CLASSIFICATION

- India has **12 major river basins** (each >20,000 sq km catchment), **46 medium river basins**, and numerous minor river basins.
- The **National Water Development Agency (NWDA, 1982)** is the nodal body for inter-basin water transfer and ILR feasibility studies.
- **Three Himalayan systems (Indus, Ganga, Brahmaputra) together drain > 43% of India's total land area**.

8.2 DRAINAGE PATTERNS & DRAINAGE BASIN CONCEPTS

A **drainage pattern** is the spatial arrangement of a river and its tributaries, governed by slope, rock type and geological structure. Recognising patterns from maps is a standard Prelims question type.

Pattern	*Description*	*Formation Condition*	*Indian Example*
Dendritic	Tree-like; irregular branching	Uniform rock with no structural control	Ganga and its plains tributaries (most common)
Trellis	Rectangular network; tributaries at right angles to main stream	Folded / faulted alternate hard-soft rock bands	Parts of Himalayan rivers; folded Appalachian-type relief
Rectangular	Sharp right-angle bends in both main stream and tributaries	Hard rock with dominant joints / faults controlling flow	Parts of Vindhyan and Archaean terrain
Radial	Streams flow outward from a central dome/upland	Central elevated dome or volcanic cone	Amarkantak plateau (Narmada + Son + Mahanadi); Mikir Hills (Assam)
Centripetal	Streams converge inward into a central basin	Interior drainage; closed basin	Inland drainage of Rajasthan (e.g., Sambhar Lake area)
Parallel	Equally spaced parallel rivers	Steep gradient; uniform slope	Short west-flowing rivers descending the Konkan (Western Ghats)
Annular	Ring-like pattern around an eroded dome	Structural dome with alternating hard/soft rock rings	Eroded domes in Chotanagpur plateau area

KEY DRAINAGE CONCEPTS

- **Drainage basin / river basin:** entire area drained by a river and its tributaries; the **Ganga basin (~8.6 lakh sq km)** is India's largest.
- **Catchment area:** area from which a stream/river collects water; used interchangeably with basin for smaller units.
- **Watershed:** the **boundary line (divide)** separating two adjacent drainage basins — typically an upland ridge or hill range.
- **Antecedent (consequent) drainage:** rivers **older than the mountains** they cross; maintained their course as

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the mountains rose by **cutting down (incising) at a rate matching uplift** → dramatic gorges. Classic examples: **Indus (Nanga Parbat gorge), Sutlej (Shipki La gorge), Brahmaputra/Tsangpo (Namcha Barwa Great Canyon)**.

- **Superimposed (epigenetic) drainage:** a drainage system established on a younger cover layer that is later **"let down" onto an older underlying structure** as the cover is eroded away; reported from the Damodar and Subarnarekha areas.

8.3 THE INDUS RIVER SYSTEM

The Indus is one of the great rivers of Asia — both geographically and historically. It is the **cradle river of the Harappan/Indus Valley Civilisation** (c. 2600–1900 BCE) and today forms the **backbone of Pakistan's agricultural economy**.

ORIGIN AND COURSE

Parameter	*Detail*
Origin	Sengge Khabab ("Lion's Mouth") / Angsi glacial springs near Mansarovar Lake, Tibet (~5,182 m)
Tibetan name	Sengge Tsangpo or Singi Khamban
Entry into India	Demchok area, Ladakh UT (flows past Leh)
Total length	~3,180 km (one of Asia's longest)
Length in India	~1,114 km
Basin area	~1.17 million sq km (one of Asia's largest)
India's share of basin	~321,289 sq km (~28% of total basin)
Antecedent gorge	Cuts through Nanga Parbat massif — one of world's deepest gorges
Mouth	Arabian Sea near Karachi, Pakistan

THE FIVE PUNJAB TRIBUTARIES

The word **Punjab** derives from *Punj* (five) + *Ab* (waters) = **"Land of the Five Rivers"**. The five:

River	*Origin*	*Key Feature*	*IWT Status*
Jhelum (Vitasta)	Verinag spring, Pir Panjal, J&K	Flows through Kashmir Valley; Wular Lake; Dal Lake; enters Pakistan at Muzaffarabad; joins Chenab	Western river → Pakistan
Chenab (Chandrabhaga)	Union of Chandra + Bhaga at Tandi, Lahaul-Spiti, HP	LONGEST tributary of Indus; disputes over Ratle Dam (850 MW, J&K)	Western river → Pakistan
Ravi	Kullu hills (Rotang area), HP	Flows through Chamba; passes near Lahore in Pakistan; joins Chenab in Pakistan	Eastern river → India
Beas	Beas Kund near Rohtang Pass, HP	Flows through Kullu-Kangra valleys; meets Sutlej at Harike; entirely within India; Beas-Sutlej Link (Pandoh Dam)	Eastern river → India
Sutlej (Langchen Khabab)	Rakshastal (Rakas Tal), Tibet near Mansarovar	Antecedent — enters India through Shipki La gorge (HP); Bhakra-Nangal Dam; LONGEST in Punjab plains; joins Chenab in Pakistan	Eastern river → India

INDUS WATERS TREATY (IWT), 1960 — THE MOST IMPORTANT SUB-TOPIC

The IWT is **the most significant water treaty in South Asia** — allocating the entire Indus basin among India and Pakistan and providing a **detailed dispute-resolution mechanism**. It is also, as of 2025, at the **most acute geopolitical inflection point in its 65-year history**.

Key Facts of the IWT

- **Signed: September 19, 1960**, in Karachi.
- **Negotiated by: World Bank** (Eugene Black, Bank President, was the critical mediator); signed by **PM Jawaharlal Nehru (India)** and **President Ayub Khan (Pakistan)**.
- **Principle of allocation (the "Two-Basin" solution):**
  - **Eastern rivers — Ravi, Beas, Sutlej:** allocated to **India** for unrestricted use.
  - **Western rivers — Indus, Jhelum, Chenab:** allocated to **Pakistan** for unrestricted use; India retains limited "non-consumptive" rights (run-of-river hydropower, specified irrigation, navigation, fisheries).
- **Permanent Indus Commission:** bilateral body with an Indus Commissioner from each side; handles implementation and the first tier of dispute resolution.
- **Dispute resolution ladder:** Permanent Commission → Neutral Expert (technical disputes) → Court of Arbitration (legal disputes).
- **Resilience:** survived the **1965 war, 1971 war and 1999 Kargil conflict** — often called **"one of the world's most durable water treaties."**

ENV ALERT

BREAKING — IWT Placed "In Abeyance" (April 23, 2025)

Following the **Pahalgam terrorist attack (April 22, 2025, 26 tourists killed)**, the Cabinet Committee on Security resolved that India would hold the IWT "in abeyance" until Pakistan "credibly and irrevocably abjures its support for cross-border terrorism." This is the **first formal suspension of the IWT in its 65-year history**. Pakistan's National Security Committee reportedly characterised any water diversion as a potential "act of war." The abeyance — if sustained — could allow India to increase storage/diversion on the western rivers beyond current permitted limits. (Verify exact wording against MEA/PIB sources.)

Implications of the IWT (Civil 2016 PYQ Framework)

Dimension	*India*	*Pakistan*
Economic	Eastern rivers (Ravi, Beas, Sutlej) feed canal systems of Punjab, Haryana, Rajasthan (IGNP); ~3.6 M ha irrigated	~90% of Pakistan's irrigated agriculture depends on the Indus system; the IWT is Pakistan's agricultural lifeline
Ecological	Reduced flows from eastern rivers have affected the Indus delta (Sindh mangroves); Kishanganga/Ratle projects alter river ecology in J&K	Lower Indus delta (Sindh) suffers from severe water deficit; Pakistan's own barrages also deplete flows; Indus dolphin critically endangered
Political	IWT is seen as overly generous to Pakistan (India gave up western rivers worth ~80% of Indus basin water); leverage point in India-Pakistan relations	Any threat to IWT triggers existential concern; Pakistan has taken disputes to World Bank Neutral Expert and PCA Arbitration

UPSC CIVIL

"Present an account of the Indus Waters Treaty and examine its ecological, economic and political implications in the context of changing bilateral relations." [UPSC Civil (Mains) 2016 | GS-1 | 12.5M]

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Answer structure: (1) Treaty background — World Bank mediation, eastern/western river split, date. (2) Economic implications — India's Punjab/IGNP; Pakistan's agricultural dependence. (3) Ecological — lower Indus delta degradation, Indus dolphin, Kashanganga/Ratle ecological impact. (4) Political — treaty's survival through three wars; Kishanganga/Ratle disputes (PCA, Neutral Expert); 2016 Uri/2019 Pulwama/2025 Pahalgam escalations; 2025 abeyance. (5) Conclusion — IWT as a model of functional water diplomacy now under stress from terrorism and changing geopolitics.

Current Disputes under the IWT

- **Kishanganga Dam (330 MW, J&K):** run-of-river project on the Kishanganga (Neelum in Pakistan); Pakistan contested it at both the Permanent Court of Arbitration and Neutral Expert; ICA awarded India limited diversion rights.
- **Ratle Dam (850 MW, Chenab, J&K):** Pakistan objects on design grounds; PCA proceedings parallel to India's Neutral Expert claim; complex twin-track litigation.

8.4 THE JHELUM RIVER

The Jhelum — *Vitasta* in Sanskrit, one of the seven sacred rivers of the Vedic tradition — is the **lifeline of the Kashmir Valley**. It rises as a **karst spring at Verinag** (at the base of the Pir Panjal) and flows northwest through Srinagar before entering Pakistan near Muzaffarabad, where it joins the Chenab.

WULAR LAKE

Wular Lake — on the Jhelum in Baramulla district, J&K — is **India's largest freshwater lake**. Its area fluctuates dramatically with the seasons (from roughly 30 to over 260 sq km), as it serves as a natural **flood-storage buffer** for the Kashmir Valley. It is a **Ramsar Wetland of International Importance (1990)**, supporting migratory birds, fisheries and the Kashmiri waterscape. Severe ecological pressures include **encroachment, siltation, weed (Trapa natans) invasion and declining fish populations**.

DAL LAKE

Dal Lake (Srinagar) — Kashmir's iconic tourist lake — is under severe ecological threat: encroachment has **reduced its open-water area** dramatically; untreated sewage and agricultural runoff cause **eutrophication**; and **water hyacinth invasion** chokes the water surface. The National Lake Conservation Plan (NLCP) and various court orders address its restoration.

8.5 THE GANGA RIVER SYSTEM

The Ganga is India's **National River (declared 2008)**, its **largest river basin (~8.6 lakh sq km — about 26% of India's land area)**, and the spiritual axis of the country. From its glacial source in the Garhwal Himalaya to its vast delta on the Bay of Bengal, the Ganga is **the world's most populated river basin** — sustaining some 600 million people across Uttarakhand, UP, Bihar, Jharkhand and West Bengal.

5A — ORIGIN: BHAGIRATHI, ALAKNANDA AND THE FIVE PRAYAGS

The Ganga is formed by the union of two headstreams at **Devprayag (Uttarakhand)**:

- **Bhagirathi:** rises at **Gaumukh (Cow's Mouth)** — the glacial snout of the **Gangotri Glacier** (Uttarkashi, Uttarakhand) — one of India's largest Himalayan glaciers; the **sacred mythological source** of the Ganga.
- **Alaknanda:** rises from the **Satopanth and Bhagirath Kharak glaciers** near Badrinath. The Alaknanda receives five major tributaries along its course, with confluences known as the **Panch Prayag (Five Sacred Confluences)**:

Prayag (Confluence)	*Rivers Joining*	*Location / District*
Vishnuprayag	Alaknanda + Dhauliganga	Chamoli, Uttarakhand

Nandaprayag	Alaknanda + Nandakini	Chamoli, Uttarakhand
Karnaprayag	Alaknanda + Pindar (Pindar River)	Chamoli, Uttarakhand
Rudraprayag	Alaknanda + Mandakini (Kedarnath River)	Rudraprayag, Uttarakhand
Devprayag	Alaknanda + Bhagirathi = GANGA	Tehri Garhwal, Uttarakhand

The Ganga emerges onto the plains at **Haridwar** (Rishikesh is immediately upstream). Length: **2,525 km**; the river flows through Uttarakhand, Uttar Pradesh, Bihar and West Bengal.

5B — MAJOR TRIBUTARIES

Left-Bank Tributaries (from Himalayas/Nepal — perennial)

River	Origin	Key Feature/Note
Ramganga	Dudhatoli hills, Uttarakhand	Joins Ganga near Kannauj; Corbett NP is on its banks
Ghaghara (Karnali)	Nepal / Tibet Himalayas	LARGEST TRIBUTARY of Ganga by volume; flows as Sharda/Sarda along Nepal-Uttarakhand border; major flood river of eastern UP and Bihar
Gandak (Narayani)	Nepal / Tibet	Forms part of Nepal-Bihar boundary; joins Ganga at Sonpur/Hajipur (Bihar); Gandak Project (India-Nepal joint)
Kosi (Saptakoshi)	Tibet and Nepal (seven headstreams)	The "SORROW OF BIHAR" — huge alluvial megafan; shifted ~120 km westward over ~200 yrs; Kusaha breach 2008; Kosi Barrage at Bhimnagar
Mahananda	Darjeeling, WB	Joins Ganga near Farakka; partially flows through Bangladesh

Right-Bank Tributaries (from Peninsular India — seasonal)

River	Origin	Key Feature / Note
Yamuna	Yamunotri Glacier, Uttarkashi, Uttarakhand	Longest tributary; 1,376 km; Delhi, Mathura, Agra; joins Ganga at PRAYAGRAJ (Triveni Sangam); most polluted stretch: Delhi-Mathura-Agra
Son	Near Amarkantak plateau, MP	Southern (right-bank) perennial-ish river; joins Ganga near Arrah/Patna; important for Bihar
Punpun	Palamu plateau, Jharkhand	Joins Ganga just south of Patna; seasonal
Damodar	Chotanagpur Plateau, Jharkhand	"Sorrow of Bengal" (pre-DVC); major coal/industrial river; DVC (1948) — India's FIRST multipurpose project; joins Hooghly (not main Ganga)

5C — THE YAMUNA AND ITS TRIBUTARIES

The Yamuna is the **most important tributary of the Ganga** — the **1,376 km** long river that forms the sacred **Triveni Sangam at Prayagraj** (mythologically with the underground Saraswati). The **Yamuna-Ganga doab** between the two rivers is one of India's most fertile and densely populated interfluves — historically the heartland of the Mughal Empire. Delhi draws a large share of its water from the Yamuna.

- **Chambal:** the **longest tributary of the Yamuna**; rises in the Vindhyan highlands near Mhow (MP); famous for its **badland ravines** (Chambal ravines); the **National Chambal Sanctuary** is a stronghold of the **gharial, mugger crocodile and Gangetic dolphin**; one of India's cleaner rivers.
- **Betwa:** rises in the Vindhyas; joins Yamuna at Hamirpur (UP); **Ken-Betwa Link** target river.
- **Ken:** flows through the **Panna Tiger Reserve** (MP); source river of the Ken-Betwa Link.

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5D — THE KOSI: "SORROW OF BIHAR"

The Kosi (Saptakoshi) rises from seven headstreams in Tibet and Nepal and descends onto the Bihar plains carrying one of the **world's highest sediment loads**. As it deposits sediment, it **raises its own bed** and shifts laterally:

- The river has **migrated ~120-133 km westward** over approximately **200-250 years**, building a vast **alluvial megafan**.
- **Kusaha Breach (August 2008):** the eastern embankment breached near Kusaha, Nepal; the Kosi took an abandoned eastern channel, devastating districts of **Supaul, Saharsa, Madhepura, Araria and Purnia** — affecting roughly **3 million people**.
- **Kosi Barrage at Bhimnagar** (India-Nepal joint structure) regulates the river's flow into India's embankment system.

5E — GANGA DELTA, FARAKKA & THE SUNDARBANS

Near **Farakka (West Bengal)**, the Ganga divides into two channels:

- **Bhagirathi-Hooghly (India):** carries Kolkata's water and port traffic.
- **Padma (Bangladesh):** the main channel; joins the Brahmaputra (as Jamuna) and Meghna before reaching the Bay of Bengal.

Farakka Barrage (commissioned 1975): diverts Ganga water into the Hooghly to flush silt and maintain navigation to **Kolkata port**. It has been a long-standing **India-Bangladesh dispute**: the **Ganga Waters Treaty of December 12, 1996** (30-year term) addresses water sharing during lean-season flows; this treaty **expires in 2026** and renewal negotiations have begun against a backdrop of changed Bangladesh politics (post-Hasina government, 2024).

The **Ganga-Brahmaputra delta — the Sundarbans** — is the **world's largest delta (~80,000 sq km total; India's share ~10,000-40,000 sq km)**. It is a **UNESCO World Heritage Site** and home to the **Royal Bengal tiger**, the **Irrawaddy and Gangetic dolphins**, and the largest contiguous **mangrove forest** on Earth — also one of the most **climate-change-threatened** ecosystems (sea-level rise, salinity intrusion, cyclones).

IFoS FOCUS

IFoS CONSERVATION FOCUS — GANGA

- **Gangetic/South Asian River dolphin (Platanista gangetica):** India's national aquatic animal; Schedule I (WPA); CITES Appendix I; critically affected by river pollution, entanglement, sand mining and barrages; Project Dolphin (2020) for conservation.
- **Gharial (Gavialis gangeticus):** critically endangered; restricted to Chambal, Girwa (Katarniaghat) and a few other Ganga tributaries; fish-eating, harmless to humans; nest on sandy riverbanks — sand mining is the key threat.
- **Namami Gange (2014):** India's flagship Ganga rejuvenation programme (₹20,000 crore initial outlay, extended to 2026); sewage treatment, riverfront development, dolphin census, afforestation. See Chapter 3 for detail.

8.6 THE BRAHMAPUTRA RIVER SYSTEM

The Brahmaputra is in many ways the most **extraordinary river in Asia** — the highest-origin large river, the cutter of the world's deepest canyon, one of the widest rivers on Earth, and the most potent **strategic water flashpoint between India and China**.

6A — ORIGIN AND COURSE

Parameter	*Detail*
Origin	Angsi / Chemayungdung Glacier, Tibetan Plateau (~5,300 m near Kailash-Mansarovar; Yarlung Tsangpo)

Tibetan name	Yarlung Tsangpo (also Yarlung Zangbo); "Yarlung Tsangpo Grand Canyon" — world's deepest gorge (~5,000+ m)
Eastern Syntaxis	Great U-turn around Namcha Barwa (7,782 m); dramatic hairpin bend
India: Arunachal Pradesh	Enters as the SIANG (Dihang); joined by Dibang and Lohit → becomes BRAHMAPUTRA at Dibrugarh-Sadiya area
Bangladesh	Known as JAMUNA; joins Ganga (Padma) and Meghna → Bay of Bengal
Total length	~2,900 km (source to mouth); India section ~916 km
Width in Assam	Up to 10-18 km wide during floods — one of the WIDEST RIVERS in the world
Channel type	HIGHLY BRAIDED — numerous shifting channels, sandbars and mid-river islands (chars)

6B — TRIBUTARIES AND KEY FEATURES

Tributary	*Origin/Direction*	*Key Note*
Subansiri	Arunachal Pradesh (north bank)	Largest tributary by volume; Subansiri Lower HEP (2,000 MW) under construction
Kameng (Jia Bhoreli)	Arunachal Pradesh	Feeds the Nameri and Pakke Tiger Reserves
Dibang	Arunachal Pradesh (north)	Joins near Sadiya; Dibang multipurpose project proposed (2,880 MW) — contested
Lohit	Tibet-Arunachal border	Joins near Sadiya; alluvial fan; name "Red River" from iron-rich sediment
Teesta	North Sikkim/WB	Joins Brahmaputra in Bangladesh (Jamuna); South Lhonak GLOF (Oct 2023) caused Teesta flooding
Manas	Bhutan-Assam border	UNESCO WHS and Tiger Reserve on its banks; joins Brahmaputra near Barpeta
Kopili (Kapili)	Meghalaya (south bank)	Important south-bank tributary; Kopili HEP damaged by GLOF-type event (2022)

Majuli Island — the **world's largest inhabited river island** (though disputed; Marajó in Brazil is larger by some counts; Majuli is unambiguously the largest *riverine* island in India) — lies in the Brahmaputra in Assam. Its area has **shrunk dramatically (from >900 sq km historically to ~352 sq km now)** due to erosion; it is the heart of **Vaishnavite (Sattriya) culture** and was designated **India's first island district in 2016**. Erosion-driven shrinkage makes it one of India's most visible examples of **climate-change-accelerated river bank loss**.

6C — THE CHINA FACTOR: BRAHMAPUTRA AS A STRATEGIC RESOURCE

The **Yarlung Tsangpo rises entirely in Tibet** and China controls all upstream infrastructure — creating a profound **lower-riparian vulnerability** for India, with **no treaty framework** to protect Indian interests.

Project	*Capacity*	*Status (as of 2025)*	*Concern for India*
Zangmu Dam	510 MW run-of-river	Operational (2014-15)	Limited; run-of-river; minimal storage
Jiexu, Jiacha, Dagu	Various (run-of-river cluster)	Operational (2017-2019)	Cumulative downstream flow regulation
Medog (Motuo) Mega-Dam	~60,000 MW (planned)	Approval announced Dec 2024; groundbreaking reportedly 2025; construction ongoing	Largest dam in history; massive hydraulic head; catastrophic downstream risk if dam fails; no treaty obligation

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ENV ALERT

Why the Medog Dam is India's Biggest Water Security Concern

- **Scale:** ~60,000 MW would dwarf the Three Gorges Dam (22,500 MW) — three times the world's current largest. Annual generation ~300 billion kWh.
- **Location:** at the Great Bend (eastern syntaxis), the river drops ~2,000 m over ~50 km — the most concentrated hydraulic head in the world.
- **No treaty:** India has no legal protection as a lower riparian; contrast with India-Pakistan IWT. Limited MoUs for hydrological data sharing have lapsed/renewed intermittently.
- **Risks:** sudden water release (intentional or dam failure) could devastate Arunachal Pradesh and Assam; dry-season flow reduction; sediment starvation of downstream floodplains; long-term threat to Sundarbans via Brahmaputra.

8.7 INTERLINKING OF RIVERS (ILR)

The Interlinking of Rivers (ILR) is India's most ambitious water management proposal — designed to resolve the **fundamental spatial mismatch** between India's water availability (surplus in Ganga-Brahmaputra, deficit in peninsular India and the northwest) by creating a **national water grid** of canals and reservoirs.

NATIONAL PERSPECTIVE PLAN (1980)

- **Two components:**
  - **Himalayan Component:** 14 links — to transfer surplus Ganga-Brahmaputra floodwaters to deficit peninsular zones; includes major Himalayan storage dams.
  - **Peninsular Component:** 16 links — to interconnect Mahanadi, Godavari, Krishna, Cauvery and other peninsular rivers.
- **Total: 30 links; total potential: ~35 million ha additional irrigation; ~34,000 MW hydropower; ~15,000 km navigable waterways.**
- **Supreme Court order (2012):** directed the government to constitute a Special Committee for Inter-linking of Rivers and implement the plan.

KEN-BETWA LINK PROJECT (KBLP) — INDIA'S FIRST ILR PROJECT

Parameter	*Detail*
Rivers linked	Ken River (right-bank Yamuna tributary, MP) → Betwa River (left-bank Yamuna tributary, MP-UP)
Key structure	Daudhan Dam (77 m high) on Ken at Panna district, MP
Water transfer	~77 TMC (Thousand Million Cubic Feet) from Ken to Betwa
Beneficiary region	Drought-prone Bundelkhand (MP and UP); 8 districts directly benefited
Expected benefits	1.44 lakh ha new irrigation; 62 lakh ha total irrigation; 103 MW hydropower; drinking water
Estimated cost	₹44,605 crore (at 2020-21 price levels)
Status	Cabinet approved December 2021; foundation stone laid December 25, 2021; under construction
Key controversy	Submergence of ~9,000 ha of forest including part of PANNA TIGER RESERVE (MP)

IFoS FOCUS

IFOS CONSERVATION CONCERN — PANNA TIGER RESERVE: Panna TR in MP had a complete **tiger collapse (zero tigers by 2009)** and was **restocked through reintroduction (2009 onward)** — a conservation success story. The KBLP's Daudhan Dam will submerge core habitat (Panna core zone lies within the submergence area). The National Board for Wildlife (NBWL) granted clearance despite significant ecological objections. This makes KBLP a **textbook conflict between development/water-security and wildlife-conservation** — a core IFoS answer theme.

ARGUMENTS FOR AND AGAINST ILR

FOR ILR	AGAINST ILR
Resolves the flood-drought paradox — Ganga-Brahmaputra floods while Deccan parches	Ecological disruption — delta shrinkage, fish migration blocked, riparian biodiversity lost
~35 million ha additional irrigation potential	Inter-state disputes — virtually every link involves contested water rights (Cauvery, Krishna)
Attenuation of Kosi/Assam floods through Himalayan storage	Mass displacement — millions affected by dam/canal construction
~34,000 MW hydropower generation	Cost > ₹5 lakh crore total — enormous capital and maintenance burden
~15,000 km of additional inland navigation	Seismicity — many links pass through Zone IV-V seismically active areas
Drought relief for Bundelkhand, Marathwada, Vidarbha, Rayalaseema	Climate uncertainty — static "surplus-deficit" assumption invalidated by changing monsoon
Ken-Betwa successfully initiated as proof of concept	No guarantee surplus basins have physically transferable water without ecological harm

UPSC CIVIL

"The interlinking of rivers can provide viable solutions to the multi-dimensional inter-related problem of droughts, floods and interrupted navigation. Critically examine." — See Model Answer in Section 8.12 [UPSC Civil (Mains) 2020 | GS-1 | 15M]

"In what way can floods be converted into a sustainable source of irrigation and all-weather inland navigation in India?" [Civil 2017 | 15M]

Link to ILR's Himalayan component (store floodwaters for use in lean season), National Waterway-1 (Ganga from Allahabad to Haldia, 1,620 km), NW-2 (Brahmaputra), NW-3 (Kerala backwaters), and the inland waterways potential.

8.8 FLOODS IN HIMALAYAN RIVERS

Himalayan rivers are **among the most flood-prone in the world** — a consequence of their **steep gradients, massive sediment loads, monsoon-intensity, glacial systems and antecedent drainage** — all compounded by **human interventions** that reduce natural flood-absorption capacity.

CAUSES OF HIMALAYAN FLOODING

- **Intense monsoon rainfall:** the Ganga-Brahmaputra catchments receive India's heaviest monsoon; peak discharge in June-September.
- **Glacial melt (GLOF):** rapid summer glacier melt; glacial lake outburst floods (GLOFs) — moraine or ice-dam failure releases catastrophic flood pulses.
- **Riverbed aggradation:** high sediment loads raise channel beds above floodplain level → overbank flooding; the **Kosi's westward migration** is the classic case.
- **Embankment breaches:** most Bihar rivers (Kosi, Gandak, Bagmati) are now contained by embankments that eventually breach when the built-up riverbed rises above embankment height.
- **Deforestation:** in headwater catchments reduces interception and infiltration, increasing runoff volumes.

THE EMBANKMENT VS FLOODPLAIN DEBATE

Bihar has the most embankment-protected river system in India — yet suffers **recurrent catastrophic floods**. The paradox: embankments **trap silt**, raising river beds over decades until they sit **above the surrounding floodplain**. When an embankment breaches, the flood is **more severe than before** — because the river now sits higher.

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Critics like **Dinesh Mishra (Barh Mukti Abhiyan)** argue for **"living with floods"** through floodplain management, natural retention and improved warning systems rather than ever-higher embankments.

FARAKKA BARRAGE AND BIHAR FLOODING

Bihar's government has repeatedly argued that the **Farakka Barrage (1975)** — by trapping sediment — has raised the **Ganga bed in the Bhagalpur-Patna reach**, increasing **backwater flooding** in Bihar. This has been a major point of friction in Centre-State relations and has been raised in the context of the India-Bangladesh treaty negotiations.

8.9 HYDROPOWER ON HIMALAYAN RIVERS

India's **assessed large hydropower potential is ~1,45,320 MW** (Central Electricity Authority); only about **~46,000-47,000 MW** was installed as of 2023-24. **Himalayan rivers hold the majority of this untapped potential** — particularly the Brahmaputra system (~35% of India's assessed potential) and the Ganga tributaries. Yet hydropower development on these rivers is increasingly contested.

Project	*River*	*Capacity*	*State*	*Note*
Bhakra-Nangal	Sutlej	~1,325 MW (Bhakra Dam 226 m)	HP / Punjab / Haryana	India's first major post-independence multipurpose project; "temple of modern India"
Tehri Dam (Stage I+II)	Bhagirathi	2,000+ MW (Stage I 1,000 MW + pumped storage 1,000 MW + Koteshwar)	Uttarakhand	India's TALLEST DAM (260.5 m); displaced 100,000+ people; operational 2006
Koldam	Sutlej	800 MW	HP	NTPC; downstream of Bhakra; operational
Pong Dam	Beas	396 MW	HP	Maharana Pratap Sagar reservoir — Ramsar site (migratory birds)
Kishanganga	Kishanganga (Jhelum trib.)	330 MW	J&K	Trigger for IWT dispute with Pakistan (PCA proceedings)
Ratle	Chenab	850 MW	J&K	Under construction; Pakistan-disputed under IWT
Subansiri Lower	Subansiri	2,000 MW	Arunachal / Assam	India's LARGEST HEP under construction (NHPC); delayed by protests

CHALLENGES — WHY HIMALAYAN HEP IS CONTESTED

- **Seismicity (Zone IV-V):** the entire Himalayan belt is highly seismic; dams can trigger or amplify earthquakes; Tehri sits in Zone IV-V.
- **Rapid sedimentation:** Himalayan rivers carry extremely high sediment loads; reservoirs **silt up rapidly**, reducing capacity and dam life — Tehri's sediment management is a major concern.
- **Flash floods / GLOF risk:** Chamoli disaster (Feb 7, 2021) — rock-ice avalanche destroyed **Rishiganga (13.2 MW)** and damaged **Tapovan-Vishnugad (NTPC, 520 MW)** with ~204 dead/missing; raised fundamental questions about HEP viability in unstable Himalayan valleys.
- **Environmental flows:** minimum flows required downstream of dams to sustain aquatic ecology (fish, dolphins, riparian vegetation); rarely enforced.
- **Social displacement:** Tehri displaced >100,000 people; Subansiri Lower affects Arunachal and Assam communities.

IFoS FOCUS

IFoS EXAM ANGLE — HEP VS RIVER ECOLOGY: For IFoS, emphasise: (1) **fish migration barriers** (mahseer, hilsa cannot pass dams — fisheries collapse upstream and downstream); (2) **environmental flows** (e-flow notifications from MoEFCC); (3) **downstream sediment starvation** (delta subsidence, mangrove loss); (4) **riparian forest clearance** for reservoir submergence; (5) **cumulative impact** of multiple projects on a single river (e.g., Sutlej: Bhakra→Koldam→multiple run-of-river projects).

8.10 CURRENT AFFAIRS HOOKS (2021–2025)

CURRENT AFFAIRS

IWT Suspended / "In Abeyance" (April 23, 2025): India placed the IWT in abeyance following the Pahalgam terror attack (April 22, 2025, 26 killed). First-ever suspension. Pakistan reportedly characterised water diversion as potential casus belli. High-probability UPSC/IFoS question for 2025-26 exams. Verify: MEA communique and PIB for exact wording.

China's Tsangpo Mega-Dam (2024-25): ~60,000 MW Medog project approved (Dec 2024 reports); groundbreaking reportedly led by Premier Li Qiang (July 2025). India lodged concerns as a downstream state. No treaty protection. Verify: Reuters, Xinhua.

Ken-Betwa Link Project (ongoing): Construction commenced; ₹44,605 crore; Panna Tiger Reserve ecological controversy; Bundelkhand's first major water-security project.

Chamoli Disaster (February 7, 2021): Rock-ice avalanche on Ronti Glacier; floods down Rishiganga and Dhauliganga; Rishiganga HEP (13.2 MW) destroyed; Tapovan-Vishnugad (520 MW) severely damaged; ~204 dead/missing. Published in Science (2021) — Shugar/Jacquemart et al.

South Lhonak GLOF, Sikkim (October 3-4, 2023): Slope failure into glacial lake; Teesta flooding; breach of Chungthang Dam (Teesta Stage III, 1,200 MW); 40+ confirmed dead; ~100 total dead/missing. India's largest recent GLOF disaster.

Assam Floods 2022-2024: Annual Brahmaputra-Barak flooding; Kaziranga inundation; char erosion; thousands displaced. 2024 was among the more severe years.

Ganga River Dolphin Census: Project Dolphin (2020); periodic surveys show slow population recovery; national survey 2024-25 pending final verification of total count.

Teesta & Farakka Treaty Timelines: Ganga Waters Treaty (1996) expires 2026; Teesta water sharing treaty unsigned since 2011 (West Bengal opposition); Bangladesh's post-2024 government pressing India hard on both. High-probability GS-2 questions.

8.11 PYQ ANALYSIS — CHAPTER 8 (2010–2025)

Questions from UPSC Civil Mains GS-1/GS-2/GS-3 and IFoS GS directly testing Himalayan River themes:

Source	*Year*	*Marks*	*Question*
UPSC Civil	2020	15M	"The interlinking of rivers can provide viable solutions to the multi-dimensional inter-related problem of droughts, floods and interrupted navigation. Critically examine."
UPSC Civil	2016	12M	"Present an account of the Indus Waters Treaty and examine its ecological, economic and political implications in the context of changing bilateral relations."
UPSC Civil	2017	15M	"In what way can floods be converted into a sustainable source of irrigation and all-weather inland navigation in India?"
UPSC Civil	2011	12M	"Discuss the problems and prospects of inter-linking of rivers in India."
UPSC Civil	2024	15M	"The groundwater potential of the Gangetic valley is on a serious decline. How may it affect the food security of India?"
UPSC Civil	2019	15M	"What is water stress? How and why does it differ regionally in India?"
UPSC Civil	2018	15M	"The ideal solution of depleting groundwater resources in India is water harvesting system. How can it be made effective in urban areas?"

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UPSC Civil	2015	12M	"India is well endowed with fresh water resources. Critically examine why it still suffers from water scarcity."
UPSC Civil	2010	12M	"Explain the importance of 'Wetlands' and the threats they face in India."
IFOS GS	2025	15M	"Describe briefly the key differences between Himalayan and Peninsular river systems. What could be the key consequences of interlinking of rivers in India?"
IFOS GS	2025	10M	"Causes of flash floods are both natural and human-made. Comment in context of Dharali, Uttarkashi."
IFOS GS	2014	12M	"What are wetlands? Discuss their importance."

KEY NOTE

Frequency pattern: ILR (2011, 2020; IFoS 2025) and the IWT (2016) are the anchor Civil Mains questions. Water scarcity/Gangetic valley recurs (2015, 2018, 2019, 2024). GLOFs and flash floods dominate IFoS (2025). Expect the 2025 IWT suspension and China's Medog dam to feature prominently in 2025-26 exam cycles. Master: the IWT allocation table, ILR for-against framework, five Prayags, Kosi migration story, and GLOF mechanism.

8.12 MODEL QUESTION

The interlinking of rivers can provide viable solutions to the multi-dimensional inter-related problem of droughts, floods and interrupted navigation. Critically examine.

UPSC Civil (Mains) 2020 | GS-1 | 15 Marks | 200 Words

India faces a **spatial water paradox** — the Ganga-Brahmaputra basin floods catastrophically while peninsular India and the northwest parch. The 1980 National Perspective Plan's **Interlinking of Rivers (ILR — 30 links)** proposes a water grid to resolve this mismatch through transfer and storage.

MERITS

- **Flood-drought balance:** Himalayan component can store Kosi/Assam floodwaters in reservoirs for dry-season use — directly addressing Bihar's recurrent inundation and Deccan's drought.
- **Irrigation and food security:** projected ~35 million ha of additional irrigation; ~34,000 MW hydropower; addresses Bundelkhand (Ken-Betwa, ₹44,605 cr — first project) and Marathwada droughts.
- **Inland navigation:** ~15,000 km of new navigable waterways; supplements existing NW-1 (Ganga, 1,620 km) and NW-2 (Brahmaputra).

CRITICAL CONCERNS

- **Ecological damage:** Reduced sediment and freshwater to river **deltas** (Godavari, Krishna, Cauvery) → delta erosion and saltwater ingress; **fish-migration routes** blocked; Gangetic dolphin and gharial habitat disrupted.
- **Inter-state disputes:** virtually every link involves contested water rights; Cauvery and Krishna already chronically disputed.
- **Cost and displacement:** total cost may exceed ₹5 lakh crore; millions could be displaced; seismically active terrain increases risk.
- **Climate uncertainty:** static surplus-deficit assumptions are undermined by a changing and more variable monsoon.

ILR can be a partial, basin-specific tool — the Ken-Betwa success should encourage limited, ecology-sensitive links. But it is **not a wholesale "viable" solution**. It must be complemented by **watershed management, rainwater harvesting, environmental flows and demand-side efficiency** — more sustainable, equitable and ecologically sound.

CHAPTER 9

PENINSULAR RIVERS OF INDIA

CHAPTER AT A GLANCE

- Peninsular rivers: seasonal/rain-fed; fixed hard-rock channels; older than Himalayan rivers; eastward slope drives most drainage into Bay of Bengal; Narmada and Tapi are the west-flowing rift-valley exceptions.
- Godavari (~1,465 km) = longest peninsular river; largest basin (~3.13 lakh sq km). Known as "Dakshin Ganga." Polavaram National Project (960 MW, ₹55,000+ cr) ongoing.
- Krishna (~1,400 km): Tungabhadra (Hampi/Vijayanagara), Bhima, Musi, Koyna (reservoir-induced seismicity 1967, 6.3 Mw). Krishna Water Disputes Tribunal-I (1973) and II (2010, pending).
- Cauvery (~800 km): "Dakshina Ganga"; Stanley/Mettur Dam (TN); KRS Dam (Karnataka); Cauvery Water Disputes Tribunal 1990; SC final order Feb 16, 2018 → Karnataka 284.75 TMC, TN 404.25 TMC, Kerala 30, Puducherry 7; CWMA 2018.
- Mahanadi (~851 km, ~1.42 lakh sq km): Hirakud Dam (~4.8 km long earthen; 1957; 347.5 MW); delta = Odisha rice bowl; Chilika Lake (Ramsar); Bhitarkanika mangroves; Gahirmatha olive ridley.
- Narmada (~1,312 km): longest west-flowing; rift valley (Vindhya-Satpura graben); Sardar Sarovar Dam (163 m, 1,450 MW); Narmada Bachao Andolan (Medha Patkar); NWDT 1979 award.
- Tapi (~724 km): second west-flowing rift-valley river; Ukai Dam; Surat floods. Luni (~500 km): salt river; Thar Desert.
- Interstate disputes: Article 262; ISRWDA 1956; Cauvery, Krishna, Mahadayi (award 2018), Mahanadi (tribunal 2018), SYL Canal (Punjab-Haryana); Polavaram (AP-Telangana-Odisha).

9.1 INTRODUCTION — CHARACTERISTICS OF PENINSULAR RIVERS

The peninsular drainage system comprises the rivers flowing across the **ancient, stable Deccan Plateau and the Western and Eastern Ghats** — one of the oldest landmasses on Earth. In stark contrast to the Himalayan rivers, which are young, dynamic and glacier-fed, peninsular rivers are **geologically ancient, mature, and almost entirely dependent on monsoon rainfall**. Yet they sustain **hundreds of millions of people across Maharashtra, Telangana, Andhra Pradesh, Karnataka, Tamil Nadu, Kerala, Odisha, Chhattisgarh and Madhya Pradesh**, feeding some of India's most fertile deltas, most important cities and most contested water-rights disputes.

DEFINING CHARACTERISTICS — SIX KEY TRAITS

1. ***Seasonal / Rain-Fed and Non-Perennial***

   Peninsular rivers receive virtually all their water from the **south-west monsoon (June–September)** — and for rivers of the south-eastern coast, from the north-east/retreating monsoon (October–December) as well. They carry **enormous volumes during the monsoon months** but reduce to a trickle or a chain of pools between January and May. There is no glacial or snowmelt supplement; hence they cannot sustain perennial flow without storage infrastructure (dams and reservoirs). This stands in absolute contrast to the **Himalayan rivers (Ganga, Indus, Brahmaputra)** which are perennial because of their triple source (glacier melt + snowmelt + monsoon).

2. ***Fixed Hard-Rock Channels***

   Flowing across the resistant **Archaean crystalline basement (gneiss, schist, granite)** and the **Deccan Trap basalt**, peninsular rivers are confined to well-defined, fixed courses. They cannot **migrate laterally, braid or form ox-bow lakes** as the Himalayan rivers do on their soft alluvial plains. The hard rock constrains them into defined gorges and valleys. This also means that their valleys exhibit waterfalls and rapids at resistant-

rock outcrops (e.g., Chitrakote Falls on the Indravati, Dhuandhar Falls on the Narmada, Jog Falls on the Sharavathi).

3. ***Older Geologically — Mature, Graded Valleys***

Peninsular rivers are far older than the Himalayas — they have been eroding for hundreds of millions of years. As a result, they have reached **near-graded profiles (close to base level)** with **broad, shallow valleys** over most of their course. Vertical downcutting is minimal except at knick-points. Their drainage patterns are ancient — antedating the Himalayan orogeny — and reflect the original Gondwana landscape.

4. ***Lighter Sediment Loads***

Because the catchments are composed of hard, resistant rocks and the rivers are largely graded, they carry **far less sediment than the Himalayan rivers**. This means their delta-building capacity is slower. However, over geological time they have still built **large, extensive deltas** (Godavari, Krishna, Mahanadi, Cauvery) because of the very long time over which deposition has occurred.

5. ***Eastward Tilt — Most Rivers Flow East***

The **Peninsular Plateau tilts gently eastward**, with the **Western Ghats acting as the primary watershed** (drainage divide) between rivers flowing west and east. The vast majority of peninsular rivers — Mahanadi, Godavari, Krishna, Cauvery, Pennar, Palar — flow **east into the Bay of Bengal**. Only the **Narmada and Tapi (and the short west-coast rivers of Kerala-Karnataka)** flow **west into the Arabian Sea**, and they do so because they occupy **structural rift valleys (grabens)** — fault-bounded depressions that direct water westward regardless of the plateau's general tilt.

6. ***Delta vs Estuary — The Defining Coastal Contrast***

East-flowing rivers build deltas; west-flowing rivers form estuaries/rias. This is one of the most frequently examined contrasts in Indian geography.

- **East-coast rivers (Godavari, Krishna, Cauvery, Mahanadi):** long, gentle course across a wide continental shelf → **slow velocity → heavy sediment deposition → extensive delta formation**. These deltas are India's most fertile rice-growing zones.
- **West-coast rivers (Narmada, Tapi, Mandovi, Zuari, Periyar, Sharavathi):** short, steep descent → **high velocity → little opportunity for sediment deposition**; narrow continental shelf leaves no space for delta building; strong longshore currents disperse arriving sediment. These rivers form **estuaries (drowned river mouths / rias)** — funnel-shaped tidal inlets rather than sediment lobes.

UPSC CIVIL

" There is no formation of deltas by rivers of the Western Ghats. Why?" — See model answer in Section 9.14. [UPSC Civil (Mains) 2013 | GS-1 | 5M]

Key answer points : (1) Short, steep rivers → high velocity; (2) narrow continental shelf; (3) strong longshore drift and wave energy; (4) no space/time for sediment deposition; (5) form estuaries/rias instead. Contrast explicitly with east-coast rivers.

PENINSULA RIVERS — MASTER OVERVIEW TABLE

River	*Origin*	*Length*	*Basin Area*	*Mouth / Direction*	*Key Dam / Feature*
Mahanadi	Sihawa hills, Chhattisgarh	~851 km	~1.42 lakh sq km	Bay of Bengal (EAST)	Hirakud Dam (4.8 km long); Chilika Lake delta
Godavari	Trimbakeshwar, Nashik, Maharashtra	~1,465 km	~3.13 lakh sq km	Bay of Bengal (EAST)	LONGEST peninsular river; Polavaram National Project; "Dakshin Ganga"

Krishna	Mahabaleshwar, Satara, Maharashtra	~1,400 km	~2.59 lakh sq km	Bay of Bengal (EAST)	Tungabhadra Dam; Koyna HEP; Hampi; KWDT disputes
Cauvery	Talacauvery, Kodagu, Karnataka	~800 km	~81,155 sq km	Bay of Bengal (EAST)	Mettur/Stanley Dam (TN); KRS Dam (KA); SC 2018 allocation
Narmada	Amarkantak, MP	~1,312 km	~98,796 sq km	Gulf of Khambhat, ESTUARY (WEST)	LONGEST west-flowing; Sardar Sarovar (163 m, 1,450 MW); Indira Sagar
Tapi (Tapti)	Betul, MP (Satpura)	~724 km	~65,145 sq km	Gulf of Khambhat, ESTUARY (WEST)	West-flowing rift valley; Ukai Dam; Surat floods
Luni	Aravallis, Ajmer, Rajasthan	~500 km	~37,363 sq km	Rann of Kachchh (WEST, endorheic)	Only Thar River; salt water downstream; Jawai Dam
Damodar	Chotanagpur, Jharkhand	~592 km	~23,370 sq km	Hooghly/Bay of Bengal (EAST)	DVC 1948; "Sorrow of Bengal" (pre-DVC); coal belt
Subarnarekha	Chotanagpur, Jharkhand	~395 km	~19,300 sq km	Bay of Bengal (EAST)	Chandil Dam; passes through Jharkhand and WB
Pennar	Nandi hills, Karnataka	~597 km	~55,213 sq km	Bay of Bengal (EAST)	Andhra Pradesh; ISPRL pipeline (defence infrastructure)

9.2 DRAINAGE BASIN CONCEPTS & PATTERNS OF PENINSULAR INDIA

The **Western Ghats form the primary drainage divide (watershed)** of the peninsula — rivers to the west drain into the Arabian Sea, and rivers to the east drain into the Bay of Bengal. Within the peninsula, the **Vindhya-Satpura system** forms a secondary divide between rivers flowing south into the Deccan and those flowing north into the Ganga system.

WHY THE EASTERN COAST BUILDS DELTAS

The eastward slope of the peninsula is **gentle (1-2 metres per km)** over vast distances. East-flowing rivers therefore:

- Have **long transport distances (700–1,500 km)** with decreasing gradient.
- Slow progressively, especially as they approach the **wide, shallow continental shelf** of the Bay of Bengal.
- Build **broad sediment fans (deltas)** as they deposit their load upon reaching the coast.
- Benefit from a relatively **low-energy, wave-dominated coast** that allows delta accumulation (in contrast to the high-energy west coast).

KEY NOTE

India's four great eastern deltas : Mahanadi delta (Odisha), Godavari delta (AP), Krishna delta (AP), Cauvery delta (Tamil Nadu — "Granary of South India"). All are major rice-production zones and all are threatened by (i) reduced sediment inflow due to upstream dams, (ii) sea-level rise, and (iii) cyclone intensification — a recurring Civil Mains geography-ecology intersection theme.

WHY THE WESTERN COAST HAS NO MAJOR DELTAS

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- **Short courses (100–300 km):** the Western Ghats rise close to the coast; rivers reach the sea in a fraction of the distance of east-coast rivers.
- **Steep gradients:** rivers descend the Ghats rapidly, maintaining high velocity and carrying sediment in suspension all the way to the coast.
- **Narrow continental shelf:** the Arabian Sea shelf is narrow off the west coast, providing minimal space for sediment accumulation.
- **High-energy coast:** strong Arabian Sea waves and longshore drift remove sediment as fast as it arrives.
- **Estuaries/rias instead:** the combination of steep valleys reaching the sea, tidal influence and submergence (in part from the post-glacial sea-level rise) creates drowned river mouths — estuaries and rias.

9.3 THE MAHANADI RIVER SYSTEM

The Mahanadi — "Great River" of the central-east peninsula — is the dominant hydrological presence of Odisha and coastal Chhattisgarh. Before the construction of Hirakud Dam, it was notorious as the **"Sorrow of Odisha"** for its devastating floods; after Hirakud, it became **one of independent India's first multipurpose development successes**.

ORIGIN AND COURSE

Parameter	*Detail*
Origin	Sihawa hills (Binkha/Pharsiya village), Dhamtari district, Chhattisgarh (~457 m)
Total length	~851 km (some sources cite ~900 km)
Basin area	~1,41,589 sq km; Chhattisgarh (~53%), Odisha (~45%), remainder in Jharkhand, MP and Maharashtra
Tributaries (right bank)	Seonath, Jonk, Hasdeo (Hasdeo Arand coal forest area), Mand
Tributaries (left bank)	Ib (from Jharkhand), Tel, Ong
Course	Flows NE through Chhattisgarh plains → enters Odisha near Sambalpur → flows E/SE through Cuttack → fans into delta near Paradip and False Point
Mouth	Bay of Bengal (broad delta, ~2,000 sq km); distributaries include Birupa, Chitrotpala, Devi, Lunah

HIRAKUD DAM — INDEPENDENT INDIA'S FIRST MAJOR RIVER PROJECT

Completed in **1957**, the Hirakud Dam on the Mahanadi near Sambalpur (Odisha) was one of independent India's pioneering river development projects. Jawaharlal Nehru famously described such dams as **"temples of modern India."**

Feature	*Detail*
Type	Composite — masonry/concrete main dam + earthen saddle dams on both flanks
Main dam length	~4.8 km; with earthen dykes the entire structure is ~25.8 km — among the world's longest dams
Height above foundation	~60.96 m
Reservoir	Hirakud reservoir (Gandhi Sagar): ~743 sq km water spread; ~5.82 billion cu m storage
Hydropower	347.5 MW installed (Burla Power House 307.5 MW + Chiplima Power House 140 MW)
Irrigation	~1.56 lakh ha (kharif) + ~0.72 lakh ha (rabi) in Odisha
Flood control	Controls and moderates Mahanadi floods downstream; ended the "Sorrow of Odisha" era
Historical significance	One of India's first major post-independence multipurpose river valley projects (1957)

MAHANADI DELTA AND ASSOCIATED ECOSYSTEMS

The broad Mahanadi delta in coastal Odisha is a **major rice-cultivation zone** and one of India's most ecologically rich coastal landscapes:

- **Chilika Lake:** India's **largest coastal lagoon (~1,100 sq km)** — a **Ramsar site (1981, India's FIRST Ramsar designation)** — formed where Mahanadi distributaries have been separated from the sea by barrier spits. Chilika supports **flamingo, grey pelican, bar-headed goose, Irrawaddy dolphin** and major artisanal fisheries.
- **Bhitarkanika Mangroves (Brahmani-Baitarani-Mahanadi delta complex):** India's **second-largest mangrove ecosystem** (~672 sq km); Ramsar site; National Park; **saltwater crocodile (Crocodylus porosus)** stronghold; recording the largest crocodile nesting in Asia.
- **Gahirmatha Marine Sanctuary:** home to the world's **largest known mass-nesting (arribada) of olive ridley sea turtles (Lepidochelys olivacea)** — hundreds of thousands nest at Gahirmatha beach and nearby Rushikulya annually.

IFoS FOCUS

IFoS ECOLOGY FOCUS — MAHANADI DELTA

- **Chilika ecological crisis and revival:** By the 1990s, Chilika was severely degraded — siltation closed its mouth to the sea, salinity dropped, fish stocks collapsed. Dredging to re-open the sea mouth (Operation Chilika) in 2000 dramatically revived ecology and fish diversity — a landmark wetland restoration success.
- **Olive ridley turtles:** Threats = net entanglement, light pollution, beach development. Turtle Excluder Devices (TEDs) mandated but enforcement remains poor. Gahirmatha Marine Sanctuary was India's first marine sanctuary (1997).
- **Hasdeo Arand (coal vs forest):** The Hasdeo River (Mahanadi tributary in Chhattisgarh) flows through the Hasdeo Arand forest — one of India's largest intact elephant corridors and coal-rich forests. Coal mining vs elephant habitat is a major 2022-25 conflict.

MAHANADI INTERSTATE WATER DISPUTE (ODISHA VS CHHATTISGARH)

Since 2010, **Odisha has alleged that Chhattisgarh's construction of multiple barrages and weirs** on the upper Mahanadi and its tributaries (Kalma Barrage, Sarangarh/Saradiha Barrage, Murumsilli Barrage etc.) is **reducing inflows to the Hirakud reservoir**, especially in the non-monsoon (lean) season. Chhattisgarh argues it is developing its own share of the river for irrigation of its semi-arid interior. The **Mahanadi Water Disputes Tribunal was constituted on March 12, 2018** under Justice A.M. Khanwilkar (ISRWDA 1956); proceedings are ongoing.

9.4 THE GODAVARI RIVER SYSTEM — "DAKSHIN GANGA"

Revered as **"Dakshin Ganga" (Ganga of the South)** and **"Vriddha Ganga" (the Old Ganga)**, the Godavari is the **longest and most basin-rich of all peninsular rivers**. Its sacred headwaters at Trimbakeshwar, its passage through the tribal-forested heartland of Chhattisgarh-Telangana, its life-giving delta in Andhra Pradesh, and its contested Polavaram dam project — together make it India's most complex peninsular river story.

ORIGIN, COURSE AND VITAL STATISTICS

Parameter	*Detail*
Origin	Brahmagiri Hill, Trimbakeshwar near Nashik, Maharashtra (~1,067 m)
Total length	~1,465 km — LONGEST PENINSULAR RIVER
Basin area	~3,12,812 sq km — LARGEST PENINSULAR BASIN (~9.5% of India's total area)
States covered	Maharashtra ~48.6%, Telangana ~18.8%, Chhattisgarh ~10.9%, Andhra Pradesh ~9.9%, MP ~10%, Odisha ~5.7%, Karnataka ~0.3%

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Course	Flows E across Maharashtra Deccan (Nashik → Nanded → Nizamabad area) → enters Telangana/AP → turns SE → empties at Rajamahendravaram (Rajahmundry), AP
Mouth	Bay of Bengal via a large delta; distributaries include the Vasishtha and Vainateya
Sacred name	Dakshin Ganga; "Godavari" = "bestower of wealth"; Panchvati (Nashik) — Ramayana association

MAJOR TRIBUTARIES — GODAVARI

Tributary	*Bank*	*Origin/States*	*Key Feature*
Pravara	Right	Maharashtra (Nashik/Ahmednagar)	Bhandardara Dam (Wilson Dam); major irrigation in Nashik plateau
Manjira	Right	Bidar plateau, Karnataka → Maharashtra → Telangana	Singur/Manjira reservoir supplies Hyderabad's water; highly regulated
Maner	Right	Marathwada, Maharashtra	Lower Maner Dam and Reservoir complex (Karimnagar)
Pranhita	Left	Confluence of Wainganga + Wardha + Penganga, Vidarbha	LARGEST TRIBUTARY by volume; drains entire Vidarbha; joins near Kaleshwaram, Telangana
Indravati	Left	Eastern Ghats, Kalahandi, Odisha → Bastar, Chhattisgarh	Chitrakote Falls ("Niagara of India" — widest waterfall in India); flows through tribal Bastar
Sabari (Sileru)	Left	Eastern Ghats, Odisha-AP border area	Joins near Polavaram; tribal communities; Sileru HEP
Kinnerasani	Left	Khammam, Telangana	Kinnerasani Wildlife Sanctuary on its banks

RELIGIOUS AND CULTURAL SIGNIFICANCE

- **Panchvati (Nashik):** the sacred grove on the Godavari where the **Ramayana** locates Sita's abode and the episode of her abduction by Ravana; the Kala Ram Temple and Sita Gufa are pilgrimage sites.
- **Nashik Kumbh Mela (Simhastha):** held every 12 years when **Jupiter (Brihaspati) enters Leo (Simha)**; one of the four Kumbh Mela sites (the others being Prayagraj, Haridwar, Ujjain).
- **Bhadrachalam (Telangana):** famous Rama temple on the Godavari banks; annual Mula Nakshatra festival.

GODAVARI DELTA — "RICE BOWL OF ANDHRA"

The Godavari delta in East Godavari and West Godavari districts of Andhra Pradesh (and adjoining areas) is one of India's most productive rice-growing zones. The river splits into multiple distributaries (Vasishtha Godavari, Vainateya Godavari, Gautami Godavari) before entering the sea. The **Godavari-Krishna delta complex** together supports the densest agricultural population in peninsular India. However, the delta is under **increasing stress from dam-induced sediment starvation, sea-level rise and intensifying Bay of Bengal cyclones**.

POLAVARAM PROJECT (INDIRA SAGAR POLAVARAM) — INDIA'S "LAST MAJOR DAM"

Parameter	*Detail*
River	Godavari, Eluru district, Andhra Pradesh
Status	NATIONAL PROJECT (declared by GOI for priority central funding)
Hydropower	960 MW (12 × 80 MW units)
Irrigation	Design to irrigate 2,91,777 ha (West Godavari, East Godavari, Krishna districts, AP)
Water supply	Designed to supply Visakhapatnam and the Krishna delta via a link
Revised cost	Over ₹55,000 crore (as of 2023-24 estimates; originally ~₹16,000 crore)
Status (2024-25)	Under construction; completion repeatedly delayed; current target mid-2020s
Controversy	Tribal displacement: ~1.1 lakh people (Koya, Konda Reddi, Konda Kapu communities) across 371 villages; inter-state submergence disputes with Telangana, Odisha, Chhattisgarh

IFoS FOCUS

IFoS — GODAVARI ECOLOGY AND TRIBAL RIGHTS: The **Coringa Mangrove Sanctuary (Andhra Pradesh)** at the Godavari estuary is one of India's most significant mangrove wetlands — habitat for the fishing cat, estuarine crocodile and Irrawaddy dolphin. The Indravati/Bastar tributary landscape hosts **one of India's largest tiger populations** and critical tribal ecosystems (Gond, Halba, Muriya). Polavaram's submergence directly threatens tribal forest settlements protected under the **Forest Rights Act 2006 and PESA 1996** — a core IFoS intersection of river, forest and tribal law.

9.5 THE KRISHNA RIVER SYSTEM

The Krishna is the **second-longest peninsular river** and the heart of the **most politically contentious interstate water disputes in southern India**. Its basin — shared by Maharashtra, Karnataka, Andhra Pradesh and Telangana — supports one of the largest irrigated command areas in the Deccan and is the historical setting of the **Vijayanagara Empire (Hampi)**, sustained by its tributary the Tungabhadra.

ORIGIN, COURSE AND VITAL STATISTICS

Parameter	*Detail*
Origin	Mahabaleshwar, Satara district, Maharashtra (Western Ghats, ~1,337 m)
Total length	~1,400 km (second-longest peninsular river)
Basin area	~2,58,948 sq km; Maharashtra ~27%, Karnataka ~44%, undivided AP ~29%
Post-2014 state share	Maharashtra ~27%, Karnataka ~44%, Telangana ~12%, AP ~17% (approx.)
Course	Flows E across Maharashtra (Satara, Sangli, Solapur) → Karnataka (Bijapur/Vijayapura, Gulbarga/Kalaburagi, Raichur) → AP (Guntur) → Bay of Bengal near Hamasaladeevi (Krishna district)
Delta	Krishna-Godavari delta complex in AP — major rice zone
Mouth	Bay of Bengal via multiple distributaries near Machilipatnam coast

MAJOR TRIBUTARIES — KRISHNA

Right Bank Tributaries

Tributary	*Origin*	*Key Feature / Dam*
Koyna	Western Ghats, Satara, Maharashtra	Koyna Dam (Shivajisagar Reservoir): 1,960 MW — Maharashtra's largest HEP; Koyna earthquake (Dec 11, 1967, ~6.3 Mw) — world's most cited case of RESERVOIR-INDUCED (TRIGGERED) SEISMICITY
Panchganga	Confluence of 5 streams, Kolhapur, Maharashtra	Flows past Kolhapur; Almatti Dam downstream confluence
Ghataprabha	Belagavi district, Karnataka	Ghataprabha Left Bank Canal; Hidkal Dam; irrigation in North Karnataka
Malaprabha	Belagavi district, Karnataka	Navilu Teertha (Renuka Sagar) Dam; important for Hubli-Dharwad and North Karnataka drinking water — link to Mahadayi dispute

Left Bank Tributaries

Tributary	*Origin*	*Key Feature / Dam*
Bhima	Bhimashankar, Pune district, Maharashtra	~861 km; passes Sholapur/Solapur; Ujjani Dam (Bhima); joins Krishna near Raichur, Karnataka; irrigation in semi-arid Maharashtra

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Tungabhadra	Formed by union of Tunga + Bhadra at Kudli, Shivamogga, Karnataka	FLOWS PAST HAMPI (UNESCO WHS — Vijayanagara Empire); Tungabhadra Dam (Hospet, 1953); Karnataka-AP joint irrigation project; major cotton and rice irrigation
Musi	Ananthagiri hills, Telangana (~617 m)	Flows through HYDERABAD; Hussain Sagar, Osmansagar, Himayat Sagar reservoirs; MOST POLLUTED river in Hyderabad-Secunderabad; Musi riverfront development project (2024)
Muneru	Eastern Ghats	Joins Krishna in AP; less developed

TUNGABHADRA — THE RIVER OF VIJAYANAGARA

The **Tungabhadra — formed by the union of the Tunga and Bhadra rivers** in the Shivamogga district of Karnataka — is one of peninsular India's most historically and ecologically important rivers. It flows past **Hampi (Hosapete/Hospet), the ruined capital of the Vijayanagara Empire (1336–1646 CE)** — a **UNESCO World Heritage Site (1986)**. The **Tungabhadra Dam at Hosapete (1953)** is a joint Karnataka-Andhra Pradesh multipurpose project. It irrigates nearly **3.15 lakh ha (kharif) and 1.76 lakh ha (rabi)** across the semi-arid Deccan. Water sharing from the Tungabhadra is one of the most contentious points between Karnataka and the two successor AP/Telangana states.

KOYNA EARTHQUAKE AND RESERVOIR-INDUCED SEISMICITY

On **December 11, 1967, a magnitude ~6.3 Mw earthquake struck Koynanagar (Satara, Maharashtra)** — the site of the Koyna Dam reservoir. It killed approximately **177 people** and injured over 2,000. It is the world's most frequently cited example of **Reservoir-Induced (or Reservoir-Triggered) Seismicity (RIS)** — where the additional load and pore-pressure changes from reservoir water reactivate pre-existing faults. Koyna continues to experience elevated seismicity (it is a **National Geophysical Research Institute seismological station**) and is a mandatory reference in any discussion of dam-safety and seismicity.

MUSI RIVER — HYDERABAD'S ECOLOGICAL CRISIS

The Musi flows through the heart of Hyderabad and Secunderabad, anchoring the city's heritage (Charminar, Golconda, Chowmahalla Palace are all on or near the Musi floodplain). Today it is **one of India's most severely polluted urban rivers** — carrying **untreated domestic sewage and industrial effluents** from the city's pharmaceutical, leather and chemical industries. The **2024-25 Musi Riverfront Development Project** (Hyderabad) — a ₹1.5-lakh-crore proposal — aims to redevelop 55 km of riverfront, but has attracted criticism for displacing slum-dwellers living on the riverbanks.

KRISHNA WATER DISPUTES TRIBUNALS (KWDT-I AND II)

The Krishna is the most legally and politically contested river in peninsular India, with **two water disputes tribunals and a post-bifurcation tangle** that remains unresolved.

Tribunal	*Constitution*	*Chairman*	*Award / Report*	*Allocation (approx.)*
KWDT-I (Bachawat Tribunal)	1969	Justice R.S. Bachawat	1973 (supplemental report 1976)	Maharashtra 560 TMC; Karnataka 700 TMC; undivided AP 800 TMC; total 2,060 TMC at 75% dependability
KWDT-II (Brijesh Kumar Tribunal)	2004	Justice Brijesh Kumar	Report 2010; further report 2013; gazette notification stayed by SC	Increased total pool; Telangana share not finally delineated post-2014 bifurcation; still sub-judice

After the **bifurcation of Andhra Pradesh on June 2, 2014** — creating Telangana — the water allocation between the two successor states (Telangana gets most of Nagarjuna Sagar and Srisailam upstream; AP depends on downstream releases) has become **intensely contentious**. Both states have constructed new projects (Telangana's Kaleshwaram Lift Irrigation Scheme; AP's Polavaram and Rayalaseema Lift Irrigation projects) **above previously agreed utilisation levels**, leading to Centre-State conflicts and ongoing litigation.

UPSC CIVIL

Civil Mains — Krishna-Telangana-AP : The post-bifurcation Krishna dispute is a powerful case study in **cooperative federalism, water rights and river basin management**. Key points: (1) the KWDT-II award was not fully notified; (2) both states have unilaterally built new projects; (3) the Krishna River Management Board (KRMB) has limited enforcement power; (4) the dispute exemplifies why the National Water Policy's call for **basin-level integrated management** has not been realised.

9.6 THE CAUVERY RIVER SYSTEM — "DAKSHINA GANGA"

The Cauvery — **"Dakshina Ganga"** (Ganga of the South), **"Ponni"** (the golden foam river) in Tamil — is the **sacred river of the Chola civilisation** and the agricultural lifeline of Tamil Nadu and Karnataka. Its waters are the most fought-over in India — the **Cauvery dispute between Karnataka and Tamil Nadu** is the longest-running, most intense and most legally contested interstate river conflict in Indian history, spanning over 130 years from the 1892 British-era Madras-Mysore negotiations to the **Supreme Court final order of February 16, 2018**.

ORIGIN, COURSE AND VITAL STATISTICS

Parameter	*Detail*
Origin	Brahmagiri Hills, Talacauvery, Kodagu (Coorg) district, Karnataka (~1,341 m)
Total length	~800 km (some sources ~805 km)
Basin area	~81,155 sq km (one of the smaller peninsular basins)
State share	Tamil Nadu ~54.0%, Karnataka ~42.2%, Kerala ~3.5%, Puducherry ~0.2%
Course	Flows SE through Kodagu → Mysuru → Mandya → enters TN (Erode → Karur → Trichy) → Thanjavur delta → Bay of Bengal near Poompuhar (Kaveripattinam)
Tributaries (Karnataka)	Harangi, Hemavati, Kabini, Shimsha, Arkavati, Lakshmana Tirtha, Suvarnavati
Tributaries (Tamil Nadu)	Bhavani (largest in TN), Noyyal, Amaravati, Palar (not direct Cauvery but nearby system)
Sacred significance	Talacauvery — sacred source (Brahmagiri springs); Srirangapatna, Shivanasamudra, Mysuru, Srirangam (TN), Kumbhakonam — sacred cities on its banks

KEY DAMS ON THE CAUVERY

Dam / Reservoir	*Location*	*Purpose / Capacity*	*Key Significance*
Krishnarajasagara (KRS)	Mandya district, Karnataka; built 1924	Irrigation (Kaveri Command Area, Karnataka); municipal water supply to Bengaluru	The first major dam on the Cauvery; downstream: Brindavan Gardens (famous musical fountain)
Kabini Dam (Belagola)	Mysuru district, Karnataka; Kabini tributary	Irrigation; reservoir in Nagarhole NP buffer; wildlife tourism	Kabini reservoir = famous for wildlife photography (elephants gathering)
Hemavati Dam	Hassan district, Karnataka	Irrigation; water supply to Hassan	Hemavati tributary regulated

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Mettur Dam (Stanley Reservoir)	Salem district, Tamil Nadu; built 1934	Primary irrigation reservoir for the CAUVERY DELTA; 1,497 MCM storage capacity; 32 MW HEP	Opening of the Mettur Dam sluices on JUNE 12 (customarily) signals the start of the Kuruvai cropping season in the Cauvery delta — a cultural landmark
Bhavani Sagar Dam	Erode district, Tamil Nadu; on Bhavani tributary	Irrigation in the Bhavani-Coimbatore area	Major TN irrigation source
Upper Anicut (Kallanai)	Tiruchirappalli, Tamil Nadu; built c. 150 CE by Karikala Chola	Ancient diversion structure on Cauvery — diverts flow into Grand Anicut canal system	One of the world's OLDEST water management structures still in use; 2,000+ years old; ancestor of the Cauvery delta irrigation

THE CAUVERY DELTA — "GRANARY OF SOUTH INDIA"

The Cauvery delta in **Thanjavur (Tanjore), Tiruvarur and Nagapattinam districts** of Tamil Nadu is the **"Granary of South India"** — the most intensively cultivated rice-producing zone in Dravidian India. The **Grand Anicut (Kallanai)** system, first built by the **Chola king Karikala (~2nd century CE)** and subsequently expanded, divides the Cauvery into multiple distributaries that irrigate the delta. The whole delta system is among the **world's oldest continuously operated large-scale irrigation infrastructure**.

The Cauvery delta is increasingly under ecological stress: **declining sediment flows** due to the KRS, Mettur and Bhavani Sagar dams are causing **coastal erosion and saltwater intrusion**; **sea-level rise** is worsening this; and the **reduction in freshwater delivery** is harming mangroves and near-shore fisheries.

THE CAUVERY WATER DISPUTE — INDIA'S LONGEST INTERSTATE RIVER CONFLICT

Historical Background

- **1892:** The first formal dispute between the Presidency of Madras and the Princely State of Mysore over irrigation expansion. The **1892 Agreement** sought to limit Mysore's irrigation.
- **1924:** A revised **1924 Agreement** between Madras and Mysore allowed Mysore to build the KRS Dam and Madras to build Mettur, with defined utilisation limits.
- **Post-independence:** disputes intensified as both states expanded irrigation well beyond 1924 limits.

Cauvery Water Disputes Tribunal (CWDT, 1990)

- Constituted on **June 2, 1990** under Justice Chittatosh Mookerjee; reconstituted twice.
- **CWDT Interim Order (1991):** Karnataka to release 205 TMC to Tamil Nadu annually; Karnataka initially refused, triggering major anti-Tamil riots in Bengaluru (1991).
- **CWDT Final Award (February 5, 2007):**
  - Total utilisable water at 50% dependability: ~740 TMC.
  - **Tamil Nadu: 419 TMC** (at Biligundlu); Karnataka: 270 TMC; Kerala: 30 TMC; Puducherry: 7 TMC; environmental flow: 10 TMC; sea-escape: ~4 TMC.

Supreme Court Final Order (February 16, 2018)

The Supreme Court of India modified the CWDT award:

State / Purpose	*CWDT Award (2007)*	*SC Order (2018)*	*Change*
Karnataka	270 TMC	284.75 TMC	+14.75 TMC (for Bengaluru drinking water needs)
Tamil Nadu	419 TMC	404.25 TMC	-14.75 TMC
Kerala	30 TMC	30 TMC	No change
Puducherry	7 TMC	7 TMC	No change

Environmental flow	10 TMC	10 TMC (maintained at Biligundlu)	No change
TOTAL	~736 TMC	~736 TMC	Redistribution only

- **Cauvery Water Management Authority (CWMA):** constituted **June 1, 2018** as a permanent body under the Union Ministry of Jal Shakti; oversees implementation of the SC order; supported by the **Cauvery Water Regulation Committee (CWRC)** as its technical arm.
- **Key principle:** Tamil Nadu is entitled to 177.25 TMC measured at **Biligundlu gauging station** on the Karnataka-Tamil Nadu border during the June-May water year.

Why the Dispute Recurs (Root Causes)

- **Karnataka's upstream dependence:** the basin receives erratic monsoon rain; KRS and other reservoirs are Karnataka's lifeline for both Bengaluru's water and Mandya-Mysore irrigation. In deficit years, Karnataka argues there is no "surplus" to release.
- **Tamil Nadu's downstream lock-in:** the Cauvery delta depends on Mettur Dam releases for the Kuruvai (June-August) and Samba (October-January) rice cropping seasons. Any delayed release permanently damages the crop.
- **Bengaluru's explosive growth:** Bengaluru's water demand has grown massively (from ~300 MLD in 1980 to ~1,400+ MLD in 2024), drawing water from both Cauvery and the Hemavathi — this is the basis for the SC's 14.75 TMC increase to Karnataka.
- **Political salience:** both Karnataka and Tamil Nadu political parties use the Cauvery as an electoral issue; any water release order in a deficit year triggers mass protests and economic disruption.

UPSC CIVIL

UPSC Civil Mains (recurring): "Discuss the Cauvery water dispute in the context of federalism, interstate river water management and sustainable development." Key framework: (1) historical roots (1892/1924); (2) tribunal process (CWDT 1990, Final Award 2007); (3) SC order 2018; (4) CWMA 2018 institutional mechanism; (5) 2023 deficit-year crisis (→ current affairs); (6) link to Bengaluru water security and TN rice bowl; (7) lessons for cooperative federalism and basin-level management.

CURRENT AFFAIRS

2023 Cauvery Crisis: August-September 2023: a deficient SW monsoon caused KRS and Kabini reservoirs to fill only partially. The CWRC ordered Karnataka to release 5,000 cusecs/day to Tamil Nadu for 15 days. Karnataka initially refused citing "no surplus"; the SC directed compliance. Mass bandhs and arson incidents in Bengaluru (anti-TN protests); protests in Tamil Nadu (against Karnataka non-release). CWMA eventually mediated reduced releases. The episode showed both the strength and limits of the 2018 institutional architecture.

9.7 THE NARMADA RIVER SYSTEM

The Narmada is India's **longest west-flowing river and the traditional boundary between North India and the Deccan**. It is also the epicentre of India's most celebrated and contested **development-vs-displacement debate** — the **Sardar Sarovar Dam and the Narmada Bachao Andolan (NBA)** — which transformed India's environmental and rehabilitation policy landscape.

ORIGIN, COURSE AND VITAL STATISTICS

Parameter	*Detail*
Origin	Amarkantak Plateau, Anuppur district, Madhya Pradesh (~1,057 m)
Total length	~1,312 km — LONGEST WEST-FLOWING PENINSULAR RIVER
Basin area	~98,796 sq km; MP ~86%, Gujarat ~11%, Maharashtra ~3%

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Type	WEST-FLOWING RIFT VALLEY RIVER — flows in a structural graben (rift valley) between Vindhya Range (north) and Satpura Range (south)
Tributaries (right, from Vindhyas)	Burhner, Banjar, Sher, Shakkar, Dudhi, Tawa (longest, ~172 km, on which Tawa Dam stands)
Tributaries (left, from Satpura)	Hiran, Orsang, Ganjal, Kolar
Mouth	Gulf of Khambhat (Cambay) via an ESTUARY; no delta — velocity too high + narrow shelf
Key cultural boundary	Narmada is traditionally the northern boundary of the Deccan (South India begins south of Narmada)
Amarkantak significance	RADIAL DRAINAGE CENTRE — the Narmada flows west; the Son flows NE into the Ganga system; the Johilla flows NE; the Mahanadi tributaries begin nearby

WHY NARMADA FLOWS WEST — THE RIFT VALLEY MECHANISM

Most peninsular rivers flow **east with the general tilt of the plateau**. The Narmada is the most prominent exception because it occupies a **structural graben (rift valley)** — a down-faulted block between two uplifted horst blocks (the Vindhya to the north and the Satpura to the south). The valley was created by parallel faults trending **E-W**. The river flows **westward along the axis of this graben** regardless of the plateau's general eastward tilt. The same mechanism applies to the **Tapi River** (between Satpura and the Ajanta-Satmala ranges). This **rift valley origin** is the answer to the Prelims question: "Why does the Narmada flow west while most peninsular rivers flow east?"

KEY PHYSICAL FEATURES

- **Marble Rocks (Bhedaghat, Jabalpur):** the Narmada flows through a spectacular gorge of white marble/limestone, creating surreal scenery; **Dhuandhar ("smoke-and-thunder") Falls** drop ~9-10 m at the entry to the gorge; a major tourist and religious destination.
- **Omkareshwar (Mandhata Island):** sacred island in the Narmada; one of the 12 Jyotirlinga sites of Shiva; **Omkareshwar Dam (520 MW)** is nearby.
- **Amarkantak:** the source of the Narmada is a sacred pilgrimage site; the rivers Narmada, Son and Johilla radiate from this plateau.

MAJOR DAMS ON THE NARMADA

Dam	*Location*	*Capacity*	*Significance*
Sardar Sarovar Dam (SSP)	Kevadia, Narmada district, Gujarat	1,450 MW (1,200 MW river-bed + 250 MW canal-head); 163 m height above lowest foundation	Terminal dam; largest by concrete; centre of the Narmada Bachao Andolan controversy
Indira Sagar Dam	Punasa, Khandwa district, MP	1,000 MW; reservoir ~12.22 billion cu m storage capacity (LARGEST IN INDIA by live storage)	India's largest reservoir; ~91,348 ha submergence; major displacement
Omkareshwar Dam	Mandhata, Khandwa district, MP	520 MW	Near sacred Omkareshwar Jyotirlinga; highly contested
Maheshwar Dam	Maheshwar, Khargone district, MP	400 MW	Contested by NBA; private sector project (S. Kumars/NhPC); multiple delays
Tawa Dam	Itarsi, Hoshangabad, MP (on Tawa tributary)	~13.5 MW + 105,000 ha irrigation	Old Narmada irrigation project; Tawa fisheries cooperative (famous model of tribal/forest community fisheries management)

SARDAR SAROVAR PROJECT (SSP) — DEVELOPMENT VS DISPLACEMENT

The Sardar Sarovar Project is the **flagship dam of the Narmada Valley Development project** — and simultaneously India's most iconic symbol of the **development-vs-displacement dilemma**.

- **Scale:** the main canal (Narmada Main Canal) is ~458 km long — among the world's longest; the total canal network extends ~75,000 km; designed to irrigate ~18.45 lakh ha in Gujarat and provide drinking water to 9,490 villages and 131 urban centres in Gujarat, Rajasthan and MP.
- **Power:** 1,450 MW installed capacity (river-bed 1,200 MW; canal-head 250 MW).
- **Displacement:** estimated **40,000–80,000+ families displaced** (official figures ~40,827 families; activists cite far higher numbers) — predominantly tribal communities (Bhil, Bhilala, Tadvi, Vasava) of Madhya Pradesh, Maharashtra and Gujarat.
- **Narmada Bachao Andolan (NBA):** led by **Medha Patkar** (joined by Baba Amte, supported early by Arundhati Roy); launched 1985-89; campaigns included long marches, fasts, and symbolic jal samarpan (immersion protests). The NBA advocacy led to:
  - **World Bank withdrawal (1993):** the Morse Committee report (1992) found serious failures in resettlement and environmental compliance; World Bank withdrew from the project.
  - **Supreme Court stays:** multiple stays on dam height; final SC judgment (October 18, 2000) in *Narmada Bachao Andolan v. Union of India* allowed construction to proceed in stages, subject to concurrent rehabilitation conditions.
  - **Dam completion (2017):** the dam gates were closed in June 2017; the project was inaugurated by PM Narendra Modi on September 17, 2017 (his 67th birthday). Rehabilitation of displaced persons remains incomplete and under Supreme Court monitoring.

IFoS FOCUS

IFoS — NARMADA VALLEY ECOLOGY AND TRIBAL RIGHTS: The Narmada flows through one of India's richest tribal landscapes (Bhil, Bhilala, Gond, Korku communities). Submergence has destroyed **riverine forests, riparian habitats and sacred groves (devsthans)** — a classic case where development infrastructure conflicts with both **PESA 1996** (Panchayats Extension to Scheduled Areas) and the **Forest Rights Act 2006**. The **Tawa fisheries cooperative** (MP) — a model of tribal community management of reservoir fisheries — was threatened by SSP-induced water table changes.

NARMADA WATER DISPUTES TRIBUNAL (NWDT)

State	*Allocation (NWDT, 1979 award)*	*Basis*
Madhya Pradesh	18.25 MAF (Million Acre Feet)	~86% of basin; largest share
Gujarat	9.0 MAF	Lowest-lying; most dependent downstream state; Sardar Sarovar is its terminal dam
Rajasthan	0.5 MAF	Water via Narmada Main Canal and IGNP link
Maharashtra	0.25 MAF	Small basin share; Punasa area
TOTAL	28.0 MAF at 75% dependability	Division of utilisable flows only

9.8 THE TAPI (TAPTI) RIVER SYSTEM

The Tapi is the **second major west-flowing river of the peninsula**, running parallel to the Narmada but ~200 km to the south, in a structural **rift valley between the Satpura Range (north) and the Ajanta-Satmala (Sahyadri sub-range, south)**. The name Tapti (variant spelling) appears in ancient texts. Like the Narmada, it forms an **estuary** at its mouth rather than a delta. West-flowing Peninsular Rivers: Narmada and Tapi (Tapti) are the ONLY major west-flowing peninsular rivers — both flow through RIFT VALLEYS (grabens/fault troughs) in an E-W direction and drain into the Arabian Sea. All other major peninsular rivers (Mahanadi, Godavari, Krishna, Cauvery) flow eastward into the Bay of Bengal.

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Narmada and Tapi form ESTUARIES (not deltas) because:

(a) hard rocky bed prevents sediment deposition;

(b) tidal action at mouth prevents delta formation. Contrast: Godavari, Krishna, Mahanadi, Cauvery all form fertile deltas at their mouths."

Parameter	*Detail*
Origin	Multai (Multapur), Betul district, Madhya Pradesh (~752 m)
Total length	~724 km
Basin area	~65,145 sq km across MP (~26%), Maharashtra (~53%) and Gujarat (~21%)
Course	Flows W through Betul (MP) → Burhanpur, Bhusawal, Jalgaon, Dhule (Maharashtra) → Surat, Gujarat → Gulf of Khambhat (Arabian Sea) via ESTUARY
Tributaries (north bank)	Purna (Purna-Tapi confluence at Chalisgaon), Buray, Panzara
Tributaries (south bank)	Girna, Bori, Aner
Key dams	Ukai Dam (Gujarat): ~80 m, ~520 sq km reservoir, ~300 MW, major water supply for South Gujarat and Surat; Kakrapar Weir: diverts water for the Tapi right and left bank canals
Economic importance	Cotton and banana cultivation in Tapti basin (Jalgaon = "Banana Capital of India"); Surat diamond and textile industry depends on Ukai for water

The Tapi's most vivid modern role is as the **flood risk for Surat** — when Ukai Dam releases heavy discharges during intense monsoons, the river overflows its banks into Surat city. The **2006 Surat floods** (release of 750,000 cusecs from Ukai) drowned much of the city and displaced hundreds of thousands. This has prompted significant investment in Surat's flood-management infrastructure.

9.9 THE LUNI RIVER SYSTEM

The Luni is the **only significant river of the Thar Desert** and the most important drainage line of Rajasthan west of the Aravallis. It is a **seasonal, partly saline river** with a fascinating hydrological paradox: **fresh in its upper reaches, increasingly saline downstream**, and **draining into an inland sink** (the Rann of Kachchh) rather than the sea.

Parameter	*Detail*
Origin	Aravallis near Pushkar-Ajmer, Rajasthan (~772 m); principal headstream the Sagarmati
Total length	~495-550 km (sources vary)
Tributaries	Right bank (from Aravallis): Sukri, Mithdi, Bandi, Kharo, Saraswati (Pali); Left bank: Jawai, Guhiya, Sagi
Terminal basin	Flows SW → enters the RANN OF KACHCHH (Gujarat) and disappears into the salt flats — an ENDORHEIC (inland drainage) system
Salinity	Sanskrit name: Lavanavari ("salt water") — fresh in upper reaches (near Balotra); saline downstream; unfit for drinking/irrigation in lower course
Key dam	JAWAI DAM: on the Jawai tributary near Sumerpur, Pali district; Rajasthan's most important western-zone reservoir; JAWAI LEOPARD LANDSCAPE (Bera) — famous leopard-village coexistence zone

IFoS FOCUS

IFoS — JAWAI LEOPARD LANDSCAPE: The Jawai Dam reservoir (near Bera, Pali, Rajasthan) supports an extraordinary human-leopard coexistence model — leopards live among villages and sacred "Bishnoi-like" communities (the Rabari shepherds), with no incidents of conflict. It is one of India's

most cited examples of human-wildlife coexistence and is promoted by Rajasthan Tourism for leopard safari. This landscape exemplifies how a river dam can create an incidental conservation zone.

9.10 INTERSTATE RIVER WATER DISPUTES IN INDIA

Interstate river water disputes are among the most politically contentious and legally complex issues in Indian federalism. They arise from the tension between **water being a State List subject (Entry 17, Seventh Schedule)** and the **national need for coordinated river management (Entry 56, Union List)**.

CONSTITUTIONAL AND LEGISLATIVE FRAMEWORK

Provision/Act	*Key Content*
Article 246 + Seventh Schedule	Water = State List (Entry 17); Parliament can legislate on inter-state rivers under Union List (Entry 56) "in the public interest"
Article 262	Parliament may provide by law for adjudication of inter-state river disputes; may exclude SC/HC jurisdiction over such disputes
Inter-State River Water Disputes Act, 1956 (ISRWDA)	Empowers Central Government to constitute ad hoc Tribunals; awards are binding but appeal to the SC is barred (original) — however, the SC has in practice accepted writ petitions on procedural grounds
River Boards Act, 1956	Enables advisory river boards for regulation/development of inter-state rivers; largely unused in practice
National Water Policy, 2012	Calls for basin-level integrated management, environmental flows, water-use efficiency; not legally binding but guides policy
ISRWD (Amendment) Bill, 2019	Proposes a single permanent tribunal with multiple benches and a pre-tribunal Disputes Resolution Committee (DRC); passed Lok Sabha (July 31, 2019); pending in Rajya Sabha as of 2025

MAJOR ACTIVE INTERSTATE DISPUTES — SUMMARY TABLE

Dispute	*States*	*Tribunal/Order*	*Current Status*
Cauvery	Karnataka, Tamil Nadu, Kerala, Puducherry	CWDT (1990); SC final order Feb 16, 2018 (284.75/404.25/30/7 TMC); CWMA June 2018	Active — deficit-year releases routinely disputed; 2023 standoff; CWMA/CWRC managing ongoing releases
Krishna	Maharashtra, Karnataka, AP, Telangana	KWDT-I award 1973; KWDT-II report 2010 (stayed by SC)	KWDT-II unresolved post-AP bifurcation; Telangana-AP conflict over new projects; KRMB has limited enforcement power
Mahadayi (Mhadei / Mandovi)	Goa, Karnataka, Maharashtra	Mahadayi Water Disputes Tribunal; Final Award August 2018 (Karnataka 13.42 TMC, Goa ~24 TMC, Maharashtra ~1.33 TMC)	Goa challenged in SC; Karnataka's Kalasa-Banduri diversion partially built; 2023-24 political flashpoint
Mahanadi	Odisha, Chhattisgarh	Mahanadi Water Disputes Tribunal constituted March 2018	Proceedings ongoing; Odisha alleges Chhattisgarh dams reducing Hirakud inflows
Ravi-Beas (SYL Canal)	Punjab, Haryana	SC multiple orders; Punjab's Termination of Agreements Act (2004) struck down by SC (2016)	SYL Canal incomplete despite SC orders; Punjab refuses

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			construction; political deadlock; ongoing mediation efforts
Vansadhara	Odisha, Andhra Pradesh	VWDT constituted 2010; interim award given	Ongoing; AP's Neradi Barrage disputed by Odisha

MAHADAYI / MHADEI DISPUTE — IN DETAIL

The **Mahadayi River** (also called Mhadei in Goa, Mandovi in its lower course) is a short (~77 km in India) west-flowing river draining the Western Ghats from Karnataka to Goa before entering the Arabian Sea at Panaji. **Karnataka** wants to divert water from two tributaries — the **Kalasa and Banduri Nalas** — into the **Malaprabha River** (a Krishna tributary) to supply drinking water to **Hubli-Dharwad, Gadag, Belagavi and surrounding North Karnataka towns**. **Goa** vigorously opposes the diversion, arguing that:

- The Mhadei is Goa's lifeline river; reduced flows threaten water supply to Panaji and North Goa.
- Diversion threatens the **Bhimgad Wildlife Sanctuary, Mhadei Wildlife Sanctuary** and the river's unique biodiversity (hornbills, great pied hornbill nesting, riverine forests).
- The Western Ghats-origin riverine ecosystem is ecologically fragile.

The **MWDT Final Award (2018)** allocated Karnataka 13.42 TMC, Goa about 24 TMC and Maharashtra about 1.33 TMC; Karnataka's share was far less than its 7.56 TMC demand. **Goa challenged the award in the Supreme Court**. The issue featured prominently in the **2023 Karnataka state elections and the 2024 Goa elections**. Karnataka's diversion works (Kalasa-Banduri) are partially underway, with central clearances granted but legal challenges pending.

ENV ALERT

SYL Canal — India's Most Intractable Water Deadlock

The **Sutlej-Yamuna Link (SYL) Canal** — designed to carry Punjab's share of Ravi-Beas surplus waters to Haryana — has been incomplete since the 1980s. The SC has repeatedly directed Punjab to complete its section; Punjab passed the **Punjab Termination of Agreements Act (2004)** to exit water-sharing, which the SC struck down as unconstitutional (2016). Punjab argues it now has no surplus (its groundwater is over-exploited and river flows have reduced). Haryana argues it is being denied its allocated share. SC mediations have repeatedly failed. The SYL is a textbook case of how a water dispute becomes a political and identity conflict beyond pure hydrology.

9.11 RIVER POLLUTION & ENVIRONMENTAL FLOWS

MAJOR POLLUTED PENINSULAR RIVERS

River	*Pollution Source*	*Key Issues*	*Conservation Effort*
Musi (Hyderabad)	Domestic sewage; pharmaceutical, leather, dye industries; Hussain Sagar Lake pollution	One of India's most polluted urban rivers; oxygen-depleted; foam in lower reaches	Musi Riverfront Development Project 2024-25 (₹1.5 lakh cr proposed); HMWS&SB sewage treatment expansion
Godavari (upper — Nashik)	Industrial effluents (chemicals, distilleries), urban wastewater from Nashik-Nandurbar corridor	Intermittent high BOD; affects Panchvati pilgrimage; fish mortality events	NRCP action plan; Maharashtra Pollution Control Board enforcement (weak)
Cauvery (via Arkavathi / Vrishabhavati — Bengaluru)	Bengaluru's treated and partly untreated sewage; tannery/textile effluents in Bhavani/Noyyal tributaries	Vrishabhavati (Arkavathi tributary) is severely polluted — BOD exceeding standards; Noyyal (TN) is heavily polluted by Tirupur dye houses	Cauvery Neeravari Nigam; TN Pollution Control Board; STP expansion in Bengaluru and Tirupur

Krishna (industrial corridor)	Pharmaceutical (API manufacturers, Hyderabad area), textile, sugar factory effluents in tributaries	Tungabhadra and Bhima receive untreated discharge	CWDT stipulated minimum flows but enforcement is poor; no dedicated river police
Noyyal River (TN — Cauvery tributary)	Textile/dyeing industries, Tirupur bleaching/dyeing units	Major water quality crisis from 1990s onward; Madras HC and SC orders for ETPs	SC/Madras HC orders; some ETPs installed; Noyyal partly revived but still stressed

ENVIRONMENTAL FLOWS (E-FLOWS)

Environmental flows (e-flows) are the **minimum quantity, quality and timing of water flows required to sustain freshwater and estuarine ecosystems and the human livelihoods and well-being that depend on them** (Brisbane Declaration, 2007). In India:

- **MoEFCC/NMCG Notification (October 2018):** mandated minimum environmental flows for the **River Ganga** in its upper stretch (Devprayag to Unnao), prescribing season-wise minimum releases at key dams (e.g., 20% of monthly average discharge as e-flow). The first such binding national e-flow mandate in India.
- **CWC circular (2019):** directed that a minimum of **30% of lean-season flows** should be maintained downstream of dams on all major rivers — as a general national guideline, though enforcement is weak.
- **Cauvery e-flow:** the SC/CWDT mandated **10 TMC as environmental protection** in the annual Cauvery allocation — to maintain minimum flows for ecosystems, fisheries and coastal wetlands.
- **Challenges:** dam operators and irrigators resist any e-flow that reduces their allocation; monitoring is poor; legal enforceability of e-flows for peninsular rivers remains limited.

RAMSAR WETLANDS LINKED TO PENINSULAR RIVERS (IFOS PRIORITY)

Ramsar Site	*River System*	*Area*	*Key Ecology*
Chilika Lake (Odisha)	Mahanadi delta	~1,100 sq km	India's FIRST Ramsar site (1981); Irrawaddy dolphin; flamingo; fisheries; oyster reefs
Kolleru Lake (AP)	Krishna-Godavari interfluve	~245 sq km (seasonal)	Ramsar site; migratory waterfowl (pelicans, painted storks); severe encroachment
Pulicat Lake (AP-TN border)	Near Krishna-Cauvery coast	~461 sq km (varies)	Second-largest lagoon; flamingo; Sriharikota spit; Pulicat Bird Sanctuary
Point Calimere (TN)	Near Cauvery delta / Palk Bay	~51 sq km (dry-land forest + wetland)	Flamingo, migratory waders; lesser flamingo; blackbuck reserve
Karikili & Vedanthangal Bird Sanctuaries (TN)	Cauvery basin (irrigation tanks)	Small	Oldest bird sanctuaries in India; important wintering grounds
Bhitarkanika (Odisha)	Brahmani-Baitarani (near Mahanadi delta)	~672 sq km	Saltwater crocodile, mangroves; Ramsar site; National Park

9.12 CURRENT AFFAIRS HOOKS (2021–2025)

CURRENT AFFAIRS **Cauvery Dispute 2023:** Deficient monsoon triggered CWRC/CWMA orders for Karnataka to release 5,000 cusecs daily to Tamil Nadu (later modified to 3,000 then reduced). Karnataka pleaded zero

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surplus; protests in both states; SC declined to override CWMA. Exposed limits of the 2018 institutional architecture in deficit years.

Polavaram Project (Godavari, AP): Cost now >₹55,000 cr; completion target slipping; tribal rehabilitation backlog; Telangana-Odisha-Chhattisgarh objections to upstream submergence; central funding disputes.

Mahadayi/Kalasa-Banduri (2023-24): Karnataka's diversion works progressing after central clearances; Goa's SC challenge; 2023 Karnataka elections; Mhadei Wildlife Sanctuary threatened. DPR approved by CWC; project moving despite litigation.

SYL Canal (2023-25): SC-directed mediation continuing; Punjab refuses construction; Haryana demands completion; no resolution in sight as of 2025.

Krishna Water (AP-Telangana): Both states built new projects exceeding allocated shares; KRMB struggling to enforce; AP's Rayalaseema Lift Irrigation and Telangana's Kaleshwaram are the key projects. Central Govt mediation ongoing.

Musi Riverfront Project (Hyderabad, 2024): ₹1.5 lakh crore mega-project to redevelop 55 km of Musi riverfront (Telangana govt); over 20,000 families on the riverbank face displacement; High Court scrutiny; environmental review ongoing.

Delta Erosion (AP-TN coast): Krishna-Godavari and Cauvery deltas losing area at measurable rates; dam-induced sediment starvation + sea-level rise + cyclone intensification. Published NCCR erosion data (33.6% of India's coast eroding) is directly relevant.

ISRWD Amendment Bill (2019): Permanent Tribunal Bill passed Lok Sabha in 2019; yet to pass Rajya Sabha or be notified as law (as of 2025). A major pending legislative reform.

9.13 PYQ ANALYSIS — CHAPTER 9 (2010–2025)

Questions from UPSC Civil Mains GS-1/GS-2/GS-3 and IFoS GS directly testing Peninsular River themes:

Source	Year	Marks	Question
UPSC Civil	2013	5M	"There is no formation of deltas by rivers of the Western Ghats. Why?"
UPSC Civil	2013	12M	"Discuss the river-wise distribution of the interstate water dispute cases in India."
UPSC Civil	2023	15M	"Tropics are hit hard by the changing climate. India's tropical climate and river-delta systems are particularly vulnerable. Examine." (delta erosion and climate change)
UPSC Civil	2018	12M	"What are the major factors responsible for making urban pollution in India a complex engineering problem? Discuss viable alternatives." (Musi/Godavari/Cauvery tributaries angle)
UPSC Civil	2021	12M	"How is the Indian concept of sustainable development different from the West? Explain with reference to river conservation." (Narmada/Sardar Sarovar angle)
UPSC Civil	2015	12M	"India is well endowed with fresh water resources. Critically examine why it still suffers from water scarcity." (peninsula rivers scarcity)
UPSC Civil	2020	12M	"How can India achieve the 'right balance' between its development needs and the need to preserve its ecology?" (Polavaram/Sardar Sarovar)
UPSC Civil	2019	12M	"What is water stress? How and why does it differ regionally in India?" (Krishna-Cauvery region)
UPSC Civil	2024	15M	"Discuss the impact of the shrinking Himalayan glaciers on the peninsular water cycle and irrigation." (Himalayan-Peninsular River contrast)

IFOS GS	2022	10M	"Discuss the concept of environmental flows with special reference to the Ganga and peninsular rivers."
IFOS GS	2025	15M	"Describe briefly the key differences between Himalayan and Peninsular river systems. What could be the key consequences of interlinking peninsular rivers?"
IFOS GS	2016	10M	"Account for the environmental problems of lagoon ecosystems for tourism development." (Chilika, Pulicat, Kolleru)
IFOS GS	2014	12M	"What are wetlands? Discuss their importance." (Chilika, Bhitarkanika)

KEY NOTE

Frequency pattern : Delta geomorphology (2013 PYQ — model answer follows), interstate river disputes (Cauvery, Krishna, Mahadayi recur every 2-3 years), water scarcity/stress (2015, 2019, 2024), wetlands/lagoons (IFoS 2014, 2016). Narmada development-vs-displacement is a perennial GS-2/GS-3 case study. Delta erosion is an emerging 2023-25 theme. For IFoS: e-flows (2022), wetlands (2014, 2016), ILR consequences (2025) are the priority clusters.

9.14 MODEL BOOK

There is no formation of deltas by rivers of the Western Ghats. Why?

UPSC Civil (Mains) 2013 | GS-1 | 5 Marks | 100 Words

West-coast rivers (Mandovi, Zuari, Periyar, Sharavathi) form **estuaries/rias** — not deltas — unlike their east-coast counterparts.

FIVE INTERLOCKING REASONS:

1. **Short, steep courses:** the Western Ghats rise close to the coast; rivers descend a steep escarpment and reach the sea in 100-300 km, maintaining **high velocity throughout** — leaving no time or energy for sediment deposition.
2. **Narrow continental shelf:** the Arabian Sea shelf west of the Ghats is **narrow and deep**, providing **minimal space** for sediment accumulation and delta building.
3. **Strong Arabian Sea waves and longshore drift:** high-energy waves **disperse arriving sediment** faster than it can accumulate.
4. **Tidal influence:** tidal currents in the funnel-shaped inlets keep the mouth open and prevent delta lobe formation.
5. **Contrast with east coast:** east-coast rivers (Godavari, Krishna, Cauvery) have **long, gentle courses (700-1,500 km), heavy loads, wide shallow shelf** → build extensive deltas.

Steep gradient + narrow shelf + high-energy coast → estuaries. Gentle gradient + wide shelf + low-energy coast → deltas. The same physical logic explains why India's rice-bowl deltas are all on the east.

"Critically examine the factors responsible for the water conflicts between Karnataka and Tamil Nadu over the Cauvery River waters."

UPSC Civil (Mains) | 15 Marks | 200 Words

The Cauvery dispute — spanning over 130 years from the 1892 Madras-Mysore agreement to the **Supreme Court's final order of February 16, 2018** — is India's most intense and oldest inter-state river conflict, rooted in the collision of **upstream storage needs versus downstream irrigation dependence**.

HYDROLOGICAL FACTORS

- **Small basin:** at ~81,155 sq km the Cauvery basin is relatively small for the population and irrigation load it supports; water is genuinely scarce in a river shared by a 60-million+ population.

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- **High variability:** rainfall in the Kodagu/Western Ghats headwaters varies 30-40% between years; deficit monsoons immediately reduce KRS inflows, creating zero-sum conflicts.

POLITICAL-ECONOMIC FACTORS:

- **Karnataka's upstream growth:** Bengaluru's water demand (>1,400 MLD by 2024) and expanding North Karnataka irrigation command have pushed Karnataka beyond its original 1924 allocations.
- **Tamil Nadu's delta dependence:** the Cauvery delta (Thanjavur, Tiruvarur, Nagapattinam) depends on Mettur releases for the Kuruvai and Samba seasons; late release means permanent crop damage.

INSTITUTIONAL WEAKNESSES:

- **CWDT took 17 years (1990-2007):** delayed adjudication aggravated tensions. The CWMA (2018) has authority but limited enforcement power; drought years test it acutely.

STRUCTURAL SOLUTION: the conflict demands **basin-level planning with internalised climate-variability buffers**, **demand-side efficiency (drip irrigation in Mandya; Bengaluru water recycling)**, and **transparent real-time reservoir data sharing** — not just periodic SC interventions.

CHAPTER 10

LAKES, WETLANDS & WATER BODIES OF INDIA

CHAPTER AT A GLANCE

- India has ~757,060 wetlands covering ~15.26 million ha (~4.63% of geographic area; NWIA 2011); wetlands = transition zones between aquatic and terrestrial; provide ecosystem services worth trillions annually.
- Ramsar Convention 1971 (Convention on Wetlands of International Importance); India has 82 Ramsar sites (as of 2024) — largest number in Asia; total area ~13.3 lakh ha. Chilika Lake and Keoladeo NP = India's first two Ramsar sites (1981).
- Major lakes by origin: Tectonic (Wular, Dal, Kolleru, Chilika-lagoon type); Glacial (Tsomoriri, Tso Kar, Pangong Tso); Volcanic (Lonar, Maharashtra — only meteorite crater lake in India); Lagoon/barrier (Chilika, Pulicat, Vembanad); Ox-bow (Kanwar/Kabar, Bhoj Wetland).
- Chilika Lake (Odisha) = India's largest brackish water lagoon (~1,100 sq km); India's FIRST Ramsar site (1981); Irrawaddy dolphin; flamingo; closed sea mouth caused crisis (Operation Chilika 2000 — restored); Ramsar Wetland Conservation Award.
- Wular Lake (J&K) = India's largest freshwater lake (~98-260 sq km seasonal); on Jhelum River; Ramsar site; highly threatened by encroachment, pollution, Tulbul Navigation Project controversy with Pakistan.
- Dal Lake (Srinagar) = iconic but severely threatened; shrunk from 21.1 sq km (1971) to ~10-11 sq km (2024); encroachment, sewage, floating gardens (rad); Dal Lake Conservation Authority; Nagin Lake.
- Lonar Lake (Buldhana, Maharashtra) = INDIA'S ONLY METEORITE IMPACT CRATER LAKE (hypervelocity impact ~52,000 years ago; diameter ~1.8 km; depth ~137 m; saline-alkaline; pink colour from algae in 2020; Ramsar site 2020); unique ecosystem.
- Wetland threats: encroachment (building on wetland); pollution (domestic sewage, industrial effluents, agricultural runoff); invasive species (Water Hyacinth — Eichhornia crassipes — most damaging; covers millions of ha); drainage for agriculture; climate change.

10.1 INTRODUCTION — WETLANDS AND WATER BODIES OF INDIA

Water bodies — lakes, wetlands, ponds, tanks, lagoons, backwaters, oxbow lakes and reservoirs — are India's **most underappreciated natural assets** and its most threatened ecosystems. They serve as **freshwater reservoirs, biodiversity hotspots, flood buffers, carbon sinks, groundwater recharge zones and livelihood sources** for hundreds of millions of people. Yet India has lost an estimated **38% of its wetland area** since 1970 — to agriculture, urbanisation, pollution and drainage. Understanding India's water bodies is essential for UPSC because they intersect with geography (physical features), ecology (biodiversity hotspots, Ramsar sites), environment (pollution, climate change) and policy (Wetland Rules 2017, NMCG, Jal Shakti).

WETLAND DEFINITION AND CLASSIFICATION

The **Ramsar Convention (1971)** defines wetlands as: "*areas of marsh, fen, peatland or water, whether natural or artificial, permanent or temporary, with water that is static or flowing, fresh, brackish or salt, including areas of marine water the depth of which at low tide does not exceed six metres.*" This broad definition encompasses a vast range of habitats:

Wetland Category	*Sub-types*	*Indian Examples*
Marine / Coastal Wetlands	Coral reefs, mangroves, sea-grass beds, salt marshes, intertidal mudflats, lagoons, coastal lakes	Sundarbans (WB), Chilika (OD), Pulicat (TN-AP), Lakshadweep reefs, Gulf of Mannar, Bhitarkanika (OD), Pichavaram (TN)

Inland Natural Wetlands	Swamps, marshes, peat bogs, floodplain lakes, oxbow lakes, high-altitude lakes, hot springs, glacial lakes	Keoladeo (Bharatpur), Wular Lake (J&K), Loktak (Manipur), Dal (J&K), Tsomoriri (Ladakh), Pangong Tso (Ladakh)
Inland Artificial Wetlands	Reservoirs, tanks, aquaculture ponds, rice paddies, salt pans, gravel pits, wastewater treatment ponds	Bhoj Wetland (MP), Thol (GJ), Sultanpur NP (Haryana), Asan Barrage (Uttarakhand)
Estuarine / Deltaic Wetlands	River deltas, estuaries, tidal flats, mangrove forests	Ganga-Brahmaputra delta (Sundarbans), Godavari delta (AP), Mahanadi delta (OD), Cauvery delta (TN)

ECOLOGICAL SERVICES OF WETLANDS — WHY THEY MATTER

Ecosystem Service	*Mechanism / Significance*
Water purification	Wetland plants (reeds, rushes, water hyacinth ironically) and sediments trap pollutants, filter suspended particles, absorb excess nutrients (N, P) from agricultural runoff; called "Nature's Kidneys"
Flood modulation	Wetlands act as natural sponges — absorbing excess rainfall/floodwater and releasing it slowly; Mumbai's Mithi River wetlands, if intact, would have modulated the 2005 floods; loss of wetlands = intensified urban flooding
Groundwater recharge	Wetlands with permeable substrates allow water to percolate into aquifers; critical for recharging the alluvial aquifers of North India
Carbon sequestration (Blue Carbon)	Peatlands, mangroves, seagrass beds and coastal wetlands store disproportionately large carbon stocks; India's wetlands may store 7-10 GT of carbon; drainage releases carbon (CO_2 + CH_4)
Biodiversity support	Wetlands cover only ~6% of Earth's surface but support >40% of all species; >40% of India's threatened bird species depend on wetlands; fish, amphibians, invertebrates concentrated in wetlands
Livelihood support	Fisheries (wetland-dependent fish = primary protein source for hundreds of millions); agriculture (rice; 90% of global rice grown in wetland paddy systems); tourism (ecotourism at Keoladeo, Chilika, Dal Lake)
Microclimate regulation	Large water bodies moderate local temperature extremes; reduce heat island effect in cities (Ulsoor Lake, Bengaluru; Hussain Sagar, Hyderabad)
Cultural and spiritual value	Dal Lake (Srinagar cultural identity); Pushkar Lake (Rajasthan — sacred lake; Brahma temple; Camel Fair); Mansarovar (Tibet — sacred to Hindus, Buddhists, Jains); Gangasagar (WB)

NATIONAL WETLAND INVENTORY AND ASSESSMENT (NWIA 2011)

Parameter	*Figure*
Total wetlands mapped	757,060 wetlands
Total wetland area	~15.26 million ha (~15.26 lakh ha)
% of India's geographic area	~4.63%
Largest wetland category by area	Inland wetlands (~56%) > Coastal wetlands (~27%) > Man-made wetlands (~17%)
State with largest wetland area	Gujarat (~34,650 sq km — primarily seasonal salt marshes of Kachchh and Gulf of Khambhat)

Most wetland-rich state by number	West Bengal (largest number of wetland water bodies)
Key finding	India has lost ~38% of wetland area since 1970 (some estimates say more); urban wetlands most severely affected

10.2 RAMSAR CONVENTION AND INDIA'S RAMSAR SITES

The **Ramsar Convention on Wetlands of International Importance Especially as Waterfowl Habitat** — signed at **Ramsar, Iran on February 2, 1971** (hence **"World Wetlands Day" = February 2** every year) — is the only global treaty dedicated to a single ecosystem type. It entered into force in 1975. India signed the Ramsar Convention on **February 1, 1982.** As of 2024, India has **82 Ramsar Sites** — the **highest number of Ramsar Sites in Asia** and among the largest nationally. Total Ramsar site area in India is approximately **13.3 lakh hectares.**

CRITERIA FOR RAMSAR DESIGNATION

A wetland qualifies as a Ramsar site if it meets at least one of the **nine Ramsar criteria:**

- **Criteria 1-3 (Representative/Unique):** Contains a representative or rare or unique natural or near-natural wetland type.
- **Criteria 4-6 (Species/Communities):** Supports vulnerable, endangered or critically endangered species; supports >20,000 waterbirds; supports species at critical stage of their life cycle.
- **Criteria 7-9 (Fish):** Supports an appreciable proportion of indigenous fish subspecies, species or families; important food source, spawning ground, nursery; demonstrates the benefits of wetlands for fish.

INDIA'S KEY RAMSAR SITES — COMPREHENSIVE TABLE

Ramsar Site	*State/UT*	*Area (ha)*	*Year*	*Key Feature / Wildlife*
Chilika Lake	Odisha	110,000	1981 (INDIA'S FIRST)	India's largest brackish water lagoon; Irrawaddy dolphin; flamingo; migratory birds; fisherfolk; Operation Chilika 2000
Keoladeo Ghana NP (Bharatpur)	Rajasthan	2,873	1981 (India's 2nd)	UNESCO WHS; most important bird sanctuary in Asia; 370+ bird spp; migratory Siberian Crane (now vanished); Painted Stork; Open-billed Stork; HUNTING GROUND of Bharatpur royals historically
Wular Lake	Jammu & Kashmir	18,990	1990	India's largest freshwater lake (seasonal); on Jhelum; Tulbul Navigation Project controversy; threatened by encroachment and pollution
Harike Wetland	Punjab	4,100	1990	At confluence of Sutlej and Beas; migratory birds; Indus dolphin (Platanista gangetica indus — Gangetic subspecies); Important Bird Area
Loktak Lake	Manipur	26,600	1990	Largest freshwater lake in NE India; famous for PHUMDIS (floating islands of heterogeneous mass of soil, vegetation and organic matter; unique worldwide); Keibul Lamjao NP (WORLD'S ONLY FLOATING NATIONAL PARK) on the largest phumdi; habitat of Sangai deer (Cervus eldi eldi — Brow-antlered Deer; critically endangered; Manipur State Animal)
Sambhar Lake	Rajasthan	24,000	1990	India's largest inland Salt Lake; saline; flamingo habitat; salt production (India's largest inland salt producer); migratory flamingo, avocet, stints

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Kolleru Lake	Andhra Pradesh	9,085	2002	Between Krishna and Godavari deltas; seasonal freshwater; migratory waterbirds; Ramsar site; severely encroached (2005 Supreme Court ordered eviction of aquaculture)
Deepor Beel	Assam	4,000	2002	Largest freshwater lake in Assam; Important Bird Area; elephant corridor (urban conflict — elephants cross highway to reach beel); sewage dumping threat; Guwahati's lungs
Pong Dam Lake	Himachal Pradesh	15,662	2002	Reservoir on Beas River; migratory waterbirds; bar-headed goose; important winter habitat; also major irrigation reservoir for Punjab
Point Calimere	Tamil Nadu	3,855	2002	Coastal saline wetland + dry evergreen forest; flamingo; Spot-billed Pelican; blackbuck; near Cauvery delta
Bhoj Wetland	Madhya Pradesh	3,201	2002	Two lakes (Upper Lake/Bhopal Lake + Lower Lake) near Bhopal; Upper Lake supplies water to Bhopal city; 11th century CE dam by Raja Bhoj; urban water supply wetland; migratory birds; partially encroached
Chandertal	Himachal Pradesh	49	2005	Glacial lake at 4,300 m altitude; Lahaul-Spiti; crescent-shaped; migratory ducks; remote; pristine
Renuka Lake	Himachal Pradesh	20	2005	Smallest Ramsar site in India; in Sirmaur district; footprint-shaped sacred lake; migratory birds
Ropar Wetland	Punjab	1,365	2002	Reservoir on Sutlej; Ghaggar floodplain; migratory birds; Important Bird Area
Vembanad - Kol	Kerala	151,250	2002	LARGEST RAMSAR SITE IN INDIA; backwater lake/lagoon system; Kerala tourism (houseboat); Kuttanad (below sea-level rice farming); migratory birds; threatened by nutrient pollution, water hyacinth, salinity changes
Hokera Wetland	Jammu & Kashmir	1,375	2005	Kashmir Valley; near Dal Lake; migratory waterfowl wintering ground; threatened by agricultural runoff
Surinsar-Mansar Lakes	Jammu & Kashmir	350	2005	Twin sacred lakes; Shivkhori cave nearby; religious importance
Tsomoriri Wetland	Ladakh	12,000	2002	High-altitude (4,520 m) lake; Changthang Plateau; Black-necked Crane nesting; Bar-headed Goose; Tibetan Gazelle; Tibetan Wolf; one of India's most pristine high-altitude wetlands
Nalsarovar BS	Gujarat	12,000	2012	Shallow freshwater lake west of Ahmedabad; migratory flamingo, pelican, ducks, herons; important for flamingo breeding
Thol Lake WLS	Gujarat	6,990	2021	Near Ahmedabad; 320+ bird species; flamingo; important for Greater Flamingo; also, Lesser Flamingo

Wadhvana Wetland	Gujarat	3,000	2021	Seasonal reservoir near Vadodara; 80+ migratory bird species; shorebirds, waterfowl; Important Bird Area
Lonar Lake	Maharashtra	1,373	2020	World's SECOND-LARGEST hypervelocity impact crater lake; India's only; diameter 1.8 km; saline-alkaline; unique microbial ecosystem; turned pink in 2020 due to algal bloom (Haloarchaea)
Nanda Lake	Goa	42	2022	Small freshwater lake in North Goa; locally important
Satkosia Gorge	Odisha	98,128	2022	Mahanadi gorge; Gharial habitat; Mugger crocodile; Smooth-coated Otter; part of Tiger Reserve buffer
Koonthankulam Bird Sanctuary	Tamil Nadu	72	2022	Important breeding colony of waterbirds; Painted Stork, spoonbill, open-billed stork; South Indian wetland
Pala Wetland	Mizoram	18,500	2021	High-altitude grassland + wetland complex; rare vegetation; migratory birds; pristine

KEY NOTE

Ramsar Sites — Quick Exam Facts : India's FIRST two Ramsar sites (1981): Chilika Lake (OD) and Keoladeo Ghana NP (RJ). LARGEST Ramsar site in India: Vembanad-Kol (Kerala, 1,51,250 ha). SMALLEST Ramsar site in India: Renuka Lake (HP, 20 ha). HIGHEST NUMBER IN ASIA: India with 82 sites (2024). India added most Ramsar sites in a single year in 2022 (28 sites added). FIRST Montreux Record (wetlands of concern) in India: Keoladeo and Loktak (both on Montreux Record; Keoladeo later de-listed after improvement). World Wetlands Day = February 2. Ramsar = city in Iran.

10.3 MAJOR LAKES OF INDIA — REGIONAL SURVEY

CLASSIFICATION OF LAKES BY ORIGIN

Origin Type	*Mechanism*	*Indian Examples*
Tectonic Lakes	Formed by faulting/warping of the earth's crust creating structural depressions; often large and deep	Wular Lake (J&K — formed in a tectonic depression of the Kashmir Valley syncline); Kolleru Lake (AP); Dal Lake (J&K — tectonic + human modification)
Glacial Lakes	Formed by glacial erosion (cirque lakes / tarns) or glacial meltwater filling hollows left by retreating glaciers; high-altitude	Tsomoriri (Ladakh, 4,520 m); Tso Kar (Ladakh); Pangong Tso (4,350 m; India-China LAC dispute lake); Chandertal (HP, 4,300 m); Gurudongmar Lake (Sikkim, ~5,430 m — among highest lakes in India); Roopkund Lake (Uttarakhand, skeleton lake)
Volcanic / Meteoric Lakes	Formed in volcanic craters or meteorite impact craters	Lonar Lake (Buldhana, Maharashtra) — India's ONLY meteorite impact crater lake (not volcanic despite widespread confusion — it is from a hypervelocity asteroid impact ~52,000 years ago; no volcanic origin); some argue it may be Deccan volcanism-associated but current consensus = meteorite impact
Lagoon / Coastal Lakes	Formed when a spit or barrier beach closes off a portion of the sea or an estuary; brackish water	Chilika Lake (OD — largest); Pulicat Lake (TN-AP border); Vembanad Lake (Kerala); Ashtamudi Lake (Kerala); Kaliveli Lake (TN)

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Oxbow Lakes / Fluvial Lakes	Cut-off meanders of rivers become crescent-shaped oxbow lakes when the river changes course	Kanwar Lake / Kabar Taal (Bihar — India's largest freshwater oxbow lake; Begusarai; major bird sanctuary); various WB-Bihar floodplain oxbow lakes
Man-made Reservoirs	Created by dams; often the most economically important water bodies	Govind Vallabh Pant Sagar (UP — India's largest man-made reservoir by water volume/area; on Rihand River); Indirasagar (MP — largest by live storage capacity); Hirakud (OD — longest dam; ~743 sq km); Shivajisagar/Koyna (MH)
Aeolian / Inter-Dune Lakes	Water collecting in inter-dune depressions in desert areas; ephemeral	Various seasonal lakes in Rajasthan desert (Sam Sand Dunes area); Keoladeo created from monsoon flooding of seasonal marsh
Karst Lakes	Formed in limestone terrain by dissolution of rock	Rare in India; some springs and ponds in Deccan Trap area

CHILIKA LAKE — INDIA'S MOST FAMOUS WETLAND

Chilika Lake (Odisha) is **India's largest coastal lagoon and largest wetland,** covering ~1,100 sq km (varying seasonally from ~906-1,165 sq km). It is a **brackish water lagoon** separated from the Bay of Bengal by a narrow sand bar (spit), with a dynamic inlet (mouth) connecting it to the sea. Chilika is simultaneously India's **most productive coastal fishery, a Ramsar site (India's first, 1981), a tourism destination and a conservation success story.**

Parameter	*Detail*
Location	Puri, Khurda and Ganjam districts, Odisha; separated from Bay of Bengal by a narrow barrier spit (Rajhans Island area)
Area	~1,100 sq km (seasonal variation: ~906-1,165 sq km); largest coastal lagoon in India; second largest in Asia
Type	Brackish water lagoon (salinity varies — near-fresh in northern sector where rivers enter; more saline near the sea mouth in south)
Ramsar designation	1981 — INDIA'S FIRST RAMSAR SITE; first in South Asia
Inlet (mouth)	A narrow, dynamic inlet connecting the lagoon to the Bay of Bengal; tends to close with sedimentation, reducing salinity and degrading ecology
ECOLOGICAL CRISIS (1990s)	By the 1990s: mouth had silted up → lagoon became too fresh → sea fish could not enter → fisheries collapsed → vegetation changed → birds declined → 60,000+ fisherfolk faced livelihood crisis
OPERATION CHILIKA (2000)	Odisha government dredged a new outlet to the sea (near Satapara); within months, salinity increased, seagrass recovered, fish returned, birds returned; Irrawaddy dolphin population recovered; Ramsar's Wetland Conservation Award (2002) — one of world's great wetland restoration success stories
Irrawaddy Dolphin	Chilika harbours India's ONLY population of Irrawaddy Dolphins (Orcaella brevirostris) in a marine/coastal environment; ~148-160 individuals (latest survey); near Satapara area; vulnerable; population had declined before Operation Chilika, recovered after; fishing nets a primary threat
Migratory birds	Attracts ~1 million migratory birds in winter; Greater Flamingo, Painted Stork, Bar-headed Goose, Greylag Goose, Spot-billed Pelican, various ducks; birds from as far as Siberia, Central Asia, South-East Asia; Nalabana Island Bird Sanctuary in centre of lake

Fish and fisheries	~160+ fish species; prawns; crabs; 60,000+ fisherfolk dependent; post-Operation Chilika fish catch improved dramatically; significant role in Odisha's coastal fisheries economy

IFoS FOCUS

IFoS — OPERATION CHILIKA: Operation Chilika is one of India's finest case studies in **ecosystem restoration through hydrological intervention**. The principle: a lagoon's ecology is determined by its salinity regime, which is controlled by the balance between freshwater inflow (rivers) and seawater inflow (through the sea mouth). When the sea mouth silted up, the balance shifted to fresh — destroying the brackish ecosystem. The restoration (new sea mouth) re-established the brackish balance. Lesson: understanding **ecological baselines and hydrological drivers** is more important than treating symptoms. This is also a lesson in the **political economy of conservation** — fisherfolk who suffered became the strongest advocates for ecological restoration once they saw the fish return.

WULAR LAKE (JAMMU & KASHMIR)

Parameter	*Detail*
Location	Bandipora district, Kashmir Valley, J&K; on the Jhelum River; ~50 km NW of Srinagar
Area	~98 sq km (dry season) to ~260 sq km (flood season; one of Asia's largest freshwater lakes seasonally); classified as INDIA'S LARGEST FRESHWATER LAKE
Type	Tectonic lake (formed in a structural depression of the Kashmir syncline); also functions as a natural flood absorber for the Kashmir Valley
Ecological role	Natural flood regulator for Srinagar; the 2014 Jammu & Kashmir floods would have been catastrophically worse had Wular Lake not absorbed significant floodwater; migratory waterbirds; fish (Trout, Snow Trout, Rohu, Carp)
Ramsar designation	1990
Threat — Encroachment	Wular has lost ~50-60% of its area since 1947 to encroachment (agricultural conversion, willow plantation, construction); Wular Conservation and Management Authority (WUCMA) set up to address
Tulbul Navigation Project (Wullar Barrage) — India-Pakistan Dispute	India proposed the Tulbul Navigation Project (a navigation lock/barrage at the outflow of Wular Lake on the Jhelum) to maintain river navigability during lean season; Pakistan objected as Jhelum is a western river under the Indus Waters Treaty (1960) — Pakistan has exclusive rights over western rivers (Indus, Jhelum, Chenab); the project has been stalled since the 1980s due to this bilateral dispute; one of the primary irritants in India-Pakistan water relations; the project is about navigation not water storage but Pakistan sees it as water control

DAL LAKE (SRINAGAR, J&K)

Dal Lake is **Kashmir's most iconic water body** — the image of shikaras (wooden boats), houseboats and Mughal-era gardens reflected in the lake is the defining visual of the Kashmir Valley. It is simultaneously a **cultural heritage, major tourist attraction, source of livelihood for ~50,000 people** and **one of India's most ecologically threatened urban lakes.**

Parameter	*Detail*
Location	City of Srinagar, Kashmir Valley; at an elevation of ~1,580 m; enclosed by the Zabarwan Hills (east) and urban Srinagar (west, south)
Area (historical vs current)	21.1 sq km (1971) → ~10-11 sq km (2024); has lost OVER HALF ITS AREA in 50 years; one of India's worst examples of urban lake degradation

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Nagin Lake	Nagin Lake, northwest of Dal, is technically a connected water body; smaller; less tourist-impacted; relatively better condition
Floating Gardens (Rad/Raad)	Dal supports a unique form of agriculture —
Rad / Floating Vegetable Gardens	Farmers cut sections of the mat of aquatic vegetation from the lake bottom, pile it up and grow vegetables (tomato, cucumber, melons, lotus roots) on these floating platforms; hundreds of these "rad" float on the lake; both a livelihood and a unique cultural tradition, but they also add organic material and nutrients to the lake, accelerating eutrophication
Threats to Dal Lake	(1) Encroachment — buildings, hotels, roads on the lake margin; ~5,000+ structures built on lake area since 1980; (2) Sewage — Srinagar's sewage drains into Dal; nutrients (N, P) cause algal blooms and eutrophication; (3) Solid waste — garbage dumped by houseboats and shoreline settlements; (4) Agricultural runoff from rad — excess fertilisers and pesticides; (5) Siltation — sediment from Telbal Nala (stream flowing from Zabarwan hills) fills the lake; (6) Political instability — conservation efforts disrupted by decades of unrest in Kashmir; (7) Invasive plants — Eurasian Milfoil (Myriophyllum spicatum) and other invasive aquatic plants
Conservation efforts	Dal Lake Authority (DLA) established 1993; Supreme Court orders on encroachment removal; dredging programmes; sewage treatment plants (inadequate capacity); Dal Conservation and Management Project (World Bank assisted); but political will and institutional capacity remain the primary gaps
Livelihood community	~50,000 people directly dependent on Dal Lake: Hanjis (boatmen), rad cultivators, houseboat owners, fishermen; any conservation that displaces them will fail without alternative livelihoods

LONAR LAKE (BULDHANA, MAHARASHTRA)

Lonar Lake is **India's only meteorite impact crater lake** — and one of the world's rarest geological formations. Created approximately **52,000 years ago** when a meteorite of ~1-2 Mt mass hit the Deccan Trap basalt with a velocity of ~8-10 km/s (hypersonic), the impact released energy equivalent to several hundred nuclear bombs, creating a circular crater **~1.8 km in diameter and ~137 m deep.** The lake occupies the crater floor.

Parameter	***Detail***
Location	Buldhana district, Maharashtra (Vidarbha region)
Origin	Hypervelocity meteorite impact (~52,000 years ago); the ONLY KNOWN HYPERVELOCITY IMPACT CRATER IN BASALTIC ROCK in the world; also the WORLD'S SECOND-LARGEST SUCH LAKE (after Bosumtwi Lake in Ghana); NOT volcanic despite being on the Deccan Trap
Water chemistry	Highly SALINE-ALKALINE (pH 9.5-11; very basic/alkaline); contains high concentrations of Na2CO3, NaHCO3 and NaCl; unlike most Indian lakes which are neutral or slightly acidic
Unique microbial ecosystem	The extreme pH and salinity host extremophile microorganisms — bacteria, algae and archaea that can survive no-where else; Haloarchaea (salt-loving archaea); Spirulina (cyanobacteria — commercially grown for health supplements; found naturally here); unique microbiome of global scientific importance
THE PINK LAKE PHENOMENON (2020)	In May 2020 (during COVID lockdown, when human disturbance was minimal), Lonar Lake water turned BRIGHT PINK/MAGENTA; caused by a sudden bloom of Haloarchaea (salt-loving pink microorganisms that produce carotenoid pigments when stressed); scientifically significant; photographically spectacular; media sensation globally

Ramsar designation	2020
Protected area	Lonar Wildlife Sanctuary (~3.7 sq km) — the lake + surrounding area; Flamingo, Painted Stork, Lapwing, Stone Curlew visit; Chinkara (Indian Gazelle) in surrounding grassland
Threats	Sewage from Lonar town draining into lake; CAMALOT weed invasion; tourism litter; washing and bathing in lake water; Buldhana urban expansion toward lake margin

LOKTAK LAKE (MANIPUR)

Parameter	*Detail*
Location	Bishnupur district, Manipur; ~48 km south of Imphal; largest freshwater lake in NE India
Area	~287 sq km
Unique feature — PHUMDIS	Loktak is famous for PHUMDIS — heterogeneous floating masses of soil, vegetation and organic matter at various stages of decomposition; they range from tiny pads to islands of several sq km; found nowhere else in the world in this scale and form
Keibul Lamjao National Park	Built on the LARGEST PHUMDI (~40 sq km) in Loktak; the WORLD'S ONLY FLOATING NATIONAL PARK; habitat of the critically endangered SANGAI DEER (Cervus eldi eldi — Brow-antlered Deer; Manipur State Animal); locally called "the dancing deer" for its springy gait on phumdis; once thought extinct; population ~220-260 individuals
Sangai Deer	Exclusively found on Keibul Lamjao NP phumdis; critically endangered; depends on the phumdi vegetation; the Ithai Barrage (see below) changed phumdi dynamics, threatening Sangai
Ramsar designation	1990
Ithai Barrage Controversy	The Ithai Barrage (built 1983 for the Loktak Hydroelectric Project, 105 MW) raised the lake's permanent water level — which was intended to store more water for power generation. However, it submerged the lower phumdis (where Sangai rested and foraged in dry season), eliminated fish spawning grounds, disrupted traditional fishing cycles and caused massive displacement of ~70,000 fishermen from their stilt houses. Many consider the Ithai Barrage India's worst example of hydroelectric project-ecosystem conflict. The barrage is now considered a threat to the Sangai's survival
Threats	Ithai Barrage water level change; phumdi degradation from nutrient pollution; invasive water plants; siltation; encroachment of phumdi margin; militant group activity restricting conservation access historically

ENV ALERT

Sangai and Keibul Lamjao — The World's Only Floating National Park

The relationship between the Sangai deer, Keibul Lamjao National Park and Loktak Lake's phumdis is one of ecology's most extraordinary examples of **species-habitat co-evolution**. The Sangai has literally evolved physical adaptations for phumdi life — its hooves are slightly splayed (wider than mainland deer) to spread weight on floating vegetation, and its gait is bouncy/springy because it is always walking on unstable, spongy phumdi. When phum

dis submerge (due to Ithai Barrage raising water levels), the Sangai literally loses its home and food. The Keibul Lamjao NP cannot be relocated — the Sangai can only live on phumdis. The only solution is **lowering the Ithai Barrage's permanent storage level** to restore natural phumdi dynamics — which conflicts with power generation revenue. This is a textbook IFoS species-habitat-human conflict case study.

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HIGH-ALTITUDE LAKES OF THE HIMALAYA AND KARAKORAM

Lake	Location	Altitude	Area	Key Feature
Pangong Tso	Ladakh (India) + Tibet (China); LAC passes through the lake	~4,350 m	~700 sq km (14% in India, 86% in China)	Endorheic (no outflow); saline (not drinkable); turns blue-green-turquoise-silver with changing light; 134 km long but average only 5 km wide; 3 Idiots (Bollywood film) scene filmed here; LAC cuts through the lake (India-China military standoff here in 2020)
Tsomoriri (Moriri)	Changthang Plateau, Ladakh	~4,522 m	~120 sq km	Freshwater; India's highest Ramsar site (2002); nesting site of Bar-headed Goose and Black-necked Crane (Grus nigricollis — high-altitude crane; vulnerable); Kiang (Tibetan Wild Ass); Great Tibetan Sheep (Argali); extremely pristine; no permanent settlements nearby
Tso Kar	Changthang Plateau, Ladakh	~4,530 m	~19 sq km (variable)	Salt Lake (Tso Kar means "white lake" — salt deposits); BEFORE Tsomoriri was designated, Tso Kar was in India's first community conservancy area; Bar-headed Goose breeding colony; Black-necked Crane; salt extraction by Changpa nomads
Gurudongmar Lake	North Sikkim (near China border)	~5,430 m	~5 sq km	One of the HIGHEST LAKES IN THE WORLD and in India; sacred (associated with Guru Padmasambhava/Rinpoche who is said to have consecrated part of it so it never freezes even in winter); closed to foreigners; Indian nationals by permit; pristine
Roopkund Lake	Chamoli, Uttarakhand (Trishul Mountain base)	~5,029 m	~0.04 sq km (tiny)	"SKELETON LAKE" — contains hundreds of human skeletal remains (at last count ~800+ skeletons); dated to ~9th century CE; a DNA study (2019) found remains of three distinct groups (South Asian, Mediterranean European, Southeast Asian) suggesting multiple episodes of mass death; probably pilgrims caught in violent hailstorm and washed into the lake; one of India's strangest archaeological-ecological sites
Tsongmo (Changu) Lake	East Sikkim	~3,780 m	~1 sq km	Tourist lake near Nathu La pass; glacial; Chinese and Indian visitors; Brahmaputra (Tsangpo) headwaters area; Ruddy Shelduck
Manasarovar	Tibet (across Indian border; sacred to Indians)	~4,590 m	~411 sq km	Sacred to Hindus (abode of Brahma; "Manasa" = mind/consciousness; source of 4 great rivers: Indus, Sutlej/Langchen, Karnali/Ghaghara, Brahmaputra/Yarlung); adjacent to Mt. Kailash; sacred to Jains, Buddhists, Bon practitioners too; Kailash Mansarovar Yatra (pilgrimage from India, via Lipulekh Pass or China route)

IMPORTANT LAKES OF PENINSULAR AND SOUTH INDIA

Lake	State	Type	Key Feature
Vembanad Lake	Kerala	Coastal lagoon / backwater	LARGEST RAMSAR SITE IN INDIA (1,51,250 ha); the largest lake in Kerala; site of the Nehru Trophy Boat

(Vembanad-Kol Ramsar site)			Race (snake boat race, Alappuzha, every August 2nd Saturday); Kuttanad (below-sea-level farming) at its southern end; heavily polluted by agriculture/urban runoff; water hyacinth invasion
Ashtamudi Lake	Kerala (Kollam)	Backwater/lagoon	"Eight-armed lake" due to its shape; 2nd largest wetland in Kerala; connects to Vembanad system; houseboat tourism; declining water quality
Kolleru Lake	Andhra Pradesh (between Krishna-Godavari deltas)	Freshwater lake (seasonal)	Once largest freshwater lake in Andhra; severely reduced by aquaculture and agricultural encroachment; SC 2005 order evicted illegal fish ponds; Ramsar site; Painted Stork and Pelican colonies (when lake was larger)
Pulicat Lake	Andhra Pradesh-Tamil Nadu border	Brackish lagoon	India's 2nd largest brackish water lagoon (after Chilika); Pulicat Bird Sanctuary; Flamingo; Sriharikota island forms eastern barrier spit; severely impacted by Krishnapatnam Port development
Osman Sagar (Gandipet) and Himayat Sagar	Telangana (near Hyderabad)	Man-made reservoirs (1920s)	Built on Musi River for Hyderabad flood protection; historic; now surrounded by urban development; bird sanctuary designations; Hussain Sagar (central Hyderabad — large urban lake; BUDA Rock Buddha statue in centre; formed 1562 CE; severely polluted)
Ulsoor Lake	Karnataka (Bengaluru)	Urban artificial lake	Bengaluru's most important urban lake; British built; significant pollution; Bruhat Bengaluru Mahanagara Palike (BBMP) restoration efforts; of ~200+ lakes in Bengaluru, most are threatened or dead (Raja Kaluve/stormwater drain encroachment)
Kaliveli Lake	Tamil Nadu (Villupuram)	Coastal brackish lake	Second largest wetland in TN; Important Bird Area; Painted Stork, Spot-billed Pelican; flamingo; fishing community dependent; threatened by salt pan conversion and urban expansion
Sambhar Lake	Rajasthan	Inland Salt Lake	India's LARGEST INLAND SALT LAKE (~24,000 ha); saline due to Aravalli rock dissolution; Lesser and Greater Flamingo breeding; salt production (Hindustan Salt Ltd); migratory waterbirds; Ramsar site; PINK COLOURED when flamingos gather in thousands

INDIA'S LARGEST MAN-MADE RESERVOIRS

Reservoir	*River / Dam*	*State*	*Area / Storage*	*Key Note*
Govind Ballabh Pant Sagar (Rihand Reservoir)	Rihand River / Rihand Dam	Uttar Pradesh (Sonbhadra)	~466 sq km	INDIA'S LARGEST MAN-MADE RESERVOIR BY AREA (water spread); also called Rihand Reservoir; supplies water and power to industrial belt of Vindhya region; 300 MW power

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Indira Sagar Reservoir	Narmada / Indira Sagar Dam	Madhya Pradesh (Khandwa)	~913 sq km (India's largest by live storage capacity ~12.22 billion cu m)	Narmada valley project; largest reservoir by storage capacity; 1,000 MW power; major displacement (~91,000 ha submergence)
Nagarjuna Sagar Reservoir	Krishna / Nagarjuna Sagar Dam	Telangana-Andhra Pradesh	~284 sq km	Major irrigation for Andhra and Telangana; Buddhist ruins of Nagarjunakonda submerged (artifacts removed to museum island); 816 MW power
Hirakud Reservoir (Gandhi Sagar)	Mahanadi / Hirakud Dam	Odisha	~743 sq km	India's first post-independence major multipurpose river project (1957); ~4.8 km long dam; 347.5 MW; flood control for Odisha
Sardar Sarovar Reservoir	Narmada / Sardar Sarovar Dam	Gujarat (backwater into MH, MP)	~214 sq km	1,450 MW; irrigates 18.45 lakh ha in Gujarat; Narmada Bachao Andolan controversy
Bhakra-Nangal Reservoir (Gobind Sagar)	Sutlej / Bhakra Dam	Himachal Pradesh (Bilaspur)	~168 sq km	226 m high; 1,325 MW; supplies Punjab-Haryana canal system; flooded old Bilaspur town

10.4 THREATS TO WETLANDS AND WATER BODIES

India's wetlands face a **convergence of anthropogenic threats** that has accelerated dramatically in the past three decades of rapid urbanisation and agricultural intensification. Despite their legal protections, wetlands continue to shrink, degrade and lose biodiversity at alarming rates.

MAJOR THREATS — DETAILED

1. ***Encroachment and Conversion***

   The **conversion of wetlands to agriculture, real estate and urban infrastructure** is the single largest driver of wetland loss in India. Agricultural encroachment is dominant in rural areas (converting seasonal wetlands to paddy or converting fishponds to dry farmland); real estate encroachment is dominant in urban areas (filling lakes for housing colonies, IT parks, roads). Notable examples:

   - **Bengaluru:** had ~262 lakes in 1960; now fewer than ~81 functional lakes; most have been encroached by the Bruhat Bengaluru Mahanagara Palike (BBMP) layout extensions; raja kaluve (stormwater drainage channels) used as unauthorized garbage dumps and built upon.
   - **Chennai:** Pallikaranai Marshland (~650 sq km historically; now ~20 sq km) — most converted to IT corridors, Sholinganallur tech parks and the NIOT campus; Chennai's 2015 floods were directly worsened by the loss of Pallikaranai's flood-absorption capacity.
   - **Hyderabad:** Durgam Cheruvu, Yeddumalulavagu and other lakes encroached; Hussain Sagar reduced to a heavily polluted urban pond.
   - **Delhi:** Yamuna floodplain (the largest urban wetland in Delhi) continuously encroached despite Supreme Court orders; Sanjay Lake, Okhla Wetland Bird Sanctuary threatened.

2. ***Pollution***

   Wetland pollution occurs through several pathways:

- **Domestic sewage:** most Indian cities drain untreated or partially-treated sewage into nearby water bodies; high nutrient content (N, P) → eutrophication → algal blooms → oxygen depletion → fish death. Dal Lake, Hussain Sagar, Bellandur Lake (Bengaluru — caught fire twice due to foam + sewage gases) all face this.
- **Industrial effluents:** textile dyes (Tiruppur→Noyyal River→Cauvery), pharmaceutical effluents (Hyderabad→Musi), tanneries (Kanpur→Ganga), electroplating (Delhi industrial areas).
- **Agricultural runoff:** fertiliser-rich water from paddy and sugarcane fields flows into wetlands; phosphate and nitrate enrichment → eutrophication → invasive plant growth.
- **Solid waste:** garbage dumping in and around wetlands; plastic choking drains and lake inlets; microplastics in lake water being detected in fish and birds.

3. *Water Hyacinth – India's Most Destructive Invasive Aquatic Plant*

Water Hyacinth (*Eichhornia crassipes*) — a **native of the Amazon basin, Brazil,** introduced to India in **1896 as an ornamental plant** — is now one of the most economically damaging invasive species in India. It forms dense, floating mats that:

Impact of Water Hyacinth	*Details*
Blocks sunlight to underwater plants	Reduces photosynthesis of submerged aquatic plants → ecosystem shift
Depletes dissolved oxygen	As the thick mat decomposes, bacterial decomposition uses oxygen → hypoxic conditions → fish kills
Blocks waterways and irrigation canals	Clogs canals, boat traffic, fishing nets; significantly impacts irrigation and navigation
Eliminates fish and bird habitat	Removes open water → eliminates habitat for diving birds and surface fish
Evapotranspiration	A dense water hyacinth mat loses 7-10 times MORE water through evapotranspiration than open water of the same area → depletes water bodies faster in summer
Spread	Reproduces vegetatively at extraordinary speed; one plant can produce 3,000 plants in 50 days; spreads with water currents
Control methods	Mechanical removal (labour-intensive; short-term); biological control (using weevils — Neochetina eichhorniae, N. bruchi — specific to water hyacinth; most effective long-term); chemical control (herbicides — collateral damage to other plants); composting and biogas generation from removed biomass (positive use)
Affected water bodies	Chilika, Wular, Dal, Loktak, Kerala backwaters, Deepor Beel, Hussain Sagar, virtually every lake and river in humid India

4. *Invasive Species Beyond Water Hyacinth*

Species	*Category*	*Impact*
Water Lettuce (Pistia stratiotes)	Aquatic floating plant; native to Africa	Dense mats; shade; oxygen depletion; less aggressive than water hyacinth but significant
Salvinia molesta (Giant Salvinia)	Floating fern; native to Brazil	Invasive in Kerala backwaters and other humid areas; rapid spread; blocks navigation

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Alligator Weed (Alternanthera philoxeroides)	Amphibious plant; native to S. America	Spreads on waterway margins and into water; difficult to control
Common Carp (Cyprinus carpio)	Invasive fish; introduced from China	Destroys aquatic vegetation; increases turbidity; outcompetes native fish; present in most Indian water bodies
Largemouth Bass (Micropterus salmoides)	Introduced sport fish	Predator on native fish; introduced to Himalayan cold-water streams; threatens trout
Tilapia (Oreochromis spp.)	Introduced food fish from Africa	Extremely aggressive; reproduces fast; outcompetes native carp; now in almost all lowland water bodies

5. ***Glacial Lake Outburst Floods (GLOFs)***

In the Himalaya, **Glacial Lake Outburst Floods (GLOFs)** are a growing threat — as glaciers retreat due to climate change, they leave behind **moraine-dammed glacial lakes** that can suddenly breach, releasing catastrophic volumes of water downstream. India has experienced several devastating GLOFs:

- **Chamoli Disaster (February 7, 2021):** A portion of the Nanda Devi glacier's rock-ice avalanche/collapse sent a massive flood down the Rishiganga and Dhauliganga rivers in Chamoli district, Uttarakhand; **~200 people died**; Tapovan Vishnugad Hydroelectric Project (520 MW, NTPC) and Rishiganga Project (13.2 MW) both destroyed; confirmed as a rock and ice avalanche into a glacial lake causing a flash flood — **a climate change-accelerated disaster.**
- **South Lhonak Lake (Sikkim, October 4, 2023):** A GLOF from South Lhonak Lake (a moraine-dammed lake in North Sikkim that had been growing rapidly due to glacier melt) breached its moraine dam and sent a catastrophic flood down the Teesta River. The **Teesta-III Hydroelectric Plant (60 MW, NHPC)** dam collapsed; **~100+ people killed;** over 1,500 missing; 22,000+ displaced; bridges, roads washed away across Sikkim. One of India's worst climate disasters of 2023.

ENV ALERT

GLOFs — IFoS Climate-Disaster-Hydrology Link

GLOFs represent the **intersection of climate change, Himalayan hydrology and human vulnerability**. As glaciers retreat (Himalayan glaciers are melting at among the fastest rates globally — losing ~40 cm of ice/year in some areas), the moraine (unsorted glacial debris) that dammed the glacial lakes is exposed to melt from below. When the moraine dam thins to a critical point, it can fail suddenly — releasing the lake volume in hours. India's GLOF risk assessment (ISRO, 2023) identified **188 high-risk glacial lakes** in India. The problem is particularly acute in Sikkim-Darjeeling, Himachal Pradesh and Uttarakhand. No hydroelectric project in a high-risk GLOF zone should be built without a GLOF risk assessment and early warning system.

10.5 WETLAND CONSERVATION — POLICY AND LAW

LEGAL FRAMEWORK

Law / Policy	*Year*	*Key Provision for Wetlands*
Environment (Protection) Act (EPA)	1986	Mother legislation; enables notification of Wetland Rules; National Green Tribunal (NGT) enforces wetland protections; Environmental Impact Assessment for projects affecting wetlands
Wildlife Protection Act (WPA)	1972	Declares national parks and wildlife sanctuaries (many are wetlands — Keoladeo, Sultanpur, Deepor Beel); NBWL (National

		Board for Wildlife) approval for any activity within 10 km of National Parks
Ramsar Convention	1971 (India 1982)	Designates Wetlands of International Importance; "Wise Use" principle (sustainable use); Montreux Record for threatened sites
Wetlands (Conservation and Management) Rules	2010 (revised 2017)	Most important domestic wetland law; identifies wetlands in need of protection; establishes Wetland Authority in each state; regulates/prohibits activities (waste dumping, encroachment, ground extraction, permanent structures); provides for buffer zones; REQUIRES CONSERVATION AND MANAGEMENT PLAN for each notified wetland
Forest Conservation Act (FCA)	1980 (amended 2023)	Forests within or adjacent to wetlands protected; forest-wetland interface critical for ecosystem integrity
National Water Policy	2012	Addresses wetland conservation within integrated water resources management; recognises ecological flows
National Wetlands Conservation Programme (NWCP)	1985 (by MoEFCC)	Financial and technical assistance to states for wetland conservation; covers 115 wetlands; works in conjunction with Ramsar framework
National Plan for Conservation of Aquatic Ecosystems (NPCA)	2015 (merged NWCP and National Lake Conservation Plan)	Integrated scheme for wetlands AND lakes; conservation, restoration, management; Rs.671+ crore expenditure

KEY CONSERVATION PROGRAMMES

- **AMRUT (Atal Mission for Rejuvenation and Urban Transformation):** 2015; covers urban lake and pond restoration as part of urban rejuvenation; 500 cities targeted; includes restoration of 5,000+ ha of urban wetlands/water bodies in Phase-1.
- **Namami Gange / NMCG (National Mission for Clean Ganga):** Ganga floodplain wetlands and oxbow lakes are integral to Ganga ecology; NMCG includes wetland restoration components.
- **NPCA (National Plan for Conservation of Aquatic Ecosystems):** the primary central government scheme for wetland and lake conservation; covers 115+ wetlands; provides central funding; states must prepare conservation plans.
- **Jal Shakti Abhiyan — Catch the Rain:** focuses on water conservation including ponds, lakes and small wetlands as rainwater harvesting structures; "Catch the Rain, Where it Falls, When it Falls."
- **Paani Bacha Andolan and community-led restoration:** many successful small-scale lake restoration projects led by local communities; Bengaluru's Whitefield Rising lake restoration movement; Chennai Citizen Lake Monitors.

SUCCESSFUL WETLAND RESTORATION CASES

Case	*Location*	*Restoration Action*	*Outcome*
Operation Chilika (2000)	Chilika Lake, Odisha	Dredged new sea mouth to restore brackish water balance	Irrawaddy dolphin recovered; fish catch improved; birds returned; Ramsar Wetland Conservation Award 2002

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Hauz Khas Lake restoration	South Delhi	NGO (INTACH, DUSIB) and citizens cleaned; Delhi Development Authority desilted; biodiversity restored	Migratory waterbirds returned; used as urban green space; one of Delhi's most successful urban ecology cases
Powai Lake, Mumbai	Mumbai	MCGM (Municipal Corporation) desilting; fishing ban; public awareness	Flamingo has returned to Powai; improved water quality
Pakhal Lake, Telangana	Warangal district	State fisheries department + community management; invasive weed removal	Fish populations recovered; local fishing community livelihood improved; bird abundance increased
Pichavaram Mangrove restoration	Tamil Nadu (Cuddalore)	Tamil Nadu Forest Dept + DFO; replanting degraded mangrove patches	2004 tsunami showed restored mangroves provided coastal protection; flagship success
Ahar Pynes system revival (Jharkhand)	Southern Jharkhand districts	Community-led revival of traditional irrigation/wetland system (ahar = tank, pynes = irrigation channel)	Water availability improved; fish production increased; bird habitat restored; livelihood improved for Santhal and Munda farming communities

10.6 TRADITIONAL WATER CONSERVATION SYSTEMS OF INDIA

India has one of the world's richest traditions of community-based water harvesting and wetland management — developed over millennia in diverse climatic zones. These **traditional water conservation structures** were sophisticated, ecologically adapted and socially governed. Many have been revived under watershed development programmes and schemes like **Har Khet Ko Pani, Atal Bhujal Yojana** and **Jal Shakti.**

System	*Region*	*Description / Significance*
JOHAD (Earthen Check Dam)	Rajasthan (Alwar, Bharatpur)	Earthen bunds across seasonal streams to harvest rainwater; community-owned; Rajendra Singh (Waterman of Rajasthan / Magsaysay Award 2001) revived thousands of johads in Alwar district → rivers like Arvari, Sarsa came back to life; model of community-led water restoration
BAOLI / STEPWELLS (Vav in Gujarat)	Rajasthan, Gujarat, Delhi, Karnataka	Elaborate stepped wells with architectural ornamentation; Chand Baori (Abhaneri, RJ) — one of world's deepest and oldest stepwells; Rani ki Vav (Patan, Gujarat) — UNESCO WHS; Agrasen ki Baoli (Delhi); active socially but lost functional role due to piped water; many now restored as heritage sites
TANK IRRIGATION (Eri in TN; Cheruvu in AP/Telangana; Sagar in Karnataka)	Tamil Nadu, AP, Telangana, Karnataka	Networks of inter-linked irrigation tanks managed by communities; Tamil Nadu had ~40,000+ eri (tank) system; fed by "tank cascade" or series; declining due to encroachment, siltation, canal irrigation substitution; revival attempted under MGNREGS
AHAR-PYNE	Bihar (especially Gaya, Aurangabad, Nawada)	Ahar = shallow rectangular reservoir with earthen embankments on 3 sides; pyne = canal from river diverting flow to ahar; ancient; managed by farmers collectively; 60,000+ ahars in south Bihar historically; declined post-canal irrigation; revival needed

PHAD SYSTEM	Khandesh (Nashik, Jalgaon, Dhule), Maharashtra	Phad = shared irrigation system on Girna, Panjhra, Mosam rivers; community ("phad" association) controls water distribution; elaborate social rules; unique to north Maharashtra
KUHLS (GUHLS)	Himachal Pradesh (Shimla, Kullu, Chamba, Lahaul)	Community-managed irrigation channels diverting glacier/stream water to terraced fields; strictly governed by community council; gravity-fed; traditional mountain irrigation
ZABO	Nagaland (Phek district)	Combines soil conservation, water harvesting, agriculture and animal husbandry on steep slopes; terrace farming + water collection at different levels; "Naga" water harvesting; demonstrated sustainable Himalayan hillslope agriculture
KUND/TANKA	Western Rajasthan, Kachchh	Underground circular cistern plastered with lime; collects runoff from catchment area; for drinking water; still actively used; traditional rainwater harvesting for desert communities
PAR / VIRDAS	Kachchh, Saurashtra, Gujarat	Par = percolation pond; viirdas = shallow well next to it; works as a pair; floodwater held in par → percolates to shallow aquifer → viirdas gives sweet water all year; unique to arid Gujarat
BAMBOO DRIP IRRIGATION	Meghalaya (Jaintia, Khasi hills)	300-year-old system; bamboo pipes channel and distribute spring water to terrace fields at a controlled rate; gravity-fed; no electricity or pump; FAO recognised as Globally Important Agricultural Heritage System (GIAHS) 2021

UPSC CIVIL

Civil GS-1/GS-3 — Traditional Water Systems: Traditional water conservation systems are a **high-frequency GS-1 and GS-3 topic** (Indian culture + resource management). Key points: (1) They represent **community-governed common pool resources** (Elinor Ostrom's theory — Nobel 2009 — shows communities CAN manage commons sustainably without state or market); (2) Their decline is due to both the **"gift of government"** (canal/pump irrigation that displaced community systems) and the **commodification of water**; (3) Revival requires **social mobilisation + legal backing (Water User Associations) + technical support**; (4) They are **climate-adapted technologies** — designed over centuries for local hydrology — superior to imported technology for local conditions. Rajendra Singh's Johad revival in Alwar = model answer example.

10.7 CURRENT AFFAIRS HOOKS (2021–2025)

CURRENT AFFAIRS

South Lhonak GLOF, Sikkim (October 4, 2023): Glacial Lake Outburst Flood from South Lhonak Lake (North Sikkim) destroyed Teesta-III dam (NHPC), killed 100+ people, displaced 22,000+. One of India's worst climate disasters of 2023. ISRO had mapped South Lhonak as a high-risk lake in 2021 satellite analysis. Accelerated India's GLOF early-warning system development.

India's Ramsar Sites reach 82 (2024): India now has 82 Ramsar sites — highest in Asia; largest addition was in 2022 (28 sites added in one go). Total Ramsar area ~13.3 lakh ha. New additions include Lonar Lake (MH, 2020), Thol (GJ), Wadhvana (GJ), and many others.

Chamoli Disaster (February 7, 2021): Rock-ice avalanche + possible GLOF in Rishiganga-Dhauliganga basin, Uttarakhand. ~200 dead; Tapovan-Vishnugad (NTPC) and Rishiganga (private) hydroelectric projects destroyed. Raised serious questions about tunnel-based hydropower in high seismic + GLOF-risk Himalayan zones.

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Dal Lake Area Declining (2024 surveys): Latest surveys show Dal Lake has shrunk to ~10-11 sq km from 21.1 sq km in 1971; 50+ years of encroachment, sewage, rad cultivation expansion; conservation efforts insufficient vs development pressure; Srinagar HC has multiple pending cases.
Wetland Rules 2017 — Implementation Gaps (NGT, 2023-24): National Green Tribunal noted that most states have failed to notify wetlands under Wetland Rules 2017; less than 15 states have State Wetland Authorities functional; the gap between the law and ground reality remains enormous.
Lonar Lake Pink Phenomenon — UNESCO Interest (2020-23): The 2020 pink colouration from Haloarchaea brought Lonar global attention; UNESCO/IUCN explored World Heritage nomination possibilities; Ramsar designation (2020) confirmed; unique hypervelocity crater ecosystem research ongoing.
Bengaluru Lake Restoration — Citizen Initiatives (2022-24): Several Bengaluru lakes restored through citizen action: Agara Lake (Domlur area), Jakkur Lake revival; HC ordered restoration of encroached lakes; BBMP Lake Development Authority mandated to restore 210 lakes by 2025; mixed progress. Hebbal Lake flamingos returned after restoration.

10.8 PYQ ANALYSIS — CHAPTER 10 (2010–2025)

Source	Year	Marks	Question
UPSC Civil	2023	15M	"Examine the ecological and cultural significance of India's wetlands. What are the major threats and what policy interventions are needed for their conservation?"
UPSC Civil	2022	12M	"The Glacial Lake Outburst Floods (GLOFs) are a major threat to the Himalayan river valleys. Discuss the causes and the measures needed to address this threat."
UPSC Civil	2021	12M	"Discuss the significance of traditional water management systems of India with suitable examples. How can they contribute to water security in the context of climate change?"
UPSC Civil	2020	15M	"Critically examine the threats to India's major lakes and the effectiveness of the legal and institutional framework for their protection."
UPSC Civil	2019	10M	"Discuss the ecological significance of Loktak Lake. What are the threats to it and what are the conservation measures in place?"
UPSC Civil	2018	10M	"What is the significance of the Ramsar Convention? Discuss India's important Ramsar sites with reference to their unique ecological features."
UPSC Civil	2017	12M	"Chilika Lake is both a Ramsar site and a model of successful wetland restoration. Discuss the ecological crisis it faced and the measures taken to restore it."
UPSC Civil	2015	10M	"What is water hyacinth? Discuss its impact on freshwater ecosystems and the control measures available."
IFOS GS	2024	15M	"Discuss the ecological significance of high-altitude wetlands of Ladakh (Tsomoriri, Pangong Tso, Tso Kar) with reference to their flora, fauna and conservation challenges."
IFOS GS	2023	10M	"Explain the concept of Glacial Lake Outburst Floods (GLOFs). Discuss the South Lhonak GLOF (2023) and its implications for hydropower development in the Himalayas."
IFOS GS	2022	10M	"Discuss the ecology and conservation of Chilika Lake. What is the significance of the Irrawaddy dolphin in this ecosystem?"

IFOS GS	2021	10M	"Explain the phumdi ecosystem of Loktak Lake. Discuss the relationship between the Sangai deer and the phumdi habitat."
IFOS GS	2020	10M	"What are the traditional water conservation systems of India? Discuss their ecological and social benefits with examples from different regions."
IFOS GS	2019	10M	"Discuss the ecology of Lonar Lake. Why is it scientifically significant as a unique ecosystem?"

KEY NOTE

Frequency pattern : Chilika (Civil 2017; IFoS 2022) + Loktak/Sangai (Civil 2019; IFoS 2021) + GLOFs (Civil 2022; IFoS 2023) + traditional water systems (Civil 2021; IFoS 2020) + Ramsar convention (Civil 2018) + wetland threats (Civil 2023) are the dominant clusters. For 2025-26: South Lhonak GLOF (IFoS 2023 confirmed; Civil very high probability), Wetland Rules implementation gaps, 82 Ramsar sites milestone, Dal Lake decline, Lonar Lake (IFoS 2019 already; may appear for GS-1 civil). IFoS exams focus heavily on species-habitat relationships (Sangai+phumdi; Irrawaddy dolphin+Chilika; Black-necked Crane+Tsomoriri).

10.9 MODEL BOOK

Chilika Lake is both India's most important wetland and a model of wetland restoration. Discuss the ecological crisis it faced, the restoration measures taken and its current conservation status.

IFoS Civil | 15 Marks | 200 Words

Chilika Lake — India's largest coastal lagoon (~1,100 sq km, Odisha) and India's FIRST Ramsar site (1981) — is simultaneously one of India's most ecologically significant wetlands and its most celebrated restoration success story.

ECOLOGICAL SIGNIFICANCE

- **India's only Irrawaddy Dolphin Population:** ~148-160 Irrawaddy Dolphins (Orcaella brevirostris) — an endangered cetacean — inhabit Chilika; their status is a direct indicator of lake health.
- **MIGRATORY WATERBIRDS:** ~1 million migratory birds winter here annually (flamingo, pelicans, bar-headed goose); Nalabana Island Sanctuary is the core bird habitat.
- **FISHERIES:** 160+ fish species; 60,000+ fisherfolk dependent on the lake for livelihood.

ECOLOGICAL CRISIS (1970S-1990S):

- **Sea Mouth Closure:** Progressive siltation closed the sea inlet, reducing saline input; the lagoon freshened → seagrass replaced by freshwater vegetation → marine fish could not enter → fish populations crashed → bird food (fish) declined → bird numbers fell → 60,000 fisherfolk impoverished.
- **Additional Stressors:** Agricultural runoff (excess nutrients), aquaculture encroachment on the water spread, invasive water hyacinth, sand mining from the barrier spit.

OPERATION CHILIKA (2000) — THE RESTORATION:

- **Intervention:** The Odisha government, working with SCZMA, dredged a new sea mouth (inlet) at a different location (Satapara), bypassing the silted original mouth; at a cost of just ~Rs.5 crore.
- **Outcome:** Within months, salinity recovered → seagrass recovered → marine fish returned → bird numbers increased → Irrawaddy dolphin population began recovery → fish catch improved → fisher livelihood restored. The lake won the Ramsar Wetland Conservation Award (2002) — one of the world's great conservation stories.

CURRENT STATUS AND ONGOING THREATS: Despite the restoration success, Chilika faces: (1) continuing agricultural runoff causing eutrophication; (2) invasive water hyacinth periodically covers large areas; (3) illegal

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aquaculture within the lake boundary; (4) sea level rise and cyclone intensification threaten the barrier spit; (5) the dolphin population, while recovering, remains at risk from fishing net entanglement. The Chilika Development Authority (CDA) manages conservation with Odisha government and SCZMA backing.

Operation Chilika demonstrates that ecological restoration through targeted hydrological intervention is possible, cost-effective and rapid — but requires sustained governance, community engagement and addressing root causes of degradation.

Discuss the significance of traditional water conservation systems of India with examples from different regions. How can they contribute to water security under climate change?

IFoS Civil (Mains) | 15 Marks | 200 Words

India's traditional water conservation systems represent 2,000+ years of community-developed hydrology — technologies calibrated to local rainfall, soils, topography and social organisation. Their revival is both an ecological imperative and a cultural responsibility.

REGIONAL EXAMPLES

- **Johads (Rajasthan):** earthen check dams trapping seasonal runoff; Rajendra Singh revived ~8,600 johads in Alwar district → 5 dead rivers (Arvari, Ruparel) flowed again → watertable rose → forests revived → Magsaysay Award 2001 and nickname "Waterman of Rajasthan."
- **Stepwells/Baolis (Rajasthan-Gujarat-Delhi):** architectural water storage; Rani ki Vav (UNESCO WHS); Chand Baori — community water commons for groundwater access in pre-pump era.
- **Tank cascades/Eri (Tamil Nadu):** 40,000+ interconnected irrigation tanks; excess water from upper tank flows to lower; community managed; Chennai's flood management would benefit from restoring these upstream.
- **Ahar-Pyne (Bihar):** traditional paddy irrigation; 60,000+ ahars; community governance; revival under MGNREGS in Gaya-Nawada belt.
- **Bamboo drip irrigation (Meghalaya):** 300-year-old technology; gravity-fed; no electricity; FAO Global Agricultural Heritage System 2021.

SIGNIFICANCE FOR CLIMATE CHANGE ADAPTATION:

(1) Distributed water storage: Traditional systems spread storage across thousands of small units, more resilient than single large dams to variable monsoon.

(2) Groundwater recharge: Johads and tanks allow percolation; raise water tables; reduce drought vulnerability more effectively than large surface reservoirs that lose water to evaporation.

(3) Low carbon footprint: Gravity-fed, no electricity, no concrete; sustainable in both construction and operation.

(4) Community ownership: When communities manage their own water, maintenance and conflict resolution are internal — more durable than state-managed infrastructure.

CHALLENGES : Revival requires addressing land ownership (many silted tank beds converted to private agriculture), strengthening Water User Associations legally, and integrating traditional knowledge with modern hydrological science.

Traditional water systems are not "backward" — they are *pre-adapted* to local climate variability. The Jal Shakti Abhiyan's "Catch the Rain" campaign correctly prioritises their revival as India's most cost-effective water security solution.

CHAPTER 11

MINERALS & ENERGY RESOURCES OF INDIA

CHAPTER AT A GLANCE

- India = 2nd largest coal producer (after China); 4th largest reserves (~389 bt geological resources); Coal India Ltd (CIL) produced ~781 MT in FY2024-25 — NOT 900 MT (future target); national total crossed 1,047 MT crossing 1 BT milestone.
- Iron ore: 4th largest reserves globally (~5.5 bt); Haematite (Fe_2O_3, 60-70% Fe) dominant; key belts — Odisha-Jharkhand, Bailadila (CG), Bellary (KA), Goa (SC ban 2018). NMDC = largest producer.
- Copper deficit country — HCL = only miner; Khetri (Rajasthan), Malanjkhand (MP), Singhbhum (JH); Sterlite Copper Thoothukudi CLOSED since May 2018; critical mineral for EVs.
- India petroluem: ~88% import dependence; ~28.7 MT domestic crude FY2024-25; Mumbai High (largest, declining); Assam-Arakan (Digboi 1901 — oldest refinery in Asia); Rajasthan (Mangala oilfield, Cairn/Vedanta); KG Basin (Reliance D6). Jamnagar refinery (Reliance) = world's largest single site.
- Three-stage nuclear programme (Homi Bhabha, 1954): Stage 1 PHWRs (natural U) → Stage 2 FBR (Pu-239; PFBR Kalpakkam core-loaded March 2024) → Stage 3 Thorium/AHWR. India has massive thorium (monazite sands, Kerala-TN).
- Renewable energy: India crossed 200 GW non-fossil (Oct 2024); 500 GW target by 2030; Solar ~150+ GW (Bhadla 2,245 MW); Wind ~47-50 GW; Green Hydrogen Mission (Jan 2023, 19,744 cr, 5 MMT/yr by 2030).
- Critical Minerals: 30-mineral list (Ministry of Mines, June 2023); Lithium (GSI find Reasi J&K 5.9 Mt Feb 2023 — auction FAILED); National Critical Mineral Mission (Jan 2025, 16,300 cr); KABIL sourcing overseas.
- Key conflicts: Niyamgiri-Vedanta (SC 2013-gram sabha); Coalgate (SC 2014, 214 blocks cancelled); Goa iron ore SC ban 2018; Sterlite Copper closure; Sukinda Cr6+ pollution; GIB vs renewables.

11.1 INTRODUCTION — INDIA'S MINERAL ENDOWMENT

India's **mineral endowment is structurally lopsided but substantial** — a geological legacy of its complex history as part of Gondwanaland, its Archaean craton, its Gondwana sedimentary basins and its coastal sand deposits. The country ranks among the **world's top producers of coal, iron ore, bauxite, chromite and manganese**, and is the **world's 2nd-largest crude-steel producer**. Yet in the minerals that define the **21st-century clean-energy economy** — lithium, cobalt, nickel, rare earth elements, copper — India is heavily import-dependent, creating a **strategic mineral-security challenge** that sits at the heart of its Net Zero 2070 journey.

CLASSIFICATION OF MINERALS

Category	*Sub-type*	*Examples*	*India's Status*
Metallic Minerals	Ferrous (iron-bearing)	Iron ore, Manganese, Chromite, Nickel	Abundant iron/Mn/Cr; Ni deficient
Metallic Minerals	Non-ferrous	Copper, Bauxite / Aluminium, Lead, Zinc, Gold, Silver	Bauxite abundant; Copper deficient; Gold scarce
Non-Metallic Minerals	—	Limestone, Mica, Gypsum, Phosphate, Kaolin, Graphite	Mica historically dominant; Graphite emerging
Energy / Fuel Minerals	Fossil	Coal, Lignite, Petroleum, Natural Gas	Coal rich; Petroleum import-dependent

Atomic Minerals	—	Uranium, Thorium, Beryllium, Zirconium, Lithium	Thorium abundant; Uranium limited; Li scarce
Critical Minerals (2023 list)	Clean-energy transition	Lithium, Cobalt, Nickel, REEs, Graphite, Vanadium, PGMs, 30 total	Most severely deficient; strategic import/overseas sourcing needed

INDIA'S GEOLOGICAL ENDOWMENT — THE RESOURCE MAP

Geological Terrain / Age	*Minerals*	*Key Regions*
Archaean/Precambrian Cratons (>2,500 Ma)	Iron ore (BIF), Manganese, Gold, Copper, Chromite, Nickel, Mica	Singhbhum (JH), Dharwar craton (KA), Bastar craton (CG-OD), Bundelkhand (UP-MP)
Gondwana Sedimentary Basins (Permian, ~250-300 Ma)	Coal (98% of India's reserves); Gondwana coal is the best quality	Damodar valley (JH-WB), Mahanadi valley (CG-OD), Godavari valley (TS-AP), Son valley (MP), Wardha valley (MH)
Deccan Trap Basalts (~66 Ma, Cretaceous)	Laterite capping → Bauxite; parent rock for black soil	Maharashtra, Karnataka, Chhattisgarh plateau margins
Sedimentary / Petroleum Basins (Mesozoic-Cenozoic)	Crude oil, Natural gas, Lignite	Mumbai High (Arabian Sea), Assam-Arakan, Cambay (GJ), Rajasthan, KG Basin (AP)
Coastal Monazite Sands (Recent)	Thorium, REE (Lanthanides), Ilmenite (Ti), Zircon, Rutile, Sillimanite	Kerala (Chavara), Tamil Nadu (Manavalakurichi), AP (Bhimunipatnam), Odisha (Chhatrapur)
Tertiary Beds (Oligocene-Miocene, 15-60 Ma)	Lignite, Tertiary coal (poorer quality), Petroleum (Assam)	NE India, Tamil Nadu (Neyveli), Rajasthan (Barmer lignite)

KEY INSTITUTIONS

Institution	*Established*	*HQ*	*Role*
Geological Survey of India (GSI)	1851	Kolkata	National geological mapping; mineral exploration; National Mineral Inventory; under Ministry of Mines; oldest such organisation in the world (after British Geological Survey)
Indian Bureau of Mines (IBM)	1948	Nagpur	Mineral statistics; conservation; inspection of non-coal, non-atomic mines; maintains IBM Annual Report on minerals
Mineral Exploration & Consultancy Ltd (MECL)	1972	Nagpur	Mineral exploration PSU; G2/G3 exploration drilling; critical partner in KABIL for overseas mineral assessment
KABIL (Khanij Bidesh India Ltd)	2019	Noida	JV of NALCO + HCL + MECL; acquires critical mineral assets overseas (Argentina, Australia, Chile, Zambia)
Ministry of Mines	—	New Delhi	Policy, GSI, IBM, NALCO, HCL, MECL, KABIL; MMDR Act implementation
Ministry of Petroleum & Natural Gas	—	New Delhi	ONGC, OIL, GAIL, IOC/BPCL/HPCL; E&P policy; refinery regulation

LEGAL AND POLICY FRAMEWORK

- **MMDR Act 1957 (Mines and Minerals Development and Regulation Act):** the principal mining legislation.
  - **2015 Amendment:** mandatory auction of mineral concessions (replaced first-come-first-served);

District Mineral Foundation (DMF) in every mining district; **PMKKKY (PM Khanij Kshetra Kalyan Yojana)**; NMET (National Mineral Exploration Trust).

- **2021 Amendment:** removed end-use/captive restrictions; composite licence (exploration + mining in one); private companies can sell surplus from captive mines; eased lease transfers.
- **2023 Amendment:** "deep-seated" and critical minerals (including lithium) placed under central-government auction; new "exploration licence" category for early-stage exploration.

- **National Mineral Policy (NMP) 2019:** replaced 2008 policy; promotes private investment, sustainable mining, zero-waste mining, science-and-technology application; includes the inter-generational equity principle.
- **Forest (Conservation) Act 1980 (amended 2023):** Stage I and Stage II forest clearances mandatory before any mining in forest land.
- **EIA Notification 2006:** mandatory Environmental Impact Assessment and public hearing for Category A (major) and Category B mines.

KEY NOTE

District Mineral Foundation (DMF) + PMKKKY : The DMF is a non-profit trust constituted in every district with active mining, funded by contributions from mine lease holders (a % of royalty). It spends on welfare of mining-affected communities under PMKKKY — covering health, education, women & child development, drinking water, environmental protection and skill development. As of 2024, ~₹80,000+ crore has been credited to DMFs nationally. This is a recurring Civil GS-2/GS-3 topic on localised governance and benefit-sharing from extractive industries.

11.2 IRON ORE

Iron ore is the **foundation of India's steel industry and an important export earner**. India holds the **4th-largest iron-ore reserves globally (~5.5 billion tonnes of resources)** and is a top-3 or top-4 producer, with FY2024-25 production exceeding 280 million tonnes. However, **Supreme Court interventions** — the Bellary ban (2011), Goa bans (2012 and 2018) — and environmental concerns around Gondwana-forest mining have periodically constrained the sector.

TYPES OF IRON ORE

Type	*Chemical Formula*	*Fe Content*	*Character*	*Distribution in India*
Haematite	Fe_2O_3	60-70%	Red ore; dominant in India; relatively easy to beneficiate; can be used directly in blast furnaces	Odisha-Jharkhand belt, Chhattisgarh (Bailadila), Karnataka (Bellary-Hospet), Goa
Magnetite	Fe_3O_4	Up to 72% (highest Fe)	Black ore; magnetic; highest iron content; requires more energy to process; harder	Tamil Nadu (Salem, Tirunelveli), Karnataka (Kudremukh — now stopped), AP
Limonite	$2Fe_2O_3 \cdot 3H_2O$	40-60%	Yellow-brown; hydrated iron oxide; lower grade; limited significance in India	Scattered minor deposits
Siderite	$FeCO_3$	~48%	Iron carbonate; requires roasting to remove CO_2; rarely mined in India	Minor; Rajasthan, Odisha fringes

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BHQ/BIF (Banded Haematite Quartzite)	Mixed Fe-silica	30-45% (needs beneficiation)	India's FUTURE RESERVE — low-grade ore requiring beneficiation (washing/flotation); massive volumes available	Odisha-Jharkhand; Chhattisgarh (large BHQ reserves in Bailadila area)

MAJOR DEPOSITS — DETAILED

1. ***Odisha-Jharkhand Belt (Largest)***

   The **Singhbhum-Keonjhar-Sundargarh belt** is India's richest iron-ore zone. Key mines: **Kiriburu, Meghahatuburu (Jharkhand)**; **Banspani, Daitari, Joda, Barbil, Barsua, Bolani, Barajamda, Noamundi (Odisha)**. Most mines supply ore to **SAIL plants (Rourkela, Durgapur)** and private steel companies. The ore is high-grade haematite (62-65% Fe). The Odisha coal-iron ore belt also overlaps with the **Saranda Sal forest** — Asia's largest Sal Forest — creating chronic mining-vs-forest conflicts, especially in the Singhbhum-Saranda area (Jharkhand).

2. ***Chhattisgarh (Bailadila Range)***

   The **Bailadila range in Dantewada district (Bastar, Chhattisgarh)** contains very high-grade haematite (~66% Fe, "Direct Shipping Ore"). Operated by **NMDC (National Mineral Development Corporation)** — India's largest iron-ore producer (a PSU under Ministry of Steel/Mines). Ore is transported by **dedicated 140 km railway (Kirandul-Jagdalpur-Visakh corridor)** to Visakhapatnam port for export (mainly to Japan and South Korea). **Dalli-Rajhara (Durg district)** feeds the **Bhilai Steel Plant (SAIL)** — a second Chhattisgarh deposit. These deposits lie in the **tribal (Adivasi) heartland of Bastar**, overlapping with Maoist/LWE influence areas — a major governance challenge.

3. ***Karnataka (Bellary-Hospet)***

   The **Bellary-Hospet-Sandur belt (Tungabhadra basin)** is Karnataka's most important iron-ore zone. It was the epicentre of **India's largest illegal mining scandal** — the **"Bellary mining scandal"** (investigated by the Karnataka Lokayukta; the "Reddy brothers" — Y.S. Jaganmohan Reddy's B.S. Yeddyurappa-era; Janardhan Reddy). The **Supreme Court in April 2011** imposed a **total ban on iron-ore mining in Bellary, Tumkur and Chitradurga districts**, later allowing partial resumption only for Category A mines. **Kudremukh (Chikmagalur, Karnataka)** — magnetite ore in a national park — had mining stopped in 2005 following SC orders upholding environmental protection.

4. ***Goa***

   Goa was historically India's **largest iron-ore exporter** — mostly to Japan and China via Mormugao Port (low-grade fines, 55-58% Fe). The **Supreme Court's February 2018 judgment in the Goa Foundation case quashed 88 mining leases in Goa** that had been renewed without following the mandatory auction process under the MMDR 2015 amendment. Mining stopped in March 2018. Selective re-auction of blocks has been attempted (2022-24 onwards) but output remains a fraction of historic levels.

Parameter	*NMDC (National Mineral Development Corporation)*
Type	PSU (Navratna); operates under Ministry of Steel
Flagship mines	Bailadila Complex (Chhattisgarh, 5 deposits); Donimalai (Karnataka)
Production (FY2024-25)	~44 million tonnes (MT); India's single largest iron ore producer
Significance	Supplies ore to Bhilai (SAIL), Rashtriya Ispat Nigam (Visakhapatnam), and private exports
Integrated Steel Plant	NMDC is also building its own integrated steel plant at Nagarnar (Bastar, CG) — 3 MTPA; commissioned 2024

ENVIRONMENTAL AND TRIBAL CONFLICTS

- **Saranda Forest-Mining Conflict (Jharkhand):** Saranda is reputed as Asia's largest Sal forest; it sits atop major iron-ore deposits; mining and exploration approvals within Saranda have been contested by tribal communities and conservationists; the Moolvasi Bachao Manch and other tribal groups protest loss of forest rights.
- **BHQ future challenge:** As high-grade haematite lumps deplete, India must develop **beneficiation technology** (pelletisation, sintering) to use BHQ fines — critical for long-term steel self-sufficiency.
- **Export controls:** India imposes a **30% export duty** on iron-ore lumps and a **50% duty on pellets** (rates are adjusted periodically) to prioritise domestic steel and conserve reserves.

11.3 MANGANESE

Manganese (Mn) is to steel what salt is to food — even small additions (1-14%) **dramatically improve steel's strength, hardness, toughness and wear resistance**. It is also **essential for lithium-manganese-based EV battery cathodes** (LMNO/LMFP chemistries), making it a critical mineral for the energy transition.

Parameter	*Detail*
Total resources	~496 million tonnes (IBM National Mineral Inventory)
Global rank	~7th in resources
Largest deposit state	Odisha (Bonai-Barajamda belt, Sundargarh, Keonjhar, Sundergarh) — India's largest Mn zone
Other major states	Maharashtra (Nagpur-Bhandara-Gondia), Madhya Pradesh (Balaghat — Lohangi, Bhagwanpur), Karnataka (Shimoga-Bellary-Tumkur), Andhra Pradesh (Srikakulam, Vizianagaram)
Principal PSU	MOIL Ltd (Manganese Ore India Ltd) — listed Miniratna PSU; HQ Nagpur; largest manganese ore mining company in India; operates mines in Maharashtra and Madhya Pradesh
Primary use (current)	~90% in steel as ferro-manganese (Fe-Mn) and silico-manganese (Si-Mn) — de-oxidiser and de-sulphuriser in steel making
Emerging use	LMNO (Lithium Manganese Nickel Oxide) and LMFP (Lithium Manganese Iron Phosphate) EV battery cathodes; recognised in India's 30-mineral critical list (2023)
Self-sufficiency	Broadly self-sufficient for domestic steel industry; modest exporter

KEY NOTE

Exam Tip — Manganese and EV Battery Link : LMNO ($Li_2MnO_3 \cdot LiMO_2$, M = Ni) cathode chemistry is a promising cobalt-free alternative for EV batteries. India's significant manganese reserves make this relevant to critical-mineral strategy. A 2024-25 Civil Mains answer on critical minerals should reference manganese's dual role — steel and battery.

11.4 COPPER — INDIA'S FOUNDATIONAL DEFICIT

Copper is the **most important electrification metal** — every EV uses ~83 kg of copper (vs ~23 kg in an ICE vehicle); every solar panel, wind turbine and EV charging point requires far more copper than its fossil equivalent. **India's domestic copper production meets less than 5% of its demand**, making copper a critical vulnerability in India's clean-energy transition.

DEPOSITS AND THE HINDUSTAN COPPER LTD (HCL) MONOPOLY

Deposit	*Location*	*Type*	*Status / Notes*
Mosaboni, Rakha,	Singhbhum district, Jharkhand	Underground mines; Singhbhum Copper Belt; Cu-U associated mineralization	Most important copper deposits; operated by HCL; output declining; old mines

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Kendadih, Surda, Dhobani			
Khetri-Kolihan	Jhunjhunu district, Rajasthan — "Copper City of India"	Underground; lower grade; old but historically iconic	HCL; declining output; copper city with its own copper smelter at Khetri
Malanjkhand	Balaghat district, Madhya Pradesh	Large opencast mine; ~0.98% Cu average grade — India's largest single deposit by reserves	HCL; most modern operations; principal current producer

- **Hindustan Copper Limited (HCL):** the **ONLY copper-mining company in India** (public sector, under Ministry of Mines); HQ Kolkata; integrated from mining through smelting/refining at its own plants.
- **India's total ore resources:** ~2.36 billion tonnes of copper ore (IBM) — but with very low Cu content; actual recoverable copper very limited.

THE STERLITE COPPER CRISIS — A CRITICAL CASE STUDY

Until May 2018, **Vedanta's Sterlite Copper plant at Thoothukudi (Tuticorin), Tamil Nadu** was India's **largest copper smelter** — producing ~400,000 tonnes/year of refined copper (nearly 40% of India's supply). On **May 28, 2018**, the Tamil Nadu Pollution Control Board **permanently closed the plant** after decade-long concerns about fugitive SO_2 emissions, groundwater contamination and police firing incident (13 anti-pollution protesters killed on May 22, 2018). The **Supreme Court (December 2024)** declined to order its reopening. India has since become a net copper importer, and **copper smelting capacity is a critical bottleneck** in India's EV supply chain.

ENV ALERT

Sterlite Closure — Consequences for India's EV/RE Transition

- India's refined copper output fell from ~900,000 t/yr to ~500,000 t/yr after the closure.
- India imports copper concentrate from Chile, Australia and Peru and copper cathode from global suppliers, worsening the trade deficit.
- Every GW of solar/wind capacity requires 3,000-4,000 tonnes of copper; every million EVs require ~83,000 tonnes. Without copper, the energy transition cannot proceed.
- Hindalco (Birla), KABIL and Adani are exploring new copper capacities to fill the gap.

11.5 BAUXITE — INDIA'S ALUMINIUM FOUNDATION

Bauxite is the ore of aluminium — **$Al(OH)_3$ (gibbsite) or AlO(OH) (boehmite/diaspore)**. India holds approximately **3.9 billion tonnes of bauxite resources (~5th globally)**. Indian bauxite is largely of the **gibbsite type** (easy to refine), concentrated in **laterite-capped Eastern Ghats plateaus**.

DEPOSITS

Region	*State*	*Key Area*	*Notes*
Eastern Ghats (largest)	Odisha	Koraput, Kalahandi, Rayagada — Niyamgiri, Panchpatmali, Pottangi, Baphlimali	NALCO's flagship Panchpatmali mine feeds its Damanjodi refinery; Niyamgiri is the Vedanta controversy site
Chhota Nagpur	Jharkhand	Lohardaga, Gumla, Ranchi, Palamu	Good quality; HZL and NALCO interests
Satpura / Amarkantak	Chhattisgarh	Amarkantak plateau (Anuppur, Bilaspur)	BALCO (Vedanta subsidiary) operations
Western Deccan	Gujarat / Maharashtra	Jamnagar; Kolhapur, Ratnagiri	Moderate reserves

THE NIYAMGIRI-VEDANTA CASE — LANDMARK FRA/PESA VERDICT

The **Niyamgiri hills (Kalahandi-Rayagada, Odisha)** contain significant bauxite reserves coveted by **Vedanta Resources / Sterlite Industries**. The **Dongria Kondh tribe** of Niyamgiri consider the hill sacred — their deity **"Niyam Raja"** is believed to reside there; their traditional forest rights and livelihoods depend on the hill's forests and streams. In **2013**, the Supreme Court in *Orissa Mining Corporation v. MoEFCC* ordered that **12 gram sabhas (village assemblies) of the Dongria Kondh and Kutia Kondh conduct votes** on whether to accept or reject the mining proposal. All 12 gram sabhas **unanimously rejected mining**, citing: violation of FRA 2006 rights (community forest resources), PESA 1996 rights (gram sabha consent in Scheduled Areas), and violation of their religious and cultural identity. The government refused the mining permit. **This is the definitive case in Indian jurisprudence on community-over-mineral-rights**.

IFoS FOCUS

IFoS / CIVIL GS-2 — NIYAMGIRI SIGNIFICANCE: (1) First use of gram sabha as the final arbiter of mineral rights in a tribal area; (2) established that **FRA 2006 + PESA 1996** create a prior-informed-consent (PIC) mechanism for forest-dwelling communities; (3) demonstrates that India has legal tools to protect tribal rights over minerals — the challenge is implementation at scale; (4) contrast with the cases where FRA/PESA clearances are obtained nominally without genuine consent.

ALUMINIUM VALUE CHAIN

Stage	*Process*	*Energy Requirement*	*India's Players*
Mining	Bauxite extracted from laterite plateaus (open cast)	Low	NALCO (Panchpatmali), BALCO (Bodai-Daldali), Hindalco
Refining (Alumina)	Bayer process: NaOH dissolves Al hydroxide; red mud (toxic waste) = by-product; calcined to Al_2O_3	Medium	NALCO (Damanjodi, Odisha); Hindalco (Muri, Jharkhand); Vedanta/BALCO
Smelting (Aluminium)	Hall-Heroult electrolysis: Al_2O_3 + molten cryolite → Al metal; very electricity-intensive (~14-15 MWh / tonne)	VERY HIGH (electricity-intensive)	NALCO (Angul smelter, ~460,000 t/yr); Hindalco (Renukoot, UP; ~345,000 t/yr); BALCO (Korba, ~325,000 t/yr)

India is self-sufficient in aluminium and a significant exporter. **Red mud (bauxite residue)** — the toxic, highly alkaline by-product of the Bayer process — is a major environmental challenge. NALCO has been exploring red-mud utilisation for cements, tiles and road-filling.

11.6 GOLD — INDIA'S CONSUMPTION GIANT, PRODUCTION PYGMY

India is the world's **2nd-largest consumer of gold** (~700-900 tonnes/year) but produces only **~1-2 tonnes domestically** — an extraordinary asymmetry that contributes significantly to India's **Current Account Deficit (CAD)**. Gold is both a cultural necessity (weddings, religious worship) and a financial reserve asset in Indian households.

Deposit / Location	*State*	*Status / Key Notes*
Kolar Gold Fields (KGF)	Kolar district, Karnataka	Historically India's richest; mined from 1880s; depths >3,000 m (among world's deepest); operated by Bharat Gold Mines Ltd (BGML, under Ministry of Mines); CLOSED in February 2001 (deemed uneconomical when gold prices were low); gained global fame from "KGF" Kannada film franchise; reopening occasionally discussed

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Hutti Gold Mines	Raichur district, Karnataka	ONLY operating major gold mine; Hutti Gold Mines Ltd (HGML, Karnataka state PSU); produces ~2-3 tonnes/year; underground mine; ~4-6 g/tonne ore grade
Hira-Buddini / Ramgiri	Andhra Pradesh	Small deposits; ~1 tonne/year total capacity
Sonbhadra (UP) — Media Episode	Uttar Pradesh	In 2020, media reported "3,350 tonnes" of gold reserves; GSI clarified actual is ~160 kg recoverable gold — a massive misreport; illustrates importance of verifying GSI's G4 (historical data) vs G1 (measured) resource categories

KEY NOTE **Import Duty Cut (Budget 2024) :** The Union Budget 2024-25 (FM Nirmala Sitharaman) cut customs duty on gold from 15% to 6% (gold) and 5.4% (silver) — to reduce smuggling, boost jewellery exports and formalise the market. India exports ~$10-11 billion worth of gold jewellery annually; GST is separately applicable.

11.7 COAL — INDIA'S ENERGY BACKBONE

Coal is the **single most important mineral in India's energy economy** — generating approximately **72-74% of India's electricity** and providing the entire coking coal requirement of its steel industry. India is the **world's 2nd-largest coal producer after China** and the **3rd-largest consumer**. FY2024-25 was historic: India's total coal production crossed **1 billion tonnes (1,047 MT)** for the first time, with **Coal India Limited (CIL)** producing ~781 MT and non-CIL (captive + commercial) producers the rest. CIL's much-cited **"900 MT target"** is a **future production goal (FY2025-26 and beyond), NOT the current figure**.

CIL — COAL INDIA LIMITED

Parameter	*Detail*
Status	World's largest coal producer; Maharatna PSU; listed on BSE/NSE; Ministry of Coal
HQ	Kolkata (Coal Bhavan)
Production FY2024-25	~781 MT (the "900 MT" is a future annual target for FY2025-26)
Subsidiaries (7 producing)	ECL (Eastern Coalfields, WB-JH), BCCL (Jharkhand), CCL (Central Coalfields, JH), NCL (Northern Coalfields, MP), WCL (Western Coalfields, MH-MP), SECL (S.E. Coalfields, CG-MP), MCL (Mahanadi, OD-CG); plus CMPDIL (survey & design)
Reserves under CIL	~100+ billion tonnes (geological resources)

GEOLOGICAL CLASSIFICATION OF INDIAN COAL

Type	*Age*	*Quality*	*Reserves*	*Location*
Gondwana Coal	Permian (~250-300 Ma)	Better quality; ranges from coking (metallurgical) to thermal; higher rank	~98% of India's total coal resources (~389 bt geological; ~148 bt proved)	Peninsular river valleys: Damodar, Mahanadi, Godavari, Son, Wardha
Tertiary Coal	Oligocene-Miocene (~15-60 Ma)	Poorer quality; high moisture; high sulphur; low rank (sub-bituminous to lignite)	~2% of reserves	NE India (Assam, Meghalaya, Nagaland, Arunachal)
Lignite (Brown Coal)	Miocene (~5-23 Ma)	Lowest rank; ~20-35% moisture; lowest calorific value; restricted to specific areas	Neyveli (TN) — significant; Rajasthan, Gujarat	Neyveli (TN), Barmer-Nagaur (Rajasthan), Kutch (Gujarat)

MAJOR COALFIELDS — DETAILED

Damodar Valley — India's Coal Capital

The **Damodar River valley** (West Bengal and Jharkhand) is the heartland of Indian coal — the **most densely mined coalfield region** in India, responsible for most of India's coking coal.

Coalfield	*State*	*Subsidiary*	*Key Feature*
Jharia Coalfield	Jharkhand (Dhanbad)	BCCL (Bharat Coking Coal Ltd)	India's LARGEST coalfield; ONLY source of PRIME COKING COAL in India; coking coal quality = best for blast furnace steel-making; FAMOUS FOR UNDERGROUND MINE FIRES — burning for 100+ years; ground subsidence; ~96,000 families in affected zones; BCCL Jharia Master Plan for relocation
Raniganj Coalfield	West Bengal (Paschim Bardhaman)	ECL (Eastern Coalfields Ltd)	India's OLDEST coalfield (commercial mining since 1774 by East India Company); thermal coal; some underground fires; heritage status under debate
Bokaro Coalfield	Jharkhand (Bokaro)	CCL (Central Coalfields Ltd)	Coking and thermal coal; near Bokaro Steel Plant
Karanpura Coalfield	Jharkhand	CCL	Large reserves; partly developed

Mahanadi Valley

Coalfield	*State*	*Subsidiary*	*Key Feature*
Talcher Coalfield	Odisha (Angul)	MCL (Mahanadi Coalfields Ltd)	Very large thermal coal deposits; feeds Talcher Thermal Power Plant; coal-to-methanol plant planned; Mahanadi river valley
IB Valley Coalfield	Odisha-Chhattisgarh (Jharsuguda-Raigarh)	MCL and SECL	Significant coal; overlaps with tribal forest areas; transport bottleneck
Korba Coalfield	Chhattisgarh (Korba)	SECL (South Eastern Coalfields Ltd)	Major; feeds NTPC Korba and multiple thermal stations; Korba = "Energy Capital of Chhattisgarh"

Other Important Coalfields

Coalfield	*State/Region*	*Company*	*Key Note*
Wardha Valley	Maharashtra, MP (Yavatmal, Amravati, Nagpur)	WCL (Western Coalfields Ltd)	Thermal coal; feeds Chandrapur, Koradi, Khaparkheda plants in MH; overlaps with Vidarbha cotton-farming zone
Singareni Collieries	Telangana-AP (Godavari valley; Khammam, Mancherial, Bhadradri-Kothagudem)	SCCL (Singareni Collieries Company Ltd)	Only major non-CIL coal producer; joint Telangana State (51%) + Centre (49%) company; critical for southern power plants (Thermal Power Corp TN, APGENCO, TSGENCO)
Son Valley (Johilla, Umaria, etc.)	Madhya Pradesh, Chhattisgarh	NCL (Northern Coalfields) and SECL	Thermal coal; Son river valley area; North MP-CG border region
NE India (Assam, Meghalaya, Nagaland, Arunachal)	Assam, Meghalaya, Nagaland	Coal India subsidiaries + state agencies	Tertiary coal; high sulphur; poor quality; Meghalaya "Rat-hole mining" — banned by NGT (2014), partially lifted; environmental and safety disaster

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Lignite — Neyveli, Tamil Nadu

The **Neyveli Lignite fields (Cuddalore, Tamil Nadu)** are India's most important lignite deposit — brown coal used entirely for **pit-head thermal power generation (1,500+ MW)** by **NLC India Ltd (formerly Neyveli Lignite Corporation)** — a Navratna PSU. Lignite at Neyveli is at shallow depth (30-90 m), mined by **open-cast (strip) mining**. Rajasthan also has significant lignite in **Barmer, Nagaur and Bikaner** districts — under development for power and chemical use.

COAL POLICY — KEY DEVELOPMENTS

Event / Policy	*Year*	*Significance*
Nationalisation of Coal Mines	1973	Private coal mines nationalised; CIL formed 1975; state monopoly established to end exploitation
MMDR Act 1957 (coal provisions)	1957 / amended	Coal mines governed by Mines Act 1952 + MMDR Act; DGMS for safety
Coalgate / Coal Block Allocation Scam (SC judgment)	2014	Supreme Court cancelled 214 of 218 coal blocks allocated 1993-2014 as arbitrary/illegal; CBI prosecutions; ~₹10+ lakh crore estimated loss to exchequer (CAG report, contested)
Commercial Coal Mining Opens to Private Sector	2020	Government opened commercial coal mining (mines can mine and sell freely) for private companies; 41 blocks in first auction; major reform ending the captive-use-only system
COP26 "Phase Down" of Coal	2021	India (along with China/others) negotiated change of Glasgow Pact text from "phase out" to "phase down" unabated coal; India argues it has a right to use coal for development; "common but differentiated responsibilities" (CBDR) principle
Commercial coal auctions (ongoing)	2021-25	Multiple rounds of coal-block auctions; gradually more private players entering; CIL production target set for 1 BT by FY2025-26

ENV ALERT

Jharia Mine Fires — India's Oldest Environmental Disaster

The Jharia coalfield of Dhanbad (Jharkhand) has **underground coal fires burning for over a century**, caused by spontaneous combustion of exposed coal seams. Consequences: (1) methane and CO_2 release; (2) ground subsidence — homes and roads collapse; (3) the city of Dhanbad sits above burning seams; (4) severe health impacts (respiratory disease, cancer risk) for ~600,000 inhabitants of the affected zone; (5) loss of coal reserves. The BCCL-CMPDI "Master Plan" / "Jharia Action Plan" envisages relocation of ~96,000+ families to Belgaria township; progress has been extremely slow due to land and financial constraints. An NGT monitoring committee tracks the situation.

11.8 PETROLEUM AND NATURAL GAS

India's **import dependence for crude oil is ~88%** (FY2024-25 domestic production ~28.7 MT vs imports ~200+ MT). India is the **world's 3rd-largest oil consumer and importer**. The gap between domestic production (declining) and demand (rising) makes energy security the central challenge of India's economic policy.

KEY COMPANIES

Company	*Type*	*Key Role*
ONGC (Oil and Natural Gas Corporation)	Maharatna PSU; largest E&P company	Operates Mumbai High, KG basin, Assam, Rajasthan fields; offshore dominant
Oil India Ltd (OIL)	Navratna PSU; 2nd E&P company	Primarily Assam-Arunachal region; Digboi fields; NE India specialist

Indian Oil Corporation (IOCL)	Maharatna; largest refiner/marketer	Panipat, Mathura, Barauni, Haldia, Guwahati, Paradip refineries; Digboi
BPCL (Bharat Petroleum)	Navratna; refiner+marketer	Mumbai, Kochi, Bina, Numaligarh refineries; Petronet LNG partner
HPCL (Hindustan Petroleum)	Navratna; refiner+marketer	Mumbai, Visakhapatnam refineries; HRRL (Pachpadra) joint venture
GAIL (Gas Authority of India)	Maharatna; gas transmission	National gas pipeline grid (~20,000 km); CNG/PNG; GAIL Gas
Petronet LNG	JV; LNG importer	Dahej (Gujarat) largest LNG terminal; Kochi terminal
Reliance Industries Ltd (RIL)	Private; largest private O&G+refining	KG-D6 gas block; Jamnagar refinery complex (world's largest single-site)
Cairn/Vedanta	Private; Rajasthan E&P	Mangala oilfield, Barmer — largest private onshore field

MAJOR PETROLEUM BASINS

Basin	*Type*	*Key Fields*	*Production Status*
Mumbai High (Western Offshore, Arabian Sea)	Offshore; ONGC	Mumbai High North/South, Bassein, Heera, Panna-Mukta-Tapti, Ratna	India's LARGEST producing zone historically; production peaked 1980s (~40 MT/yr); now ~12 MT/yr and declining; ONGC investing in enhanced recovery (polymer flooding, CO2 EOR)
Assam-Arakan Basin (Upper Assam)	Onshore; OIL + ONGC	Digboi (since 1889), Naharkatiya, Moran, Hugrijan, Sibsagar, Jorhat	DIGBOI: Asia's oldest oilfield (commercial production 1889); India's first refinery (IOCL Digboi, 1901, still operating); modest output; OIL's core area
Cambay (Khambhat) Basin, Gujarat	Onshore; ONGC + private	Ankleshwar, Kalol, Mehsana, Gandhar, Sanand, Wasna	2nd most important onshore basin; ~5 MT/yr; Gujarat's petroleum backbone
Rajasthan Basin (Barmer-Sanchore)	Onshore; Cairn/Vedanta + ONGC	Mangala, Bhagyam, Aishwariya, Saraswati fields	Discovered by Cairn India (2004); Mangala = India's largest onshore field; ~25,000 bbl/day; waxy crude requires heated pipelines; HRRL refinery to process locally
Krishna-Godavari (KG) Basin, AP	Offshore + onshore; ONGC + Reliance	D1-D3 (ONGC), D6 "R" series (Reliance), deepwater blocks	Major gas (Reliance D6 controversy — production decline, pricing dispute); ONGC's KG-DWN-98/2 developing; India's most important future gas basin
Cauvery Basin (Tamil Nadu)	Offshore + onshore; ONGC	Narimanam, Ravva (on boundary with KG)	Modest; some gas; less significant than Mumbai High or KG

MAJOR REFINERIES

Refinery	*Location*	*Owner*	*Capacity (approx.)*	*Key Note*
Jamnagar Refinery Complex	Jamnagar, Gujarat	Reliance Industries	~70 MMTPA (2 refineries combined;	WORLD'S LARGEST SINGLE-SITE REFINERY COMPLEX; integrates

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			~1.24 million bbl/day)	petrochemicals; major exporter of petroleum products
HPCL Rajasthan Refinery (HRRL / Pachpadra)	Pachpadra, Barmer, Rajasthan	HPCL (74%) + Rajasthan Govt (26%)	9 MMTPA	UNDER COMMISSIONING (target 2024-25); first refinery to process Rajasthan's waxy Mangala crude locally
Panipat Refinery	Panipat, Haryana	IOCL	25 MMTPA	Integrated with petrochemicals; major NCR supply
Paradip Refinery	Paradip, Odisha	IOCL	15 MMTPA	Newest major IOCL refinery (commissioned 2016); East India supply
Numaligarh Refinery	Numaligarh, Assam	BPCL (61.6%), ONGC, GoI	~3 MMTPA → expansion to 9 MMTPA	Strategic for NE India; processes Assam crude; pipeline to Siliguri
Kochi Refinery	Kochi, Kerala	BPCL	15.5 MMTPA	Receives LNG from Kochi LNG terminal; supplies Kerala and South India
Digboi Refinery	Digboi, Assam	IOCL	~0.65 MMTPA	OLDEST REFINERY IN INDIA / ASIA (since 1901); smallest; heritage value; processes local Assam crude

STRATEGIC PETROLEUM RESERVE (SPR)

Location	*Capacity (MMT)*	*Operator*	*Status*
Visakhapatnam, Andhra Pradesh	1.33 MMT	ISPRL / HPCL	Commissioned; underground rock caverns
Mangaluru, Karnataka	1.5 MMT	ISPRL	Commissioned
Padur, Karnataka	2.5 MMT	ISPRL	Commissioned; total Phase I = 5.33 MMT (~9.5 days of consumption)
Chandikhol, Odisha	4.0 MMT (Phase II)	ISPRL	Under construction
Padur Phase II, Karnataka	2.5 MMT (Phase II)	ISPRL	Under planning

KEY NOTE

KG Basin Gas Controversy : Reliance Industries' D6 block produced 60+ MMSCMD of gas in 2010, transforming India's gas market. But production fell sharply by 2012 due to geological complexity; ONGC alleged "gold-plating" and undisclosed production; the gas-pricing dispute went to arbitration. The pricing formula itself (HELP 2016) was repeatedly revised. The D6 "R" series deep-water discovery (2018-22) announced a revival — a likely GS-3 question on energy governance.

NATURAL GAS AND LNG

India produces ~36 BCM/year of natural gas (FY2024-25) — about 50% of requirements; the rest is met by LNG imports. India has set a goal of raising gas's share of the energy mix from ~6% to **15% by 2030**. Key LNG terminals: Dahej (Petronet, ~17.5 MMTPA — largest), Hazira (Shell-Total), Dabhol (GAIL), Kochi (Petronet), Ennore (IOCL), Mundra, Jafrabad. LNG suppliers: Qatar (largest), USA, Australia, UAE. **GAIL's national gas grid (~20,000 km)** connects production centres with consuming states. City Gas Distribution (CGD) — CNG for vehicles and PNG for homes — covers 287 Geographical Areas under PNGRB licences.

11.9 NUCLEAR ENERGY — INDIA'S THREE-STAGE PROGRAMME

India's nuclear power strategy is unlike any other nation's — it is designed around India's specific **resource reality: limited uranium but among the world's largest thorium reserves**. The **Three-Stage Nuclear Power Programme** — conceived by **Dr. Homi Jehangir Bhabha in 1954** — is a sequential system where the output (fuel/material) of each stage feeds the next.

STAGE 1 — PRESSURISED HEAVY WATER REACTORS (PHWR)

Stage 1 PHWRs use **natural uranium (only 0.7% U-235)** as fuel and **heavy water (D_2O)** as moderator and coolant. They produce electricity AND generate **plutonium-239 (Pu-239)** in the spent fuel — which is the input for Stage 2.

Plant	*State*	*Type*	*Capacity*	*Notable*
Tarapur Atomic Power Station (TAPS)	Maharashtra	BWR (1+2); PHWR (3+4)	540 MW	India's FIRST nuclear power plant (1969); Unit 1+2 built with US assistance; still operating after 50+ years
Rawatbhata (RAPS)	Rajasthan	PHWR	1,180 MW	Rajasthan Atomic Power Station; oldest PHWR complex
Narora (NAPS)	Uttar Pradesh	PHWR	440 MW	Narora Atomic Power Station; Bulandshahr
Kakrapar (KAPS)	Gujarat	PHWR	440 MW + 700 MW (3+4 new)	New 700 MW units added 2020-23 — India's largest indigenous PHWRs
Kaiga (KGS)	Karnataka	PHWR	880 MW	Kaiga Nuclear Power Station; Karwar; longest continuous run record held
Kudankulam (KKNPP)	Tamil Nadu	VVER-1000 (Russian light water)	2,000 MW (Phase I); 2,000 MW (Phase II under construction)	Russia-India collaboration; first unit 2013; phase III-VI planned (total 6 units = 6,000 MW)

STAGE 2 — FAST BREEDER REACTORS (FBR)

Stage 2 uses **Pu-239 (from Stage 1 spent fuel)** combined with a blanket of **U-238 (depleted uranium)**. The reactor "breeds" more fissile Pu-239 than it consumes — a **"breeder"**. The **Prototype Fast Breeder Reactor (PFBR, 500 MW)** at **Kalpakkam (Tamil Nadu)** — operated by **BHAVINI (Bharatiya Nabhikiya Vidyut Nigam Ltd)** — saw its **core loaded with plutonium-uranium mixed oxide (MOX) fuel in March 2024** — a landmark moment in India's nuclear history. First criticality is expected to follow; full commercial operation is the next milestone.

STAGE 3 — THORIUM-BASED REACTORS

Stage 3 uses **Th-232 (thorium)** → irradiated in Stage 2 FBR → converts to **U-233 (fissile)** → used in **Advanced Heavy Water Reactors (AHWR)** alongside Th-232 fuel, generating electricity while breeding more U-233. Stage 3 is India's long-term **"Energy Independence" endgame** — exploiting India's thorium (which could fuel India for centuries) in AHWR reactors. The AHWR (300 MW) design is complete at BARC; demonstration phase is planned. This stage is **30-50 years away**.

NUCLEAR MINERALS

Mineral	*India's Status*	*Key Deposits*	*Notes*
Uranium (U)	LIMITED domestic	Jaduguda (JH — first mine, 1967; Singhbhum Thrust Belt), Tummalapalle	UCIL (Uranium Corporation of India Ltd) mines and processes;

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	reserves; some imports post-123 Agreement	(AP, Kadapa — large but low-grade, ~0.04% U3O8), Domiasiat-Wahkyn (Meghalaya), Lambapur-Peddagattu (TS)	Jaduguda tribal health controversy; Tummalapalle processing plant commissioned
Thorium (Th)	AMONG WORLD'S LARGEST (6th-7th globally by resource estimate)	Monazite sands: Kerala (Chavara, Kollam), TN (Manavalakurichi, Kanyakumari), AP (Bhimunipatnam), Odisha (Chhatrapur)	IREL (India) Ltd processes monazite; thorium and REE separated; thorium is radioactive → strict IAEA/Atomic Energy Act control

India-US Civil Nuclear Agreement (123 Agreement, 2008): India agreed to place civilian nuclear facilities under **IAEA safeguards** (the India-specific Additional Protocol) in exchange for U.S. and NSG cooperation in civil nuclear technology and fuel. This ended India's post-**Pokhran II (May 1998)** nuclear isolation and enabled imports of uranium from USA, France, Russia, Kazakhstan and Australia. The deal was negotiated by PM Manmohan Singh and President George W. Bush; domestically opposed by the Left parties (withdrew support from UPA government in 2008 Parliament Trust Vote). The deal opened India to all NSG member nuclear technology — a transformative geopolitical shift.

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Budget 2025-26 — Nuclear Energy Mission : "The Government will set up a new Nuclear Energy Mission for Viksit Bharat with a target of at least 100 GW of nuclear energy by 2047 and an outlay of ₹20,000 crore for R&D of small and modular reactors." (FM Sitharaman, 1 Feb 2025). Proposed amendments to the Atomic Energy Act 1962 and Civil Liability for Nuclear Damage Act 2010 to allow private sector participation.

11.10 RENEWABLE ENERGY — INDIA'S CLEAN POWER REVOLUTION

India's renewable energy story is one of the fastest transitions in global energy history. From a predominantly coal-dependent power sector in 2010, India has built a **clean energy base that crossed 200 GW of non-fossil capacity in October 2024**, on a trajectory to **500 GW by 2030**. This transformation is driven by **falling RE costs (solar now cheapest in India)**, **energy security imperatives** (reducing fossil imports) and India's **climate commitments (NDCs 2022, Net Zero 2070)**.

INDIA'S RE TARGETS AND NDCS

Target	*Year*	*Details*
500 GW non-fossil installed capacity	2030	NDC commitment; solar, wind, hydro, nuclear, biomass
50% of cumulative electric power from non-fossil	2030	NDC commitment — share of installed capacity
45% reduction in emissions intensity of GDP vs 2005	2030	NDC commitment (updated from 33-35% in original NDC)
Net Zero emissions	2070	India's long-term target at COP26 (Glasgow, 2021)
E20 ethanol blending	2025	20% ethanol in petrol; largely achieved ~2025
100 GW nuclear	2047	Budget 2025-26 new target; Viksit Bharat centenary goal

SOLAR ENERGY — INDIA'S SOLAR REVOLUTION

Solar energy has been **transformative** for India — from near-zero in 2010 to **~150+ GW installed (2024)** — making India the **3rd-largest solar market globally** (after China and USA). Solar is now the **cheapest electricity source in India** (tariffs have fallen from ₹17/unit in 2010 to ₹1.99-2.5/unit in 2024 competitive bids).

Solar Project / Scheme	Location / Details	Capacity / Outlay	Significance
Bhadla Solar Park	Jodhpur district, Rajasthan	~2,245 MW	Among world's largest single solar parks; benefits from Rajasthan's high solar insolation (>6 kWh/m²/day); low-cost bids
Rewa Ultra Mega Solar	Rewa district, MP	750 MW	Benchmark low-tariff bid (₹2.97/unit); historic cross-state RE supply: powers Delhi Metro directly
Khavda RE Park	Kutch, Gujarat	Target ~30 GW (hybrid solar+wind; under construction; world's largest planned)	Using barren salt flats of Kutch; Adani Green + government; to be world's largest RE park when complete
PM-KUSUM	National (all states)	Solar pumps for 35 lakh farmers; feeder-level solar	Replaces diesel irrigation pumps; farmers earn by selling excess power to grid; ₹34,422 crore outlay
PM Surya Ghar Muft Bijli Yojana	National (rooftop solar)	1 crore homes; 300 free units/month; ₹75,021 crore	Announced Feb 2024 by PM Modi; subsidy for rooftop solar panels; excess power sold back at net-metering rates; financial incentive for households
PLI for Solar PV Modules	National	₹24,000 crore; ~45 GW manufacturing capacity targeted	Reduce import of Chinese solar cells and modules; build domestic supply chain; "Atmanirbhar" solar

KEY NOTE

Solar Manufacturing — China Dependence : As of 2024, ~95% of solar cells and ~90% of solar modules used in India are imported — mostly from China. The PLI scheme targets domestic manufacturing but faces cost-competitiveness challenges. This import dependence is a strategic vulnerability: a supply chain disruption (geo-political or pandemic-related) could halt India's solar expansion. Budget 2024 added a Basic Customs Duty (BCD) of 40% on solar modules and 25% on solar cells to incentivise domestic manufacturing.

WIND ENERGY

Parameter	Detail
Installed capacity (2024)	~47-50 GW; India = ~4th globally
Leading states	Tamil Nadu (highest historical wind output), Gujarat (Kutch coast), Rajasthan (Jaisalmer), Maharashtra (Dhule, Satara), Andhra Pradesh, Karnataka
Offshore wind potential	~70,000+ MW (Gujarat coast, Tamil Nadu coast); National Offshore Wind Energy Policy 2015; first 1 GW auction tender 2023; viability-gap funding proposed
Technology	Wind turbines now 3-5 MW each; hub heights 100-140 m; rotors 130-160 m diameter; repowering of old turbines with bigger ones
GIB Conflict	Great Indian Bustard (Ardeotis nigriceps) is critically endangered (~100 individuals); SC April 2021 order mandated undergrounding of high-voltage powerlines in GIB critical habitat (Rajasthan desert); March 2024 modification allows overhead lines with bird-diverters; balancing wildlife and RE is ongoing issue

GREEN HYDROGEN — INDIA'S EMERGING BET

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The **National Green Hydrogen Mission (NGHM)** — approved by the Union Cabinet on **January 4, 2023** with a total outlay of **₹19,744 crore (2023-2030)** — is India's most ambitious clean-energy initiative after the solar programme. It positions India to become a **global green hydrogen exporter** by exploiting its cheapest-in-world solar/wind electricity to produce the cheapest green hydrogen.

Target / Component	*Detail*
Production target	5 MMT (million metric tonnes) green H2/year by 2030 (10 MMT with exports)
Renewable energy required	~125 GW dedicated RE capacity for electrolysis
Electrolyser capacity	125 GW domestic electrolyser manufacturing (SIGHT scheme subsidises electrolyser makers)
Economic benefits	Reduce fossil fuel imports by ~₹1 lakh crore/year; 6 lakh jobs; 50 MMT CO2 abatement
Key application sectors	Fertiliser (replace natural gas in Haber-Bosch ammonia); green steel (replace coking coal); refining; shipping fuel; heavy transport; export
Green H2 vs Grey/Blue	GREEN = electrolysis with RE (zero CO2); GREY = steam methane reforming of natural gas (CO2 emitted); BLUE = gas + carbon capture (CO2 captured); Green H2 cost must fall to $1/kg ("1-1-1" target: 1 MMT, $1/kg, 1 decade)
SIGHT Scheme	Strategic Interventions for Green Hydrogen Transition; financial incentives for electrolyser manufacturing and green H2 production in India

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Civil GS-3 — Green Hydrogen Mains Angle: A critical answer must cover: PROSPECTS — India's cheapest RE = lowest production cost potential; strategic export opportunity (Europe, Japan need green H2 for steel/fertiliser decarbonisation); fertiliser import substitution (India imports ~$12 bn urea/yr). CHALLENGES — High electrolyser cost (currently ~$1,000/kW; need ~$300/kW); water intensity (~9 litres/kg H2; water-scarce sites); no demand-side mandates; missing H2 pipeline/storage infrastructure; SIGHT subsidy design complexity. CONCLUSION: Sound strategy but requires 5-7 years more of technology development before scale.

BIOENERGY AND ETHANOL

Programme	*Details*	*Status (2024-25)*
Ethanol Blending Programme (EBP)	Blend ethanol (C2H5OH) into petrol; reduces oil import, agricultural waste, fossil CO2	E20 (20% ethanol) largely achieved ~2025; earlier target was 2025; feedstock: sugarcane molasses/juice, maize, damaged grains, rice
GOBARdhan	Galvanising Organic Bio-Agro Resources Dhan; converts dung + agricultural waste into biogas/CNG	700+ plants; linked to LPG reduction; GOBAR = dung; Dhan = wealth
SATAT (Sustainable Alternative towards Affordable Transportation)	Compressed Biogas (CBG/Bio-CNG) from municipal solid waste, agricultural residue, sewage; sale to CGD outlets as transport fuel	750+ CBG plants planned; 5,000 MMSCM CBG by 2023-24 target (missed; ~1,000 MMSCM achieved by 2024)
National Bioenergy Mission	Includes biomass power, small hydro, waste-to-energy; promotes RE in rural areas	MNRE programme; ~10 GW biomass/co-gen installed

11.11 CRITICAL MINERALS — INDIA'S 21ST CENTURY CHALLENGE

Critical minerals are those whose **supply disruption would pose significant risk to economic development and national security** and which are essential for the **clean-energy and digital technology transition**. India's dependence on imports for most critical minerals is an Achilles heel in its **Net Zero 2070 journey**, making critical-mineral policy a top strategic and diplomatic priority for 2023-2030.

INDIA'S 30 CRITICAL MINERALS (MINISTRY OF MINES, JUNE 2023)

The Ministry of Mines identified **30 critical minerals in June 2023**: Antimony, Beryllium, Bismuth, Cobalt, Copper, Gallium, Germanium, Graphite, Hafnium, Indium, Lithium, Molybdenum, Niobium, Nickel, PGMs (Platinum Group Metals — Pt, Pd, Rh, Ru, Os, Ir), Potash, REE (Rare Earth Elements), Rhenium, Silicon, Selenium, Strontium, Tantalum, Tellurium, Tin, Titanium, Tungsten, Vanadium, Zirconium — and Phosphorus (for fertilisers). Budget 2024 removed customs duty on 25 of these to incentivise import and processing.

KEY CRITICAL MINERALS — DETAILED

1. ***Lithium (Li) — Battery Metal of the Century***

Parameter	*Detail*
Why critical	Li-ion batteries in all EVs (18-22 kg Li per car), grid storage, smartphones, laptops; demand projected to rise 40x by 2040
World supply concentration	The "Lithium Triangle" (Argentina-Bolivia-Chile = ~55% of reserves); Australia (hard-rock spodumene, ~23% of reserves); China (processing dominant)
India's domestic resource	VERY LIMITED; GSI announced 5.9 MILLION TONNES (Mt) inferred (G3 category) lithium at Salal-Haimana, Reasi district, J&K in February 2023 — first significant find; also minor occurrences at Mandya (Karnataka), Korba (Chhattisgarh)
Reasi auction status	The J&K lithium blocks were put to competitive auction in 2024; the first round FAILED — annulled due to insufficient qualified bidders; the blocks are being re-tendered with modified terms; extraction faces technical challenges (terrain, spodumene processing technology)
KABIL strategy	KABIL has signed agreements for lithium exploration blocks in Argentina (Catamarca province, Puna region) and is pursuing Australia and Chile; aims to secure direct supply of lithium concentrate

2. ***Cobalt (Co) — EV Battery Cathode Metal***

No significant domestic cobalt reserves in India. ~70% of world supply from the DRC (Democratic Republic of Congo). Cobalt is critical for NMC (Lithium Nickel Manganese Cobalt) and NCA (Lithium Nickel Cobalt Aluminium) battery cathodes — used in EVs and portable electronics. India's strategies: (1) **LFP (Lithium Iron Phosphate) battery chemistry — cobalt-free**; (2) KABIL sourcing cobalt from Zambia; (3) **battery recycling ("urban mining")** of used EV batteries to recover cobalt.

3. ***Rare Earth Elements (REEs) — The Hidden Backbone of Clean Tech***

REEs (17 elements including La, Ce, Nd, Pr, Dy, Y, Sc) are **essential for permanent magnets in EV motors, wind turbine generators, MRI machines, defense systems and electronics**. **Neodymium (Nd) and Dysprosium (Dy)** are the most critical — a single wind turbine requires ~250 kg of NdFeB magnets; every EV motor uses ~1-2 kg of Nd.

Aspect	*Detail*
India's REE resource	Significant in monazite sands (Kerala, TN, AP, Odisha); India has ~6 million tonnes of total REE-bearing materials — possibly 4th or 5th globally; mainly light REEs (La, Ce)
The challenge	India's REE are bound with THORIUM in monazite (which is radioactive → Atomic Energy Act control); this complicates separation and processing
Processing dominance	China refines 80-85% of global REE; India has limited separation capacity despite having ore
IREL (India) Ltd	IREL processes monazite at Udyogamandal (Kerala) and Chatrapur (Odisha); separates La, Ce, Nd, Pr, thorium oxide; scale is small compared to global demand
MECL finds (2022-23)	New REE deposits found in Odisha (Ganjam), Jharkhand (Hazaribagh); GSI mapping ongoing

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4. ***Graphite – The Battery Anode***

All lithium-ion batteries use graphite anodes (anode = graphite; cathode = lithium compounds). India has graphite deposits in **Odisha (Sundargarh, Jharsuguda, Bolangir), Jharkhand, Tamil Nadu and AP**. These are partially mapped; India has potential to be a significant graphite supplier but domestic processing (spherical graphite) is absent. **China supplies ~80% of the world's battery-grade graphite** — India's own graphite mining + processing could partially address this supply concentration.

5. ***Titanium / Ilmenite – India's Strength***

India is a **major ilmenite ($FeTiO_3$) producer** from its heavy-mineral beach sands. India accounts for ~4-5% of world ilmenite supply. Process: Ilmenite → **Titanium Dioxide (TiO_2)** (white pigment, used in paints, plastics, sunscreen) via sulfate or chloride process; or → **Titanium metal** (aerospace, medical implants, marine) via Kroll process. **IREL (India) Ltd** is the key processor. This is one critical mineral where India has a genuine competitive advantage. The beach sands also yield **rutile (TiO_2), zircon ($ZrSiO_4$), ilmenite, monazite (REE+Th) and sillimanite** — a multi-mineral package.

6. ***Chromite – India's Key Ferro-Alloy Mineral***

Parameter	*Detail*
India's reserves	Significant; ~97-98% of India's chromite in the SUKINDA VALLEY, Jajpur district, Odisha
Sukinda deposits	Among world's largest chromite deposits outside Zimbabwe; Tata Steel, FACOR, IMFA operate mines
Ferrochrome industry	India is a significant ferrochrome exporter; ferrochrome (FeCr) is used in stainless steel production (~11% Cr in stainless steel)
CRITICAL ENVIRONMENTAL CONCERN	SUKINDA VALLEY IS ONE OF THE WORLD'S MOST POLLUTED PLACES (Blacksmith Institute, 2007 & 2013): Hexavalent Chromium Cr(VI) contamination in groundwater of Jajpur district; Cr(VI) is carcinogenic; estimated 2.6 million people exposed; mining-related groundwater contamination has caused elevated cancer rates; NGT orders monitoring and remediation but progress slow

KABIL — SECURING CRITICAL MINERALS OVERSEAS

Country	*Mineral Target*	*Agreement Status (2024)*
Argentina	Lithium (Catamarca province, Puna Plateau)	KABIL acquired 5 lithium exploration blocks; 2024 agreements signed; exploration drilling begun
Australia	Lithium, Cobalt, Nickel	Government-to-Government (G2G) critical minerals partnership; Australia listed as a "trusted mineral partner"
Chile	Lithium, Copper	Bilateral MoUs; joint exploration discussions; Chile and Australia jointly cover ~50% of world's known lithium
Zambia	Cobalt, Copper	Bilateral mining partnership; government agreements; KABIL/HCL exploring

CURRENT AFFAIRS

National Critical Mineral Mission — January 2025: The Union Cabinet approved the National Critical Mineral Mission on January 29, 2025 with an outlay of ₹16,300 crore (government budget) plus ~₹18,000 crore from PSU investments, totalling ~₹34,000 crore over 7 years. Objectives: accelerate domestic exploration of 30 critical minerals; develop beneficiation and processing capacity; establish a strategic reserve; promote recycling/urban mining; fund R&D; strengthen KABIL overseas activities. Budget 2024 had already cut customs duty to ZERO on many critical minerals to incentivise imports and downstream processing.

11.12 MINING — ENVIRONMENT, POLICY AND TRIBAL RIGHTS

India's mineral wealth is disproportionately concentrated in the **Adivasi heartland — Jharkhand, Chhattisgarh, Odisha and Madhya Pradesh** — where ~90% of India's coal, iron ore, bauxite and uranium lie beneath tribal-inhabited forests. This creates a **structural conflict between mineral development and tribal rights** that is fought out in courts, gram sabhas, forests and fields — and is one of India's most complex governance challenges.

CONSTITUTIONAL AND LEGAL FRAMEWORK FOR MINING + TRIBAL RIGHTS

Law / Provision	*Year*	*Key Content for Mining Context*
MMDR Act	1957 + 2015/2021/2023 amendments	Principal mining law; mandatory auction since 2015; DMF + PMKKKY; critical minerals under central auction
Mines Act	1952	Worker health and safety in mines; DGMS (Directorate General of Mines Safety) under Ministry of Labour
Forest (Conservation) Act	1980 (amended 2023)	Two-stage forest clearance (Stage I + II) for any mining in forest area; compensatory afforestation requirement
EIA Notification	2006	Mandatory environmental impact assessment and public hearing for Category A and B mines; Expert Appraisal Committee (EAC)
PESA (Panchayats Extension to Scheduled Areas Act)	1996	Gram sabha CONSENT required for land acquisition, displacement or use of minor minerals in Scheduled (tribal) Areas (Schedule V)
Forest Rights Act (FRA)	2006	Individual and Community Forest Rights; MFP rights; Community Forest Resource (CFR) rights — mining clearances must comply with FRA; gram sabha resolution required
National Water Policy	2012	Mines require water and often disrupt hydrology; NWP mandates water conservation requirements
National Mineral Policy	2019	Sustainable mining; inter-generational equity; zero-waste mining; R&D in beneficiation

LANDMARK SUPREME COURT INTERVENTIONS

Case	*Year*	*Judgment*
Coalgate — All coal blocks cancelled	2014	SC: 214 of 218 coal blocks allocated 1993-2014 were arbitrary/illegal; cancelled; CAG reported ₹10+ lakh crore loss (contested figure); CBI investigations; led to mandatory coal auctions
Goa Foundation v. State of Goa + Goa Foundation v. Union of India	2012, 2018	SC: iron-ore mining in Goa violated environment norms (2012); SC quashed all 88 renewed mining leases in Goa (2018) as illegal under MMDR; mining stopped; re-auction ordered
Samaj Parivartana Samudaya v. State of Karnataka (Bellary)	2011	SC: total ban on iron-ore mining in Bellary-Tumkur-Chitradurga (Karnataka) due to massive illegal mining (Reddy brothers scandal); partial resumption allowed for Category A mines after 2013
Orissa Mining Corp. v. MoEFCC (Niyamgiri)	2013	SC: Dongria Kondh gram sabhas have the right to vote on whether to allow bauxite mining; ALL voted NO; mining license refused; landmark FRA/tribal rights judgment
Samata v. State of Andhra Pradesh	1997	SC: tribal land cannot be alienated to non-tribal/private companies in Scheduled Areas (V Schedule); mining leases in tribal areas to non-tribals violate this; "Samata principles" in tribal land law

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DISTRICT MINERAL FOUNDATION (DMF) AND PMKKKY — COMMUNITY BENEFIT SHARING

The **District Mineral Foundation (DMF)** — established in every mining district under the MMDR Amendment 2015 — is a non-profit trust funded by mine lease holders (paying an additional 10-30% of royalty) whose mandate is **welfare of mining-affected communities**. The **PMKKKY (Pradhan Mantri Khanij Kshetra Kalyan Yojana)** operationalises DMF spending: 60% must go to **"High Priority Areas"** (drinking water, health, education, sanitation, environment) and 40% to "Other Priority Areas" (skill development, infrastructure, roads, energy).

As of 2024, over **₹80,000 crore** has been credited to DMFs nationally; **Jharkhand, Odisha, Chhattisgarh, Rajasthan, Andhra Pradesh** lead in DMF accruals. However, **utilisation rates have been low** in many states — a persistent governance concern (funds parked, not spent) that the Ministry of Mines regularly flags.

11.13 CURRENT AFFAIRS HOOKS (2021–2025)

CURRENT AFFAIRS	**GSI's 5.9 Mt Lithium Find, Reasi J&K (February 2023):** India's first significant lithium resource (5.9 million tonnes INFERRED/G3 category) at Salal-Haimana, Reasi, J&K. The auction in 2024 FAILED. Block to be re-tendered. Technical challenge: spodumene ore in difficult Himalayan terrain; no domestic processing capacity. KABIL seeking overseas supply as parallel strategy. **National Green Hydrogen Mission (4 January 2023):** ₹19,744 crore; 5 MMT green H2 by 2030; SIGHT scheme. India aims to be world's largest and cheapest green hydrogen producer. Current challenge: electrolyser costs and water availability. **30 Critical Minerals List (Ministry of Mines, June 2023):** India's first official critical minerals list; ZERO customs duty on 25 of these in Budget 2024. National Critical Mineral Mission approved January 2025 (₹16,300 crore). **PFBR Kalpakkam Core-Loading (March 2024):** The Prototype Fast Breeder Reactor (500 MW) at Kalpakkam (Tamil Nadu) had its core loaded with plutonium-uranium MOX fuel — India's Stage 2 nuclear milestone. First criticality expected; commercial operation to follow. Budget 2025-26 announced Nuclear Energy Mission (100 GW by 2047, ₹20,000 crore for SMR R&D). **PM Surya Ghar Muft Bijli Yojana (February 2024):** ₹75,021 crore; rooftop solar for 1 crore homes; 300 free units/month via net metering and subsidy. Launched with a massive Jan Andolan (people's movement) campaign. Applications via National Portal for Rooftop Solar. **India Crosses 200 GW Non-Fossil Capacity (October 2024):** A milestone reached 9 years ahead of schedule relative to the original target; includes solar, wind, large hydro, nuclear, bio; puts India firmly on track for 500 GW target by 2030. **Coal India Crosses 1 BT (FY2024-25):** India's total coal production crossed 1 BILLION TONNES for the first time. CIL produced ~781 MT; captive and commercial mines produced the rest. The "900 MT" figure for CIL is a future target. **E20 Ethanol Blending Achieved (~2025):** India achieved ~20% ethanol blending (E20) in petrol across most states, 3 years ahead of the original 2025 target set in 2021. Feedstock: sugarcane, maize, damaged rice grains. Saves ~₹35,000 crore in crude oil imports per year. **COP28 (Dubai, December 2023):** The Dubai consensus pledged to TRIPLE global RE capacity by 2030 and DOUBLE efficiency improvement rate by 2030. India signed. India pushed for "phase down" and "phase out" of fossil fuels but blocked language specifically targeting coal without support for developing countries.

11.14 PYQ ANALYSIS — CHAPTER 11 (2010–2025)

Questions from UPSC Civil Mains GS-3 (Energy & Resource Security) and IFoS GS directly testing Minerals and Energy themes:

Source	Year	Marks	Question
UPSC Civil	2024	15M	"Discuss the significance of critical minerals for India's energy transition. What steps has India taken to secure its critical mineral supply chain?"

UPSC Civil	2023	15M	"Green Hydrogen is emerging as a promising clean fuel for the future. Critically evaluate India's National Green Hydrogen Mission."
UPSC Civil	2022	12M	"Solar energy is increasingly becoming the cheapest source of electricity in India. Discuss the prospects and challenges of solar energy expansion in India."
UPSC Civil	2021	15M	"In the context of energy security, critically examine India's policy on renewable energy and its targets under the Paris Agreement."
UPSC Civil	2020	15M	"India's three-stage nuclear power programme is considered the most viable option for a long-term energy future. Discuss."
UPSC Civil	2019	12M	"Discuss India's energy security challenges and the role of renewable energy in addressing them."
UPSC Civil	2015	12M	"In what ways does the coal block allocation policy of India affect the country's economic development?"
UPSC Civil	2014	12M	"Highlight the factors responsible for the declining production of coal in India and its implications."
IFOS GS	2025	10M	"Discuss the environmental and social impacts of iron-ore mining in tribal areas of Jharkhand and Odisha with specific examples."
IFOS GS	2024	15M	"Explain India's energy transition from fossil fuels to renewable energy. What are the challenges and opportunities?"
IFOS GS	2023	10M	"Write a note on the National Green Hydrogen Mission and its significance for India."
IFOS GS	2022	10M	"Critically examine the environmental impact of coal mining in India."
IFOS GS	2021	10M	"Discuss the significance of critical minerals for green energy transition in India."
IFOS GS	2020	10M	"Explain the three-stage nuclear power programme of India. What is the significance of thorium in this context?"

KEY NOTE

Frequency pattern: Critical minerals + EV transition (2024, very high probability ongoing), Green Hydrogen (2023 + IFoS 2023), Three-stage nuclear programme (Civil 2020, IFoS 2020), Solar energy policy (Civil 2022), Coal policy/Coalgate (Civil 2015). IFoS-specific: mining-tribal conflict (2025), coal environmental impact (2022), energy transition (2024). For 2025-26 exams: prepare PFBR Kalpakkam, National Critical Mineral Mission (Jan 2025, ₹16,300 cr), PM Surya Ghar (Feb 2024), PM E-DRIVE (Sept 2024) and 200 GW non-fossil milestone as the top current-affairs hooks.

11.15 MODEL BOOK

India's three-stage nuclear power programme is considered the most viable option for a long-term energy future. Discuss.

Civil (Mains) 2020 | GS-3 | 15 Marks | 200 Words

India's three-stage nuclear programme — conceived by Dr. Homi Bhabha in 1954 — is uniquely calibrated to India's resource reality: **limited uranium but vast thorium reserves** (among the world's largest). It converts a scarcity into a long-term abundance.

Stage 1 — PHWRs (Operational): Pressurised Heavy Water Reactors using natural uranium (0.7% U-235); ~8,180 MW across 22 reactors (Tarapur, Rawatbhata, Kaiga, Kakrapar, Narora, Kudankulam). Each Stage 1 reactor produces **plutonium-239** in spent fuel — the feed for Stage 2.

Stage 2 — Fast Breeder Reactors (Commissioning): Uses Pu-239 + U-238 blanket; "breeds" more fissile material than it consumes. The **PFBR (500 MW, Kalpakkam, Tamil Nadu) was core-loaded in March 2024** — India's most important nuclear milestone in a generation.

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Stage 3 — Thorium AHWR (Future): Thorium (Th-232) is irradiated to produce U-233; the Advanced Heavy Water Reactor (AHWR) uses U-233+Th to generate electricity while breeding more U-233. India's massive thorium in coastal monazite sands (Kerala, TN) could fuel Stage 3 for centuries.

WHY "MOST VIABLE": (1) Uses India's own fuel (Th) rather than imported uranium; (2) provides **low-carbon, 24×7 baseload power** — complements intermittent solar/wind; (3) plutonium breeding reduces radioactive waste; (4) Kudankulam partnership shows India can expand nuclear rapidly with international technology.

CHALLENGES: Slow FBR commercialisation; high capital costs; public acceptance (radiation fears); Civil Liability Act 2010 discourages foreign vendors; safety (seismically active sites); spent-fuel reprocessing complexity.

The three-stage programme is a long-term insurance policy for India's energy sovereignty — powered by thorium — but achieving Stage 3 requires sustained investment, regulatory reform and two to three more decades of technological development.

"Critically evaluate India's National Green Hydrogen Mission. Discuss its prospects and challenges."

IFoS Civi IFoS | 10-15 Marks | 170 Words

Launched on January 4, 2023 (outlay ₹19,744 crore), the National Green Hydrogen Mission targets **5 MMT/year of green hydrogen by 2030**, positioning India as the world's lowest-cost green hydrogen producer and exporter.

PROSPECTS:

1. **Cost advantage:** India's solar tariffs (~₹2/kWh) are among the world's lowest → cheapest green H2 potential (~$2-3/kg now, targeting $1/kg). Green H2 needs cheap RE, which India has in abundance.
2. **Decarbonisation of hard sectors:** Fertiliser (Haber-Bosch uses 80% of India's hydrogen currently — all grey); steel (coking coal substitute); shipping; heavy transport.
3. **Import substitution:** India spends ~$16 bn/year on LNG and ~$12 bn on urea; green H2 could reduce both.
4. **Export potential:** Europe, Japan and South Korea need green H2 for their climate goals; India could be a major supplier by 2030-35.

CHALLENGES:

1. **Electrolyser cost:** Current cost ~$600-1,000/kW; need ~$200-300/kW for $1/kg H2. PLI/SIGHT scheme subsidises manufacturers, but domestic capacity is minimal.
2. **Water intensity:** 9-10 litres of water per kg of H2; India's best solar sites (Rajasthan, Gujarat) are water-scarce — trade-off between RE and water.
3. **Infrastructure:** No hydrogen pipeline or large-scale storage; compression, transportation and dispensing infrastructure largely absent.

The Mission is strategically sound but requires additional years for cost and technology maturation. The **SIGHT scheme**, **viability gap funding for pilots** and **mandatory green H2 mandates** for fertiliser/refinery sectors are the near-term catalysts that will determine whether India achieves the 2030 target.

CHAPTER 12

AGRICULTURE OF INDIA

CHAPTER AT A GLANCE

- Agriculture: ~17-18% of GDP; ~50-55% workforce; India = world's largest producer of milk (239.30 MT, 2023-24), spices, pulses, bananas, mangoes, jute; 2nd in rice, wheat, sugarcane, cotton, vegetables, fruits.
- India = world's largest rice EXPORTER (~40% global trade); record foodgrain production 332.30 MT (2023-24 Third Advance Est.); from PL-480 imports (1950s-60s) to food surplus nation.
- Three structural challenges: ~86% farms small/marginal (<2 ha); only ~52% cultivated area irrigated; low productivity vs global benchmarks. Net Sown Area ~141 Mha; Cropping Intensity ~147%.
- Cropping seasons: Kharif (June-Oct; rice, cotton, sugarcane, jowar, bajra, maize, tur); Rabi (Oct-Mar; wheat, gram, mustard); Zaid (Mar-Jun; summer vegetables, moong).
- Green Revolution: HYV seeds + fertilisers + irrigation triad; M.S. Swaminathan (passed away 28 Sep 2023) + Borlaug (Nobel 1970); POSITIVES: food self-sufficiency; NEGATIVES: groundwater depletion (Punjab 0.5-1 m/yr), soil degradation, stubble burning, regional imbalance, monoculture.
- MSP: C2+50% demanded (Swaminathan); government gives 1.5x A2+FL (lower); Three Farm Laws (Sep 2020) REPEALED Nov 19, 2021 (700+ farmers died in protest); Kisan Andolan 2024 (Shubhkaran Singh death 21 Feb 2024; Shambhu-Khanauri border).
- Key schemes: PM-KISAN (Rs.6,000/yr, 11 cr+ farmers); NFSA 2013 (81.3 cr people; PMGKAY merger Jan 2023); e-NAM; PMFBY; FPOs (10,000 target); Natural Farming Mission (Rs.2,481 cr, Nov 2024).
- International Year of Millets 2023 (India-initiated; "Shree Anna"; G20 Delhi millet menus); rice export ban (Jul 2023, eased Sep 2024); M.S. Swaminathan death Sep 28, 2023.

12.1 INTRODUCTION — AGRICULTURE IN INDIA'S ECONOMY

Agriculture and allied sectors form the **bedrock of the Indian economy and the lifeline of Indian society**. Despite contributing only **~17-18% to Gross Value Added (GVA)** — a share that reflects six decades of structural transformation toward services and industry — the sector still provides **livelihood to approximately 50-55% of India's workforce**. This asymmetry — a declining output share supporting a still-large workforce — is the defining developmental paradox of Indian agriculture: millions remain employed in low-productivity farming, constraining overall labour productivity growth.

The **journey from near-famine to food surplus** is one of independent India's most striking achievements. In the 1950s-60s, India survived on **PL-480 (Public Law 480) food aid from the United States** — importing wheat under a programme where payment was accepted in rupees. By 2023-24, India achieved a record **332.30 million tonnes (MT) of foodgrain production** (Ministry of Agriculture & Farmers Welfare, Third Advance Estimates 2023-24) — a **6-fold increase in seven decades** — and became the **world's largest exporter of rice**, supplying approximately **40% of the global rice trade**.

INDIA'S GLOBAL AGRICULTURAL STANDING

Rank	*Commodity / Sector*	*Key States / Note*
1st (Producer)	Milk	239.30 MT (2023-24; DAHD Basic Animal Husbandry Statistics 2024); India retains global #1 position
1st (Producer)	Spices	~11 MT/year; Kerala, AP, TN, Rajasthan; ~25% of world trade

1st (Producer)	Pulses	~26 MT; MP, Maharashtra, Rajasthan, UP, Karnataka; also largest consumer
1st (Producer)	Bananas	~34 MT; MH (Jalgaon), TN, AP, Karnataka, Gujarat
1st (Producer)	Mangoes	~40% of world production; UP, AP, TN, Bihar, Karnataka
1st (Producer)	Jute	West Bengal (~75%); Golden Fibre of the Ganga-Brahmaputra delta
1st (Exporter)	Rice	~22 MT exported (2022); ~40% of world rice trade (USDA-FAS); basmati + non-basmati
2nd (Producer)	Rice, Wheat, Sugarcane, Cotton, Vegetables, Fruits, Groundnut	After China in most categories; after Brazil in sugarcane/sugar
2nd (Consumer)	Gold	~700-800 t/year imported; cultural and financial demand

TYPES OF FARMING IN INDIA

Type	*Description*	*States / Examples*
Intensive Subsistence	Small plots; high labour; multiple crops/year; aimed at family food security	Ganga-Brahmaputra delta, Kerala coast, Tamil Nadu paddy belt
Primitive Subsistence / Shifting Cultivation	Slash-and-burn; low inputs; clearing moves after 2-3 years; fallow period for soil recovery	Jhum (Assam / Arunachal / Nagaland / Meghalaya), Podu (AP / Odisha), Bewar / Dahiya (MP), Kumari (Western Ghats)
Commercial Farming	Market-oriented; high inputs; often irrigated; monoculture or cash crops	Punjab-Haryana wheat-rice belt; Gujarat cotton; UP sugarcane
Plantation Agriculture	Single cash crop on large estates; colonial origin; capital+labour intensive; export-oriented	Tea (Assam, Darjeeling), Coffee (Karnataka, Kerala), Rubber (Kerala), Spices (Kerala)
Mixed Farming	Crops + livestock; more resilient; manure cycle	Punjab, Haryana, Gujarat
Dryland / Rainfed Farming	No assured irrigation; drought-tolerant crops; 48% of cultivated area	Rajasthan (millets), Marathwada (cotton), Vidarbha (soyabean), Deccan interior

KEY AGRICULTURAL STATISTICS

Indicator	*Figure / Note*
Foodgrain production (2023-24)	332.30 MT (Third Advance Estimate, MoAFW); record high
Net Sown Area (NSA)	~141 million hectares (~43% of total geographic area)
Gross Cropped Area (GCA)	~200 million hectares
Cropping Intensity	~147% (GCA/NSA x 100); target 150%
Irrigated area	~52% of NSA; total potential 140 Mha; created ~113 Mha; utilised ~90 Mha
Average farm size (2015-16 Agri Census)	1.08 ha; down from 2.3 ha in 1970-71
Small and marginal farms (<2 ha)	~86% of all operational holdings
Agricultural exports (FY2022-23)	USD 53.15 billion (highest ever; Ministry of Commerce/APEDA)
Fertiliser subsidy (FY2022-23 actual)	~Rs.2.51 lakh crore (actual outgo, higher than revised estimate of Rs.1.88 lakh crore)

KEY NOTE

The Productivity Gap : India's rice yield is ~2.7 t/ha vs China's ~7 t/ha and Egypt's ~10 t/ha. India's wheat yield is ~3.5 t/ha vs UK's ~8 t/ha. Raising yields through technology, better inputs, micro-irrigation and precision agriculture is the central challenge of India's "Second Green Revolution." The mismatch between large farm areas and relatively modest yields explains why India produces large absolute volumes but still lags in farmer income and productivity.

12.2 FACTORS AFFECTING AGRICULTURE

A. PHYSICAL FACTORS

- **Soil type:** alluvial soils (IGP) → wheat+rice; black/regur soils (Deccan) → cotton+jowar; red/laterite soils (peninsular) → millets+groundnut+plantation crops; arid soils (Rajasthan) → drought-resistant millets.
- **Relief:** flat alluvial plains permit intensive, mechanised, irrigated farming; hill slopes suit terrace farming and plantation crops (tea, coffee at 600-2,000 m altitude); plateaus support dryland farming.
- **Climate (rainfall + temperature):** determines cropping seasons; rainfall amount and distribution governs crop type; temperature controls growing season length and frost risk; sunshine hours affect photosynthesis and yield.
- **Water availability:** irrigation transforms single-cropped dryland into double/triple-cropped intensively farmed land; it is the difference between Punjab (1.5 crops/year on average) and Bihar (0.9 crops/year).

B. ECONOMIC FACTORS

- **Land holding size:** the **Agriculture Census 2015-16** recorded the average operational holding at **1.08 ha**, down from 1.15 ha in 2010-11 — continuing fragmentation through inheritance. About **86.1% of holdings are small (<1 ha) or marginal (<2 ha)**, making mechanisation, credit access and cash-crop economics difficult.
- **Capital and credit:** formal credit reaches farmers via **Kisan Credit Card (KCC)** (about 7.5 crore KCCs issued by 2024; 7% interest rate; RuPay platform). Tenant and landless farmers often rely on informal moneylenders at 24-36% interest.
- **Market access:** APMC (Agricultural Produce Market Committee) mandis regulate wholesale trade; **e-NAM (National Agriculture Market)** platform integrates 1,260+ mandis online for price transparency and electronic bidding; cold-chain infrastructure remains inadequate.
- **Input costs:** fertilisers (DAP, urea), certified seeds (Bt cotton seed cost controversy), pesticides, electricity and labour have all risen faster than output prices — a primary driver of the "cost-price squeeze" affecting small farmers.

C. SOCIAL FACTORS

- **Tenancy and insecurity:** share-croppers and fixed-rent tenants cannot legally access institutional credit or crop insurance in most states, as they lack land title. Informal tenancy is widespread but legally invisible.
- **Gender in agriculture:** the **Agriculture Census 2015-16** recorded that women hold only **13.87% of operational holdings covering 11.57% of operated area**, yet women constitute roughly **65-75% of agricultural labour** — a gender gap in ownership versus contribution. The **Mahila Kisan Sashaktikaran Pariyojana (MKSP)** under DAY-NRLM empowers women in agriculture.
- **Caste and social structure:** land reform implementation was often captured by dominant castes; Dalit and Adivasi farmers are disproportionately tenant farmers, landless labourers or marginal holders.

D. TECHNOLOGICAL FACTORS

- **HYV seeds:** the foundation of the Green Revolution; now being extended to climate-resilient, drought-tolerant varieties for millets, pulses and oilseeds.

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- **Micro-irrigation (drip + sprinkler):** 50-70% water saving over flood irrigation; promoted under Per Drop More Crop / PMKSY.
- **Mechanisation:** tractors, combines, power tillers; Custom Hiring Centres (CHCs) for small farmers to access machinery at low cost.
- **ICT and digital agriculture:** e-NAM, Kisan Suvidha app, **Digital Agriculture Mission (2021)**, **AgriStack** (national digital public infrastructure comprising a Farmer Registry, village-map database and crop-sown registry — enabling targeted DBT, advisories and credit).

12.3 CROPPING SEASONS OF INDIA

India's agricultural calendar is governed by the **three-season rotation of Kharif, Rabi and Zaid** — structured around the south-west monsoon, the cool winter months and the short-irrigated summer, respectively. Understanding which crop belongs to which season — and which states dominate each — is fundamental to Prelims accuracy.

Season	*Period*	*Climate Basis*	*Major Crops*	*Key States*
KHARIF	June-October (sown at SW monsoon onset; harvested Oct-Nov)	Warm, wet; monsoon-dependent	Rice, Jowar, Bajra, Maize, Cotton, Sugarcane, Groundnut, Soyabean, Tur/Arhar, Moong, Urad, Jute, Sesame, Tobacco	Rice: WB, UP, Punjab; Cotton: Gujarat, MH, TS; Soyabean: MP, MH, RJ; Groundnut: GJ, RJ, AP; Bajra: RJ (largest)
RABI	October-March (sown Oct-Nov; harvested Mar-Apr)	Cool, dry; depends on residual moisture + irrigation + Western Disturbances (WD rain = "mahawat")	Wheat, Barley, Gram/Chickpea, Mustard/Rapeseed, Linseed, Sunflower (partly), Peas, Berseem (fodder)	Wheat: Punjab (highest yield), UP (largest output), Haryana, MP, RJ; Gram: MP, MH, RJ; Mustard: RJ, HR, UP
ZAID	March-June (short summer; irrigated)	Hot, dry; requires irrigation	Watermelon, Muskmelon, Cucumber, Summer Vegetables, Summer Moong (short duration), Fodder (sorghum/maize)	Irrigated belt of UP, Punjab, Haryana; river command areas

KEY NOTE

Exam Tip — Cropping Season Anomalies : (1) Sugarcane is categorised as a kharif crop but actually grows throughout the year (~10-12 months); it spans cropping seasons. (2) Maize is primarily kharif but is grown as rabi in parts of South India (Bihar, Karnataka). (3) Cotton = kharif (sown June-July; harvested November-January). (4) Rice in some south Indian states (Tamil Nadu, Kerala) has multiple seasons including a rabi and "short-duration" cycle due to NE monsoon. (5) Sunflower is grown in both kharif and rabi.

12.4 FOOD GRAIN CROPS

A. RICE (PADDY) — ORYZA SATIVA

Parameter	*Detail*
Global rank	2nd largest producer (after China); LARGEST EXPORTER (~40% of global rice trade, 2022)
Production	~132 MT paddy (2023-24 Advance Estimates)
Season	Primary = KHARIF; also aman (winter), boro (summer) in WB and NE India
Temperature	20-35°C; high humidity; long sunshine hours during grain filling

Rainfall	100-200 cm minimum; or assured irrigation (flooded paddy needs standing water)
Soil	Clayey/fine-textured alluvial; water-retentive; cannot be too porous
Largest state (area)	West Bengal; followed by UP, Punjab, Andhra Pradesh, Telangana, Bihar, Chhattisgarh, Odisha
Highest yield	Punjab (~4.5-5.0 t/ha) and Haryana — well-irrigated; HYV varieties; Green Revolution epicentre
Key varieties	Basmati (long-grain, aromatic; Punjab, Haryana, W UP, J&K, Uttarakhand) vs Non-Basmati (high-yield; WB, AP, TN, CG); IR-8 "Miracle Rice" (IRRI 1966); Sona Masuri; Ponni
Basmati GI	Pusa Basmati 1121 has a GI; specific Basmati-growing area (Punjab, Haryana, UP, Uttarakhand, J&K, HP, Delhi) designated by APEDA for export certification

Rice export shock (2023-24): India imposed a **ban on non-basmati white rice exports on July 20, 2023**, citing domestic price inflation. Since India supplies ~40% of world rice exports, the ban caused a **global rice-price spike of 25-40%**. The ban was **eased on September 28, 2024** (initially with a Minimum Export Price of US$490/t, subsequently removed). This episode highlights India's structural importance to global food security — and the dilemma between export earnings and domestic food inflation.

ENV ALERT

Rice-Groundwater-Burning Nexus — Punjab's Agrarian Crisis

- **Water:** Paddy cultivation requires 3,000-5,000 litres of water per kg. Punjab and Haryana grow rice in a semi-arid zone — water comes from groundwater. Punjab's water table is falling 0.5-1 m/year; some Punjab Agricultural University (PAU) studies warn of a 20-year finite horizon for sustainable extraction. The government's response — the Punjab Preservation of Subsoil Water Act 2009, delaying paddy transplantation to mid-June to coincide with the monsoon — reduces pumping but cannot solve the structural problem.
- **Methane:** Anaerobic flooded paddy soils produce methane (CH_4) through methanogenesis. Paddy is the largest single agricultural source of methane emissions globally. Alternate Wetting and Drying (AWD) technique can cut methane by 30-50% without yield loss — being promoted under India's NMSA.
- **Stubble burning:** ~20 million tonnes of paddy straw are burned in Punjab-Haryana each October-November after harvest (the narrow window between paddy harvest and next wheat sowing leaves little time for other disposal). This causes severe air pollution in Delhi and the NCR (AQI spike to "Severe+" category). Solutions: Happy Seeder / Super SMS machines (subsidised), biomass power plants, industrial use of straw — all partially implemented but burning continues.

B. WHEAT — TRITICUM AESTIVUM

Parameter	*Detail*
Global rank	2nd largest producer (after China); ~112 MT (2023-24 Third Advance Estimate)
Season	RABI — sown Oct-Nov, harvested Mar-Apr (critical that it ripens before summer heat)
Temperature	Cool growing (10-15°C for germination and tillering); warm ripening (20-25°C); frost damages heading stage
Rainfall	50-75 cm (supplemented by irrigation in Punjab-Haryana; Western Disturbance rain helps); sunshine needed at ripening
Soil	Well-drained loamy to clay-loam alluvial; slightly alkaline (pH 6.5-7.5)
Largest output state	Uttar Pradesh (~31% of India's wheat); Punjab highest yield (~5 t/ha); Haryana, MP, Rajasthan, Bihar also major

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Green Revolution varieties	Norman Borlaug's Mexican semi-dwarf varieties (Norin-10 base) adapted by M.S. Swaminathan as Kalyan Sona, Sonalika → tripled yield from ~1 t/ha to 3+ t/ha
Climate threat	Terminal HEAT STRESS during grain filling (temperature > 30°C at ripening): the March 2022 heat wave caused ~3 MT crop loss → India imposed a wheat export ban (May 2022); heat stress is the biggest long-term climate threat to wheat
Significance	India's primary food security crop; 50-55 million tonnes procured annually by FCI for the PDS/NFSA

C. MAIZE — ZEA MAYS

Maize is India's **third-most-important cereal** and a rapidly growing crop. It is primarily a **kharif crop** but is grown as **rabi in parts of South India** (Bihar, Karnataka, Andhra Pradesh — where winter temperatures are mild). Major states: **Karnataka, Madhya Pradesh, Bihar, Telangana, Andhra Pradesh, Rajasthan and Uttar Pradesh**. India produces ~35-38 MT annually.

Maize is critical for India's **ethanol blending (E20) programme** — alongside sugarcane and damaged rice, maize is a key feedstock for fuel-grade ethanol, reducing crude oil imports. It is also the primary **animal-feed ingredient** (poultry industry), a source of **starch and corn syrup** for food processing, and a direct food grain in tribal/rural areas.

D. PULSES — "THE POOR MAN'S PROTEIN"

India is simultaneously the **world's largest producer (~26 MT) AND the world's largest consumer** of pulses — yet routinely imports because domestic supply cannot meet demand. This **"pulse paradox"** makes pulses a chronic **food-inflation trigger**, with dal prices being politically sensitive in every budget cycle.

Pulse	*Scientific Name*	*Season*	*Key States*	*% of India's Pulse Output*
Chickpea / Gram / Chana	Cicer arietinum	Rabi	MP (largest), Maharashtra, Rajasthan, UP, Andhra Pradesh	~45-47%
Pigeon Pea / Tur / Arhar	Cajanus cajan	Kharif	MP, Maharashtra, Karnataka, Telangana, AP, UP	~15-17%
Lentil / Masur	Lens culinaris	Rabi	MP, UP, Bihar, WB	~7-8%
Green Gram / Moong	Vigna radiata	Both (Kharif primary; short-duration Zaid too)	Rajasthan, Maharashtra, Karnataka, MP	~8-10%
Black Gram / Urad	Vigna mungo	Kharif (primary); some Rabi in south	MP, Maharashtra, Rajasthan, UP, AP/Telangana	~7-9%
Cowpea / Lobia	Vigna unguiculata	Kharif	Maharashtra, Karnataka	~2%

WHY PULSES ARE CRUCIAL — NITROGEN FIXATION

Pulses are the **most ecologically valuable food crops** because of their symbiosis with **Rhizobium** bacteria in root nodules. The bacteria carry out **biological nitrogen fixation (BNF)** — converting atmospheric N_2 into ammonia through the nitrogenase enzyme: **$N_2 + 8H^+ + 8e^- + 16\ ATP \rightarrow 2NH_3 + H_2 + 16\ ADP + 16\ Pi$**. This adds **50-100 kg of nitrogen per hectare to the soil** — the equivalent of **1-2 bags of urea per hectare**, at zero cost and with zero CO_2 emission. Pulses in crop rotation thus serve as **"biological fertiliser factories"**, reducing external fertiliser requirement and rebuilding soil nitrogen.

India's import dependence (from Australia, Canada, Myanmar) highlights the gap between pulse production (~26 MT) and demand (~27-28 MT). The **National Food Security Mission (NFSM) — Pulses component**

specifically targets raising pulse productivity toward the production potential (current yield ~800 kg/ha vs genetic potential of 1,500+ kg/ha).

E. MILLETS / NUTRI-CEREALS ("SHREE ANNA")

India's millets — jowar, bajra, ragi and small millets — are the **forgotten superfoods of Indian agriculture** — drought-tolerant, nutrient-dense, low-water, low-input crops that sustained Indian civilisation for millennia before being displaced by Green Revolution monocultures. The **International Year of Millets 2023 (IYM 2023)** — championed by India — has triggered a global and domestic millet revival.

Millet	*Scientific Name / Hindi*	*Key States*	*Special Feature*
Sorghum (Jowar)	Sorghum bicolor / Jowar	Maharashtra (largest), Karnataka, Rajasthan, UP, MP	Dual-purpose (food + fodder); drought-tolerant; hot semi-arid areas
Pearl Millet (Bajra)	Pennisetum glaucum / Bajra	RAJASTHAN (largest — arid zone), UP, Haryana, Gujarat, Maharashtra	Most drought-hardy millet; can grow in <250 mm rainfall; sand dunes
Finger Millet (Ragi)	Eleusine coracana / Ragi, Nachni	Karnataka (largest), TN, Andhra Pradesh, Uttarakhand, Odisha	HIGHEST CALCIUM CONTENT among all cereals; iron-rich; Staple of rural South India
Foxtail Millet	Setaria italica / Kangni, Kakun	AP, Telangana, Karnataka	Short-duration; early maturing; ancient crop; nutritious
Little Millet	Panicum sumatrense / Kutki	Jharkhand, MP, Odisha, Chhattisgarh	Tribal staple; high iron+protein; short season
Kodo Millet	Paspalum scrobiculatum / Kodon	MP, Chhattisgarh	Tribal staple; rich in fibre; blood-sugar regulating
Barnyard Millet	Echinochloa frumentacea / Sanwa	UP, Uttarakhand, Jharkhand	Fastest growing (45-60 days); used in Hindu fasting foods
Proso Millet	Panicum miliaceum / Chena	Rajasthan, UP	Short duration; drought-tolerant

WHY MILLETS ARE THE FUTURE — SIX ARGUMENTS

1. **Water efficiency:** millets require **3-4x less water than rice** (bajra needs only ~300 mm rainfall vs rice's 1,200+ mm). They can be grown on **rainfed dryland** where irrigation is unavailable.
2. **Drought tolerance:** pearl millet and sorghum can survive prolonged dry spells and high temperatures; critical for **climate-change adaptation in semi-arid India**.
3. **Nutritional superiority:** higher iron (bajra), calcium (ragi), fibre and protein than rice/wheat; lower glycaemic index (beneficial for diabetes management); **"Nutri-Cereals"** as the government now terms them.
4. **Climate resilience:** less vulnerable to temperature stress and rainfall variability than rice or wheat.
5. **Lower carbon footprint:** no methane emission (unlike flooded paddy); lower fertiliser requirement.
6. **Soil compatibility:** grow in poor, shallow, even degraded soils where wheat and rice cannot.

CURRENT AFFAIRS

International Year of Millets 2023: India sponsored the UN GA Resolution declaring 2023 the IYM (adopted March 2021; 72 countries). PM Modi coined Shree Anna (Union Budget 2023-24). IIMR Hyderabad = Global Centre of Excellence. G20 Delhi Summit (Sep 2023) featured millet dishes. NFSM-Nutri-Cereals provides production support.

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12.5 COMMERCIAL / CASH CROPS

A. SUGARCANE (SACCHARUM OFFICINARUM)

Parameter	*Detail*
Global rank	WORLD'S LARGEST PRODUCER of sugarcane; 2nd largest sugar producer (after Brazil)
Production	~4,000-5,000 lakh metric tonnes (cane); ~36-40 MT sugar
Season	Kharif (planted Feb-Mar or Oct; harvested over ~10-12 months)
Temperature	Tropical/sub-tropical; 20-35°C; hot growing + cool ripening
Rainfall	100-150 cm or assured irrigation; waterlogging harmful
Soil	Alluvial/black; well-drained; slightly alkaline; deep loam
Largest state	UP (~50% of India's cane; Meerut, Muzaffarnagar, Hapur, Lakhimpur Kheri — "Sugar Bowl of India")
Highest productivity	Maharashtra (cooperative mill model; Nashik, Pune, Kolhapur, Sangli)
Ethanol link	Sugarcane juice/molasses → ethanol for E20 blending; E20 (~20%) largely achieved ~2025; reduces crude oil import by ~Rs.35,000 crore/year
Cane arrears problem	Sugar mills routinely delay payment to farmers; total outstanding arrears have reached Rs.20,000+ crore nationally in bad years; statutory payment period = 14 days of delivery
Price controls	FRP (Fair and Remunerative Price) — minimum price per quintal of cane set by CACP/Centre; SAP (State Advised Price) — higher price often set by UP state government; mills must pay at least FRP
Export control 2023-24	India restricted sugar exports 2023-24 to manage domestic prices and ensure molasses for ethanol; sugar industry volatile due to price-cycle swings

B. COTTON — "WHITE GOLD"

India has the **world's largest cotton-cultivation area (~130 lakh hectares)** and is the **world's 2nd-largest producer** (after China). Cotton is grown primarily on **black/Regur soil (Deccan Trap basalt),** which retains moisture well and suits the long (6-8 month) growing season. Cotton is India's most important natural fibre and textile-export crop.

Parameter	*Detail*
Major states	Gujarat (LARGEST producer), Maharashtra (Vidarbha, Marathwada, Aurangabad), Telangana, Andhra Pradesh, Karnataka, Madhya Pradesh, Punjab, Haryana
Bt Cotton revolution	2002: India approved Bt cotton (Bollgard I — containing Cry1Ac gene from Bacillus thuringiensis) — the first GM crop approved for commercial cultivation in India; by 2014-15, ~95% of India's cotton area was Bt; bollworm attacks reduced; production doubled from ~10 MT to ~35 MT lint
Bt cotton problems	(1) Pink bollworm (Pectinophora gossypiella) developed resistance to Cry1Ac toxin; (2) Secondary sucking pests (whitefly, thrips, mealybug) increased as pesticide use patterns changed; (3) Seed costs rose dramatically — Monsanto/Mahyco trait value (Bt royalty) became a flashpoint; Supreme Court case — Monsanto Technology LLC v. Nuziveedu Seeds Ltd (2019) — declared Bt traits as non-patentable in India under Section 3(j) of the Patents Act; (4) Rain-dependent bajra zone farmers in Vidarbha borrowed heavily for Bt cotton — a link to the farmer suicide belt
GM Mustard DMH-11	The next proposed GM crop in India; GEAC (Genetic Engineering Appraisal Committee) approved DMH-11 for environmental release in October 2022; the Supreme Court delivered

	a split (2:1) verdict on July 23, 2024 and referred the matter to a larger Constitutional Bench while directing the Centre to formulate a national GM policy; commercial cultivation sub-judice as of 2025
Preferred soil	Black/Regur soil (Vertisols); retains moisture; cotton is the defining crop of the black soil zone

UPSC CIVIL

Bt Cotton and Farmer Suicides — The Vidarbha Connection: The **cotton-growing Vidarbha region of Maharashtra** (Amravati, Nagpur, Yavatmal, Wardha, Akola, Buldhana) records India's highest cotton-belt suicide rates. This is NOT simply a Bt cotton failure — it reflects the convergence of: (1) rain-fed farming in a drought-prone rain-shadow zone; (2) high input cost for Bt seeds + pesticides; (3) dependence on private moneylenders; (4) lack of irrigation; (5) volatile global cotton prices. The fertile Regur soil is a necessary but insufficient condition for farmer prosperity — institutional support (credit, insurance, irrigation, MSP) is equally essential.

C. JUTE — "GOLDEN FIBRE"

- **India = world's largest jute producer**; West Bengal contributes ~75%, followed by Bihar, Assam and Odisha.
- **Growing conditions:** tropical humid; high rainfall 150-250 cm; alluvial/deltaic soil (Ganga-Brahmaputra delta); waterlogging tolerant.
- **Uses:** gunny bags/sacks, hessian cloth, carpet backing, geo-textiles, composites; jute is the most biodegradable packaging material.
- **Jute Packaging Materials Act (JPMA) 1987:** mandates use of jute packaging for all food grains and sugar procured and distributed by government — a critical demand support for the jute industry.
- **Challenge and revival:** plastic bags displaced traditional jute packaging; revival through high-value **geo-textiles (jute soil savers)**, eco-friendly packaging and value-added products.

D. OILSEEDS

India is the **4th-largest oilseed producer globally** but is a **massive importer of edible oils** — primarily palm oil (from Indonesia and Malaysia) and soyabean oil (from Brazil and Argentina) — contributing significantly to the trade deficit (~Rs.1.4 lakh crore annual edible-oil import bill in recent years). India's edible-oil self-sufficiency is only ~40-45%, making price stability a chronic challenge.

Oilseed	*Hindi Name*	*Key States*	*Notes*
Groundnut (Arachis hypogaea)	Moongfali	Gujarat, Rajasthan, Andhra Pradesh, TN, Karnataka	INDIA'S MOST IMPORTANT OILSEED by area; kharif; rain-fed red/sandy soils; also edible snack; exports to SE Asia
Mustard / Rapeseed (Brassica juncea)	Sarson / Rai	RAJASTHAN (largest), Haryana, UP, MP, WB	RABI oilseed; fastest-growing edible oil sector; cold-pressed "kachi ghani" premium market; GM Mustard debate
Soyabean (Glycine max)	Soya	MP (largest — "Soya State"), Maharashtra, Rajasthan	Fastest-growing; kharif; also protein meal for poultry; ethanol link; India imports soya oil but exports soya meal
Sunflower (Helianthus annuus)	Surajmukhi	Karnataka, Andhra Pradesh, Maharashtra	Both kharif and rabi; high-value oil; polyunsaturated
Sesame/Gingelly (Sesamum indicum)	Til	Rajasthan, Madhya Pradesh, UP, Gujarat	Oldest oilseed; "queen of oilseeds"; high nutritional value; export to Middle East
Linseed (Linum usitatissimum)	Alsi	MP, Chhattisgarh, Bihar, UP	RABI; oil (paint, varnish) + fibre; declining area

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CURRENT AFFAIRS

NMEO-OP (National Mission on Edible Oils — Oil Palm, 2021): A dedicated central scheme to expand domestic oil-palm cultivation (Elaeis guineensis) targeting northeast India (Assam, Tripura, Meghalaya, Manipur, Mizoram, Nagaland, Arunachal Pradesh) and Andhra Pradesh/Telangana. Target: ~10 lakh ha by 2025-26. Palm oil gives the highest yield per hectare (~3.5-4 t oil/ha vs mustard's ~0.6 t/ha). Incentives: price assurance, planting material subsidy, INR input support. First Indian refined palm oil product launched 2022-23. This could significantly reduce Indonesia/Malaysia palm oil imports over 5-10 years.

E. RUBBER (HEVEA BRASILIENSIS)

Parameter	*Detail*
Global rank	3rd largest producer (~800,000 t); 4th largest consumer
Leading state	Kerala: ~90% of India's rubber (Kottayam, Thrissur, Ernakulam, Pathanamthitta); also Karnataka (Kodagu), TN
Growing NE India	Tripura (2nd state after Kerala and growing rapidly); Assam, Meghalaya — NE India rubber zone expanding
Climate	Tropical humid; >150 cm rainfall; temperature 25-35°C; relative humidity >80%; elevation <600 m
Soil	Well-drained laterite soils (reddish-brown); slightly acidic (pH 4.5-6.0)
Silviculture	Para rubber tree tapped 6-7 years after planting; ~5-7 months/year latex collection; lifespan ~30 years then felled for timber
Regulator	Rubber Board of India (Kottayam): research, market development, quality control, export promotion; under Ministry of Commerce & Industry
Issues	Declining global rubber prices; aging plantations; labour shortage for tapping; smallholder-dominated; competition from synthetic rubber (petrochemical-based)

12.6 PLANTATION CROPS

TEA (CAMELLIA SINENSIS)

India is the **world's 2nd-largest producer (~1.3 billion kg)** and the **world's largest consumer of tea** — a paradox that limits export despite high production. The tea industry employs approximately **1 million permanent workers** and over 2 million in associated activities, making it one of India's largest private-sector employers.

Region	*Character*	*Output Share*	*Key Notes*
Assam	CTC (Crush-Tear-Curl) tea; large-leaf Assamica variety; strong, malty, bold; "Breakfast tea"; Brahmaputra valley (upper Assam — Dibrugarh, Jorhat, Sibsagar, Tinsukia, Sonitpur districts)	~55% of India's output	Largest tea-growing state; multiple flushes; flood/frost vulnerability; labour relations historically contentious (Tea Garden Workers Act/Plantation Labour Act 1951)
Darjeeling (West Bengal)	Small-leaf sinensis variety; high-altitude (600-2,000 m); delicate muscatel flavour; 87 tea gardens; 3 flushes (First = light/delicate; Second = full muscatel; Autumnal = mellow)	~8-10 million kg/year (small volume, high price)	INDIA'S FIRST GI TAG (2004); "Champagne of Teas"; most expensive Indian tea globally; threatened by climate change (reduced rainfall, altered temperature), labour exodus, aging bushes

Nilgiris (TN)	High-altitude (1,200-2,500 m); Ooty, Kotagiri, Coonoor; clean, bright, mild tea	~15-18% of India	Good quality; proximity to Malabar/Cochin ports; blending demand globally
Kangra Valley (HP)	Low volume; green tea speciality; Kangra Kangra area; premium niche market	<1%	Mountain teas; tourism link
Munnar (Kerala)	Idukki district; High-range (Highrange) teas; Kanan Devan brand (TATA)	~3-4%	Western Ghats ecology; wildlife (Nilgiri tahr); ecotourism overlap

Growing conditions: Acidic soil (pH 4.5-5.5); well-drained hill slopes (waterlogging kills roots); annual rainfall 150-300 cm (well-distributed year-round); temperature 13-29°C; high relative humidity (>70%); frost is fatal.

Tea Board of India (Kolkata): the statutory body under Ministry of Commerce that regulates the tea industry — production standards, licensing, export promotion, GI certification, market development and research (UPASI Tea Research Foundation, Valparai).

COFFEE

India ranks among the **world's top 7-8 coffee producers (~400,000-450,000 tonnes annually)** and exports approximately 80% of production — making it an export-led sector. Indian coffee has two defining characteristics: the **shade-grown model** (grown under a forest canopy) and the **Western Ghats biodiversity context**.

Parameter	*Arabica*	*Robusta*
Scientific name	Coffea arabica	Coffea canephora
Flavour / character	Mild, aromatic, nuanced, low caffeine; smooth acidity	Bold, bitter, high caffeine; strong body; earthy
Altitude	900-1,800 m above sea level	300-900 m above sea level
Principal states	Karnataka (Kodagu/Coorg, Chikkamagaluru, Hassan, Sakleshpur area), Kerala (Wayanad), TN (Nilgiris, Yercaud)	Kerala (Wayanad, Thrissur, Palakkad) — dominant; also Karnataka (low-elevation areas)
Market value	Higher-value; specialty coffee; export to Europe/USA	Lower-value; used in espresso blends, instant coffee
GI tags	Coorg Arabica Coffee, Chikmagalur Arabica Coffee, Araku Valley Arabica Coffee (AP/TS border — tribal cooperative)	Wayanad Robusta Coffee, Bababudangiri Arabica (used for both types)

IFoS FOCUS

IFOS ECOLOGY FOCUS — SHADE-GROWN COFFEE AND WILDLIFE: Indian coffee is overwhelmingly shade-grown under a multi-canopy, multi-strata agroforestry system — coffee bushes under fruit trees, under larger timber or pepper-trained trees, under emergent forest species. This creates a **wildlife-friendly agricultural landscape** that supports:

A. **Lion-tailed macaque (Macaca silenus):** Critically endangered; uses coffee shade gardens extensively for foraging; estimated half their range overlaps coffee estates in the Anamalai hills.
B. **Indian elephant:** coffee estates serve as corridors between forest patches; elephant-human conflict in coffee belts is a management challenge.
C. **Great hornbill, Malabar pied hornbill, Indian grey hornbill:** nest in large shade trees on coffee estates; habitat connectivity depends on shade canopy.
D. **Leopard:** uses coffee estate thickets as cover; Coorg has one of India's densest leopard populations.

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Shade-grown coffee is also carbon-sequestrating (trees above coffee store carbon), reduces chemical runoff (soil is retained by roots), and requires less pesticide (natural pest control). This makes it an ecologically superior production system — which IFoS exams reward in questions on agroforestry, biodiversity and sustainable land use.

SPICES — INDIA AS THE "SPICE GARDEN OF THE WORLD"

India is the **world's largest producer, consumer and exporter of spices** — producing ~11 MT/year, exporting ~2 MT (worth ~USD 4 billion, accounting for ~25% of global spice trade). Spices have been central to India's trade history: they drew Arab traders, Portuguese navigators and British colonisers, and their trade routes shaped world history.

Spice	*Title / Fact*	*Growing Hub / GI*	*Climate / Key Note*
Black Pepper (Piper nigrum)	KING OF SPICES; India's most historically important spice	Kerala (Idukki, Wayanad); GI: Malabar Black Pepper	Tropical humid; >200 cm rainfall; climbing vine on arecanut/jack/coconut support trees; berries turn red when ripe
Cardamom (Elettaria cardamomum)	QUEEN OF SPICES; world's 2nd most expensive spice (after saffron)	Kerala Cardamom Hills (Idukki); TN (Anaimalai, Palani); GI: Coorg Green Cardamom; also Large Cardamom (Amomum subulatum) from Sikkim/NE is a different species	High altitude (600-1,500 m); forest understory; humid; shade-tolerant; Cardamom Hills of Western Ghats
Chilli (Capsicum annuum)	India = world's largest producer + consumer+exporter of chilli	AP (Guntur — "Chilli Capital of India"), Telangana, Karnataka, UP, Maharashtra; GIs: Byadagi Chilli (KA), Guntur Sannam (AP), Teja (AP)	Warm tropical; well-drained soil; needs warm nights; Guntur accounts for ~30% of India's chilli
Turmeric (Curcuma longa)	India = world's largest producer, consumer and exporter (~80% of global supply)	Telangana (Nizamabad-Adilabad — "Turmeric City"), Erode TN ("Yellow City"), AP, Maharashtra, Odisha; GIs: Lakadong Turmeric (Meghalaya — highest curcumin ~7%), Salem Turmeric (TN)	Tropical; deep loamy soil; 1,500+ mm rainfall; shade beneficial; rhizome crop
Cumin / Jeera (Cuminum cyminum)	India = world's largest producer (80%+) and exporter	Rajasthan (Jodhpur belt, Pali, Nagaur, Barmer) — dominant; Gujarat (Banaskantha)	Arid/semi-arid; rabi crop; cool+dry climate; frost-tolerant; sandy loam
Saffron (Crocus sativus)	World's most expensive spice; Rs.3-4 lakh/kg; stigmas hand-picked from flowers	Pampore, Pulwama district, J&K — world's best quality saffron; GI: Kashmir Saffron (2020)	Temperate; specific chilling requirement (cold winter needed for corm dormancy); threatened by reduced snowfall and rising temperatures in Kashmir; low water requirement

Ginger (Zingiber officinale)	India = largest producer; medicinal + culinary	Kerala, NE India (Meghalaya, Assam), UP, Odisha, WB	Tropical humid; well-drained; shade beneficial; rhizome
Coriander (Coriandrum sativum)	Dual-use (leaves = green coriander; seeds = spice)	Rajasthan (Kota-Baran-Jhalawar belt), MP, Gujarat, AP	Rabi; cool; semi-arid; rain-fed possible

12.7 HORTICULTURE — INDIA'S GROWING AGRICULTURAL SECTOR

India is the **world's 2nd-largest producer of both fruits and vegetables** (after China). Horticulture sector annual output now **exceeds foodgrain tonnage by volume** (~350 MT fruits+vegetables vs ~332 MT foodgrain), making it the numerically dominant agricultural sub-sector. Horticulture is also **more labour-intensive, higher-value and more export-oriented** than foodgrain farming, making it key to farmer income growth.

MIDH (Mission for Integrated Development of Horticulture): the central umbrella scheme that covers fruits, vegetables, root+tuber crops, mushrooms, spices, flowers, aromatics, coconut, cashew, cocoa and bamboo — integrating production, post-harvest and market development.

MAJOR FRUITS AND THEIR GEOGRAPHY

Fruit	*Global Rank / Note*	*Key States*	*GI Tags / Special Feature*
Mango (Mangifera indica)	WORLD'S LARGEST PRODUCER (~40% of global); "King of Fruits"	Uttar Pradesh (largest output), Andhra Pradesh, Telangana, Tamil Nadu, Bihar, Karnataka, Gujarat	Alphonso/Hapus (Ratnagiri-Sindhudurg MH + GJ-KA border); Dasheri (Malihabad, UP); Langra (Varanasi); Safeda/Dussehri; Banaganapalli (AP); Himayat (TS)
Banana (Musa spp.)	WORLD'S LARGEST PRODUCER (~34 MT)	Maharashtra (Jalgaon — "Banana Capital"), TN, AP, Karnataka, Gujarat, Kerala, Bihar	Grand Naine variety dominant; Poovan (traditional); export to UAE/Gulf; tissue culture revolution in Maharashtra
Apple (Malus domestica)	Significant producer; mainly domestic consumption	Himachal Pradesh (Shimla, Kinnaur — premium Kinnauri apple), Jammu & Kashmir (Kashmir Valley), Uttarakhand	HP produces ~25% of India's apples; Kinnaur apples fetch premium; climate change = THREAT (fewer cold chilling hours needed for fruit set = rising concern in HP/J&K)
Grapes (Vitis vinifera)	Significant producer; major exporter	Maharashtra (Nashik-Pune-Sangli = 80%+ of India's grapes); Karnataka (Vijayapura/Bijapur)	Nashik = "Wine Capital of India"; Sula and Fratelli wineries; Thompson Seedless (export); raisin production; table grapes to Europe
Citrus (mandarin, kinnow, lime)	2nd largest citrus-producing country	Nagpur (MH) — Nagpur Mandarin GI ("Orange City"); AP, MP, Rajasthan, Punjab (kinnow)	Vidarbha orange belt; kinnow dominant in Punjab-Rajasthan (table fruit export)
Litchi (Litchi chinensis)	Major producer; limited season	Bihar (Muzaffarpur — "Litchi Capital"), Jharkhand, Uttarakhand, WB	Shahi Litchi GI (Muzaffarpur); Acute Encephalitis Syndrome (AES) in Muzaffarpur controversially linked to unripe litchi toxin (MCPG) in malnourished children

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Pomegranate (Punica granatum)	India = world's largest producer	Maharashtra (Nashik, Solapur, Sangli), Gujarat, Karnataka, Rajasthan, AP	Bhagwa variety; major export to Europe, Gulf; drought-tolerant (key for Marathwada)
Guava (Psidium guajava)	World's largest producer	Uttar Pradesh (Allahabad), MP, Bihar, WB	Allahabad Safeda variety famous; rich in Vitamin C

KEY VEGETABLES

Vegetable	*Key States*	*Note*
Potato (Solanum tuberosum)	Uttar Pradesh (largest), West Bengal, Bihar, MP, Punjab, Gujarat	3rd-largest global producer; rabi crop; Agra, Aligarh, Kannauj belt in UP; cold storage dependent; price volatility
Onion (Allium cepa)	Maharashtra (Nashik, Pune — "Onion Capital"); MP, Karnataka, AP, Bihar	India = 2nd-largest global producer; MAJOR EXPORT (but export bans during price spikes cause global onion price crisis — India is the world's largest onion exporter)
Tomato	MP, AP, Karnataka, TN, Maharashtra	Price extremely volatile (Rs.5/kg to Rs.200/kg same year); lacks cold chain
Cauliflower	Bihar (largest), UP, WB, MP	Bihar dominates India's cauliflower; supply chains to Delhi, Mumbai markets
Brinjal (Eggplant)	WB, Odisha, Karnataka, Bihar, UP	India = 2nd globally; Bt Brinjal was India's first GM food crop proposed but environmental release moratorium (2010) continues

12.8 IRRIGATION IN INDIA

Irrigation is the **single most transformative input for Indian agriculture** — converting rain-dependent, one-crop-per-year farming into multi-cropped, high-productivity systems. India has one of the world's most complex and extensive irrigation systems, yet large gaps remain.

INDIA'S IRRIGATION SITUATION AT A GLANCE

Parameter	*Figure*
Ultimate irrigation potential (UIP)	~140 million hectares (Mha)
Irrigation potential created (IPC)	~113 Mha (as of recent estimates)
Irrigation potential utilised (IPU)	~90 Mha
% of Net Sown Area irrigated	~52%
Unirrigated / rain-fed area	~48% of NSA (~68 Mha) — dependent on monsoon alone
Groundwater share of irrigation	~60-65% of total irrigated area
Canal share of irrigation	~26-30% of total irrigated area
Tank share of irrigation	~4-5% of total irrigated area (declining)
Micro-irrigation (drip+sprinkler) area covered	~15-20 Mha (growing under NMMI/PMKSY)

SOURCES OF IRRIGATION — DETAILED

1. ***Groundwater Irrigation (Tube Wells / Bore Wells) – Dominant but Unsustainable***

   Groundwater is the **largest single source of irrigation in India (~60-65% of irrigated area)**. Tube wells and bore wells allow precise, on-demand irrigation; they have democratised irrigation access for small farmers. However, the cost is severe:

- **Overexploitation:** the **Central Ground Water Board (CGWB)** classifies groundwater assessment units (blocks/taluks) as "Over-Exploited" (annual extraction > annual recharge), "Critical" (>90% recharge) or "Semi-Critical" (70-90%). The number of over-exploited units has risen sharply — Punjab, Haryana, western UP and Rajasthan are the worst-affected.
- **Punjab-Haryana crisis:** paddy cultivation in these semi-arid states (which should naturally grow wheat, mustard and dryland crops) requires groundwater because paddy needs standing water that the monsoon cannot adequately provide. Water tables are falling **0.5-1 m/year in most Punjab districts**. PAU (Punjab Agricultural University) studies suggest a 20-year finite horizon. The **Punjab Preservation of Subsoil Water Act (2009)** delays paddy transplantation to June 10+ to reduce pumping.
- **Free electricity = free pumping:** agricultural power is heavily subsidised (often free) in Punjab, Haryana, Rajasthan and AP — eliminating any economic incentive to conserve groundwater. This **"perverse subsidy"** is the most intractable political economy challenge in agricultural water management.
- **Atal Bhujal Yojana (2020):** a World Bank-assisted scheme for community-led groundwater recharge in 7 states; Gram Panchayats manage water conservation plans; ₹6,000 crore, 5 years.

2. ***Canal Irrigation***

Canals serve ~26-30% of irrigated land and are the primary irrigation source for large command areas in Punjab (Bhakra canal system), Rajasthan (IGNP/Indira Gandhi Nahar Pariyojana), UP (Ganga Canal — world's longest irrigation canal), Andhra Pradesh (Nagarjuna Sagar Canal, Pochampad/Srisailam left/right bank canals) and Bihar. Canal irrigation is cheaper per unit of water but requires large upfront infrastructure investment and maintenance, and suffers from waterlogging and salinisation in flat command areas with poor drainage.

3. ***Tank Irrigation***

Traditional rainwater-harvesting tanks (reservoirs) have historically been dominant in South India — Tamil Nadu, Andhra Pradesh and Karnataka. The Vijayanagara Empire and Chola kings built thousands of interconnected tanks. Today, **tanks account for only ~4-5% of irrigated area** — many have been **encroached upon, silted up, or their catchments degraded** by urban expansion and deforestation. Revival of tanks under watershed programmes and MGNREGS is a conservation priority.

4. ***Micro-Irrigation — Drip and Sprinkler***

Type	Mechanism	Water Saving	Best Suited Crops / Uses	Indian Adoption
Drip Irrigation	Water delivered directly to root zone through emitters on pipes; minimal evaporation and runoff	50-70% vs flood irrigation	Fruits, vegetables, cotton, sugarcane, spices, grapes, banana; row crops; horticultural crops	Israel technology; India has world's 2nd largest drip area; Maharashtra, Gujarat, AP, Rajasthan lead
Sprinkler Irrigation	Water sprinkled from overhead pipes/rotating sprinklers, simulating rainfall	30-50% vs flood irrigation	Wheat, vegetables, groundnuts, maize; uneven terrain where drip is difficult	Rajasthan, Haryana, UP; growing in hilly areas

PM Krishi Sinchayee Yojana (PMKSY, 2015): An umbrella scheme integrating **Har Khet Ko Pani** (irrigation connectivity to every farm; through AIBP — Accelerated Irrigation Benefits Programme for completing long-pending large/medium irrigation projects), **Per Drop More Crop** (micro-irrigation; National Mission on Micro

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Irrigation — NMMI), and **Command Area Development** (using created irrigation infrastructure efficiently). Target: cover ~69 Mha under micro-irrigation.

12.9 LAND REFORMS AND LAND USE

PRE-INDEPENDENCE LAND TENURE SYSTEMS

System	*Areas*	*Character*	*Colonial Purpose*
Zamindari	Bengal, Bihar, Odisha, UP, parts of MP and Andhra (Permanent Settlement 1793)	Landlords (zamindars) as revenue collectors between riots and state; peasants as tenants/serfs; absentee landlordism	British revenue certainty; no incentive for zamindars to improve agriculture — just extract rent
Ryotwari	Madras (Tamil Nadu, AP, Karnataka), Bombay (MH, GJ)	Individual ryots (cultivators) dealt directly with state; settled periodically	More direct; higher proportion of revenue to state; no intermediary BUT heavy assessment
Mahalwari	Punjab, UP (NW provinces), Central Provinces	Revenue collected from villages/mahals as a whole; joint responsibility	Village-level assessment; some communal elements

POST-INDEPENDENCE LAND REFORMS (1950S-1980S)

1. ***Abolition of Zamindari / Intermediaries***

   All states abolished zamindari by the mid-1950s through state legislation (land reform is a State List subject under Article 246 + Schedule VII). **~20 million zamindars were eliminated as intermediaries**; their tenants gained ownership rights over ~20 million acres. However, **benami transfers** (transferring land to family members to circumvent ceiling limits), **false evictions of tenants before abolition** and **court delays** diluted the impact significantly.

2. ***Tenancy Reforms***

   Most states passed laws to: (a) provide **security of tenure** to tenants; (b) regulate rent (fixed at 1/4 to 1/5 of produce); and (c) give purchase rights to long-standing tenants. Implementation remained partial — many tenants remained "oral tenants" without written agreements, outside legal protection.

3. ***Land Ceiling Laws***

   Each state set a **maximum amount of land one person/family can hold (ceiling)** — typically 5-25 acres of irrigated land (or equivalent). Land above the ceiling was to be acquired and redistributed to landless poor. About **70-75 lakh hectares** of land was redistributed — a small fraction of potentially available land due to benami, legal contests and political interference. The reform energy had largely dissipated by the 1980s.

INDIA'S LAND USE PATTERN

Land Use Category	*Area (approx.)*	*Significance*
Net Sown Area (NSA)	~141 Mha	Cultivated at least once; ~43% of total geographic area; stable
Current Fallow	~15 Mha	Not cultivated this year; will be sown next year; needed for soil recuperation
Other Fallow	~10 Mha	Not cultivated for 1-5 years; partially degraded; often due to lack of water/inputs

Culturable Waste	~14 Mha	Degraded but recoverable; can be reclaimed with investment; important potential
Permanent Pastures and Grazing	~10.5 Mha	Declining; many encroached; critical for livestock which supports 30 crore farmers
Forest (recorded/legal)	~71 Mha (~21.76%; ISFR 2023)	Legal forest area; distinct from "forest cover" based on canopy density
Misc. Tree Crops, Groves	~3.5 Mha	Orchards, plantations outside forest
Barren and Uncultivable	~17 Mha	Rocky, very high altitude, desert; cannot be cultivated
Non-Agricultural Use	~26 Mha	Settlements, roads, railways, industries; growing with urbanisation

A. **DILRMP (Digital India Land Records Modernisation Programme):** digitises land records (Record of Rights/RoR), cadastral maps and registration of deeds; >90% of land records digitised by 2024 under MoRD; reducing fraud and disputes.

B. **SVAMITVA Scheme (Survey of Villages & Mapping with Improvised Technology in Village Areas):** uses drones to map rural inhabited (abadi) land; issues **Property Cards** to rural households (legal proof of ownership of residential land); Ministry of Panchayati Raj; launched 2020; 1.5 crore+ cards distributed as of 2024; enables property-based credit.

12.10 THE GREEN REVOLUTION — LEGACY AND CRITIQUE

The Green Revolution is **India's most consequential agricultural policy intervention** — transforming a famine-prone nation into a food-surplus one. But its **second-generation costs are now as important as its first-generation gains** — framing the case for an "Evergreen Revolution."

THE TRIAD AND KEY FIGURES

The Green Revolution = HYV seeds + chemical fertilisers + assured irrigation — supported by MSP, institutional credit, procurement infrastructure (FCI) and extension services (KVKs).

A. **Dr. M.S. Swaminathan (1925-2023):** "Father of India's Green Revolution"; plant geneticist at IARI who led the adaptation of Norman Borlaug's Mexican semi-dwarf wheat varieties to Indian conditions; developed Kalyan Sona and Sonalika varieties; later became Director General of ICAR and IRRI; chaired the **National Commission on Farmers (NCF/Swaminathan Commission, 2004-06)**; **passed away on 28 September 2023**.

B. **Dr. Norman Borlaug (1914-2009):** "Father of the Green Revolution"; developed high-yielding semi-dwarf wheat at CIMMYT (Mexico); Nobel Peace Prize 1970; his varieties were based on Japanese Norin-10 dwarf genes crossed with Mexican commercial varieties.

C. **IR-8 "Miracle Rice" (1966):** developed by IRRI (International Rice Research Institute), Philippines; semi-dwarf; highly responsive to nitrogen; revolutionised rice yields in AP, TN and Punjab.

OUTCOMES OF THE GREEN REVOLUTION

Dimension	*Positive Outcomes*	*Negative Consequences*
Food production	50 MT (1950s) → 332 MT (2023-24); record buffer stocks 100+ MT in 2021-22; PL-480 imports ended by late 1970s; no famine since 1943	Wheat-rice monoculture; loss of crop diversity; vulnerability to new pests/diseases (Irish Potato Famine risk)
Water	Irrigation expanded; tube wells enabled year-round cultivation	Punjab/Haryana groundwater table falling 0.5-1 m/year; "dark zones"; unsustainable groundwater abstraction; salinisation in canal command areas

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Soil	Improved soil management; mechanisation reduced drudgery	Micronutrient depletion (Zn, Fe, S deficiency widespread); acidification from urea overuse; compaction from heavy machinery; 97.85 Mha degraded land (ISRO 2021)
Environment	Some efficiency gains in food production per land unit	Pesticide pollution (Punjab "cancer train" — elevated cancer rates along Bhatinda-Hanumangarh belt); 20 MT paddy straw burned annually; N2O greenhouse gas from fertiliser overuse
Economics	Increased rural incomes in Punjab-Haryana; agri-labour wages rose; rural transformation	Fertiliser subsidy ~Rs.2.51 lakh crore (FY2022-23); power subsidy for irrigation; input-output price squeeze; farmer indebtedness rising
Social / Regional	Broad food security; reduction in overall poverty	Punjab-Haryana-UP benefited most; eastern India (Bihar, Odisha), dryland/tribal India largely bypassed; geographic dualism entrenched

SECOND/EVERGREEN GREEN REVOLUTION (THE WAY FORWARD)

- **Extension to eastern India:** West Bengal, Bihar, Odisha, Assam have high production potential but low current yields; focus of BGREI (Bringing Green Revolution to Eastern India) scheme.
- **Millet/pulse/oilseed promotion:** diversify beyond wheat-rice; reduce import dependence on edible oils and pulses; IYM 2023 aligned with this.
- **Micro-irrigation for dryland:** extend drip/sprinkler to rain-fed tribal/dryland areas.
- **Natural/organic farming:** National Mission on Natural Farming (₹2,481 crore, Nov 2024); reduce chemical load on soils.
- **Precision agriculture:** satellite-guided variable-rate fertiliser application; drones for spraying; reduces waste.
- **Climate-smart agriculture:** drought-tolerant/heat-tolerant varieties (DRR Dhan for drought-tolerant rice; DBW303 for heat-tolerant wheat); AWD for methane reduction.

12.11 FOOD SECURITY AND PUBLIC DISTRIBUTION SYSTEM

Food security, as defined by the **Food and Agriculture Organization (FAO)**, has four dimensions: **(1) Availability** (sufficient food produced/imported), **(2) Access** (affordability and physical proximity), **(3) Utilisation** (nutrition absorbed by the body — dependent on safe water, sanitation, healthcare), and **(4) Stability** (reliable access over time). India has largely addressed availability since the Green Revolution, but access, utilisation and stability remain challenges.

NATIONAL FOOD SECURITY ACT (NFSA) 2013

Feature	*Detail*
Coverage	75% of rural population + 50% of urban population = ~81.35 crore (813.5 million) beneficiaries in 2013 estimate; updated with Census
Entitlement	5 kg of foodgrain (rice, wheat, coarse grain) per person per month at subsidised price; Rs.3/kg rice, Rs.2/kg wheat, Rs.1/kg coarse grain
From Jan 2023	Food grains under NFSA now provided FREE (Rs.0/kg) following the PMGKAY merger
Special category	Antyodaya Anna Yojana (AAY): poorest of the poor; 35 kg/family/month; now also free
Implementation	FCI procures, stores and releases; state governments distribute through Fair Price Shops (FPS = ration shops)
Maternal benefit	Pregnant women and lactating mothers entitled to 6,000 cash under PMMVY (linked to NFSA)

FOOD CORPORATION OF INDIA (FCI)

The **FCI (1965)** is the backbone of India's food security architecture — responsible for procuring grain at MSP from farmers, storing it in warehouses (WDRA-registered) and distributing it to states for PDS. FCI maintains **buffer stocks** that peaked at over **100 MT in 2021-22** — the world's largest food stockpile. The **Open Market Sale Scheme (OMSS)** releases grain from buffer stocks into the open market to moderate prices.

KEY PDS REFORMS

- **One Nation One Ration Card (ONORC):** migrants can access their PDS entitlement at **any Fair Price Shop in India** using their Aadhaar-linked ration card. This portability system has been implemented across all 36 states/UTs and was especially critical during COVID migration. About **9+ crore portable transactions per month** have been recorded in recent years.
- **PMGKAY (PM Garib Kalyan Anna Yojana):** launched April 2020 as COVID food relief (additional 5 kg free grain/month over and above NFSA entitlement). Extended multiple times. **Merged with the regular NFSA distribution from January 1, 2023** — food grains under NFSA now provided free of cost (Rs.0) to all ~81 crore beneficiaries. This makes India's food security programme one of the world's most expansive.
- **Leakage reduction through Aadhaar seeding:** biometric-authenticated distribution at FPS has significantly reduced diversion; National Food Security Mission data suggests substantial improvement in targeting.

12.12 AGRICULTURAL POLICY, REFORMS AND SCHEMES

MINIMUM SUPPORT PRICE (MSP)

Aspect	*Detail*
What is MSP?	A floor price announced by the government for specific crops; intended to ensure farmers receive at least this price if they sell through government channels or mandis; FCI procures wheat/rice at MSP
Announced by	CACP (Commission for Agricultural Costs and Prices, 1965; HQ New Delhi; an advisory body under DAC&FW); CACP recommends; Cabinet Committee on Economic Affairs (CCEA) decides
Crops covered	23 crops: 14 Kharif (paddy, jowar, bajra, maize, tur, moong, urad, groundnut, soyabean, sunflower, sesame, cotton (medium+long staple)); 6 Rabi (wheat, barley, gram, mustard, safflower, lentil); 4 others (sugarcane FRP, jute, copra, de-husked coconut)
Cost concepts used	A2 (actual paid-out costs for seeds, fertilisers, pesticides, hired labour, irrigation, etc.); A2+FL (A2 + imputed value of family/household labour); C2 (A2+FL + imputed rent for owned land + imputed interest on owned capital)
Current policy	PM announced in 2018: MSP will be set at "at least 1.5 times the production cost (A2+FL basis)". Implemented since 2018-19
Swaminathan Commission demand	MSP should be set at C2+50% (i.e., 50% profit over comprehensive cost C2) — this is higher than the current 1.5x A2+FL; the difference is the core MSP dispute
Example (Paddy KMS 2025-26)	MSP = Rs.2,369/quintal (announced July 2025); illustrates regular hike; paddy KMS 2024-25 was Rs.2,300/quintal
Why MSP alone is insufficient	MSP is announced but procurement guaranteed mainly for wheat and rice (in Punjab, Haryana, MP); for pulses, oilseeds, and crops in eastern/southern India, actual procurement often falls short — so many farmers sell below MSP in glut years

THREE FARM LAWS (2020) AND THEIR REPEAL — A LANDMARK EPISODE

In **September 2020**, Parliament passed three agricultural reform laws:

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A. **Farmers' Produce Trade and Commerce (Promotion and Facilitation) Act, 2020:** allowed farmers to sell outside the APMC mandi system; any trader could buy from farmers; aimed at breaking the APMC monopoly.
B. **Farmers (Empowerment and Protection) Agreement on Price Assurance and Farm Services Act, 2020:** created a legal framework for contract farming — pre-agreed prices between farmers and companies/aggregators.
C. **Essential Commodities (Amendment) Act, 2020:** removed cereals, pulses, oilseeds, onion and potato from the Essential Commodities list except in extreme circumstances; allowed large stockholding (deregulation of stocking limits).

The laws triggered a massive **year-long protest (November 2020 - November 2021)** centred at Delhi's borders (Tikri, Singhu, Ghazipur) — primarily by Punjab, Haryana and western UP farmers who feared: (1) MSP system being undermined if private trade outside APMC flourishes without MSP guarantee; (2) corporate take-over of agriculture; (3) loss of existing mandi-based earnings.

PM Narendra Modi announced the **repeal of all three laws on 19 November 2021 (Gurupurab/Guru Nanak Jayanti)**; Parliament formally repealed them in December 2021. It was a rare and historic reversal of major legislation. **Over 700 farmers reportedly died during the protest period** (from cold, accidents, illness). The core demand — a **legal guarantee for MSP** — was NOT conceded and remains the central agricultural policy demand as of 2025.

KEY AGRICULTURAL SCHEMES AT A GLANCE

Scheme	*Year*	*Ministry*	*Key Feature / Target*
PM-KISAN (PM Kisan Samman Nidhi)	2019	Agriculture & Farmers Welfare	Rs.6,000/year to all land-holding farmers in 3 instalments of Rs.2,000; ~11+ crore beneficiaries; DBT to bank account; ~Rs.60,000 crore/year; world's largest agri direct benefit transfer programme
e-NAM (National Agriculture Market)	2016	Agriculture	Online integrated mandi platform; 1,260+ mandis; real-time price discovery; electronic bidding; SFAC implementing; reduces middlemen and commission layers
FPO promotion (Farmer Producer Organisations)	2020	Agriculture (Central Sector Scheme)	Form collectives of 300+ farmers each; Rs.6,865 crore scheme; 10,000 FPOs target by 2024-25 (7,000+ formed by end-2024); access to markets, credit, inputs
PMFBY (PM Fasal Bima Yojana)	2016	Agriculture	Crop insurance; farmer premium 1.5% (rabi)/2% (kharif)/5% (horticulture); government pays balance; technology-based loss assessment (satellite, remote sensing); voluntary from 2020; >Rs.1.6 lakh crore claims settled since launch
Soil Health Card Scheme	2015	Agriculture	Free soil testing; nutrient-specific fertiliser recommendations; 22.97 crore cards (Phase I+II)
PM-PRANAM (2023)	2023	Agriculture / Chemicals	Incentivise states to reduce chemical fertiliser use; soil carbon restoration
National Mission on Natural Farming (NMNF)	Approved Nov 2024	Agriculture	Rs.2,481 crore; 1 crore farmers over 2 years; SPNF/Subhash Palekar method; 10,000 Bio-Input Resource Centres

PKVY (Paramparagat Krishi Vikas Yojana)	2015	Agriculture	Organic farming in clusters (50 farmers/cluster); 3-year support; PGS-India certification; linked to organic markets
Kisan Credit Card (KCC)	1998 (revised 2012)	Finance / RBI / NABARD	Short-term credit at 7% (with interest subvention); flexible credit limit; ~7.5 crore KCCs issued; RuPay KCC now standard
NABARD (National Bank for Agriculture & Rural Development)	1982	Finance	Apex development finance institution; refinancing to rural banks; RIDF (Rural Infrastructure Development Fund); watershed development; SHG-Bank Linkage Programme
PM-KUSUM (Pradhan Mantri Kisan Urja Suraksha Evam Uttham Mahabhiyan)	2019	New & Renewable Energy	Solar pumps (2-7.5 HP) for farmers; feeder-level solarisation; 35 lakh solar pumps target; reduces groundwater pumping cost
MIDH (Mission for Integrated Development of Horticulture)	2014	Agriculture	Umbrella for fruits, vegetables, spices, flowers, mushrooms, coconut, cashew, bamboo; production+post-harvest+market development; ~Rs.2,000 crore/year

12.13 AGRICULTURAL DISTRESS — FARMER SUICIDES, DEBT AND THE WAY FORWARD

Despite record foodgrain production and schemes like PM-KISAN, Indian agriculture remains a site of profound distress. The **NCRB's Accidental Deaths and Suicides in India 2022** recorded **11,290 suicides in the farming sector** — 5,207 farmers/cultivators and 6,083 agricultural labourers — a figure widely regarded as an undercount (due to classification issues, gender exclusion of women farmers, and social stigma around suicide reporting). This translates to **approximately 31 farmer/agricultural worker suicides per day**.

HOTSPOT STATES

State	*Key Affected Region*	*Dominant Crop / Crisis Link*
Maharashtra	Vidarbha (Amravati division), Marathwada (Aurangabad division)	Rain-fed Bt cotton; high input costs; limited irrigation; drought-prone; cooperative sugar mills' arrears
Karnataka	Northern Karnataka (Bidar, Kalaburagi, Vijayapura, Belagavi)	Cotton, tur; dryland; water stress; moneylender dependence
Telangana	Adilabad, Nalgonda, Warangal, Nizamabad	Cotton, paddy; Rythu Bandhu scheme (income support) is TG's response
Andhra Pradesh	Rayalaseema (Kurnool, Kadapa, Chittoor, Anantapur)	Drought-prone; tobacco, groundnut, cotton
Madhya Pradesh	Vidisha, Sehore, Morena, Sheopur, Mandsaur	Soyabean, wheat; Mandsaur firing incident 2017
Chhattisgarh	Raipur, Rajnandgaon	Paddy, vegetables; input costs; climate extremes

ROOT CAUSES — THE DEBT-DISTRESS-DEATH SPIRAL

A. **Indebtedness:** the NSSO 70th Round (2012-13) found that ~52% of agricultural households were indebted. High-interest informal borrowing (at 24-36% annual interest) for seeds, fertilisers and social obligations (weddings, funerals) creates unsustainable debt.

B. **Crop failure and climate risk:** dryland farmers (48% of cultivated area) have zero income buffer when the monsoon fails; one crop failure = immediate debt default.

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C. **Input cost inflation vs output price stagnation:** the "cost-price squeeze" — input costs (seeds, fertilisers, pesticides, labour) rising faster than farm gate prices (which fluctuate and are often below MSP for non-supported crops).
D. **Land fragmentation:** below 2 ha, cash-crop economics barely work; scale cannot cover fixed costs of irrigation, mechanisation and input procurement.
E. **MSP non-realisation:** even where MSP exists, actual procurement outside wheat-rice is limited; in glut years, market prices fall below MSP and no government buyer appears.
F. **Missing safety nets:** life/health insurance coverage, legal representation, dispute resolution — all thin for the agricultural poor.

THE SWAMINATHAN COMMISSION RECOMMENDATIONS (NCF 2004-06)

The **National Commission on Farmers (NCF)** — 5 reports (2004-06), chaired by **Dr. M.S. Swaminathan** — is the most comprehensive policy framework for addressing farmer distress. Key recommendations:

- **MSP = C2 + 50%:** at least 50% profit over comprehensive cost C2.
- **Universal crop insurance:** mandatory, affordable; now partially addressed by PMFBY.
- **Access to credit:** interest-free (or very low interest) credit to small farmers; expanded KCC coverage.
- **Irrigation expansion:** access to water as a right; particular focus on rainfed eastern India.
- **Soil health management:** soil testing, micronutrient supplementation; now addressed by Soil Health Card scheme.
- **Debt restructuring:** one-time restructuring and waiver for farmers who suffered crop losses.
- **Land rights for women:** joint land titles for female farmers.

Most recommendations remain partially or wholly unimplemented 20 years later.

CURRENT AFFAIRS	**Kisan Andolan 2024 — Delhi Chalo 2:** Following repeal of farm laws (2021), farmers renewed protests early 2024. Demands: (1) Legal MSP guarantee at C2+50%; (2) Debt waiver; (3) Farmer pension; (4) Compensation for 2020-21 protest families. **Shubhkaran Singh** (21 yrs, Bathinda) died 21 February 2024 at Khanauri border. Farmers blocked at Shambhu and Khanauri borders. Jagjit Singh Dallewal conducted prolonged hunger strike Nov 2024. As of 2025, MSP legal guarantee NOT conceded.

12.14 CURRENT AFFAIRS HOOKS (2021–2025)

CURRENT AFFAIRS	**International Year of Millets 2023:** India-initiated; UN resolution; "Shree Anna" branding; G20 Delhi millet menus (Sep 2023); IIMR Hyderabad as Global Centre of Excellence; India's millet exports rose by ~50% in 2023; NFSM-Nutri-Cereals supportive. **Three Farm Laws Repeal (19 November 2021):** PM Modi announced on Gurupurab; Parliament passed repeal December 2021; 700+ farmers died in protest; Kisan Andolan 2024 renewed demands (MSP, Shubhkaran Singh, Shambhu-Khanauri borders). **Paddy Stubble Burning (Oct-Nov annually):** Punjab-Haryana burn ~20 MT rice straw; Delhi AQI goes "Severe+"; government subsidises Super SMS/Happy Seeder machines; NGT monitors; partially under control but structural fix pending. **Rice Export Ban (20 July 2023 to 28 September 2024):** Non-basmati white rice exports banned; global prices spiked 25-40%; India's 40% share of global rice trade made this a food-inflation event worldwide; restrictions eased Sep 2024 (MEP US$490/t, later removed fully). **Sugar Export Restrictions (2023-24):** India restricted sugar exports to maintain domestic availability and manage inflation; ethanol policy balanced with food security.

National Mission on Natural Farming (NMNF): Union Cabinet approved 25 November 2024; Rs.2,481 crore; 1 crore farmers over 2 years; 10,000 Bio-Input Resource Centres (BIRCs); Subhash Palekar Natural Farming (SPNF) based; aligned with PM-PRANAM.

M.S. Swaminathan death (28 September 2023): "Father of India's Green Revolution"; Padma Vibhushan, World Food Prize, Borlaug Award; his NCF recommendations on MSP=C2+50% remain central to the farm protest.

MSP Hike Kharif 2025-26: CCEA approved paddy MSP Rs.2,369/quintal for KMS 2025-26; highest ever; but legal MSP guarantee still pending.

Digital Agriculture Mission + AgriStack: Farmer Registry being built; crop-sown registry; geo-referenced village maps; intended to enable precision DBT, advisory services and credit access at scale.

NMEO-OP (Oil Palm Mission, 2021): NE India + AP oil palm expansion; target 10 lakh ha; first domestic refined palm oil launched; aims to cut Indonesia/Malaysia import bill over 10 years.

12.15 PYQ ANALYSIS — CHAPTER 12 (2010–2025)

Source	Year	Marks	Question
UPSC Civil	2023	15M	"Assess the role of the Green Revolution in transforming Indian agriculture. What were its negative consequences?"
UPSC Civil	2022	15M	"What are the challenges to food security in India? How can the country achieve sustainable food security?"
UPSC Civil	2022	12M	"What are the likely consequences of implementation of 'Farm Laws' brought in 2020 in the context of agricultural marketing in India? Discuss the key issues." (asked before repeal)
UPSC Civil	2021	15M	"What are the major challenges faced by Indian farmers in marketing their produce? Explain the steps taken by the government." (MSP, e-NAM, FPOs)
UPSC Civil	2020	12M	"What is the significance of the Swaminathan Commission Report? How does the report address the chronic challenges of Indian farmers?"
UPSC Civil	2019	15M	"How are India's national food security objectives being addressed via the MSP and public procurement system? Discuss the challenges."
UPSC Civil	2018	15M	"What are the salient features of the 'Pradhan Mantri Fasal Bima Yojana'? Discuss its implementation and challenges."
UPSC Civil	2017	12M	"What are the major threats to food security in India? Discuss the role of biotechnology in ensuring food security."
UPSC Civil	2013	12M	"What do you understand by the term food security? How is it ensured in India through the National Food Security Act, 2013?"
IFOS GS	2023	15M	"Shade-grown coffee and tea in India contribute significantly to biodiversity conservation. Explain with reference to Western Ghats and North-East India."
IFOS GS	2022	10M	"What are the ecological significance and threats to spice cultivation in the Western Ghats?"
IFOS GS	2021	10M	"Discuss the role of agroforestry in sustainable land management with examples from India."
IFOS GS	2020	10M	"Explain the concept of zero budget natural farming. What are its advantages for small farmers?"
IFOS GS	2019	10M	"Discuss the significance of millets in the context of food security and dryland agriculture in India."

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KEY NOTE

Frequency pattern: Green Revolution critique (Civil 2012, 2017, 2023) + MSP/farmer income (Civil 2018-2022) + food security/NFSA (Civil 2013, 2017, 2019, 2022) are the three anchor clusters. IFoS focuses on plantation ecology (shade coffee, tea biodiversity), agroforestry, organic/natural farming and millet ecology. For 2025-26: Kisan Andolan 2024 + MSP legal guarantee + NMNF (Natural Farming Mission Nov 2024) + NMEO-OP (oil palm) + IYM 2023 fallout are the top current-affairs hooks.

12.16 MODEL BOOK

Assess the role of the Green Revolution in transforming Indian agriculture. Also discuss its negative consequences and the path forward.

Civil (Mains) 2023 | GS-3 | 15 Marks | 200 Words

The Green Revolution (1966-68) — built on HYV seeds, chemical fertilisers and assured irrigation — transformed India from a PL-480 food-aid recipient to a foodgrain-surplus nation producing a record **332.30 MT (2023-24)**. M.S. Swaminathan (passed away 28 September 2023) and Norman Borlaug (Nobel 1970) were its human architects.

KEY POSITIVE OUTCOMES:

- **Food self-sufficiency:** production rose ~6x in 70 years; buffer stocks crossed 100 MT (2021-22); PL-480 imports ended; India now exports ~40% of global rice trade.
- **Poverty reduction:** rural incomes in Punjab-Haryana rose sharply; agri-labour wages increased; overall food inflation moderated.

NEGATIVE CONSEQUENCES:

- **Groundwater depletion:** Punjab's water table is falling 0.5-1 m/year; paddy-wheat cycle in a semi-arid state is ecologically unsustainable.
- **Soil degradation:** micronutrient depletion, acidification, salinisation; 97.85 Mha of land degraded (ISRO-SAC 2021).
- **Regional imbalance:** Punjab-Haryana-UP benefited; eastern India, drylands and tribal areas were bypassed.
- **Environmental costs:** Punjab "cancer belt" (pesticide-linked); 20 MT paddy stubble burned annually (Delhi AQI crisis); fertiliser subsidy ~Rs.2.51 lakh crore (FY2022-23).
- **Biodiversity erosion:** hundreds of local varieties replaced by monocultures — a genetic vulnerability.

PATH FORWARD — THE EVERGREEN REVOLUTION: Diversify toward millets ("Shree Anna"/IYM 2023), pulses and oilseeds; extend irrigation to eastern India (BGREI); promote micro-irrigation (Per Drop More Crop); adopt natural farming (NMNF Rs.2,481 crore, Nov 2024); use precision agriculture to reduce input waste; ensure remunerative MSP across diverse crops; and extend technology to rain-fed dryland regions — combining sustainability, equity and farmer income.

"In India, farmer suicides are a complex socio-economic problem. Critically examine the structural causes of agrarian distress and suggest comprehensive policy solutions."

Civil (Mains) | 15 Marks | 200 Words

India recorded **11,290 farmer/agricultural worker suicides in 2022** (NCRB) — approximately 31 per day. The problem is concentrated in Maharashtra's Vidarbha-Marathwada, Karnataka's north, Telangana, AP and MP, pointing to **structural, not merely personal, causes**.

STRUCTURAL CAUSES (THE "DISTRESS PENTAGON")

1. **Indebtedness:** ~52% of farm households indebted (NSSO); informal credit at 24-36% interest; debt for seeds, inputs and social obligations.

2. **Input-output price squeeze:** input costs (Bt cotton seeds, fertilisers, pesticides) rising faster than farm gate prices; MSP not legally enforceable and procurement absent for most crops.
3. **Climate risk:** 48% of cultivated area is rain-fed; one crop failure → immediate debt crisis → suicide.
4. **Land fragmentation:** average 1.08 ha (Agriculture Census 2015-16) is uneconomic for cash-crop farming.
5. **Missing institutions:** no crop insurance for tenants, inadequate health insurance, absence of agricultural labour rights.

POLICY SOLUTIONS

- **MSP LEGAL GUARANTEE AT C2+50%** (Swaminathan Commission); universal crop insurance (improve PMFBY coverage for tenants); Rs.6,000 PM-KISAN enhanced for most-distressed farmers.
- **IRRIGATION EXPANSION** to eastern/rainfed India; PM-KUSUM solar pumps.
- **MARKET REFORM** via e-NAM + FPOs (10,000 target); reduce middlemen; cold-chain investment.
- **CROP DIVERSIFICATION** to millets + pulses + horticulture — less input-intensive, more nutritionally and environmentally viable.

addressing farmer suicides requires institutional reform (MSP guarantee, formal credit), ecological reform (irrigation, natural farming) and economic reform (market access, income diversification) — an integrated agrarian renewal, not piecemeal palliatives.

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CHAPTER 13

INDUSTRIES OF INDIA

CHAPTER AT A GLANCE

- Industry = ~28% of GDP; ~12-15% workforce; merchandise exports ~$447 bn FY2023-24; India = 5th largest economy (~$3.7 tn); 2nd largest steel producer (~140 MT 2023-24); 2nd largest mobile phone manufacturer (PLI success).
- Textile: India = 2nd largest producer; 45 mn workers; Mumbai (Manchester of India), Ahmedabad (Boston of India), Coimbatore (Manchester of South India), Tiruppur (Knitting Capital), Surat (Synthetic City). PM MITRA = 7 Mega Textile Parks.
- Iron and Steel: Bhilai (USSR; largest SAIL plant; 60% of India's rails), Rourkela (West Germany), Durgapur (UK), Bokaro (USSR). Private: Tata Steel Jamshedpur (1907 — oldest); JSW Bellary/Dolvi; RINL Visakhapatnam (only coastal plant). Target 300 MT by 2030.
- Pharma: India = largest generic drug supplier globally (~20-23% of global generic exports by volume); Hyderabad (Genome Valley/Pharma Capital), Ahmedabad, Mumbai, Bengaluru; PLI for Pharma (Rs.15,000 cr) and APIs (Rs.6,940 cr); 3 Bulk Drug Parks; API dependence on China = strategic vulnerability.
- IT-BPM: ~$245 bn revenue FY2023-24; 5.4 mn employees; Bengaluru (Silicon Valley), Hyderabad (Cyberabad), Chennai, Pune, NCR. 1,700+ GCCs. Semiconductor Mission: Micron (Sanand-GJ), Tata Semiconductor (Dholera-GJ), CG Power-Renesas.
- Automobiles: India = 3rd largest globally; Chennai (Detroit of India -- Hyundai, TVS, Ashok Leyland); NCR-Haryana (Maruti Suzuki); Pune (Tata, Mahindra, Bajaj). EV: PM E-DRIVE (Sep 2024, Rs.10,900 cr); PLI for ACC batteries (Rs.18,100 cr).
- Defence exports: Rs.21,083 cr FY2023-24 (record); target Rs.50,000 cr by 2028-29. UP and TN Defence Corridors. iDEX for startups. BrahMos exported to Philippines.
- Make in India (2014), PLI (14 sectors, ~Rs.2 lakh cr), PM GatiShakti, National Logistics Policy 2022, DMIC (Delhi-Mumbai Industrial Corridor), Startup India. Manufacturing GDP share ~17% vs 25% target.

13.1 INTRODUCTION — INDUSTRIALISATION IN INDIA

Industry and manufacturing form the **second pillar of India's economic structure** — after the services sector, which contributes ~55% of GDP, and before agriculture. Industry contributes approximately **~28% of GDP** (manufacturing ~17% + construction ~8% + mining ~3%), employs **~12-15% of the workforce** directly, and generates **merchandise exports worth ~$447 billion (FY2023-24)**. India's industrial journey encompasses one of the most dramatic transformations in economic history — from colonial de-industrialisation to becoming the **world's 5th largest economy (~$3.7 trillion nominal GDP),** the **2nd-largest steel producer,** the **largest generic-drug exporter,** and the **2nd-largest mobile phone manufacturer**

COLONIAL DE-INDUSTRIALISATION

British colonial policy **systematically dismantled India's indigenous manufacturing** — particularly its world-renowned textile industry. The finest Indian cottons — **Dacca muslin, Dhaka cotton and Calicut cloth** — were priced out of markets by machine-made Manchester cotton flooding India tariff-free under the East India Company's trade monopoly. By 1800-1850, Indian handloom weavers who had supplied **25% of world textile trade** were reduced to destitution. India was simultaneously reduced to a supplier of **raw materials (cotton, jute, indigo, opium)** and a captive market for British manufactures — the classic colonial "raw material exporter-manufactured goods importer" trap.

The Swadeshi Movement (1905), triggered by Lord Curzon's Partition of Bengal, became the first organised push for industrial self-reliance — burning British cloth, promoting khadi and indigenous industries, and laying the intellectual groundwork for India's post-independence industrial policy.

POST-INDEPENDENCE INDUSTRIALISATION — THE NEHRU-MAHALANOBIS MODEL

Period/Policy	*Key Content*	*Impact*
Industrial Policy Resolution 1948	Three schedules: (1) Government monopoly — arms, railways, atomic energy, aircraft; (2) Mixed sector — coal, steel, cement; (3) Private sector — rest	Foundation of state-led industrialisation; ensured basic industries stayed public
Industrial Policy Resolution 1956 (IPR 1956) — "Economic Constitution of India"	17 industries in Schedule A exclusively reserved for public sector; 12 industries in Schedule B for mixed (state + private); rest for private; laid groundwork for PSU era	Expanded public sector; created the heavy industry base through SAIL, BHEL, ONGC, HAL, DRDO etc.
Second Five-Year Plan (1956-61) — MAHALANOBIS MODEL	Prof. P.C. Mahalanobis's model: invest in capital goods/heavy industry to create the means of production (Soviet-style); consumer goods as secondary; agriculture residual; Nehru's "Socialist Pattern of Society"	Built steel (Bhilai, Rourkela, Durgapur), power, engineering foundations; but neglected agriculture and consumer goods
MRTP Act 1969 (Monopolies and Restrictive Trade Practices Act)	Prevent concentration of economic power in private hands; licence required for large companies to expand; "Permit-Licence Raj" reached its zenith	Stifled private sector; limited competition; India's industrial output stagnated relative to East Asian tigers
New Industrial Policy 1991 (LPG Reforms)	Liberalisation: abolished industrial licensing (except 6 industries); Privatisation: PSU disinvestment; Globalisation: opened FDI; devalued rupee; reduced import tariffs; PM P.V. Narasimha Rao + FM Manmohan Singh	Transformed India; unleashed private sector; IT boom; auto-liberalisation; first significant FDI; GDP growth accelerated from 3.5% to 6%+
Make in India 2014	PM Modi flagship; 25 focus sectors; FDI liberalisation; ease of doing business; "Zero Defect, Zero Effect"	Mixed results; FDI increased; manufacturing GDP share stuck at ~17% vs 25% target; PLI schemes as refinement from 2020
National Manufacturing Policy 2011	Target manufacturing at 25% of GDP; 100 million jobs by 2022	Targets not met; PLI approach (2020-21) is the refined successor

KEY NOTE

Mahalanobis Model — Exam Insight : The Second Five Year Plan's Mahalanobis strategy is tested repeatedly. Key features: (1) Two-sector model: capital goods (Machine-making machines) sector + consumer goods sector; (2) Priority to capital goods = self-sustaining industrial growth over time; (3) Inspired by Soviet planning; (4) Neglected agriculture → food crisis by early 1960s; (5) Led to the "Green Revolution" as a corrective in agriculture. Today's "Make in India + PLI" is the market-economy successor to the Mahalanobis heavy-industry vision.

13.2 TEXTILE INDUSTRY — INDIA'S OLDEST AND LARGEST MANUFACTURING SECTOR

The textile industry is **India's oldest modern industry** and still one of its most important — contributing ~7% of industrial production, ~12% of total export earnings, and providing employment to approximately **45 million workers directly** (2nd largest employer after agriculture). India is the **2nd largest textile producer and 5th largest textile exporter** globally, with a sector worth ~$155-165 billion.

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COTTON TEXTILES — THE CORE SUB-SECTOR

Centre	*State*	*Nickname*	*Key Characteristics / Historical Note*
MUMBAI	Maharashtra	"Manchester of India"	Most historically important cotton mill city; first Bombay Spinning and Weaving Company mill (1854); ~140 mills at peak; humid climate helped (cotton yarn less brittle); Dacoiit Bhau Rangari (first mill); DECLINED after Bombay Textile Strike 1982 (Datta Samant-led; 18-month strike; ~250,000 workers; killed the mill industry; mill land now BKC/Worli commercial real estate)
AHMEDABAD	Gujarat	"Boston of India" / "Manchester of the East"	2nd most important; first mill 1861; proximity to Gujarat cotton belt; strong local entrepreneurship (Ahmedabad Millowners Association); Calico Museum of Textiles; Gandhi's Sabarmati Ashram link to khadi
SURAT	Gujarat	"Synthetic City of India" / "Silk City"	India's largest man-made fibre / synthetic textile producer; polyester, viscose, nylon fabrics; ~8 lakh power-loom operators; also diamond polishing
COIMBATORE	Tamil Nadu	"Manchester of South India"	Largest spinning industry centre in India; ~35% of India's spinning capacity; strong entrepreneurship
TIRUPPUR	Tamil Nadu	"Knitting Capital of India" / "T-Shirt Capital of the World"	~Rs.34,000 crore+ in knitwear/hosiery exports; T-shirts, inner wear, sportswear; Europe, USA main markets; mainly small enterprises
KANPUR	Uttar Pradesh	"Manchester of the North" / "Manchester of Northern India"	Cotton textiles + woollens; historically important industrial city; Kanpur leather industry also important
SOLAPUR	Maharashtra	—	Cotton textiles (towels, bedsheets); cotton belt proximity
NAGPUR	Maharashtra	—	Proximity to Vidarbha cotton; synthetic fibre units growing
MADURAI / ERODE / SALEM	Tamil Nadu	—	Handloom and power-loom cotton; Salem sarees; Kancheepuram silk (nearby)

Why Has Cotton Textiles DECENTRALISED from Mumbai? (Most Exam-Important Sub-Topic)

The migration of cotton textiles from its traditional Mumbai hub to inland centres and small towns is one of India's most important industrial geography questions. Six structural reasons explain this decentralisation:

1. **Power looms and handlooms:** unlike large spinning mills that need capital-intensive infrastructure, power looms and handlooms can operate anywhere — even in homes and small workshops. This technology change freed the industry from urban concentration.
2. **Proximity to cotton:** moving production to Gujarat, Maharashtra's Vidarbha-Marathwada and Telangana — closer to the raw cotton belt — reduces transportation costs significantly.
3. **Cheaper labour:** production in Tier-2 and Tier-3 cities (Tiruppur, Coimbatore, Bhiwandi, Erode, Salem) benefits from lower wage costs than Mumbai.
4. **State incentives:** state governments offered tax concessions and subsidised land/power to textile units in smaller cities to promote industrial dispersal.
5. **5. Synthetic/blended fibre rise:** Surat's man-made fibre industry developed independently of the cotton belt — it imports petrochemical-based fibres from Jamnagar/Dahej and weaves synthetic fabric. This decoupled textiles from the cotton supply constraint.
6. **Infrastructure improvement:** better roads, expressways and container logistics have reduced the advantage that Mumbai's port location gave — textiles from Tiruppur or Bhiwandi can reach ports as efficiently today.

JUTE TEXTILES

Aspect	Detail
India's rank	World's largest jute goods producer; ~60+ jute mills concentrated in West Bengal
Location cluster	HOOGHLY RIVER BELT (West Bengal): 80 km radius from Kolkata; both banks of the Hooghly from Rishra (north) to Naihati (south) and across to Budge Budge; also some mills in Shibpur, Titagarh, Barrackpore
Why Hooghly belt?	(1) Proximity to jute-growing Ganga-Brahmaputra delta (WB, Bihar, Assam); (2) Kolkata port for colonial-era exports (jute once India's largest export); (3) Cheap labour from Bihar and UP; (4) Damodar Valley coal for energy; (5) British merchant capital historically
Jute products	Gunny bags/sacks, hessian cloth, carpet backing, geo-textiles, composites, jute handicrafts, jute-based biodegradable packaging
Key support	JPMA 1987 (Jute Packaging Materials Act): mandatory jute packaging for food grains and sugar procured by government; National Jute Policy 2005; Jute Technology Mission
Challenges	Plastic and synthetic substitutes; Bangladesh competing strongly in jute goods (now world's largest exporter of jute goods, while India leads in raw jute); declining area under jute cultivation; labour-intensive production costs
Revival strategy	High-value geo-textiles (jute soil savers for road and slope stabilisation, very high demand); eco-friendly packaging (plastic ban creates new opportunity); technical textiles

SILK INDUSTRY

Silk Type	Region / GI Tag	Key Species	Note
Mulberry Silk (Bombyx mori)	Karnataka (Mysore, Ramanagara, Kolar, Hassan) — "MYSORE SILK" GI tag; also WB (Murshidabad), J&K, TN	Bombyx mori (mulberry silkworm)	Karnataka = ~75% of India's raw silk; Mysore-Bengaluru belt; silk sarees famous (Mysore Silk GI); Ramanagara = "Cocoon City"
Banarasi / Zari Silk	Varanasi (Uttar Pradesh) — "BANARASI SILK" GI tag	Mulberry silk + zari (gold/silver thread)	UNESCO-protected weaving craft; brocade and kincob; Mughal-era origin; heavily handloom-based
Muga Silk	Assam — GI tag	Antheraea assama (muga silkworm; wild)	UNIQUE TO ASSAM; golden-yellow lustre; State symbol of Assam; most durable natural fibre; Sualkuchi = "Manchester of Assam"
Eri Silk (Peace Silk)	Assam, Meghalaya, Manipur — GI tag	Samia ricini (eri/castor silkworm)	Non-violent silk (pupa not killed; moth exits naturally); tribal communities; coarser but durable; used for shawls
Tussar / Kosa Silk	Bhagalpur (Bihar) — "Bhagalpur Silk" GI; also Jharkhand (Ranchi area), Chhattisgarh (Raigarh — "Kosa Silk")	Antheraea mylitta (wild silkworm on arjun/asan trees)	Rough, textured, natural gold colour; eco-friendly (wild silk); India's largest tussar-producing area; Bhagalpur = "Silk City"
Chanderi Silk	Chanderi, Ashoknagar district, MP — GI tag	Mixed silk + cotton	Chanderi sarees; very fine, sheer; Madhya Pradesh craft tradition
Kanchipuram Silk	Kanchipuram, TN — GI tag	Mulberry silk	Heaviest silk saree; temple border design; traditional South Indian wedding saree

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PM MITRA SCHEME AND PLI FOR TEXTILES

Scheme	Launch	Details
PM MITRA (PM Mega Integrated Textile Region and Apparel Parks)	2021-22 Budget; 7 parks sanctioned 2022-23	Integrated plug-and-play textile parks covering the full 5F value chain: Farm (fibre) to Fibre to Fabric to Fashion to Foreign (export); provides common infrastructure; each park ~1,000 acres; States: Tamil Nadu (Virudhunagar), Telangana (Warangal), Gujarat (Navsari), Karnataka (Kalaburagi), MP (Dhar-Pithampur), UP (Lucknow), Maharashtra (Amravati); Central grant Rs.500 crore/greenfield park
PLI for Textiles	2021; Rs.10,683 crore over 5 years	Covers man-made fibre (MMF) garments and technical textiles; incentivises companies to invest in MMF production lines; addresses gap in MMF where India lags China; targets Rs.19,788 crore in new investment and ~7.5 lakh jobs
National Technical Textiles Mission (NTTM)	2020-21; Rs.1,480 crore	Technical textiles (agro-textiles for crop protection, medical textiles, geo-textiles for roads/slopes, protective textiles for defence/fire); aims to increase India's technical textile market from $16 bn to $40 bn

13.3 IRON AND STEEL INDUSTRY

India is the **world's 2nd-largest steel producer (~140 million tonnes, FY2023-24),** having surpassed Japan and holding position behind China (which produces ~1,000 MT). India's National Steel Policy 2017 targets **300 MT capacity by 2030** — which would make India the world's 2nd-largest steel nation by a wide margin. Steel is central to India's infrastructure ambitions (railways, highways, housing) and the energy transition (wind turbines, solar structures, EVs).

LOCATION FACTORS FOR IRON AND STEEL PLANTS

Factor	Importance	Example
Iron ore proximity	Most critical; ore is bulky and expensive to transport; ideally within 250 km	Bhilai (Bailadila ore); Rourkela (Odisha ore); Tata Jamshedpur (Singhbhum ore)
Coking coal	Iron is reduced in blast furnace using coking coal (metallurgical coal); also bulky; must be prime coking coal	Jharia coalfield (only prime coking coal in India) supplies Bhilai, Bokaro, Durgapur
Water	Enormous quantities for cooling blast furnaces, processing; rivers essential	Bhilai on Sheonath River; Rourkela on Brahmani/Sankha; Jamshedpur on Subarnarekha and Kharkai
Limestone / Dolomite	Flux in blast furnace to remove impurities as slag	Nandini (near Bhilai); Birmitrapur (Rourkela); Sundargarh (Rourkela)
Transport (Railways)	For raw material movement and finished steel dispatch	All plants are on railway networks; Bhilai benefits from South-East Central Railway
Power	Continuous heavy power consumption; proximity to coal-based or hydro power preferred	Damodar Valley Corporation powers Bokaro, Durgapur; Hirakud powers Rourkela
Labour	Large skilled and unskilled workforce	Chotanagpur plateau area supplies tribals as unskilled labour; engineers from IITs/NITs
Market proximity	Minimises distribution cost	Bokaro near Jharkhand-WB industrial belt; Jamshedpur serves East India auto/engineering industries

PUBLIC SECTOR — SAIL (STEEL AUTHORITY OF INDIA LTD)

SAIL — Steel Authority of India Ltd — is India's largest public sector steel company (Maharatna PSU). It operates five integrated steel plants and several alloy/special steel plants.

Plant	*Location*	*Collaboration*	*Capacity (approx.)*	*Key Products / Significance*
BHILAI STEEL PLANT (BSP)	Bhilai, Durg district, Chhattisgarh	USSR / Soviet Union (1954-55)	~8 MT crude steel; Blast Furnaces: 8 BFs	LARGEST SAIL plant; LARGEST integrated steel plant in India; produces ~60% of India's rail output (critical for railways); products: rails, heavy structurals, large angles, wire rods; raw material: Bailadila iron ore (Dantewada, CG); coking coal from Jharia; limestone from Nandini
ROURKELA STEEL PLANT (RSP)	Rourkela, Sundargarh, Odisha	West Germany / FRG (1955-56)	~4.5 MT crude steel	INDIA'S FIRST INTEGRATED STEEL PLANT to use the LD (Linz-Donawitz oxygen converter) process; products: HR coils, sheets, plates, pipes — flat products for automobile, engineering, oil sectors; raw material: Kalta/Barsua/Bolani iron ore (Odisha); limestone from Birmitrapur
DURGAPUR STEEL PLANT (DSP)	Durgapur, Paschim Bardhaman, West Bengal	United Kingdom / British (1956-57)	~2.5 MT crude steel	Damodar Valley coal belt; products: rails, billets, alloy steel, special steels; serves Bengal-Bihar industrial region; alloy steel plant at Durgapur (Durgapur Alloy Steel Plant = DASP)
BOKARO STEEL PLANT (BSL)	Bokaro, Jharkhand	USSR / Soviet Union (1965; 2nd Soviet collaboration after Bhilai)	~5.45 MT crude steel	Produces HR/CR coils for automobile industry; near Jharia coking coal; Damodar Valley power; one of the largest plants; Nehru inaugurated land in 1955
IISCO STEEL PLANT	Burnpur, Asansol, West Bengal	British (historical; oldest — 1918; acquired by SAIL 1978)	~2.5 MT (modernised)	India's OLDEST STEEL PLANT CITY; near Raniganj coal; modernised 2015; products: long products, structurals, rails

PRIVATE SECTOR STEEL

Company / Plant	*Location*	*Capacity*	*Key Note*
TATA STEEL (Jamshedpur)	Jamshedpur (Tatanagar), East Singhbhum, Jharkhand	~12 MT (Jamshedpur); +8 MT Kalinganagar, Odisha (new greenfield)	India's OLDEST STEEL PLANT (1907; J.N. Tata's vision); "Steel City of India" / Tatanagar; pioneered integrated industrial township (hospital, school, clubs — model welfare capitalism); Singhbhum copper+iron+uranium belt proximity; coking coal from Jharia

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JSW STEEL (Vijayanagar / Bellary)	Toranagallu, Vijayanagar (formerly Bellary), Karnataka + Dolvi (Raigad, MH)	~28+ MT total group capacity; Vijayanagar = ~13 MT; Dolvi ~10 MT	Largest private steel company in India; Bellary (Vijayanagar) uses Sandur/Bellary iron ore; Dolvi uses imported iron ore via sea (Raigad port); produces HR coils, plates; Maharashtra steel for automobiles
RASHTRIYA ISPAT NIGAM LTD (RINL) / Vizag Steel	Visakhapatnam, Andhra Pradesh	~7.3 MT	ONLY COASTAL INTEGRATED STEEL PLANT in India; uses imported iron ore and Telangana coal; sea-based logistics; under government privatisation discussions (2021-23; currently deferred)
JINDAL STEEL AND POWER (JSPL)	Angul (Odisha) + Raigarh (CG) + Patratu (JH)	~10+ MT total	Coal-based DRI (Direct Reduced Iron) + EAF route; cost-competitive; also power generation; Angul plant = mega-integrated unit
ESSAR / ArcelorMittal Nippon Steel India (AM / NS India)	Hazira (Surat, Gujarat)	~8.6 MT	Sea-based plant; uses imported ore via Hazira port; produces flat products; acquired from Essar in IBC resolution (2020) by ArcelorMittal-Nippon joint venture
NMDC Steel Ltd (Nagarnar)	Nagarnar, Bastar, Chhattisgarh	~3 MT	Government-owned new plant; transferred from NMDC-to-NMDC Steel Limited; commissioned 2023-24; uses Bailadila ore; significant for tribal region employment

CURRENT AFFAIRS

Green Steel — The Next Frontier (2024-25): Conventional steel-making uses coking coal in blast furnaces to reduce iron ore ($FeO + CO \rightarrow Fe + CO_2$). This is carbon-intensive (~1.8 tonnes of CO_2 per tonne of steel, accounting for ~7-9% of global CO_2). The future is:

- **Hydrogen-based DRI (H-DRI):** replace coking coal with green hydrogen as the reducing agent; $3Fe_2O_3 + H_2 \rightarrow 2Fe_3O_4 + H_2O$ (simplified); zero CO_2 emission. Tata Steel, JSW, SAIL exploring this aligned with the National Green Hydrogen Mission.
- **Electric Arc Furnace (EAF):** melts scrap steel using electricity; ~35% of India's steel currently via EAF (vs USA ~70%); growing as scrap availability rises; much lower CO_2 than blast furnace if powered by renewable energy.

National Green Steel Mission: under discussion; aims to achieve 30-50% of India's steel via green route by 2030-35. This links the National Steel Policy (300 MT) with the Paris Agreement.

13.4 CEMENT INDUSTRY

India is the **world's 2nd-largest cement producer (after China)** — with an installed capacity of ~590 MT and production of ~380-390 MT (FY2023-24). Cement is essential for India's infrastructure boom (roads, railways, housing, urban development, dams), and the industry is growing rapidly with the government's infrastructure push.

LOCATION PRINCIPLES

Cement is a **raw-material-oriented industry** — limestone (the principal raw material, ~1.5 tonnes per tonne of cement) is heavy and expensive to transport. **Plants are always located near limestone deposits.** Coal is needed for kiln heat; gypsum is added for setting time control; fly ash and slag are used in blended cement to reduce clinker and CO_2.

MAJOR CEMENT CLUSTERS

State	Key District/Cluster	Significance
Rajasthan	Chittorgarh, Kotputli, Sirohi, Jodhpur, Nagaur	LARGEST CEMENT-PRODUCING STATE; abundant high-grade limestone in Vindhyan/Aravalli rocks; ACC, UltraTech, Shree Cement, Dalmia, Ambuja all have major plants here
Madhya Pradesh	Satna-Rewa ("Cement City of India"), Jabalpur, Katni	Satna belt = historically India's oldest cement cluster; MP has the highest-quality limestone; ACCplant at Kymore (Katni); Prism Cement, UltraTech, JK Cement
Andhra Pradesh	Kurnool, Nalgonda, Yerraguntla, Guntur	Rich Vindhyan/Cuddapah limestone; several plants from Vicat, Dalmia, UltraTech, Kesoram; bulk of raw material exports to other states
Tamil Nadu	Ariyalur (LARGEST CONCENTRATION in TN), Tirunelveli, Trichy	Ariyalur district = India's 3rd-largest cement hub; Dalmia Bharat, India Cements, Ramco, Chettinad Cement
Karnataka	Gulbarga/Kalaburagi, Bagalkot	UltraTech Rajashree plant; Deccan Trap limestone
Gujarat	Junagadh, Saurashtra	Ambuja Cement (now ACL under Adani); Sudarshan Cement
Himachal Pradesh	Solan, Arki	ACC, Ambuja flagship historic plants; Shivalik rock limestone

Company	Market Share (approx.)	Notable Plants
UltraTech Cement (Aditya Birla Group)	~30% — India's largest	Rajashree (KA), Kotputli (RJ), Arasmeta (CG), Sewagram (TN); 25+ plants
Ambuja Cements (now Adani-acquired, 2022)	~8%	Ambujanagar (GJ), Dadri (UP), Farakka (WB); merged with ACC under Adani Cement
ACC Ltd (now Adani-controlled)	~7-8%	Kymore (MP), Bargarh (OD), Wadi (KA), Gagal (HP)
Shree Cement	~8-9%	Beawar (RJ), Bangur (RJ); cost-efficient model; recently expanded east
Dalmia Bharat	~6-7%	Ariyalur (TN), Kadapa (AP), Rajgangpur (OD); East India focus
India Cements	~3%	Sankarnagar (TN), Yerraguntla (AP); South India focus; now acquired by UltraTech (2024)

ENV ALERT

Cement and CO2 — The Decarbonisation Challenge:
Cement production accounts for ~7-8% of global CO2 emissions - one of the hardest to decarbonise.
Main culprit: CLINKER PRODUCTION ($CaCO_3$ heated to 1450 deg C decomposes: $CaCO_3$ to $CaO + CO_2$ - a process emission that cannot be eliminated by switching to renewable energy, unlike combustion emissions).
Solutions: (1) Blended cement - replace clinker with fly ash or GBFS (reduces CO2/tonne); (2) Carbon Capture and Storage (CCS) - pilot plants; (3) Novel binders (geopolymer cement, calcium sulfo-aluminate); (4) Efficiency improvements. BEE's PAT (Perform Achieve and Trade) scheme targets energy efficiency in cement.

13.5 CHEMICAL AND PHARMACEUTICAL INDUSTRY

CHEMICAL INDUSTRY

India is the **6th-largest chemical producer globally** — a ~$220-250 billion market employing ~2 million people. The chemical industry is India's 3rd-largest industrial sector and contributes ~14% to India's total exports.

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Cluster	State	Key Products / Significance
Jamnagar-Vadodara Belt	Gujarat	Reliance petrochemicals at Jamnagar (PX, MEG, PTA — polyester intermediates); ONGC Petro additions (OPaL) at Dahej; PCPIR (Petroleum, Chemical and Petrochemicals Investment Region at Dahej)
Surat-Ankleshwar-Vapi Belt	Gujarat	India's largest specialty chemical cluster; Ankleshwar = densest concentration of chemical units; Vapi = historically one of India's most polluted industrial areas (CrVI contamination, CETP needed); chlor-alkali, dyes, pesticides, pigments
Mumbai-Thane-Pune Corridor	Maharashtra	BPCL/HPCL downstream; pharma; polymers; Ambernath industrial area
GAIL Pata	Uttar Pradesh (Prayagraj/Anta)	GAIL's gas-based petrochemical complex; ethylene, polyethylene; supplies PE to packaging/pipe industry across North India
Haldia Petrochemicals	West Bengal	Eastern India's petrochemical anchor; HP-owned; ethylene crackers
Chemicals in Rajasthan/MP	Rajasthan, Madhya Pradesh	Mining chemicals, phosphatic fertilisers, cement chemicals

PHARMACEUTICAL INDUSTRY — "PHARMACY OF THE WORLD"

India has achieved a remarkable global position in generic pharmaceuticals — supplying **~20-23% of global generic exports by volume** (though only ~3-4% by value, reflecting the low-price generic model). India provides **~50% of the USA's generic drug requirement**, **~25% of UK's generic medicines** and **~40% of generic demand in Africa**. India exports pharmaceuticals to **more than 200 countries** — earning ~USD 27 billion in pharma exports (FY2023-24).

Hub	State	Key Companies / Profile
HYDERABAD ("Genome Valley" / "Pharma Capital of India")	Telangana	World's largest bulk drug + formulation cluster; Cyberabad/HITEC City area; Dr. Reddy's Laboratories, Aurobindo Pharma, Hetero Drugs, Divi's Laboratories, MSN Labs, Laurus Labs; also biopharmaceuticals (Biological E, Bharat Biotech — Covaxin maker)
AHMEDABAD / VADODARA / ANKLESHWAR	Gujarat	Sun Pharmaceutical Industries (largest Indian pharma company), Zydus (Cadila), Alembic Pharma, IPCA Labs; India's largest pharma export hub by shipment value; Sarkhej-Bavla (GIDC) = pharma GIDC
MUMBAI	Maharashtra	Cipla, Wockhardt, Abbott India, Lupin; formulations hub; oldest pharma cluster; proximity to Nhava Sheva/JNPT port for exports
BENGALURU	Karnataka	Biocon (Kiran Mazumdar-Shaw; biopharmaceuticals, insulin biosimilars), Strides Pharma, Sequent; also medical devices
BADDI (Solan, HP)	Himachal Pradesh	India's largest pharma hub by number of manufacturing units (~700+); driven by excise and income-tax exemptions (early 2000s); Torrent, Alembic, Sun, Cadila plants here
VIZAG / HYDERABAD PHARMA CITY (AP)	Andhra Pradesh	Pharma City Visakhapatnam (400 acres dedicated pharma zone); Aurobindo Pharma origin

API (Active Pharmaceutical Ingredient) Dependence on China — Strategic Vulnerability

An **Active Pharmaceutical Ingredient (API)** is the biologically active component in a medicine. India imports **~68-**

70% of its APIs from China — including 80-90% of APIs for key antibiotics (penicillin, amoxicillin), antipyretics (paracetamol/acetaminophen), vitamins, and many bulk drugs. COVID-19 revealed this as a **critical strategic vulnerability** when Chinese API supply was briefly disrupted in early 2020. Government response:

- **PLI for Bulk Drugs / APIs (Rs.6,940 crore, 2020):** incentivises domestic API production; 41 products covered; targets Rs.46,202 crore additional domestic production and ~Rs.19,000 crore in API exports within 6 years.
- **3 Bulk Drug Parks approved:** Himachal Pradesh (Una/Nalagarh), Andhra Pradesh (Visakhapatnam/Orvakal), and Gujarat (Bharuch/Dahej); each park receives Rs.1,000 crore central grant; COMMON INFRASTRUCTURE for API manufacturing.
- **PLI for Pharmaceuticals (Rs.15,000 crore, 2021-22):** targets high-value products: biopharmaceuticals (complex proteins, mAbs), patented drug analogues, complex generics, orphan drugs, repurposed drugs. 55 companies selected.

CURRENT AFFAIRS

Serum Institute and the Vaccine Capital : India is the "Vaccine Capital of the World" — producing more than half the world's vaccine doses annually. The SERUM INSTITUTE OF INDIA (Pune, Maharashtra) is the world's largest vaccine manufacturer by dose volume. It produced COVISHIELD (the Indian-made Oxford-AstraZeneca COVID vaccine) which was supplied to ~160+ countries. SII also makes polio, measles, hepatitis B, influenza and other vaccines. Dr. Cyrus Poonawalla's SII supplies ~80% of children's vaccines distributed by UNICEF globally. This extraordinary capacity was instrumental in India's COWIN (COVID-19 Vaccine Intelligence Network) vaccination programme — the world's largest — administering ~220 crore doses.

FERTILISER INDUSTRY

Parameter	*Detail*
India's rank	2nd largest urea producer globally; 3rd-4th in total fertilisers
Key companies	IFFCO (Indian Farmers Fertiliser Cooperative — largest cooperative; plants at Kalol-GJ, Aonla-UP, Phulpur-UP, Kandla-GJ, Paradeep-OD); NFL (National Fertilisers Ltd); Chambal Fertilisers; RCF (Rashtriya Chemicals and Fertilisers, Trombay-Mumbai); Coromandel International (MH/AP); Tata Chemicals
Urea	Key input; Centre fixes MRP at Rs.242/45 kg bag; difference between cost of production and MRP is the fertiliser subsidy (~Rs.2.51 lakh crore in FY2022-23)
DAP (Di-ammonium Phosphate)	Imported significantly from Saudi Arabia, Jordan, Morocco, Russia, China; India has limited phosphate rock deposits
MOP (Muriate of Potash)	Entirely imported; India has NO potash deposits; imports from Canada (Potash Corp), Belarus, Russia, Laos; import cost ~Rs.40,000 crore/year
New Urea Plant Revival	5 shut-down fertiliser plants being revived (Ramagundam-TS, Talcher-OD, Gorakhpur-UP, Sindri-JH, Barauni-BR) under a national urea sufficiency mission
Nano Urea	IFFCO's Nano Urea Liquid (500 ml bottle = 1 bag of urea in terms of fertiliser sufficiency claim); reduces logistics cost and subsidy burden; controversial on efficacy

13.6 INFORMATION TECHNOLOGY (IT) AND IT-ENABLED SERVICES (ITES)

India's IT-BPM (Information Technology and Business Process Management) sector is one of the world's most consequential industrial success stories — growing from near-zero in 1990 to a **~$245 billion revenue sector (FY2023-24),** employing **~5.4 million professionals directly** and creating ~13 million indirect jobs. India holds **~55% of the global IT-BPO outsourcing market,** reflecting a unique international competitiveness built on English-speaking engineering talent, time-zone advantages (supporting US and European clients) and relative cost efficiency.

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MAJOR IT HUBS

City	Nickname / Label	Key Companies / Institutions	Scale / Significance
BENGALURU	Silicon Valley of India; IT Capital of India	Infosys (HQ), Wipro (HQ), TCS, IBM, Accenture, Oracle, SAP, Google, Intel, Microsoft; also ISRO, HAL, NAL, DRDO labs; Biocon	India's largest IT hub; ~1.7 million IT employees; Whitefield, ITPL, Electronic City campuses; largest contribution to India's software exports
HYDERABAD	Cyberabad; Hyderabad IT Capital	Microsoft (India Dev Centre), Google, Amazon, Facebook/Meta, Apple, Delloite; Dr. Reddy's Genome Valley; IT HITEC City; T-Hub (startup incubator)	2nd largest IT hub; ~1 million IT workers; TG government's IT policy aggressive; also biotech+pharma+AI crossover
CHENNAI	Chennai IT Hub; South Indian IT Capital	Cognizant (originated here), Wipro, TCS, Infosys; TIDEL PARK (Asia's largest IT park when built); also BFSI, KPO, engineering R&D	3rd hub; ~500,000 IT workers; auto + IT convergence; strong BPO industry
PUNE	Pune IT / Pune IT Hub	Infosys, TCS, Wipro; Rajiv Gandhi Infotech Park (Hinjewadi); also engineering R&D for auto and defence	~500,000 IT workers; engineering R&D + IT crossover; university-industry linkage (Pune University)
NCR (GURUGRAM / NOIDA)	Millennium City (Gurugram); NCR IT Hub	HCL Technologies (HQ Noida), Tech Mahindra, DXC Technology; Cyber City Gurugram; SEZ Noida	~500,000 IT workers; BPO/ITES dominant; BFSI and startup ecosystem
MUMBAI	SEEPZ-SEZ; Bandra-Kurla Complex	Mastech, fintech startups, Tata Consultancy (HQ), BFSI IT	Financial capital overlap; fintech unicorns; SEEPZ software export zone
KOCHI / THIRUVANANTHAPURAM	Kerala IT Capital; INFOPARK/ TECHNOPARK	Infosys, TCS, UST Global; TECHNOPARK (India's first IT park, 1995)	Emerging hub; KERALA IT Policy; strong government push; TECHNOPARK = India's 1st dedicated IT park

GLOBAL CAPABILITY CENTRES (GCCS) — INDIA'S RISING SECOND WAVE

A **Global Capability Centre (GCC)** is an offshore unit of a multinational company performing high-value work — R&D, engineering design, analytics, legal processing, HR — rather than just routine BPO. India had **~1,700 GCCs by end-2024,** employing ~1.66 million professionals and generating ~$46 billion in revenue. This represents a **structural upgrade** from India being a back-office destination (data entry, call centres) to being a **global R&D and innovation hub**. Key GCC examples: APPLE (design center, Hyderabad), MICROSOFT (MSRIT India — ML research), GOOGLE (AI research, Hyderabad and Bengaluru), BOEING (engineering design, Bengaluru), JP MORGAN (tech, Mumbai). The GCC sector grew ~12-15% in 2024 as companies reoriented global talent strategies post-COVID.

INDIA SEMICONDUCTOR MISSION — "ATMANIRBHAR" IN CHIPS

Project	*Company*	*Location*	*Investment*	*Details*
Micron Semiconductor	Micron Technology (USA)	Sanand, Ahmedabad, Gujarat	~$825 million; GoI incentive ~Rs.11,000 crore	SEMICONDUCTOR ASSEMBLY, TEST AND PACKAGING (ATMP) facility; not a full fab; produces NAND flash memory and DRAM chips for India's electronics manufacturing; announced June 2023; construction began 2023; FIRST foreign semiconductor investment under ISM
Tata Semiconductor Assembly and Test (TSAT)	Tata Electronics + Taiwan's Powerchip Semiconductor Manufacturing Corp (PSMC)	Dholera Special Investment Region (SIR), Gujarat	~$10-11 billion (one of India's largest ever single investments)	INDIA'S FIRST SEMICONDUCTOR FABRICATION (FAB) PLANT; 28nm chip technology; will manufacture chips for automobiles, telecom, consumer electronics; Cabinet approved Feb 2024; construction started 2024
CG Power-Renesas-Stars Micro	CG Power (Murugappa Group) + Renesas (Japan) + Stars Microelectronics (Thailand)	Sanand, Gujarat	~$730 million; GoI incentive Rs.7,600 crore	Semiconductor ATMP; power semiconductors; smaller-scale fab; Cabinet approved Feb 2024

UPSC CIVIL

Civil GS-3 — Semiconductor Strategy : India Semiconductor Mission (ISM, 2021): outlay of Rs.76,000 crore (~$10 bn) to attract semiconductor fabs and ATMP facilities. India is NOT targeting advanced 5nm or 3nm chips (TSMC/Samsung territory) — it is targeting 28nm and above chips used in automobiles, power electronics, industrial and consumer devices — where most of India's import substitution opportunity lies. The strategic rationale: Taiwan-China tensions create global supply-chain anxiety; India offers a stable, democratic, English-speaking semiconductor location. Challenges: semiconductor fabs are among the most capital-intensive and technically complex manufacturing in the world; India lacks the talent and supply chain ecosystem that Taiwan/South Korea have built over 40 years.

13.7 AUTOMOBILE INDUSTRY

India is the **world's 3rd-largest automobile manufacturer** (after China and USA) and the **2nd-largest two-wheeler market**. The industry contributes ~7% of India's GDP and ~45% of India's manufacturing GDP, employing directly and indirectly over **37 million people**. India produces ~24+ million vehicles annually (FY2023-24) and is a significant two-wheeler exporter and tractor exporter.

MAJOR AUTOMOBILE CLUSTERS

Cluster	*Key Companies / Brands*	*Segment Strength*
GURUGRAM-MANESAR-HARYANA (NCR)	Maruti Suzuki (Gurugram plant + Manesar plant = India's largest car factory complex; ~43% of India's passenger car market share); Hero MotoCorp; Honda Motorcycle (nearby)	Passenger cars dominant; Maruti Suzuki India manufactures ~2+ million cars/year; Manesar SEZ; proximity to Delhi parts market

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PUNE-CHAKAN-RANJANGAON-NASHIK (Maharashtra)	Tata Motors (Pimpri-Chinchwad; HQ also in Mumbai); Bajaj Auto (Chakan, Waluj-Aurangabad); Mahindra (Chakan); Force Motors; Skoda Volkswagen (Pune); Piaggio	Maharashtra = balanced mix of passenger cars, SUVs, commercial vehicles (Tata trucks), two/three-wheelers; strong engineering talent (COEP, MIT Pune)
CHENNAI-SRIPERUMBUDUR-ORAGADAM (Tamil Nadu)	Hyundai India (Sriperumbudur — largest Hyundai plant outside Korea); Renault-Nissan (Oragadam); BMW India assembly; Ashok Leyland (HQ Chennai); TVS Motor; MRF; Apollo Tyres	DETROIT OF INDIA; largest concentration of car manufacturers; South Indian auto export hub; Ford (exited 2021); Royal Enfield; largest auto cluster by FDI and export volume
BENGALURU-BIDADI (Karnataka)	Toyota Kirloskar (Bidadi); TVS (partial); BEML (defence vehicles, mining equipment); HAL (aerospace overlap)	Japanese-model manufacturing; Toyota's India R&D; Bidadi = Toyota's India Mfg Hub
RAJASTHAN (Bhiwadi, Tapukara, Jaipur)	Honda Cars India (Tapukara plant — now partially moth-balled post COVID slowdown); Yamaha; Hero MotoCorp Neemrana plant	Two-wheelers + passenger cars; benefits from NCR proximity
UTTARAKHAND (Haridwar, Pantnagar, Rudrapur)	Hero MotoCorp (Haridwar); Bajaj Auto; Honda Scooters; Mahindra (Pantnagar)	Two-wheelers dominant; tax incentives drove this cluster; Pantnagar = SIDCUL industrial estate

ELECTRIC VEHICLE (EV) TRANSITION

Scheme / Policy	*Year*	*Outlay*	*Key Feature*
FAME-I (Faster Adoption and Manufacturing of Hybrid and EV)	2015-17 (Phase I)	Rs.895 crore	First EV promotion scheme; focused on two-wheelers; limited uptake
FAME-II	2019-2024 (extended from 2022 to 2024)	Rs.10,000 crore	Two-wheelers (Rs.15,000/kWh incentive), three-wheelers, buses (1,000 e-buses ordered); charging infrastructure; ~1.5 mn EVs supported; ended March 2024
PM E-DRIVE (PM Electric Drive Revolution in Innovative Vehicle Enhancement)	September 2024	Rs.10,900 crore (FY2024-26)	Replaces FAME-II; electric two-wheelers (Rs.5,000/kWh, max Rs.10,000/vehicle), three-wheelers, buses (10,000 e-buses for State Transport Undertakings); electric ambulances (for PM Ayushman Bharat); EV public charging stations; more targeted than FAME-II
PLI for ACC (Advanced Chemistry Cell) Batteries	2021	Rs.18,100 crore over 5 years	Domestic Li-ion battery cell manufacturing; 50 GWh capacity; selected companies: Ola Electric, Reliance Industries, Rajesh Exports, Lucas TVS, Hyundai; to reduce battery import cost and make EVs cheaper
PM SURYA GHAR (charging interface)	2024	Part of broader scheme	Rooftop solar + EV charging nexus; net metering for EV charging from solar

India's EV Market Leaders: Tata Motors holds ~70-75% of India's EV passenger car market (Nexon EV, Tiago EV, Tigor EV, Punch EV); Mahindra launched the XEV 9e and BE 6e (2025); Hyundai (Creta Electric, Ioniq 5); OLA ELECTRIC MOBILITY leads in electric two-wheelers (~35-40% market share; S1 scooter series; its own gigafactory in Krishnagiri, Tamil Nadu = "Future Factory" — 500,000+ scooters/year capacity); ATHER ENERGY and TVS iQube are other major two-wheeler EV players.3

13.8 DEFENCE MANUFACTURING — INDIA'S ATMANIRBHAR AMBITION

India was the **world's largest arms importer for much of 2012-2021** (SIPRI data) — spending ~$15 billion annually on defence imports. "Atmanirbhar Bharat in Defence" is PM Modi's most ambitious industrial transformation target: converting India from import-dependent to a significant **defence exporter by 2028-29 (target: Rs.50,000 crore in defence exports)**. India's defence exports reached a **record Rs.21,083 crore in FY2023-24** — a 32.5-fold increase from Rs.686 crore in FY2013-14.

KEY DEFENCE PRODUCTION ORGANISATIONS

Organisation	*Full Name / HQ*	*Products / Role*
DRDO	Defence Research and Development Organisation; New Delhi	60+ labs across India; develops missiles (Agni, Prithvi, BrahMos jointly with Russia), weapons, radars, electronics, armour; civilian spinoffs including COVID diagnostics
HAL	Hindustan Aeronautics Ltd; Bengaluru (HQ)	TEJAS LCA (Light Combat Aircraft) Mk1/Mk1A — India's indigenous fighter; Dhruv Advanced Light Helicopter; Chetak; Ajeet; Su-30MKI license assembly; engines; avionics
BEL	Bharat Electronics Ltd; Bengaluru (HQ)	Electronic warfare, radars, sonar, night vision, communication, space electronics; listed PSU
BDL	Bharat Dynamics Ltd; Hyderabad (HQ)	Guided missiles, torpedoes, underwater weapons; Akash SAM (Surface-to-Air Missile) production
BEML	BEML Ltd (formerly Bharat Earth Movers Ltd); Bengaluru	Mining equipment, rail coaches, bulldozers; defence vehicles (high mobility vehicles, snow trekkers, howitzers)
7 DPSUs (from OFB)	Munitions India Ltd, Armoured Vehicles Nigam Ltd, Advanced Weapons and Equipment India Ltd, Troop Comforts Ltd, Yantra India Ltd, India Optel Ltd, Gliders India Ltd	Seven PSUs created in 2021 when the Ordnance Factory Board was dissolved; ammunition, tanks, artillery, personal equipment, optics

DEFENCE INDUSTRIAL CORRIDORS

Corridor	*States / Cities*	*Target Investment*	*Key Companies / Projects*
UP Defence Industrial Corridor	Lucknow, Agra, Aligarh, Jhansi, Chitrakoot, Kanpur (6 nodes)	Rs.50,000 crore	BrahMos Aerospace (BrahMos cruise missile plant at Lucknow, signed 2022); Bharat Forge; MSME defence components; Yogi govt providing land and incentives
Tamil Nadu Defence Corridor	Chennai, Coimbatore, Hosur, Salem, Trichy (5 nodes)	Rs.20,000 crore	HAL, DRDO labs; auto-defence overlap (Ashok Leyland, Tata Motors defence vehicles in Chennai); aerospace components (Coimbatore engineering); MSME components

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Defence Export / Achievement	Detail
BrahMos export to Philippines (2022-24)	First BrahMos cruise missile system exported; ~$375 million deal (Jan 2022 signed); deliveries started 2024; Philippines = first export customer; more countries in pipeline (Indonesia, UAE, others negotiating)
Tejas LCA export discussions	India negotiating with Malaysia, Egypt, Argentina, others for Tejas Mk1A; no final deal signed as of 2025
Pinaka MLRS exports	Pinaka multi-barrel rocket launcher being developed for export; Armenia, Egypt, Vietnam among potential buyers
HAL Chetak helicopter exports	Helicopter exports to Nepal, Mauritius, Suriname
Drones (MALE UAS)	DRDO's TAPAS BH-201 MALE drone under development; private: Alpha Design, ideaForge; major defence drone ecosystem building
iDEX (Innovations for Defence Excellence)	2018; empowers startups for defence technology; 300+ challenges launched; 200+ startups funded; fastest route to defence tech innovation

13.9 FOOD PROCESSING INDUSTRY

India is the **world's 6th-largest food processing nation** — with a market valued at ~$535 billion and growing at ~10-15% per annum. Given that India is the world's 2nd-largest food producer, the food processing sector represents the most important link between farm and consumer — and the biggest opportunity to **reduce post-harvest losses (currently 15-25%), increase farmer incomes and add value to agricultural output.**

MAJOR FOOD PROCESSING SEGMENTS

Segment	Scale / Significance	Key Companies / Region
Dairy processing	India = world's largest milk producer (239 MT); Rs.1+ lakh crore dairy industry; cooperative model is transformative	AMUL (GCMMF, Gujarat — "Taste of India"; Asia's largest dairy cooperative; Anand Pattern created by Dr. Verghese Kurien — Operation Flood transformed India from milk-deficient to milk-surplus); Mother Dairy, Nestlé, Britannia (dairy division)
Fruits and vegetables processing	Rs.60,000+ crore; 6-8% of F&V production processed (vs 35-40% in advanced nations); huge scope	ITC Agri, HUL (Kissan), Pepsi AgriBusiness; Maharashtra (tomato puree, grape juice, onion powder); AP (chilli processing Guntur); Tamil Nadu (banana chips Kozhikode); NE India (pineapple, ginger processing)
Marine / seafood processing	India = one of world's top 5 seafood exporters; ~Rs.60,000 crore exports	Kerala, AP, TN, Gujarat, WB coast; MPEDA (Marine Products Export Development Authority, Kochi) regulates; frozen shrimp = largest seafood export; Black tiger shrimp, white shrimp
Grains / rice milling	India = world's largest rice exporter; massive rice milling industry	Punjab, Haryana, AP, WB; KRBL (largest basmati exporter — "India Gate" brand); LT Foods
Spice processing	India = largest spice exporter; ~Rs.30,000 crore spice exports	Kerala (cardamom, pepper), AP (chilli), TN, Rajasthan (cumin); Everest, MDH, MTR (spice brands)
Ready-to-eat / convenience foods	Fast-growing; Indian and multinational brands	HUL, Nestle, ITC, PepsiCo, Britannia; growing organised segment; cold chain needed

KEY GOVERNMENT SCHEMES

Scheme	Year	Details
PM-FME (PM Formalisation of Micro Food Processing Enterprises)	2020-21; Rs.10,000 crore, 5 years	Formalise 2 lakh micro food processing units; 35% credit-linked subsidy (max Rs.10 lakh); common infrastructure support; branding and marketing support; linked to ONE DISTRICT ONE PRODUCT (ODOP) for local specialties
Mega Food Parks (MFP scheme)	2008-09 onwards; 42 sanctioned	Central processing core facility + primary processing centres + collection centres; cold chain; processing units; common utilities; Rs.50 crore per park central grant
PLI for Food Processing	2021; Rs.10,900 crore	Four categories: innovative/organic products; processed fruits & vegetables; marine products; mozzarella cheese; targets Rs.33,494 crore additional sales and Rs.7,535 crore exports in 6 years
Agri-Export Zones (AEZ)	2001 onwards	Location-specific; crop-linked; 60+ AEZs; specific crops (Alphonso mango Ratnagiri, Basmati rice Punjab, grapes Nashik) promoted with end-to-end export support
SAMPADA (PM Kisan Sampada Yojana)	2017; Rs.4,600 crore	Integrated scheme for food processing; covers Mega Food Parks, cold chain, agro-processing clusters, backward-forward linkages, food safety/quality infrastructure

13.10 INDUSTRIAL REGIONS OF INDIA

India's industries are spatially concentrated in a small number of metropolitan and coastal industrial regions — a legacy of colonial port-city development, post-independence heavy-industry location decisions, and the agglomeration benefits of established industrial ecosystems.

Industrial Region	States / Anchor Cities	Principal Industries	Key Feature
MUMBAI-PUNE METROPOLITAN REGION	Maharashtra (Mumbai, Thane, Pune, Nashik, Aurangabad)	Petrochemicals, pharmaceuticals, automobiles (Pune), financial services, IT, cotton textiles (historically), engineering	India's most diversified industrial region; both manufacturing and services; Pune = auto and IT; Mumbai = finance and pharma; NH-48 expressway corridor
BENGALURU-CHENNAI-COIMBATORE BELT	Karnataka + Tamil Nadu	IT (Bengaluru), automobiles (Chennai), textiles (Coimbatore), aerospace and defence (Bengaluru-ISRO-HAL), electronics, knitwear (Tiruppur)	South India's powerhouse; most FDI in manufacturing; Chennai = "Detroit of India"; Bengaluru = "Silicon Valley of India"; Hosur = electronics + defence crossover
CHOTA NAGPUR INDUSTRIAL REGION (Jharkhand Plateau + W Bengal + Odisha margins)	Jharkhand, West Bengal, Odisha	Iron and steel (Jamshedpur, Bokaro, Rourkela, Durgapur), coal mining (Jharia, Bokaro, Raniganj), copper (Singhbhum), mica, heavy engineering	India's "Ruhr Valley"; resource-rich; tribal-mining conflict zone; Damodar Valley Corporation (DVC) powers the region
HOOGHLY RIVER REGION	West Bengal (Kolkata + Hooghly district)	Jute textiles (70+ mills on Hooghly banks),	Declining industrial region; jute JPMA support; new industries: IT

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		engineering, chemicals, food processing, paper	(Kolkata IT Park, Sector V), automotive ancillaries
AHMEDABAD-SURAT-VADODARA-ANKLESHWAR BELT	Gujarat	Cotton + synthetic textiles (Ahmedabad, Surat), chemicals (Ankleshwar, Vapi), petrochemicals (Jamnagar, Dahej), pharmaceuticals (Ahmedabad), diamonds (Surat), cement (Saurashtra)	India's most industrially diverse state belt; Surat = "Diamond City of India" (polishes ~90% of world's rough diamonds); Gujarat = most FDI-friendly state
DELHI-NCR-HARYANA INDUSTRIAL BELT	Delhi, Haryana (Gurugram, Faridabad, Manesar), UP (Noida, Greater Noida, Ghaziabad)	Automobiles (Maruti Suzuki), electronics, IT, engineering, consumer goods, FMCG, light manufacturing	India's largest single consumer market overlap; Gurugram = India's start-up capital; Noida = electronics manufacturing hub (mobile phones PLI)
VISAKHAPATNAM-GUNTUR BELT	Andhra Pradesh	Steel (RINL), chemicals, shipbuilding, pharmaceuticals, tobacco processing, marine products, fertilisers	AP's industrial backbone; Visakhapatnam = India's only city with both a seaport and an airport and a natural harbour; shipbuilding (Visakhapatnam Shipyard)

13.11 INDUSTRIAL POLICY, SPEVIA; ECONOMIC ZONES AND INDUSTRIAL CORRIDORS

MAKE IN INDIA (2014)

Launched by PM Modi on **25 September 2014**, make in India (MII) is the flagship manufacturing promotion initiative — aiming to transform India into a global manufacturing hub. Key elements: (1) 25 focus sectors (now expanded to 27) across manufacturing (automobiles, defence, aviation, pharma, textiles, chemicals, IT, food processing, etc.); (2) FDI liberalisation (most sectors at 100% automatic route); (3) Ease of Doing Business (EoDB) improvement; (4) reduction of compliance burden.

Make in India 2.0 (2020+): revised to focus on 27 sectors with a dual emphasis: 15 in manufacturing and 12 in services. Linked to PLI schemes as the implementation mechanism.

PLI (PRODUCTION LINKED INCENTIVE) SCHEMES — INDIA'S INDUSTRIAL POLICY 2.0

PLI schemes, announced starting 2020-21, offer **financial incentives (3-10% of incremental sales over a base year)** to domestic and foreign companies for producing specified goods in India, above a threshold investment. Unlike the old subsidies approach, PLI is performance-linked — companies must actually produce and sell to receive the incentive.

PLI Sector	*Outlay (Rs. crore)*	*Key Outcome / Achievement*
Mobile Phones and Electronics (Large Scale)	Rs.40,951 crore (LSEM); Rs.4,425 crore (IT hardware)	MOST SUCCESSFUL PLI: Apple (Foxconn, Pegatron, now Tata Electronics), Samsung; India exports ~Rs.1 lakh crore+ in smartphones; India = 2nd largest mobile phone manufacturer globally (after China)
Pharmaceuticals (PLI)	Rs.15,000 crore	55 companies; targeting biopharmaceuticals, complex generics, high-value active APIs; Rs.57,000 crore additional production targeted

Bulk Drugs / APIs	Rs.6,940 crore	41 products; reduce China dependence; 3 Bulk Drug Parks supporting
Automobiles and Advanced Automotive Technology	Rs.25,938 crore	Covers EVs (CNG vehicles, hydrogen fuel cell), auto components; Tata Motors, M&M, Bajaj, Hyundai, Suzuki selected
ACC Battery (Advanced Chemistry Cell)	Rs.18,100 crore	50 GWh manufacturing; Ola Electric, Reliance, Rajesh Exports, Lucas TVS, Hyundai selected; Li-ion cells to reduce EV cost
Man-Made Fibre Textiles + Technical Textiles	Rs.10,683 crore	Address gap in MMF (India lags China); technical textiles for defence, infrastructure, agriculture
Telecom and Networking Products	Rs.12,195 crore	5G equipment, core networking hardware; Dixon Technologies, VVDN, STL; reduce import from China/Huawei
Food Processing	Rs.10,900 crore	Ready-to-eat, fruit/vegetable, marine products, mozzarella cheese
Solar PV Modules	Rs.24,000 crore (ALMM + PLI)	Domestic solar manufacturing; Adani, Waaree, Vikram Solar, Premier Energies; to reduce China solar module import
White Goods (AC, LED)	Rs.6,238 crore	Air conditioners and LED lights manufacturing
Specialty Steel	Rs.6,322 crore	High-value specialty steel (grain-oriented electrical steel, coated steel, high-strength steel) currently imported; Tata, JSW, AMNS India
Medical Devices	Rs.3,420 crore	Reduce import of medical equipment; masks, ventilators, syringes, CT scan components

DELHI-MUMBAI INDUSTRIAL CORRIDOR (DMIC)

Parameter	*Detail*
Length	~1,504 km; Western Dedicated Freight Corridor (WDFC) as the spine
Concept	Japan-India collaboration; smart industrial cities along the freight corridor; "plug and play" infrastructure; greenfield development
Industrial Nodes	Dholera (Gujarat — most advanced; Dholera Special Investment Region/DSIR = one of India's largest greenfield smart cities; also Tata Semiconductor fab here); Aurangabad Industrial City/AURIC (Maharashtra); Greater Noida-Dadri (UP); Manesar-Bawal (Haryana); Khushkhera-Bhiwadi-Neemrana (Rajasthan); Vikram Udyogpuri (MP); Ahmedabad-Dholera SIR
Investment target	~$100 billion (Rs.7.5 lakh crore) in 7 industrial nodes and related infrastructure
Progress	WDFC (Western Dedicated Freight Corridor) operationalised Dec 2020 (New Palanpur-Vaitarna section, 306 km); Dholera SIR progressing; AURIC first units operational; overall progress slower than projected

Policy / Scheme	*Year*	*Key Points*
Special Economic Zones (SEZ) Act	2005	Export-oriented units with tax concessions, simplified regulations; 430+ notified SEZs; 5 lakh+ workers; Noida SEZ (oldest NOIDA Export Processing Zone — 1985), Falta WB, SEEPZ Mumbai, Kandla GJ; declining interest due to tax regime changes (MAT applicability)
National Logistics Policy (NLP)	2022	PM Modi launched; reduce logistics cost from ~13-14% of GDP to <8%; ULIP (Unified Logistics Interface Platform) integrating data; PM GatiShakti integration; target 2030

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PM GatiShakti National Master Plan	2021 (PMO initiative)	GIS-based digital platform integrating infrastructure plans of 16 ministries + states; identifies bottlenecks and synchronises investments; highways, railways, ports, airports, waterways, logistics parks; infrastructure convergence for industrial productivity
Startup India	2016	DIPP recognition system; 80,000+ recognised startups by 2024; Rs.10,000 crore Fund of Funds (SIDBI); 3-year income tax exemption; simplify exit
MSME Udyam	2020	New MSME registration portal replacing UAM; 4.5+ crore registered enterprises; simplified investment+turnover criteria

13.12 CURRENT AFFAIRS HOOKS (2021–2025)

CURRENT AFFAIRS

India becomes 5th largest economy (2023): India surpassed the United Kingdom in nominal GDP (~$3.7 trillion) in 2023, becoming the world's 5th largest economy. India is 3rd in PPP terms (after China and USA). Target: 3rd largest by 2027-28.

Semiconductor Mission — 3 projects approved (Feb 2024): Cabinet approved (i) Tata Semiconductor Assembly and Test (TSAT) at Dholera, Gujarat ($10-11 bn; 28nm fab with PSMC); (ii) Micron ATMP plant, Sanand, Gujarat (~$825 mn); (iii) CG Power-Renesas-Stars Micro ATMP, Sanand (~$730 mn). India's first semiconductor fab is TSAT Dholera.

Defence Exports Record (FY2023-24): India's defence exports reached Rs.21,083 crore in FY2023-24 — a record; 32x increase from FY2013-14's Rs.686 crore; exports to 85+ countries; key products: BrahMos (Philippines), Tejas components, Akash SAM, ammunition, Chetak helicopter. Target: Rs.50,000 crore by 2028-29.

PLI Achievements — Mobile Phones: India is now the world's 2nd-largest smartphone manufacturer; Apple's Indian-made iPhones (via Foxconn-Sriperumbudur, Tata Electronics-Hosur) reached ~25% of Apple's global iPhone production; India exported ~$15 billion+ in smartphones; India's PLI for mobile phones = most successful industrial policy in decades.

PM E-DRIVE Scheme (September 2024, Rs.10,900 crore): Replaces FAME-II (which ended March 2024); includes electric two-wheelers (Rs.5,000/kWh incentive, max Rs.10,000/vehicle), electric three-wheelers, 10,000 electric buses for STUs, electric ambulances, EV charging stations. More targeted and better-monitored than FAME-II.

PM MITRA (7 Textile Parks sanctioned 2022-23): States: TN (Virudhunagar), Telangana (Warangal), Gujarat (Navsari), Karnataka (Kalaburagi), MP (Dhar), UP (Lucknow), Maharashtra (Amravati). Integrate 5F value chain. Infrastructure under construction 2023-25.

GCC Boom (2024-25): India has 1,700+ Global Capability Centres employing 1.66 mn professionals; revenue ~$46 bn; record additions in 2024 as multinationals shift R&D, analytics and engineering to India. Hyderabad and Bengaluru gaining most GCC additions.

Manufacturing GDP Share Challenge: Despite Make in India (2014) and PLI, manufacturing's share of GDP remains ~17% — well below the 25% target set in the National Manufacturing Policy 2011. Services (especially IT) and construction dominate. The PLI mobile-phone success is the bright spot but broader manufacturing needs more structural support.

13.13 PYQ ANALYSIS — CHAPTER 13 (2010–2025)

Source	Year	Marks	Question
UPSC Civil	2022	15M	"Discuss the factors responsible for the decentralisation of the cotton textile industry away from its traditional centres in India."
UPSC Civil	2022	12M	"What is the significance of the Production Linked Incentive (PLI) scheme? Critically evaluate its achievements across key sectors."

UPSC Civil	2021	12M	"Faster, cheaper, and reliable Internet access is a key factor influencing the location of IT industry in India. Discuss."
UPSC Civil	2021	12M	"Critically evaluate the Make in India initiative with respect to manufacturing's share in GDP and employment generation."
UPSC Civil	2020	15M	"Discuss the role of Special Economic Zones (SEZs) in India's export-led growth strategy. Evaluate their performance."
UPSC Civil	2019	12M	"Discuss the challenges faced by the Indian MSME sector and the measures taken by the government to promote it."
UPSC Civil	2019	12M	"Examine the significance of the National Logistics Policy for India's economic competitiveness."
UPSC Civil	2018	12M	"Discuss the factors for the location of the iron and steel industry in India. Is the pattern changing with changing technology?"
UPSC Civil	2016	12M	"Is industrialisation the only option to create employment in developing countries? Discuss this with examples."
IFOS GS	2024	10M	"Examine the impact of industrial pollution on forest ecosystems in Chotanagpur plateau with reference to iron/steel and mining industries."
IFOS GS	2023	10M	"Discuss the pharmaceutical industry in India with special reference to the role of generic drug exports in public health in developing countries."
IFOS GS	2022	10M	"Explain the concept of green steel and its relevance in the context of India's climate commitments."
IFOS GS	2021	10M	"Write a note on the Defence Industrial Corridors of India and their importance for indigenous defence manufacturing."
IFOS GS	2019	10M	"What are the environmental consequences of automobile pollution in India? Discuss government measures to promote electric vehicles."

KEY NOTE

Frequency pattern: Cotton textile decentralisation (Civil 2012, 2022) — most tested industrial geography question; PLI and Make in India (Civil 2021, 2022 recurring); iron and steel location (Civil 2018; IFoS geography question); EV/FAME (Civil + IFoS since 2019); defence manufacturing (IFoS 2021); pharma generics (Civil 2023; IFoS 2023). For 2025-26: semiconductor mission (very high probability), green steel (IFoS recurring), GCC boom, PM E-DRIVE and PLI mobile phone success.

13.14 MODEL BOOK

Discuss the factors that have led to the spatial decentralisation of the cotton textile industry away from its traditional centres in India.

Civil (Mains) | 15 Marks | 200 Words

The cotton textile industry, once concentrated in Mumbai ("Manchester of India") and Ahmedabad ("Boston of India"), has progressively decentralised to Tiruppur, Coimbatore, Surat, Bhiwandi, Ludhiana and smaller inland centres — driven by a combination of technology change, market forces and policy incentives.

1. **Technology change — power looms:** The shift from large, capital-intensive spinning mills to small, flexible power looms and handlooms has freed the industry from the agglomeration requirements of large factories. Power looms can operate in homes and workshops in any location.
2. **Proximity to cotton:** Moving production to Gujarat, Vidarbha-Marathwada, Telangana and Andhra Pradesh — closer to the cotton belt — reduces raw-material transportation costs significantly.
3. **Labour cost:** Smaller cities offer significantly lower wages than Mumbai, giving them a competitive cost advantage in a labour-intensive industry.

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4. **Policy incentives:** State governments offered tax concessions, subsidised power and land to attract textile units, accelerating the dispersal from metropolises.
5. **Rise of synthetics — Surat:** Surat's emergence as India's synthetic-textile capital (man-made fibres from Jamnagar/Dahej) created a new industrial geography entirely independent of the cotton belt — demonstrating that technology can override traditional location factors.
6. **Post-Mumbai collapse:** The Bombay Textile Strike of 1982 (Datta Samant) permanently deindustrialised Mumbai's mill districts — the land was converted to commercial real estate, and production shifted to cheaper locations.

Technology democratisation (power looms), market forces (labour and material costs), policy dispersal incentives and the traumatic collapse of Mumbai's mill industry have together produced a spatially dispersed cotton textile industry that is more broadly competitive but less organised than its mill-era predecessor.

Critically evaluate India's Make in India initiative with respect to manufacturing's share in GDP and employment generation. What has PLI achieved?

Civil | 15 Marks | 200 Words

Launched in 2014, Make in India (MII) sought to raise manufacturing's share of GDP to 25% and create 100 million manufacturing jobs — targets tied to the National Manufacturing Policy 2011.

ACHIEVEMENTS

1. **FDI surge:** India's FDI inflows rose from ~$36 billion (2013-14) to ~$71 billion (2023-24); sectors like defence (74% automatic), insurance and railways were opened.
2. **PLI success:** The PLI for mobile phones is transformative — Apple, Samsung, and others have set up large-scale manufacturing; India is now the world's 2nd-largest smartphone manufacturer (~$15 billion+ exports). India Semiconductor Mission (3 projects, Feb 2024) signals deeper manufacturing ambition.
3. **Defence exports:** Rs.21,083 crore in FY2023-24 (32x increase from 2014) — MII in defence has succeeded.

SHORTFALLS

1. **Manufacturing GDP share stagnant:** Manufacturing remains ~17% of GDP — unchanged from 2014, well below the 25% target. Services (especially IT) have grown faster.
2. **Employment:** The 100-million-jobs target by 2022 was missed by a wide margin; manufacturing employment as a share of total employment has barely budged.
3. **Structural constraints:** Land acquisition difficulty, labour law rigidity, logistics cost (~13-14% of GDP vs global best of 8%), and infrastructure gaps limit manufacturing competitiveness.

WAY FORWARD: National Logistics Policy (2022) + PM GatiShakti + dedicated freight corridors (WDFC, EDFC) + PLI across 14 sectors + semiconductor manufacturing must converge into a coherent industrial ecosystem. India must capture a larger slice of the China+1 global supply-chain diversification wave.

CHAPTER 14

TRANSPORT OF INDIA

CHAPTER AT A GLANCE

- Transport = economic lifeline; India's logistics cost ~13-14% of GDP vs global best ~8% (USA, EU); National Logistics Policy 2022 targets <8% by 2030; PM GatiShakti National Master Plan (Oct 2021) integrates 16 ministries on GIS platform.
- Railways: World's 4th largest network; ~68,000 km routes; ~1.5 mn employees (largest single employer); 18 zones; 100% BG electrification achieved 2023-24; KAVACH anti-collision system; Vande Bharat (100+ sets); Mumbai-Ahmedabad Bullet Train (508 km; Shinkansen/JICA).
- DFCs: WDFC (Ludhiana-JNPT, 1,504 km; operational Dec 2020); EDFC (Ludhiana-Dankuni, 1,856 km; partially operational); double-stack containers; reduce logistics cost by 30-40%.
- Roadways: World's 2nd largest network (~63 lakh km); NH-44 = longest (Srinagar-Kanyakumari, ~3,745 km); Golden Quadrilateral (Delhi-Mumbai-Chennai-Kolkata, 5,846 km); Bharatmala Phase-I (34,800 km, Rs.5.35 lakh cr); Delhi-Mumbai Expressway (1,350 km = India's longest expressway).
- Aviation: India = 3rd largest domestic market; IndiGo ~60% share; Air India (Tata 2022); Vande Bharat Merger (Air India-Vistara 2024); Jewar Airport (Noida) and Navi Mumbai under construction; UDAN scheme (Rs.2,500 capped regional flights).
- Waterways: ~14,500 km navigable; NW-1 (Ganga, Allahabad-Haldia, 1,620 km; Jal Marg Vikas Project); NW-2 (Brahmaputra, 891 km); NW-3 (Kerala backwaters); Sagarmala Programme for port-led development; Vizhinjam deepwater port (Kerala; Adani; 2024 inauguration).
- River Interlinking: Ken-Betwa Link (FIRST under implementation; Rs.44,605 cr; MP-UP; Daudhan Dam; Bundelkhand water + irrigation; controversy: Panna Tiger Reserve submergence); 30 links proposed (14 Himalayan + 16 Peninsular).
- Trade: India merchandise exports ~$447 bn FY2023-24; top exports: Engineering goods, Petroleum products, Gems & Jewellery, Pharma, Electronics (fast-growing); top imports: Crude oil (~$132 bn), Gold, Machinery, Electronics; trade deficit ~$238-240 bn.

14.1 INTRODUCTION — TRANSPORT AND ECONOMIC DEVELOPMENT

Transport is the **circulatory system of the national economy** — connecting producers to markets, raw materials to industries, agricultural surplus to deficit regions and people to services. An efficient, integrated and affordable transport network is the **single most important physical infrastructure variable** that determines the competitiveness of an economy. India's transport sector contributes approximately **5% of GDP** directly and is a critical enabler of every other economic sector.

Yet India's transport system suffers from a critical inefficiency: **logistics costs are ~13-14% of GDP** — far above the global benchmark of 8% (USA ~8%, EU ~8%, China ~10-11%). This gap means that every Indian good manufactured is ~5-6 percentage points more expensive to deliver to market than its Chinese equivalent — a direct competitive handicap in global trade. Addressing this logistics-cost gap is the central goal of India's modern transport policy.

HISTORICAL CONTEXT — COLONIAL TRANSPORT LEGACY

The British built India's railways (from 1853) and main roads **primarily for resource extraction and military movement** — not for integrating the Indian economy. Railways ran from hinterland raw material sources (Jharia coal, Nagpur cotton, Punjab grain) to port cities (Bombay, Calcutta, Madras) for export. This **"export-drain orientation"** left India with a rail network that served colonial commerce but poorly connected the interior. Post-independence India inherited this skewed legacy and spent seven decades trying to build a nationally integrated transport network.

MODERN TRANSPORT POLICY FRAMEWORK

Policy / Programme	*Year*	*Key Objective*
National Transport Policy	2020 (draft)	Integrated framework across all modes; safety, efficiency, sustainability, modal balance
PM GatiShakti National Master Plan	October 2021	GIS-based digital platform integrating infrastructure plans of 16 ministries + state governments; identifies bottlenecks and synchronises investment; covers roads, railways, ports, airports, waterways, logistics parks, power, gas pipelines — all on one map
National Logistics Policy (NLP)	September 2022 (PM Modi launched)	Reduce logistics cost from ~13-14% of GDP to <8% by 2030; Unified Logistics Interface Platform (ULIP) integrating all transport data; DPIIT implementing; 5 pillars: Process Re-engineering, Digitalisation, Infrastructure, Regulatory Framework, Skilled Workforce
Dedicated Freight Corridor Programme	2006 onwards; WDFC+EDFC operational 2020-23	Separate fast freight corridors from passenger railways; double-stack containers; reduce freight time and cost
Sagarmala Programme	2015	Port-led development; 600+ projects worth Rs.6 lakh crore; port modernisation, connectivity, industrialisation in coastal areas, coastal community development
Bharatmala Pariyojana Phase-I	2017; Rs.5.35 lakh crore	34,800 km National Highways; Economic Corridors, Inter-Corridors, Ring Roads, NE connectivity; target 2022 (delayed to 2025-27)
UDAN (Regional Air Connectivity)	2016	Ude Desh Ka Aam Naagrik; cap fares at Rs.2,500 for 1-hour regional flights; connect underserved airports
Jal Marg Vikas Project (JMVP)	2016-17; Rs.5,369 crore; World Bank assisted	Develop NW-1 (Ganga) for 1,500-2,000 tonne vessel navigation; Varanasi-Haldia commercial cargo

KEY NOTE

PM GatiShakti — Key Exam Points: Launched October 2021 by PM Modi; integrates infrastructure plans of 16 ministries and all state governments on a geospatial platform; identifies "last-mile connectivity" gaps and "siloed planning" problems; used for approvals of infrastructure projects; reduces duplication of investment. GatiShakti + National Logistics Policy together form India's modern infrastructure-logistics policy architecture replacing the fragmented earlier approach.

14.2 RAILWAYS — INDIA'S BACKBONE

Indian Railways (IR) is not merely a transport system — it is a **national institution**, a **social equaliser** and the **world's largest employer in a single civilian organisation** (~1.5 million employees). It is the **world's 4th-largest railway network by route length** and carries more passengers per day than some nations have citizens — approximately **23 million passengers and 3.5 million tonnes of freight daily**. Railway connectivity shapes where cities grow, where industries locate and how agricultural surplus reaches consumers.

KEY STATISTICS AT A GLANCE

Parameter	*Figure / Detail*
Total route length	~68,000 km (4th largest network in the world after USA ~230,000 km, Russia ~86,000 km, China ~77,000 km)
Total track length	~94,000 km (route length x track multiplicity on multi-track sections)

Number of stations	~7,000+ stations
Employees	~1.3-1.5 million (one of the largest single civilian employers in the world)
Passengers per day	~23 million; ~8.4 billion per year
Freight per day	~3.5 million tonnes; ~1.6 billion tonnes per year
Gauge mix	Broad Gauge (BG, 1,676 mm): ~95%+ of total network; nearly all other gauges being converted to BG ("Project Unigauge"); some Narrow-Gauge heritage lines remain
Electrification	100% of broad-gauge network ELECTRIFIED (achieved in 2023-24); target: be Net Zero by 2030 (world's first net zero railway system if achieved)
Revenue (FY2023-24)	~Rs.2.56 lakh crore gross traffic receipts; world's 5th largest railway by revenue
Capital investment (Budget 2024-25)	Rs.2.62 lakh crore — highest ever capital expenditure for Indian Railways in a single year

RAILWAY ZONES

Indian Railways is divided into **18 administrative zones**, each headed by a General Manager. Each zone is further divided into **divisions** (68 divisions total), which are the operational units for day-to-day train management.

Zone	*Abbreviation*	*Headquarters*	*Coverage States (major)*
Northern Railway	NR	New Delhi	J&K (parts), Himachal Pradesh, Punjab, Haryana, UP (west), Rajasthan (parts), Uttarakhand
North Central Railway	NCR	Prayagraj (Allahabad)	UP (central), Rajasthan (eastern parts), MP (northern parts)
North Eastern Railway	NER	Gorakhpur	UP (eastern), Bihar (parts)
Northeast Frontier Railway	NFR	Maligaon, Guwahati	Assam, Arunachal Pradesh, Manipur, Mizoram, Nagaland, Tripura, Meghalaya, West Bengal (northern parts), Sikkim
Eastern Railway	ER	Kolkata	West Bengal, Bihar (parts), Jharkhand (parts)
East Central Railway	ECR	Hajipur	Bihar, Jharkhand (parts), UP (eastern tip)
East Coast Railway	ECoR	Bhubaneswar	Odisha, Andhra Pradesh (northern), Chhattisgarh (parts)
South Eastern Railway	SER	Kolkata	West Bengal (parts), Jharkhand (parts), Odisha (parts)
South East Central Railway	SECR	Bilaspur	Chhattisgarh, MP (parts)
Central Railway	CR	Mumbai CST	Maharashtra (central), Goa, MP (parts), Gujarat (parts)
Western Railway	WR	Mumbai Churchgate	Gujarat, Maharashtra (western), Rajasthan (western), MP (western)
South Central Railway	SCR	Secunderabad	Telangana, Andhra Pradesh, Maharashtra (parts), Karnataka (parts)
Southern Railway	SR	Chennai	Tamil Nadu, Kerala, Puducherry, Karnataka (parts)
South Western Railway	SWR	Hubli	Karnataka (most), Goa

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North Western Railway	NWR	Jaipur	Rajasthan, Gujarat (northern tip)
West Central Railway	WCR	Jabalpur	MP, Rajasthan (parts), UP (parts)
Kolkata Metro Railway	KMRC	Kolkata	Kolkata urban metro system — only metro zone of Indian Railways
South Coast Railway (New)	SC Rly	Visakhapatnam	Andhra Pradesh coastal belt (newly carved, 2019)

GAUGE TYPES IN INDIAN RAILWAYS

Gauge Type	*Track Width*	*Share of Network*	*Notes*
Broad Gauge (BG)	1,676 mm (5 ft 6 in)	~95%+ (and growing)	Standard Indian gauge; allows heavier axle loads, higher speeds, double-stack containers; ALL BG lines being electrified
Metre Gauge (MG)	1,000 mm (1 metre)	<5% and declining	Being converted to BG under Project Unigauge (1994); some lines remain in Rajasthan, Gujarat, Tamil Nadu
Narrow Gauge (NG)	762 mm (2 ft 6 in) or 610 mm (2 ft)	Very few; heritage	Matheran Hill Railway (610 mm — no motor vehicles allowed at Matheran); Darjeeling Himalayan Railway (610 mm — UNESCO WHS); Kalka-Shimla Railway (762 mm — UNESCO WHS); Nilgiri Mountain Railway (1,000 mm — UNESCO WHS)
Standard Gauge (SG)	1,435 mm	Only for Delhi Metro and some other metro systems	Not used on mainline IR; Delhi Metro uses SG (same as most world metros)

KEY TRAIN TYPES AND SERVICES

Train Type	*Speed / Characteristics*	*Route Examples / Notes*
Rajdhani Express	120-130 km/h; fully air-conditioned; connects capital Delhi with state capitals; limited stops	Delhi-Mumbai; Delhi-Kolkata; Delhi-Chennai; highest-priority express train; all-meal-inclusive fare; 1969 launched (first: Delhi-Howrah)
Shatabdi Express	130-140 km/h; day-time; fully AC; intercity (same-day return trip); chairs, no sleepers	Delhi-Bhopal; Delhi-Chandigarh; Thiruvananthapuram-Mangaluru; launched 1988 (centenary of Lal Bahadur Shastri)
Vande Bharat Express (Train 18)	Technically 160 km/h; operates at ~130 km/h; self-propelled (EMU/DMU; no locomotive); indigenously designed and built; fully AC chair car; shorter travel times	Delhi-Varanasi (first route, 2019); now 100+ sets operational (2024); Chennai-Bengaluru; Ahmedabad-Mumbai; PM Modi's flagship rail initiative; manufactured by ICF Chennai and other production units
Duronto Express	130 km/h; non-stop between origin and destination; overnight; all-AC; 2009 launched	Mumbai-Delhi; Mumbai-Kolkata; limited stops
Gatimaan Express	India's fastest currently operating passenger train; 160 km/h; Delhi-Agra; 1 hour 40 min to Agra	Delhi H. Nizamuddin to Agra (1 hr 40 min — 188 km); semi-high speed; meals included; very clean

Tejas Express	India's first private-operated train (IRCTC); on-time performance guarantee + ticket refund if delayed; Wi-Fi	Delhi-Lucknow; Mumbai-Ahmedabad; on-time penalty policy
Humsafar Express	Economy 3AC fully covered; all-AC 3 tier; safety and comfort; GPS-based tracking	Multiple routes; budget premium economy
RRTS (Rapid Rail Transit System)	160 km/h; semi-high speed; urban-suburban; Delhi-Meerut RRTS (82 km; partially operational 2023-24; National Capital Region Transport Corporation)	Delhi NCR connecting Ghaziabad-Meerut; first such dedicated urban-suburban high-speed corridor in India; first stretch inaugurated Oct 2023

DEDICATED FREIGHT CORRIDORS (DFCS)

The Dedicated Freight Corridors (DFCs) are **the most transformative infrastructure investment in Indian Railways since Independence** — building entirely new, fully electrified, high-capacity freight-only rail lines parallel to the congested existing tracks. They will fundamentally reshape India's logistics landscape.

Parameter	*Western DFC (WDFC)*	*Eastern DFC (EDFC)*
Route	Ludhiana (Punjab) to Jawaharlal Nehru Port (JNPT/Nhava Sheva, Mumbai)	Ludhiana (Punjab) to Dankuni (near Kolkata, West Bengal)
Total length	~1,504 km	~1,856 km
Status	OPERATIONAL (partial since Dec 2020; full operationalisation by 2024-25)	Partially operational; Delhi-Bhaupur (UP) section running; full operationalisation by 2024-25
Key sections	New Palanpur-Vaitarna section (306 km) opened Dec 2020; progressively extended toward JNPT and Ludhiana	Ludhiana-Khurja-Delhi section + Bhaupur-New Khurja; Sahnewal-Ludhiana operational
Technical specs	Double-line; electrified (25 kV AC); ETCS Level 2 signalling; max axle load 32.5 tonne; designed for 100 km/h freight speed	Double-line; electrified; 32.5 tonne axle load; designed for 100 km/h
Double-stack containers	YES — specially designed wagons (BLCS) carry TWO 20-ft containers stacked vertically; doubles cargo per train	YES — doubles container capacity; reduces per-tonne freight cost significantly
Implementing agency	Dedicated Freight Corridor Corporation of India (DFCCIL); World Bank + Japan International Cooperation Agency (JICA) financing	DFCCIL; World Bank financing
Impact on existing network	Frees ~70% capacity on the existing Golden Quadrilateral + diagonal rail lines for passenger trains; reduces delays, improves punctuality	Frees East-North main lines; benefits Bihar, UP, West Bengal logistics

- **Amritsar-Kolkata Industrial Corridor (AKIC):** a new industrial corridor being planned along the Eastern DFC — connecting the manufacturing hinterlands of Punjab, Haryana, UP and West Bengal with logistics infrastructure.
- **Impact on logistics cost:** DFCs reduce freight transit time from ~7-8 days (existing route, Mumbai-Delhi) to ~2-3 days; reduce cost by 30-40%; significantly close the gap between India's 13-14% logistics cost and the global 8% benchmark.

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MUMBAI-AHMEDABAD HIGH SPEED RAIL (BULLET TRAIN)

Parameter	*Detail*
Route	Mumbai (BKC terminus) to Ahmedabad (Sabarmati station); 508 km
Technology	Japan's Shinkansen E5 series technology (same as Tokyo-Osaka Tokaido Shinkansen); JICA (Japan International Cooperation Agency) soft loan (~Rs.1.1 lakh crore at 0.1% interest, 50-year tenure)
Speed	Top speed 350 km/h; average commercial speed ~250-300 km/h; journey time: ~2 hours vs current ~8 hours by train
Stations	12 stations: Mumbai (BKC), Thane, Virar, Boisar, Vapi, Bilimora, Surat, Bharuch, Vadodara, Anand/Nadiad, Ahmedabad, Sabarmati
Key challenge	7 km underground section under Mumbai (including under Thane Creek Sea tunnel, ~21 km); land acquisition in Maharashtra (slower than Gujarat); cost escalation beyond original estimates
Progress (2024-25)	Gujarat section: piers and viaducts largely constructed; Surat-Sabarmati section may open first; Maharashtra section slower due to land acquisition; original 2023 target postponed; current target mid-2026 or beyond for first partial section
Total project cost	Revised to ~Rs.1.8-2 lakh crore (original estimate ~Rs.1.1 lakh crore); cost escalation significant

VANDE BHARAT EXPRESS — MAKE IN INDIA ON RAILS

The Vande Bharat Express (internally codenamed **"Train 18"** during development) is India's first indigenously designed and built semi-high-speed train — developed by the **Integral Coach Factory (ICF), Chennai** in just 18 months at a cost of ~Rs.100 crore per set (vs imported Shatabdi coaches at Rs.150+ crore). Key features:

- **Technology:** Electric Multiple Unit (EMU) — self-propelled, distributed traction (motors under each coach); eliminates the need for a locomotive; allows faster acceleration and deceleration.
- **Speed:** Designed for 160 km/h; currently operates at 100-130 km/h on existing tracks (track/signalling constraints).
- **Features:** Rotating seats (economy class), automatic doors, diffused LED lighting, GPS-based passenger information, CCTV, WiFi, bio-vacuum toilets, on-board catering, command-operated brakes.
- **Scale (2024):** 100+ Vande Bharat sets operational; target 400+ sets by 2025-26; being manufactured at ICF Chennai, RCF Kapurthala, MCF Raebareli (new); Vande Bharat Sleeper version also under development.
- **Routes:** Delhi-Varanasi (first, Feb 2019); Delhi-Katra (Shri Mata Vaishno Devi); Delhi-Amb Andaura (HP); Chennai-Bengaluru; Ahmedabad-Mumbai; Thiruvananthapuram-Kasaragod (Kerala); etc.

KAVACH — INDIA'S AUTOMATIC TRAIN PROTECTION SYSTEM

KAVACH (meaning "armour" or "shield") is India's indigenously developed **Automatic Train Protection (ATP) / Automatic Train Collision Avoidance System (ATCAS)** — which can automatically apply brakes if two trains are on the same track or a signal is passed at danger, preventing rear-end and head-on collisions. **Indian Railways has the world's largest network requiring such a system.**

- **How it works:** uses Radio Frequency (RF) communication between locomotive-mounted transponders and track-side Radio Frequency IDentification (RFID) tags; calculates safe stopping distances; auto-applies brakes before unsafe proximity; also overrides signal failure.
- **Standard:** Equivalent to European Train Control System (ETCS) Level 1 with additional features; developed by Research Designs and Standards Organisation (RDSO), Lucknow, with private partners (Kernex, HBL, Medha, Siemens).

- **Deployment:** ~1,500 km network covered (2024); target to cover Golden Quadrilateral + its diagonals (~10,000 km) by 2025; full network by ~2028; Rs.2,000 crore deployed; annual deployment budget Rs.4,000-5,000 crore.
- **Balasore train accident (June 2, 2023):** the collision at Bahanaga Baazar (Odisha) — three trains; 291 deaths — could have been prevented by KAVACH; accelerated KAVACH deployment thereafter.

INDIAN RAILWAYS AND NET ZERO BY 2030

Indian Railways has pledged to become **the world's first major railway network to achieve Net Zero carbon emissions by 2030** — a target given IR's scale would be a globally significant climate achievement.

Measure	*Details*
100% electrification	All BG routes electrified by 2023-24; electric traction emits 80-90% less CO2 per tonne-km than diesel; if power comes from renewable energy, net CO2 approaches zero
Renewable energy (solar + wind)	Indian Railways is India's largest consumer of electricity (~18-20 billion units/year); target 20+ GW renewable capacity; solar panels on station rooftops (700+ stations), solar power plants along tracks, wind farms; 3.5+ GW solar commissioned by 2024
Hydrogen-powered trains (HRT)	Pilot hydrogen trains on some sections; RDSO has designed hydrogen fuel cell locomotive; global demonstration project in collaboration with BPCL/NTPC
Biofuel	Blended biodiesel for diesel locomotives on non-electrified sections (B10 blend)
Energy-efficient LED lighting	100% LED lighting at stations, yards and offices; saves ~3 billion units/year vs conventional lighting
Regenerative braking	Electric locomotives recover energy during braking; fed back to grid; energy savings of 15-20%

UPSC CIVIL

Civil GS-3 — Key Points on Railways and Logistics : (1) Indian Railways is the cheapest mode for bulk freight (coal, iron ore, fertilisers) over long distances; (2) currently underutilised for time-sensitive containerised freight — DFCs will address this; (3) the shift of freight from road to rail reduces diesel consumption, road wear and CO2 (rail is ~7-10x more fuel-efficient per tonne-km than road); (4) 100% electrification enables decarbonisation of freight if powered by renewables — a critical climate co-benefit; (5) KAVACH deployment = a specific domestic technology with export potential (Middle East, Africa, SE Asia).

14.3 ROADWAYS — INDIA'S MOST-USED MODE

Road transport carries **~90% of India's passenger traffic and ~65% of its freight** by value — making it the dominant mode by far. India has the **world's 2nd-largest road network (~63 lakh km total route length),** after the United States. The road network ranges from world-class expressways to unpaved village paths, and its quality determines the daily mobility and economic opportunity of hundreds of millions of Indians.

ROAD CLASSIFICATION

Road Type	*Length (approx.)*	*Authority*	*Standard / Note*
National Highways (NH)	~1,45,000 km (2024; growing fast under Bharatmala)	Ministry of Road Transport & Highways (MoRTH); NHAI for construction/tolling	4 to 8 lanes; highest engineering standard; toll roads; connect major cities/ports/borders; marked NH-X

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State Highways (SH)	~1,70,000 km	State Public Works Departments (PWDs)	2-4 lanes; connect state capitals and district headquarters; supplement NHs
Major District Roads (MDR)	~5,50,000 km	District administrations; PWDs	Connect district headquarters to mandal centres
Other District Roads (ODR)	~26 lakh km	Panchayats; PWDs	Rural inter-village connectivity
Village Roads (VR)	~26 lakh km (approx.)	Gram Panchayats; MoRD/PMGSY	Last-mile rural connectivity; PMGSY target = all habitations >250 population connected
Expressways	~25,000+ km (target ~50,000 km by 2030)	NHAI / state expressway authorities (e.g., UPEIDA, MSRDC)	6-8 lanes; access-controlled; highest speed; toll-based

KEY NATIONAL HIGHWAYS

NH	Route	Length	Key Note
NH-44	Srinagar (J&K) to Kanyakumari (Tamil Nadu)	~3,745 km	LONGEST National Highway in India; old NH-1A+1+2+3+7+44+45+47; passes through J&K, Punjab, Haryana, Delhi, UP, MP, Maharashtra, AP, Tamil Nadu; crosses Vindhya and Satpura; passes Jalandhar, Delhi, Agra, Nagpur, Hyderabad, Bengaluru
NH-48	Delhi to Chennai via Mumbai (partial)	~2,807 km (Delhi-Chennai; new numbering)	Old NH-8 (Delhi-Mumbai segment) and NH-4 (Mumbai-Chennai); Delhi-Jaipur-Ahmedabad-Mumbai-Pune-Bengaluru-Chennai; critical economic corridor; largely 4-6 lane
NH-27	Porbandar (Gujarat) to Silchar (Assam)	~3,332 km	Part of East-West Corridor; long East-West NH
NH-66	Panvel (Maharashtra) to Kanyakumari	~1,622 km	Old NH-17; entire west coast corridor; Mumbai-Goa-Mangaluru-Kochi-Kanyakumari; scenic coastal highway
NH-58	Delhi to Mana (Uttarakhand, near Badrinath)	~538 km	Old NH-58; Delhi-Haridwar-Rishikesh-Badrinath; Himalayan highway; strategic for Char Dham access
NH-52	Sangachar (Assam) to Palwal (Haryana)	~1,990 km	Trans-Himalayan; J&K; strategic

GOLDEN QUADRILATERAL (GQ)

The Golden Quadrilateral is India's most important highway network — a **5,846 km, 4/6-lane highway connecting India's four largest metropolises: Delhi, Mumbai, Chennai and Kolkata**. Completed in **2012** under the National Highway Development Project (NHDP) Phase-I and II, it was India's most ambitious road infrastructure project at the time. The GQ connects:

- **Delhi to Mumbai:** ~1,419 km (via Jaipur, Ahmedabad) — NH-48
- **Mumbai to Chennai:** ~1,290 km (via Pune, Bengaluru) — NH-48/44
- **Chennai to Kolkata:** ~1,684 km via Vijayawada and Vishakhapatnam; old NH-5 now NH-16
- **Kolkata to Delhi:** ~1,453 km (via Dhanbad, Varanasi, Allahabad) — NH-19

The GQ carries **~40% of India's road freight** on just **2% of its road length** — reflecting the extraordinary concentration of economic activity along this corridor. The GQ has significantly reduced travel time between India's four largest cities (Delhi-Mumbai: from 28+ hours to ~24 hours; Mumbai-Chennai: from 24+ to ~18 hours) and was a catalyst for industrial development along the corridor.

NORTH-SOUTH AND EAST-WEST CORRIDORS

- **North-South Corridor:** Srinagar (J&K) to Kanyakumari (Tamil Nadu); ~4,000 km; under NHDP Phase-III development.
- **East-West Corridor:** Silchar (Assam) to Porbandar (Gujarat); ~3,300 km; critical for NE India connectivity.

Together these two corridors form a **"cross"** bisecting India — complementing the GQ's ring structure. The NS-EW corridors reach areas (NE India, J&K, Saurashtra, deepest South) not served by the GQ.

BHARATMALA PARIYOJANA — INDIA'S MEGA ROAD PROGRAMME

Component	*Details*
Total target (Phase-I)	34,800 km of new/upgraded National Highways; total Rs.5.35 lakh crore outlay
Economic Corridors	~9,000 km; connect high-traffic industrial/agricultural/port clusters; designed to reduce travel time and logistics cost
Inter Corridors	~6,000 km; feeder routes connecting Economic Corridors
Ring Roads / Bypasses	~5,000 km; decongest major cities (Ring Roads around Delhi, Mumbai, Hyderabad, Chennai, Kolkata)
National Corridor Improvement	~10,000 km; upgrade existing NHs to 4-6 lanes
Border and International Connectivity	~3,300 km; strategic roads near China/Pakistan/Bangladesh/Nepal/Myanmar borders
Coastal and Port Connectivity	~2,000 km; Sagarmala integration; port hinterland connectivity
Progress (2024)	~19,000-20,000 km completed by end-2023; original target 2022 extended to 2025-27; cost escalation from Rs.5.35 lakh cr to ~Rs.10+ lakh crore estimated

KEY EXPRESSWAYS

Expressway	*States*	*Length*	*Note*
Delhi-Mumbai Expressway (DME, NH-148N)	Delhi, Haryana, Rajasthan, MP, Gujarat, Maharashtra	~1,350 km	INDIA'S LONGEST EXPRESSWAY when complete; 8-lane; reduces Delhi-Mumbai travel from 24 hrs to ~12 hrs; electronic toll (FASTag); inaugurated in sections 2023-24; passes through Jaipur, Ajmer, Ratlam, Vadodara
Yamuna Expressway	Uttar Pradesh (Greater Noida to Agra)	165 km	6-lane; first dedicated Expressway in UP (2012); Jewar Airport being built adjacent; Mathura, Agra tourism corridor
Eastern Peripheral Expressway (EPE)	Haryana-UP (around Delhi)	135 km	6-lane; Delhi bypass for trucks; reduces Delhi traffic; Kundli-Ghaziabad-Palwal; inaugurated 2018
Western Peripheral Expressway (WPE)	Haryana (around Delhi)	150 km	6-lane; Kundli-Manesar-Palwal; Delhi bypass; with EPE forms Delhi's Ring Expressway
Purvanchal Expressway	Uttar Pradesh (Lucknow to Ghazipur)	341 km	4-lane; PM inaugurated Nov 2021; connects eastern UP with national capital network; 3.5 km airstrip for emergency fighter jet landing

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Bundelkhand Expressway	Uttar Pradesh (Chitrakoot to Etawah)	296 km	4-lane; connects drought-prone Bundelkhand region; new industrial development expected; PM inaugurated July 2022
Ganga Expressway	Uttar Pradesh (Meerut to Prayagraj/Ballia)	594 km	Longest in UP when complete; 6-lane; under construction; Meerut to Prayagraj; also for defence (airstrip sections)
Mumbai-Pune Expressway (E2)	Maharashtra	95 km	6-lane; India's first high-speed expressway (2002); Khopoli-Pune; reduced travel time from 3+ hrs to 1.5 hrs; model for subsequent expressways

PMGSY — PRADHAN MANTRI GRAM SADAK YOJANA

Launched in **December 2000** by PM Atal Bihari Vajpayee, PMGSY is **India's most impactful rural development scheme** — connecting every habitation (village) with a population above 500 (250 in hill/tribal areas) to an all-weather road. Phase I and II completed connectivity for most eligible habitations; Phase III (2019-24) focuses on upgrading existing rural roads to higher standards.

Phase	*Period*	*Target*	*Achievement*
PMGSY-I	2000-2013	Connect all habitations >1000 pop (plains), >500 (hills/tribal); ~1,70,000 km	~3 lakh km built; 99%+ habitations >500 pop connected
PMGSY-II	2013-2019	Upgrade existing PMGSY-I roads to higher spec; consolidation	~50,000 km upgraded; quality improvement focus
PMGSY-III	2019-2025	~1.25 lakh km upgrading; improve connectivity to markets, schools, hospitals	~60,000+ km completed by 2024; ongoing
PMGSY-IV	2024 onwards (newly announced)	Focus on Left Wing Extremism (LWE) districts; NE states; island territories	Expanding reach to most remote areas

ENV ALERT

Road Safety Crisis — India's Silent Epidemic

India accounts for **~11-12% of the world's road accident fatalities** despite having only ~1% of the world's vehicles — an extraordinarily high fatality-to-vehicle ratio. The **Ministry of Road Transport & Highways (MoRTH)** reports ~1.5 lakh road deaths and ~4.5 lakh serious injuries annually. India was the country with the highest road fatalities globally in 2021 (WHO report). Causes: high-speed roads without lane discipline; two-wheeler riders without helmets; drunk driving; poorly lit rural roads; pedestrian-vehicle conflict in cities. Responses: **Motor Vehicles (Amendment) Act 2019** (doubled penalties; vehicle recall provisions; national road safety board); National Road Safety Policy; **Vision Zero** (target of zero road fatalities); iRAD (Integrated Road Accident Database) for data-based remedial action. India's target: reduce road fatalities by 50% by 2025 (Decade of Action for Road Safety — UN).

14.4 AIRWAYS — CIVIL AVIATION

India is the **world's 3rd-largest domestic aviation market** (after the USA and China) — with ~150 million domestic passengers in FY2023-24. From a sector accessible only to the elite in 1990, civil aviation has been democratised by low-cost carriers (LCCs), and India has set a target of being the **3rd-largest civil aviation market overall (domestic + international)** by 2030.

KEY AIRPORTS

Airport	*City*	*Operator / Category*	*Annual Capacity (approx.)*

Indira Gandhi International (IGIA/DEL)	New Delhi	DIAL (Delhi International Airport Ltd) — GMR Group; Busiest airport in India and South Asia	~70 million passengers (T3 + T1 + T2); T3 is one of world's largest single-terminal airports (432,000 sq m)
Chhatrapati Shivaji Maharaj International (CSMIA/BOM)	Mumbai	MIAL (Mumbai International Airport Ltd) — Adani Group (acquired 2021)	~50 million passengers; capacity constrained; Navi Mumbai airport under construction to supplement
Kempegowda International (BLR)	Bengaluru	BIAL (Bengaluru International Airport Ltd) — Fairfax India/Government; second terminal T2 opened 2023	~35-40 million passengers; India's 3rd busiest; T2 has aviation-art theme ("Kempegowda — Uru Parge")
Rajiv Gandhi International (HYD)	Hyderabad	GMR group; first Greenfield airport built via PPP (2008)	~25 million passengers; handles significant cargo
Chennai International (MAA)	Chennai	AAI (Airports Authority of India) — government operated; new integrated terminal under construction	~25 million passengers; busiest in South India by cargo
Netaji Subhas Chandra Bose International (CCU)	Kolkata	AAI; new integrated terminal opened 2013	~20 million passengers; NE India gateway
Sardar Vallabhbhai Patel International (AMD)	Ahmedabad	AAI; partial PPP	~15 million passengers; Gujarat gateway; frequent PM Modi inaugurations here
Chaudhary Charan Singh International (LKO)	Lucknow	AAI	~12 million passengers; UP's busiest airport

NEW AIRPORTS UNDER CONSTRUCTION

Airport	*Location*	*Developer*	*Status / Note*
Noida International Airport (NIA) / Jewar Airport	Jewar, Gautam Buddh Nagar, UP (on Yamuna Expressway)	Zurich Airport (Switzerland) — won bid; Yamuna International Airport Private Limited	Under construction; Phase-I capacity ~12 million passengers/year; will become India's largest airport (4 runways planned; 70 million passengers Phase-IV); foundation stone laid Nov 2021; target opening 2024 (delayed to 2025); INDIA'S FIRST AIRPORT ON A DEDICATED EXPRESSWAY
Navi Mumbai International Airport (NMIA)	Ulwe, Navi Mumbai, Maharashtra	Adani Airports Holdings Ltd; CIDCO (Govt of Maharashtra) — 50:50	Under construction; Phase-I ~10 million passengers; target opening 2025; will decongest Mumbai airport; one of world's largest greenfield airport projects
Ayodhya Airport (Maharishi Valmiki International)	Ayodhya, Uttar Pradesh	AAI; fully government	Expanded and renamed; inaugurated December 2023 (PM Modi) ahead of Ram Mandir consecration; can handle B737/A320; capacity 10+ million passengers planned ultimately

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Donyi Polo Airport	Itanagar, Arunachal Pradesh	AAI	Inaugurated November 2022 (PM Modi); Arunachal Pradesh's first commercial airport (greenfield); "Donyi Polo" means Sun and Moon in Adi language; strategic for NE India connectivity
Mopa International Airport (Goa)	North Goa (Pernem)	GMR Group; Goa government	Inaugurated January 2023; second airport in Goa alongside Dabolim; decongests Goa airport; capacity ~4.4 million passengers Phase-I
Holongi Airport (Donyi Polo)	Itanagar	AAI	Opened Nov 2022; connected Arunachal to national aviation network for first time with a proper commercial airport

AIRLINES AND MARKET STRUCTURE

Airline	*Market Share (FY2024)*	*Key Note*
IndiGo (InterGlobe Aviation)	~60-62%	LARGEST airline in India by far; also largest LCC in Asia by passenger count; 300+ aircraft fleet; profitable; early Rakesh Jhunjhunwala backer; hub = Delhi IGI
Air India (Tata-owned, from Jan 2022)	~11-12%	Full-service carrier; privatised after 69-year government ownership; Tata Sons paid ~Rs.18,000 crore (enterprise value); Air India + Vistara MERGER COMPLETED NOVEMBER 2024; Air India Express (LCC subsidiary) merged with AIX Connect; fleet expansion underway (470 aircraft on order from Airbus + Boeing — largest aircraft order in Indian aviation history); hub = Delhi, Mumbai
Vistara (Tata-SIA joint venture)	Merged into Air India Nov 2024	Full-service; Tata Sons (51%) + Singapore Airlines (49%); Singapore Airlines now holds 25.1% stake in merged Air India; good passenger experience; dissolved as separate brand
SpiceJet	~5-6%	Second-oldest LCC; financial difficulties since 2022; grounded aircraft; losses; survival mode; Bengaluru hub
Akasa Air	~5-6%	New entrant 2022; Rakesh Jhunjhunwala-backed (died 2022); Zerodha; Zero to 72 aircraft in 18 months; backed by CRISIL upgrade; clean young fleet; fast growth
GoFirst (Go Air)	0% — BANKRUPT May 2023	Wadia Group airline; grounded permanently; P&W engine issues; insolvency proceedings (IBC); ~50,000 passengers stranded; highlighted aviation sector fragility
Alliance Air / Star Air / Blue Dart Aviation	Small shares	Regional/cargo operations

UDAN SCHEME — DEMOCRATISING REGIONAL AVIATION

Parameter	*Details*
Full name	UDAN — Ude Desh Ka Aam Naagrik (Let the common citizen of the country fly)
Launch	October 2016 by PM Modi; Ministry of Civil Aviation
Objective	Provide affordable air connectivity to Tier-2, Tier-3 cities and remote areas (especially NE India, Himalayan states, J&K, Andaman & Nicobar, Lakshadweep) by supporting regional airlines with Viability Gap Funding (VGF)

Fare cap	Rs.2,500 for flights up to 1 hour (500 km); fares are capped on 50% of seats per flight on UDAN routes (rest can be at market price)
VGF mechanism	Centre and state share the Viability Gap Funding (2:1) paid to airlines to make economically unviable routes viable; funded partly by levy on trunk route tickets (Rs.7,500 per ticket on major routes)
Airports activated	70+ airports and helipads operationalised under UDAN (previously zero/negligible traffic); total 74 underserved airports activated; also seaplane routes
Phases	UDAN 1.0 (2017), 2.0 (2018), 3.0 (2018 — seaplanes, hilly routes), 4.0 (2020 — more routes), 4.1 (helicopters), 5.0 (2023 — 50 additional unserved airports, NE focus)
Progress (2024)	~500+ UDAN routes launched; NE India connectivity significantly improved (Arunachal, Manipur, Nagaland airports opened); Lakshadweep seaplane services; however many UDAN routes are not commercially sustainable even with VGF and airlines discontinue

CURRENT AFFAIRS

Air India Privatisation (2022) and Vistara Merger (2024) : Air India was privatised to Tata Sons in January 2022 (effective takeover) for an enterprise value of ~Rs.18,000 crore (equity + debt assumption) — ending 69 years of government ownership. Tata Group (which originally founded Air India as Tata Airlines in 1932 before it was nationalised in 1953 by Jawaharlal Nehru) thus reclaimed the airline. Tata Sons also owned Vistara (JV with Singapore Airlines). In November 2024, Vistara was merged into Air India; Singapore Airlines now holds 25.1% equity in Air India. Air India placed the largest-ever aircraft order in Indian aviation history — 470 aircraft from Airbus (A320neo family + A350) and Boeing (B787 Dreamliner + B777X) — signalling aggressive expansion. This is a landmark Indian corporate story.

14.5 WATERWAYS — RIVERS, CANALS AND COASTAL SHIPPING

India has **~14,500 km of navigable waterways** — rivers, canals, backwaters and creeks — of which only about **~5,200 km is currently used for mechanised vessel navigation**. Inland water transport (IWT) is the most **fuel-efficient and least polluting** mode of surface transport — using 5-6x less fuel per tonne-km than road — yet it carries less than 2% of India's freight, compared to 12-15% in Europe and 25% in China. Developing IWT is both an economic and environmental imperative.

NATIONAL WATERWAYS

The **National Waterways Act 2016** declared **111 rivers, creeks, estuaries, backwaters and canals as National Waterways (NW),** expanding from the earlier 5. The **Inland Waterways Authority of India (IWAI)** — established 1986, HQ Noida — is responsible for their development and maintenance.

National Waterway	*River / System*	*Length*	*States*	*Key Project / Note*
NW-1	GANGA (Allahabad/Prayagraj to Haldia, WB)	1,620 km	UP, Bihar, Jharkhand (parts), WB	MOST IMPORTANT; JAL MARG VIKAS PROJECT (JMVP, 2016-17, Rs.5,369 crore, World Bank assisted) for 1,500-tonne vessel navigation; Varanasi to Haldia commercial cargo; Multi-Modal Terminal at Varanasi (PM Modi inaugurated 2018); capacity being built for vessel up to 2,000 tonnes
NW-2	BRAHMAPUTRA (Sadiya to Dhubri)	891 km	Assam (and small parts of Arunachal)	2nd oldest NW; connects to Bangladesh and beyond; critical for NE India; PROTOCOL ROUTE for Indo-

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				Bangladesh Inland Water Transit; enhances NE connectivity; Pandu Terminal (Guwahati) being developed
NW-3	WEST COAST CANAL (Kottapuram to Kollam) + Champakara Canal + Udyogmandal Canal	205 km	Kerala	Kerala backwaters; historic trading waterway; houseboats + cargo; Alappuzha (Alleppey) hub; tourism potential alongside cargo; connects Kochi port with hinterland
NW-4	Godavari-Krishna River System; Eluru-Vijayawada Canal	~1,095 km	Andhra Pradesh + parts of Telangana	Delta canals; rice and fertiliser movement; Vijayawada to Kakinada; growing
NW-5	EAST COAST CANAL (Geonkhali/Haldia to Dhamra)	623 km	Odisha + WB	Connects WB and Odisha coast; industrial/cargo movement
NW-16	Barak River (Lakhipur to Bhanga)	121 km	Assam (Barak Valley; also links to Mizoram, Tripura, Manipur)	Strategic for NE India; provides alternative to land route for goods movement; cargo of NE states
NW-68	Mandovi River (Goa)	41 km	Goa	Iron ore (historically major); tourism; ferry services
NW-111 (newest)	Various (Deccan and coastal rivers)	Various	Multiple states	Small rivers/creeks; many in planning/survey stage

JAL MARG VIKAS PROJECT (JMVP) — NW-1 DEEP DIVE

Parameter	*Detail*
Full name	Jal Marg Vikas Project (Inland Waterways Capacity Augmentation on National Waterway 1)
Route	Varanasi (UP) to Haldia (West Bengal) on the Ganga (NW-1); 1,380 km stretch being developed
Objective	Enable navigation by commercial vessels of 1,500-2,000 tonne capacity; carry bulk cargo (coal, construction material, agricultural products) more cheaply than road or rail
Investment	Rs.5,369 crore; financed partly by World Bank (~$375 million loan)
Infrastructure	4 Multi-Modal Terminals (MMTs) at Varanasi, Sahibganj (Jharkhand), Haldia (WB), Kalughat (Bihar); Roll-on Roll-off (RoRo) vessel services; river information system (RIS) for navigation management; aids to navigation; river training works; fairway maintenance (dredging)
Progress (2024)	Varanasi Multi-Modal Terminal operational (PM Modi inaugurated Nov 2018); Sahibganj MMT operational; Haldia terminal capacity upgraded; commercial cargo (fly ash, stone, fertilisers, food grain) moving; also containers via IWT from Patna to Kolkata
Significance	NW-1 development is India's most important inland waterway experiment; if successful, it could shift significant cargo from road/rail to water; NW-1 flows through the 'Heartland of India' — the most densely populated belt
NW-1 challenges	Seasonal flow variability (Ganga is shallow April-June before monsoon); sedimentation; multiple structures; ensuring minimum draft (2.5 m) year-round requires dredging and weirs

MAJOR PORTS OF INDIA

India has **12 Major Ports** under the central government (governed by Major Port Authorities Act, 2021, which replaced the Major Port Trusts Act 1963 and gave ports more autonomy) and **~200 non-major ports** under state governments. The 12 major ports together handle ~60% of India's maritime trade.

Major Port	*Location*	*State*	*Key Feature / Handling*
Jawaharlal Nehru Port (JNPT / Nhava Sheva)	Navi Mumbai (Raigad district)	Maharashtra	INDIA'S BUSIEST CONTAINER PORT; handles ~50-55% of India's containerised trade; capacity ~8 million TEUs; dedicated rail link from JNPT to WDFC (critical link for DFC); PPP-operated terminals (PSA-DP World-APM Terminals); Vadhavan Port being built nearby to supplement
Mundra Port	Mundra, Kachchh	Gujarat	INDIA'S LARGEST PORT BY CARGO VOLUME (total tonnage); Adani Ports (private); 300+ MT/year; handles coal, crude oil, containers; connected to WDFC; fastest-growing port
Kandla / Deendayal Port	Gandhidham, Kachchh	Gujarat	Oldest Major Port; petroleum products, fertilisers, salt; part of the Kachchh coast; renamed Deendayal Port Authority (2017)
Mumbai Port (MPT)	Mumbai city, Ballard Estate	Maharashtra	Old city port; passenger terminal (cruise ships); historical importance; lower cargo now vs JNPT
Visakhapatnam Port (VPT)	Visakhapatnam	Andhra Pradesh	Iron ore, coal, crude oil; deep natural harbour; Naval Station nearby; second-largest major port by cargo
Paradip Port	Paradip, Jagatsinghpur	Odisha	Coal, POL, bulk cargo; IOCL refinery adjacent; growing rapidly; largest port on East Coast
Chennai Port	Chennai	Tamil Nadu	Containers, vehicles (auto hub link), coal; second port with Ennore (Kamarajar) nearby
Kamarajar Port (Ennore)	Ennore, Chennai outskirts	Tamil Nadu	LNG terminal; coal for thermal plants; PPP port; corporatised independently
V.O. Chidambaranar Port (Tuticorin)	Tuticorin (Thoothukudi)	Tamil Nadu	Cotton, coal, salt, containers; trade with Sri Lanka; STERLITE COPPER SITE controversy nearby
Kochi Port	Kochi	Kerala	LNG terminal (Petronet); containers; cruise; proximity to Vizhinjam deepwater port (new, Adani, under construction 15 km away)
New Mangalore Port	Mangaluru	Karnataka	Petroleum, LPG, fertilisers; Mangaluru Refineries feed; minor container handling
Mormugao Port (MPT)	Panaji area, Vasco	Goa	Iron ore (historically dominant; now declining after SC bans); coal imports

Vizhinjam International Deepwater Transshipment Port (Kerala)

The **Vizhinjam International Seaport** near Thiruvananthapuram is one of India's most strategically important infrastructure projects. It is a **deepwater transshipment container port** — meaning it can receive the world's largest container ships (Ultra Large Container Vessels, >18,000 TEUs) that currently call only at Colombo (Sri Lanka) and Singapore (because most Indian ports are too shallow). India currently loses **~75% of its transshipment business to Colombo and Singapore** — ships bring containers to Colombo and small feeder vessels distribute them to Indian ports. Vizhinjam, with a natural depth of 18-20 m, can directly receive ULCVs.

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Parameter	Detail
Developer	Adani Ports and SEZ Ltd (concessionaire); Kerala government (land/infra provider)
Investment	~Rs.7,525 crore (Phase-I); target Rs.~11,000 crore (all phases)
Capacity (Phase-I)	1 million TEUs; eventually 6+ million TEUs over all phases
Natural depth	18-20 m natural; can accommodate ships up to 22,000 TEU (world's largest class)
Progress	Phase-I inaugurated by PM Modi and Kerala CM on July 7, 2024 (first commercial shipment); major milestone; Adani signed commercial agreement with MSC (world's largest shipping line) as anchor client
Significance	Could capture significant India-origin transshipment traffic from Colombo and Singapore; Rs.10,000+ crore annual savings in transshipment fees; reduces shipping cost for Indian exporters/importers
Controversy	Vizhinjam Harbour Action Council (VHAC) — local traditional fishermen protested displacement and coastal erosion from port construction; hunger strikes; police action; partially resolved but tensions remain

SAGARMALA PROGRAMME

Pillar	Description / Key Projects
Port Modernisation and New Port Development	Capacity expansion; mechanisation; automation; draught deepening; Vadhavan new port; Enayam (Tamil Nadu near Colachel — another deep-water project)
Port Connectivity Enhancement	Road, rail, pipeline and waterway connections from port to hinterland; Rail siding at each major port; NH connectivity to ports; NW-1 Haldia connection
Port-Led Industrialisation	14 Coastal Economic Zones (CEZs); promote industries near ports to reduce logistics cost; ship-breaking, chemicals, SEZs near ports
Coastal Community Development	Social infrastructure in coastal fishing communities; coastal tourism; fishermen welfare; skill development; SAGAR MITRA (fishermen welfare officers)
Coastal Shipping	Promote cargo movement along Indian coast (much cheaper than road); container coastal service Kochi-Kolkata; Ro-Ro (Roll-on Roll-off) ferry services (Mumbai-Mandwa; soon Kochi-Lakshadweep)

14.6 PIPELINES — INDIA'S INVISIBLE TRANSPORT NETWORK

Pipelines are the most efficient and safest mode for transporting liquids and gases — crude oil, natural gas, petroleum products and even slurries. Once built, pipelines have very low operating costs, are invisible, require no road/rail infrastructure, and do not congest highways. India's pipeline network has grown significantly but is still underdeveloped relative to its petroleum needs.

MAJOR PIPELINES

Pipeline / Network	Operator	Route	Type / Length
HVJ Pipeline (Hazira-Vijaipur-Jagdishpur)	GAIL	Hazira (Gujarat) to Jagdishpur (UP); via Vijaipur (MP)	India's longest gas pipeline; ~1,750 km; brings gas from Hazira to industrial clusters of UP and Delhi NCR; source: Rajasthan gas, imported LNG
GAIL National Gas Grid	GAIL	Pan-India network; connects production centres, LNG terminals, CGD networks	~20,000 km total gas pipeline network; plan to expand to 35,000 km by 2030; connects Dahej-Hazira-Bengaluru-Kochi trunk (Kochi-Koottanad-Bangalore-Mangaluru Pipeline - KKBMPL) and others

Naharkatiya-Barauni-Kanpur Pipeline	OIL (Oil India Ltd) and IOCL	Naharkatiya oilfield (Assam) to Barauni refinery (Bihar) to Kanpur (UP)	~1,157 km; crude oil pipeline; India's first major oil pipeline (built 1964); oldest oil pipeline in India; transports Assam crude
Mumbai High Offshore Pipeline	ONGC	Mumbai High offshore fields to Hazira (Gujarat); also to Uran (Maharashtra)	Offshore crude pipeline + gas pipeline from India's largest offshore oil field; ~200 km offshore + onshore segments
Koyali-Ahmadabad Pipeline	IOCL	Koyali Refinery to Ahmedabad	Refined products pipeline (POL); ~116 km
Paradip-Raipur-Ranchi Pipeline	IOCL	Paradip refinery (Odisha) to Raipur (CG) to Ranchi (JH)	~664 km; petroleum products; serves East-Central India market
HPCL Rajasthan Refinery Pipeline	HPCL	Barmer (Rajasthan) oilfield to Pachpadra refinery; products to various depots	New pipeline as part of HRRL project; strategic western India petroleum supply

Water Pipelines — Ken-Betwa Link Canal: While not a pipeline in the petroleum sense, the **Ken-Betwa River Link Project** involves a **221 km canal (effectively a water pipeline)** to transfer water from the Ken River (Bundelkhand, MP) to the Betwa River (MP-UP border). This is covered in detail in Section 14.7 on River Interlinking.

Slurry Pipelines (historical): The Kudremukh-Mangalore iron ore slurry pipeline (250 km; Karnataka) was once a landmark project — pumping magnetite iron ore slurry from the Kudremukh mines to Mangalore port. **Mining at Kudremukh was stopped in 2005 by Supreme Court order** (as the mine was within a National Park and caused massive environmental damage), and the pipeline was decommissioned. This is an important IFoS case study on mining-environment conflict.

14.7 RIVER INTERLINKING — INDIA'S MOST AMBITIOUS WATER PROJECT

The **National River Linking Project (NRLP),** also called the National Perspective Plan for Water Resources Development (NPP, 1980), envisions creating a **network of 30 inter-river links** connecting India's major rivers — 14 Himalayan links and 16 Peninsular links — to transfer water from water-surplus basins (Ganga, Brahmaputra) to water-deficit basins (Rajasthan, Gujarat, Peninsular India). The total cost is estimated at **Rs.5.5 lakh crore (at 2002 prices; current cost ~Rs.10-15 lakh crore),** and the project would transfer **174 billion cubic metres of water** annually, irrigate **34 million hectares** and generate **34,000 MW of hydropower**.

THE 30 LINKS — OVERVIEW

Component	*Number of Links*	*Key Links Proposed*
Himalayan Component	14 links	Manas-Sankosh-Tista-Ganga Link; Ganga-Damodar-Subarnarekha Link; Kosi-Mechi Link; Kosi-Ghaghra Link; Brahmaputra-Ganga Link (major inter-basin diversion)
Peninsular Component	16 links	Mahanadi-Godavari Link; Godavari-Krishna Link; Krishna-Pennar Link; Pennar-Cauvery Link; Ken-Betwa Link (FIRST UNDER IMPLEMENTATION); Par-Tapi-Narmada Link; Pamba-Achankovil-Vaippar Link

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KEN-BETWA RIVER LINK — FIRST PROJECT UNDER IMPLEMENTATION

The **Ken-Betwa River Link Project (KBRLP)** is the **first of the 30 planned inter-river links to be under actual construction** — a landmark in India's water history. It transfers water from the **Ken River (a Yamuna tributary) to the Betwa River (also a Yamuna tributary)** in the Bundelkhand region of Madhya Pradesh and Uttar Pradesh.

Parameter	*Detail*
Rivers involved	Ken River (originates in Kaimur hills, MP; joins Yamuna at Banda, UP) TO Betwa River (originates in Raisen, MP; joins Yamuna at Hamirpur, UP)
States benefiting	Madhya Pradesh and Uttar Pradesh (Bundelkhand region — one of India's most water-stressed and drought-prone areas)
Key structure	DAUDHAN DAM on Ken River (77 m height; reservoir 2,853 Mha; Chhatarpur district, MP); 221 km link canal to carry water from Ken basin to Betwa basin
Benefits	Irrigation: 8.11 lakh hectares (6.35 lakh ha in MP + 1.76 lakh ha in UP); Drinking water for 62 lakh people (Bundelkhand); 103 MW hydropower
Total cost	Rs.44,605 crore (Cabinet approved Dec 2021); Union government funding 90% (Rs.39,317 crore); MP and UP share 10%
Environmental controversy — PANNA TIGER RESERVE	The Daudhan Dam submergence will submerge ~10.07% of the CORE ZONE of Panna Tiger Reserve (MP); ~9,000 ha of forest area; Panna TR = a landmark conservation success story (tigers became locally extinct ~2009 and were successfully reintroduced from other reserves by 2012); environmentalists argue submergence will undo 15 years of conservation effort; NTCA (National Tiger Conservation Authority) gave conditional clearance; Ken river's ecosystem (Gharial habitat; Striped Hyena, Vulture nesting) would be significantly altered
Progress (2024-25)	Foundation stone laid by PM Modi (December 2021); MoU between MP and UP signed; tenders invited; land acquisition ongoing; construction of Daudhan Dam started; expected completion 2027-28 for Phase-I

ENV ALERT

Ken-Betwa vs Panna Tiger Reserve — The Central Conservation Dilemma:

- **Conservation case AGAINST:** Panna TR was dead (no tigers 2009) and revived through a decade of scientific reintroduction; it now has 50+ tigers; submerging 10% of its core zone destroys critical habitat corridors; Ken river is habitat for Gharial (Gavialis gangeticus — critically endangered), Smooth-coated Otter, Indian Skimmer (a bird), Vulture roosts and cliff-nesting birds; ecological flow of the Ken downstream will be severely reduced after water diversion.
- **Development case FOR:** Bundelkhand is among India's most impoverished and drought-prone regions; water scarcity causes farmer suicides, distress migration; 8 lakh ha of new irrigation could transform the region's agriculture; 62 lakh people get drinking water. The trade-off between conservation and human welfare in a water-stressed, poor region is genuinely difficult.

The Ken-Betwa case will define **India's precedent for balancing environmental law (Wildlife Protection Act, Forest Conservation Act) with water development law** — a landmark intersection of environmental governance.

ARGUMENTS FOR AND AGAINST RIVER INTERLINKING

Arguments FOR	*Arguments AGAINST*
Transfers water from "surplus" to "deficit" basins; reduces flood-drought cycle	No river is truly surplus; what is surplus in one year may not be the next; ecological flows are systematically underestimated

Irrigates 34 Mha; provides drinking water to water-scarce regions (Bundelkhand, Rajasthan)	Displaces millions of people; thousands of villages would be submerged by the new dams required
Generates 34,000 MW hydropower	Environmental destruction: river ecologies, wildlife corridors, fish habitats, downstream delta ecology disrupted
Reduces inter-state water conflicts (allocates more water to deficit states)	May actually worsen inter-state tensions (source-state political opposition to losing "their" water)
China has done large-scale river diversions (South-North Water Transfer Project)	China's diversion has caused massive environmental damage; not a model to copy uncritically
Reduces inland navigation constraints if rivers stay full year-round	Cost escalation (current estimates 3-5x original 2002 estimate); time overruns; fiscal burden

14.8 INDIA'S EXTERNAL TRADE

India's external trade is the material expression of its engagement with the global economy. India's total merchandise trade (exports + imports) crossed **USD 1.1 trillion in FY2022-23** — placing India among the world's top-10 trading nations. Managing the trade deficit and current account is one of India's central macroeconomic challenges.

INDIA'S MERCHANDISE TRADE AT A GLANCE (FY2023-24)

Parameter	*FY2023-24 Figure*	*Note*
Total Merchandise Exports	~$447 billion	7th largest merchandise exporter globally; 2% of world merchandise trade
Total Merchandise Imports	~$677-680 billion	High import bill driven by crude oil, gold, machinery and electronics
Trade Deficit	~$238-240 billion	Large and persistent; services surplus partially offsets it
Current Account Deficit (CAD)	~1.2-2% of GDP	Moderate; services exports (IT, tourism) and remittances partially offset goods deficit
Services Exports	~$340+ billion	IT-BPM (~$245 bn) + tourism + financial services; India = 2nd largest services exporter in Asia
Remittances	~$120 billion	India = world's largest remittance RECIPIENT (2023, World Bank); from Gulf, USA, UK, Canada

TOP EXPORTS AND IMPORTS

Top Exports (FY2023-24)	*Value (USD bn approx.)*	*Key Destination*
Engineering Goods (machinery, vehicles, metals, electronics)	~$109 billion	USA, Europe, Middle East, Africa
Petroleum Products (refined petroleum from Jamnagar/other refineries)	~$78-80 billion	Middle East, Netherlands, Singapore, USA (India = largest petroleum product exporter in Asia)
Gems and Jewellery (diamonds, gold jewellery)	~$35-38 billion	USA, UAE, Hong Kong; Surat (diamond polishing), Mumbai (gold jewellery)
Chemicals and Pharmaceutical products	~$30-32 billion	USA, UK, Africa (generic drugs); specialty chemicals to Europe
Electronic Goods (growing fast due to PLI)	~$25-27 billion	USA, Europe; Apple iPhones are now India's single largest export product category by some counts

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Agricultural Products (rice, spices, marine, cotton, sugar)	~$48-50 billion	USA, China, Bangladesh, UAE; India's rice export restriction 2023-24 reduced agri exports
Textiles and Apparel	~$34-36 billion	USA, EU, UK, UAE; Bangladesh competes strongly

Top Imports (FY2023-24)	Value (USD bn approx.)	Why Imported
Crude Oil	~$120-132 billion	~88% of crude imported; India = 3rd largest oil consumer; Saudi Arabia, Iraq, Russia, UAE main suppliers
Electronic Goods	~$85-90 billion	Smartphones, computers, components; China = 40%+ supplier; PLI trying to reduce this
Gold and Silver	~$45-50 billion	Cultural demand (jewellery); financial investment; 2nd largest gold consumer
Machinery, Mechanical appliances	~$40-45 billion	Capital goods for industry; mainly China, EU, USA
Coal, Coke, Petroleum coke	~$30-35 billion	Coking coal for steel (Australia, USA); thermal coal for power; petroleum coke for cement
Edible Oils	~$15-18 billion	Palm oil from Indonesia/Malaysia; soyabean oil from Brazil; domestic production insufficient
Fertilisers (DAP, MOP, intermediates)	~$12-15 billion	No potash reserves; limited phosphate; imports from Russia, Canada, China, Jordan

INDIA'S TRADE PARTNERS AND FTAS

Trade Relationship	Details
USA — largest export destination	India's single largest merchandise export destination; ~18-19% of India's merchandise exports; IT services also to USA; growing tensions over trade barriers (pharma, agricultural tariffs)
China — largest import source	India's largest single import partner; ~14-15% of India's imports; electronics, chemicals, machinery, APIs from China; MASSIVE TRADE DEFICIT with China (~$65-70 billion); strategic concern as China is also an adversary
UAE — key trade partner (India-UAE CEPA 2022)	India-UAE Comprehensive Economic Partnership Agreement (CEPA) signed May 2022 — India's first CEPA with an Arab/Gulf country; reduces tariffs on ~80% of goods; India's largest FTA with a Gulf partner; gems+jewellery exports to Dubai benefit most
India-Australia ECTA (2022)	Economic Cooperation and Trade Agreement; signed April 2022; India-Australia FTA; Coal and critical minerals from Australia; IT/professional services from India; fast-tracked during QUAD partnership
India-UK FTA	Under negotiation since 2022; very significant (UK = 5th largest economy; Brexit creates opportunities); whisky, automobiles from UK; IT services, textiles, pharmaceuticals from India; tariff on Indian manufactured goods = key UK ask; visa for Indian professionals = key India ask; still not concluded as of 2025
RCEP (withdrawn)	India withdrew from RCEP (Regional Comprehensive Economic Partnership) in November 2019, citing fears that cheap Chinese goods would flood Indian markets through RCEP partners (ASEAN, Australia, Japan, Korea) — a controversial decision debated by economists

14.9 CURRENT AFFAIRS HOOKS (2021–2025)

CURRENT AFFAIRS

Vande Bharat — 100+ Sets (2023-24): Indian Railways crossed 100 Vande Bharat Express sets in service in 2023-24; routes spanning from J&K (Katra) to Kanyakumari; Vande Bharat Sleeper version under development; manufacturing at ICF Chennai, RCF Kapurthala, MCF Raebareli; export discussions with Middle East and SE Asia.

KAVACH — Accelerated Post Balasore (2023): The Balasore triple-train accident (June 2, 2023; 291 dead; Odisha) — India's worst railway disaster in decades — accelerated KAVACH deployment; Railway Budget 2024-25 allocated maximum-ever capital for KAVACH; target entire Golden Quadrilateral by 2025.

Western DFC Full Operationalisation (2024-25): WDFC progressively operationalised; double-stack container trains running; JNPT to Rewari; first meaningful shift of freight from road to dedicated rail; logistics cost reduction beginning.

Jewar Airport (Noida International) Under Construction: Under construction; target 2025; Zurich Airport operator; India's first expressway airport; will be India's largest airport when all phases complete (70 million passengers); will also serve F1 (Buddh International Circuit) and Greater Noida industrial area.

Navi Mumbai Airport (Under Construction): Adani Airports; target 2025-26; Phase-I 10 million passengers; will massively decongest Mumbai airport (which is India's 2nd busiest and severely capacity-constrained).

Vizhinjam Port Phase-I Inauguration (July 7, 2024): Kerala's deepwater transshipment port (Adani) inaugurated by PM Modi; first commercial shipping; MSC (world's largest shipping line) as anchor; India's first transshipment port capable of handling largest container ships.

Ken-Betwa River Link (Under Construction, Dec 2021-): India's first river interlinking project under implementation; Daudhan Dam construction started; Panna Tiger Reserve controversy ongoing; target 2027-28 completion.

National Logistics Policy (Sep 2022) — Progress: ULIP (Unified Logistics Interface Platform) integrating transport data of 30+ systems (FOIS, PCS1x, ICEGATE, VAHAN, Sarathi, NHA Toll); e-log book for trucks; multi-modal logistics parks (MMLPs) being developed at 35 locations; logistics cost reduction from 13-14% to target 8% by 2030.

14.10 PYQ ANALYSIS — CHAPTER 14 (2010–2025)

Source	*Year*	*Marks*	*Question*
UPSC Civil	2024	15M	"Critically examine the significance of the Dedicated Freight Corridors for India's economic development and logistics competitiveness."
UPSC Civil	2023	15M	"Discuss the importance of inland waterways for India's transport and logistics. Evaluate the Jal Marg Vikas Project on National Waterway 1."
UPSC Civil	2023	10M	"What are the environmental and social concerns associated with the Ken-Betwa River Interlinking Project? How should India balance development and ecology in such projects?"
UPSC Civil	2022	12M	"Critically evaluate the UDAN (Ude Desh Ka Aam Naagrik) scheme in transforming regional air connectivity in India."
UPSC Civil	2021	15M	"Discuss the significance of National Logistics Policy 2022 for India's manufacturing competitiveness. What structural reforms are needed to reduce India's logistics cost?"
UPSC Civil	2020	12M	"Evaluate the performance of India's major seaports. What is the significance of the proposed Vadhavan Port and Vizhinjam Port for India's trade?"

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UPSC Civil	2019	12M	"Discuss the impact of the Golden Quadrilateral on India's road transport and economic development."
UPSC Civil	2018	12M	"What are the merits and demerits of the National River Interlinking Project? Discuss with special reference to the Ken-Betwa Link."
UPSC Civil	2016	10M	"Discuss the significance of the Sagarmala project for port-led development in India."
IFOS GS	2024	10M	"Examine the ecological impacts of river interlinking with special reference to the Ken-Betwa Link and Panna Tiger Reserve."
IFOS GS	2023	10M	"Discuss the significance of India's inland water transport for the ecology of river systems. What are the environmental concerns of the Jal Marg Vikas Project on the Ganga?"
IFOS GS	2022	10M	"How does transport infrastructure development impact forest ecosystems in India? Discuss with reference to highways in the Western Ghats and roads in the Himalaya."
IFOS GS	2021	10M	"Explain the environmental consequences of road network expansion in ecologically sensitive zones of India."
IFOS GS	2019	10M	"Discuss the ecological impact of the Kudremukh iron ore slurry pipeline and mining on the Western Ghats. What lessons does it offer for infrastructure-environment balance?"

KEY NOTE

Frequency pattern: DFCs (Civil 2024; very high frequency); inland waterways / Jal Marg Vikas (Civil 2023; IFoS 2023); Ken-Betwa + river interlinking (Civil 2018, 2023; IFoS 2024); logistics/Sagarmala (Civil 2016, 2021); Golden Quadrilateral (Civil 2019); UDAN (Civil 2022). IFoS focuses on ecological impact of transport infrastructure — highways through forests (Western Ghats; Himalaya), river projects (NW-1 Ganga ecology), river interlinking (Panna TR). For 2025-26: Vizhinjam Port, Navi Mumbai/Jewar airports, WDFC full operation, KAVACH, National Logistics Policy progress.

14.11 MODEL BOOK

Critically evaluate India's Make in India initiative with respect to manufacturing's share in GDP and employment generation. What has PLI achieved?

Civil (Mains) | 15 Marks | 200 Words

India's logistics cost (~13-14% of GDP vs global benchmark 8%) is its single largest competitiveness handicap in manufacturing. The Dedicated Freight Corridors — two fully electrified freight-only railways totalling ~3,360 km — are the most significant logistics infrastructure investment since Independence.

WHY DFCS ARE TRANSFORMATIVE

1. **Capacity:** The Eastern (EDFC, 1,856 km, Ludhiana-Dankuni) and Western (WDFC, 1,504 km, Ludhiana-JNPT) DFCs run freight-only trains at higher speeds (100 km/h vs current 26 km/h on shared tracks) and free up ~70% capacity on the existing rail network for passenger trains — improving overall railway efficiency on both freight and passenger sides.
2. **Double-stack containers:** WDFC carries double-stacked containers (two 20-ft containers vertically) — doubling cargo per train, reducing per-tonne cost and making Indian rail more competitive with road for time-sensitive containerised cargo.
3. **Logistics cost reduction:** DFCs reduce freight transit time from Delhi to JNPT from 3-4 days to 1-2 days; cost reduction estimated 30-40%; directly supports the National Logistics Policy 2022 target of <8% logistics cost.

4. **Industrial corridor synergies:** DMIC (Delhi-Mumbai) runs parallel to WDFC; AKIC (Amritsar-Kolkata) parallels EDFC; industrial townships (Dholera, AURIC) draw on DFC connectivity as their key competitive advantage.
5. **Sustainability:** DFCs are 100% electrified; shifting freight from diesel trucks to electric rail cuts CO2 emissions and reduces India's oil import bill.

CHALLENGES: WDFC operationalisation has been slower than planned; last-mile connectivity from factories/farms to DFC sidings is missing; private freight terminal development is lagging; full operational impact will take 3-5 years more to materialise.

DFCs are India's most important logistics reform in decades — but their impact depends on last-mile connectivity, port integration (JNPT), and industrial cluster development along the corridor.

"The Ken-Betwa River Interlinking Project exemplifies the tension between development and ecology in India. Discuss the case for and against, and suggest a balanced approach."

IFoS Civil (Mains) | 15 Marks | 200 Words

The Ken-Betwa River Link (Rs.44,605 crore; Daudhan Dam on Ken + 221 km canal; MP-UP) — India's first implemented river interlinking project — crystallises India's deepest development-environment dilemma: the water needs of a drought-stricken poor region vs the ecological integrity of a revived tiger reserve.

CASE FOR

- **Human welfare in Bundelkhand:** 8.11 lakh ha of new irrigation; drinking water for 62 lakh people; reduction of distress migration and farmer suicides in one of India's poorest, most drought-prone regions. Water scarcity is itself an ecological and human catastrophe.
- **Energy:** 103 MW hydropower; partial clean energy benefit.

CASE AGAINST

- **Panna Tiger Reserve:** Submergence of 10.07% of Panna's core zone destroys habitat of 50+ tigers reintroduced after local extinction (2009-2012); the reintroduction is among India's greatest conservation successes. Loss of core habitat creates fragmentation, reduces prey base and increases human-tiger conflict.
- **Ken River ecology:** Ken is habitat for Gharial (critically endangered), Indian Skimmer, Smooth-coated Otter; reduced downstream flow post-diversion threatens their survival; delta ecology near Yamuna confluence disrupted.

BALANCED APPROACH

1. **Environmental flows:** Mandate legally binding minimum ecological flows (e-flows) in the Ken year-round below the dam — the NTCA conditional clearance should be strictly enforced.
2. **Wildlife corridor:** Compensatory habitat outside the reserve must be secured BEFORE submergence begins.
3. **Demand management:** Combine supply-side (Ken water) with demand-side (drip irrigation, crop diversification, watershed revival in Bundelkhand) so less diversion is needed.

Ken-Betwa sets a critical precedent. India must refuse the false binary of "development vs environment" — the Bundelkhand drought crisis can be substantially addressed with less ecological cost through micro-watershed revival, demand-side efficiency and compensatory conservation. The project's implementation must be the strictest test yet of India's environmental governance.

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CHAPTER 15

CYCLONES, DROUGHTS OF INDIA

CHAPTER AT A GLANCE

- India is among the world's most disaster-prone countries: 59% of land vulnerable to earthquakes; 12% to floods; 8% to cyclones; 68% of cultivable area drought-prone; ~8% to landslides. Average annual loss ~Rs.50,000 crore (pre-2020 estimate; rising sharply).
- Cyclones: tropical storms with sustained winds >63 km/h; Bay of Bengal has ~5-6% of world's tropical cyclones but causes ~80% of world's cyclone deaths (due to shallow water, funnel shape, high density coastal population). India's most cyclone-prone coast: Andhra Pradesh, Odisha (North Bay). Major recent: Amphan 2020 (Rs.1 lakh cr loss); Yaas 2021; Biparjoy 2023 (Gujarat).
- Cyclone naming: IMD names cyclones since 2004; current list (13 countries) names since 2020; Mala, Biparjoy, Hamoon, Midhili, Michaung (2023); JTWC (USA) also names. IMD HQ: Mausam Bhawan, New Delhi.
- Drought: prolonged rainfall deficiency leading to water stress; India uses SPI (Standardised Precipitation Index) and NDVI-based monitoring; 68% of agricultural land is drought-prone; 3 types: meteorological, hydrological, agricultural. El Nino years = drought years in India (1987, 2002, 2009, 2015-16 — confirmed pattern).
- Floods: most common natural disaster in India; ~40 million ha flood-prone; Ganga-Brahmaputra-Meghna basin = most flood-prone; Assam (Brahmaputra) and Bihar (Kosi) flood every year; urban flooding growing (Mumbai 2005, Chennai 2015, Bengaluru 2022, Delhi 2023).
- NDMA (National Disaster Management Authority): established under Disaster Management Act 2005; chaired by PM; makes national disaster management plans; NDRF (National Disaster Response Force) = 16 battalions for rapid response; SDMA (State level); DDMA (District level).
- Sendai Framework for Disaster Risk Reduction 2015-2030: 4 priorities (understanding risk, governance, investment in risk reduction, response & recovery); India signatory; SFDRR replaced Hyogo Framework 2005-2015.
- Climate change is intensifying all three hazards: cyclones becoming more intense (Category 4-5) though not more frequent; droughts becoming longer and more severe; urban floods worsening due to urban heat island + wetland loss + impervious surfaces.

15.1 INTRODUCTION — INDIA'S DISASTER GEOGRAPHY

India's geographic location — at the junction of tectonic plates, flanked by two active ocean basins, straddling a monsoon-driven climate zone and supporting 1.4 billion people on a finite land area — makes it **one of the world's most disaster-vulnerable nations.** The three major hydrometeorological hazards — cyclones, droughts and floods — are not aberrations but **structural features of India's climate and geography** that have shaped its history, agriculture, economy and social structure for millennia.

The **economic cost of disasters in India is staggering and rising** — as the interaction between natural hazards and growing exposure (urbanisation in flood plains, agriculture in drought-prone zones, coastal settlement) intensifies losses. Climate change is **amplifying all three hazards** — making cyclones more intense, droughts longer and urban floods more severe. Understanding these hazards is essential for UPSC both as geography (physical processes) and as policy (Sendai Framework, NDMA, disaster management legislation).

INDIA'S DISASTER VULNERABILITY — STATISTICAL OVERVIEW

Hazard	*Area/Population at Risk*	*Annual Impact (approx.)*	*Trend*
Cyclones	~8,000 km coastline; ~600 km most cyclone-prone; AP,	~6-7 cyclones per year strike India; some years more;	Intensification (more Cat 4-5); slightly fewer storms but

	Odisha, WB, TN most exposed; ~50 million coastal population directly at risk	deaths declining due to early warning; economic losses rising	more extreme; climate change signal detected
Droughts	68% of agricultural land (nearly all of peninsular India) is drought-prone; ~330 million people at risk of severe drought in bad years	Crop losses of Rs.20,000-50,000 crore/year in drought years; rural distress, migration, farmer suicides; drinking water scarcity	El Nino years = severe drought (see Section 15.3); climate change extending drought durations
Floods	~40 million ha flood-prone (12% of land area); ~30 million people affected annually on average; ~4,000-5,000 deaths/year	~Rs.40,000-60,000 crore economic loss/year (rising); crop damage, infrastructure damage, urban flooding	Intensifying with climate change; urban flooding growing fastest
Landslides	Himalaya + Western Ghats + NE India hills; ~15% of total land area; NH routes through hills highly vulnerable	~3,000-4,000 deaths/year; road blockages; ~Rs.5,000-10,000 crore loss	Increasing with extreme rainfall events and construction activity

DISASTER MANAGEMENT FRAMEWORK IN INDIA

Institution / Law	*Role / Details*
Disaster Management Act 2005	Mother legislation; establishes NDMA, SDMA, DDMA; defines roles; created after 2004 Indian Ocean Tsunami; based on Madhav Gadgil and subsequent committee recommendations
NDMA (National Disaster Management Authority)	Apex body; chaired by PM; members include cabinet ministers; issues guidelines for cyclone, flood, earthquake, tsunami, chemical disasters; prepares National Disaster Management Plan (NDMP)
NDRF (National Disaster Response Force)	16 battalions (~12,000 personnel) trained and equipped for specialised disaster response; deployed for cyclone, flood, earthquake, building collapse, chemical disasters; among the world's largest dedicated disaster response forces; HQ New Delhi
SDMA (State Disaster Management Authority)	State-level; chaired by CM; prepares State DM Plans; controls SDRF (State Disaster Response Fund)
DDMA (District Disaster Management Authority)	District-level; chaired by Collector; operational arm; prepares District DM Plans; first responder
IMD (India Meteorological Department)	Provides weather forecasting, cyclone tracking, monsoon prediction, drought monitoring; 120+ year-old institution; HQ Mausam Bhawan, Safdarjung Airport, New Delhi; operates Doppler radar network; issues cyclone warnings 72-120 hrs before landfall
INCOIS (Indian National Centre for Ocean Information Services)	Hyderabad; issues tsunami early warnings; provides ocean state forecasts; operates DART (Deep-ocean Assessment and Reporting of Tsunamis) buoys in the Indian Ocean
National Crisis Management Committee (NCMC)	Cabinet Secretary chairs; coordinates central government response during major disasters; above NDMA in operational chain

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KEY NOTE

Sendai Framework for DRR 2015-2030: Adopted at the Third UN World Conference on DRR in Sendai, Japan (March 2015); succeeded the Hyogo Framework for Action (HFA) 2005-2015. FOUR PRIORITIES: (1) Understanding disaster risk; (2) Strengthening disaster risk governance; (3) Investing in DRR for resilience; (4) Enhancing disaster preparedness. SEVEN GLOBAL TARGETS including: substantially reduce global disaster mortality by 2030; reduce number of affected people; reduce direct economic losses; reduce infrastructure damage; increase international cooperation; increase access to early warning systems. India is a signatory; National Disaster Management Plan (NDMP) 2019 is aligned to Sendai Framework.

15.2 TROPICAL CYCLONES — ORIGIN, STRUCTURE AND INDIA'S VULNERABILITY

A **tropical cyclone** is an intense, rotating, organised system of clouds and thunderstorms that originates over tropical or subtropical waters, has a closed, low-level atmospheric circulation, low central pressure and maximum sustained surface winds of at least **63 km/h (34 knots).** They are called **cyclones in the Indian Ocean, hurricanes in the Atlantic/East Pacific, and typhoons in the West Pacific** — same phenomenon, different names. India faces cyclones from **BOTH the Bay of Bengal (more frequent and more deadly) and the Arabian Sea (less frequent but increasing with climate change).**

FORMATION CONDITIONS — SIX REQUIREMENTS

Condition	*Threshold / Mechanism*
Warm Sea Surface Temperature (SST)	Minimum 26-27°C to a depth of 50-60 m; provides the latent heat energy that fuels the cyclone; SST > 28°C = ideal; rapid intensification occurs at > 30°C
Coriolis Force	Sufficient latitude (>5° from equator); needed to initiate and maintain rotation; cyclones do not form at the equator (Coriolis = zero)
Low Vertical Wind Shear	Wind speed should not change much with altitude; high wind shear disrupts the organised convective structure of a developing cyclone
Pre-existing Disturbance	A weak low-pressure area, trough or tropical wave to initiate organisation; Bay of Bengal monsoon depressions often evolve into cyclones
High Relative Humidity	High moisture in the mid-troposphere (800-500 hPa level); prevents dry air entrainment which would weaken convection
Upper-level Outflow	Efficient divergence of air at the upper troposphere (200 hPa) to allow the surface low to deepen; cyclone is like a heat engine — needs a way to exhaust warm air at the top

CYCLONE STRUCTURE

A tropical cyclone has a characteristic structure:

- **Eye:** calm centre; clear skies; lowest pressure (sometimes <900 hPa in super cyclones); warm, sinking air; diameter 5-60 km; the most dangerous deception — people caught in the eye think the storm is over, then the second eyewall hits.
- **Eyewall:** ring of thunderstorms around the eye; highest wind speeds; heaviest rainfall; most destructive zone; multiple eyewalls can form (eyewall replacement cycles).
- **Rainbands:** spiral bands of convective clouds extending outward from the eyewall; each band can produce heavy rain and gusty winds; can extend hundreds of km from the centre.
- **Outflow layer (upper):** at 12-15 km altitude; warm moist air that has risen through the eyewall cools and flows outward; cirrus clouds visible from satellite.

IMD'S CYCLONE CLASSIFICATION

IMD Category	Wind Speed (3-minute sustained)	WMO equivalent	India's terminology
Depression	31-50 km/h	Tropical Depression	Low pressure area to Depression
Deep Depression	51-61 km/h	Tropical Depression (stronger)	Depression to Deep Depression
Cyclonic Storm	62-88 km/h	Tropical Storm	CS
Severe Cyclonic Storm	89-117 km/h	Tropical Storm/Cat 1	SCS
Very Severe Cyclonic Storm	118-167 km/h	Category 1-2	VSCS
Extremely Severe Cyclonic Storm	168-221 km/h	Category 3-4	ESCS
Super Cyclonic Storm	>222 km/h	Category 5	SuCS

KEY NOTE

Bay of Bengal vs Arabian Sea Cyclones: Bay of Bengal generates ~5x more cyclones than the Arabian Sea. Bay of Bengal is warmer (higher SST), receives more moisture from the monsoon, and has lower vertical wind shear. Arabian Sea cyclones were historically weaker and rarer — but INTENSIFICATION in the Arabian Sea has been observed (Ockhi 2017; Gonu 2007 in Oman; Biparjoy 2023 — the longest-lived pre-monsoon cyclone in the Arabian Sea). Climate change is warming the Arabian Sea faster than the Bay of Bengal, increasing Arabian Sea cyclone frequency and intensity.

WHY BAY OF BENGAL IS MORE DEADLY — FIVE REASONS

1. **Funnel shape:** The Bay narrows northward — coastal geometry amplifies storm surge height (a cyclone pushing water north finds less space → higher storm surge). The Ganges-Brahmaputra delta coast is especially vulnerable: land elevation is only 1-5 m above sea level for hundreds of km inland.
2. **Shallow continental shelf:** The Bay of Bengal has a wide, shallow continental shelf, especially off the Bangladesh-Odisha-AP coast. Shallow water amplifies storm surge height dramatically — the same cyclone produces much higher surge in shallow water than deep water.
3. **High population density:** The deltaic and coastal plains of AP, Odisha, WB and Bangladesh are among the most densely populated coastal zones in the world. Millions of people live within 10-20 km of the coast, many in kuchcha houses that cannot withstand cyclone winds.
4. **Warm Sea Surface Temperature:** The Bay of Bengal maintains SST >28°C from April to December — an exceptionally long favourable window for cyclogenesis (cyclone formation) compared to most ocean basins.
5. **Pre-monsoon and post-monsoon peak seasons:** Cyclones peak in April-May (pre-monsoon) and October-November (post-monsoon) in the Bay of Bengal — these coincide with periods of maximum SST and low wind shear.

STORM SURGE — THE DEADLIEST CYCLONE HAZARD

A **storm surge** is an abnormal rise in sea water level above the predicted astronomical tide, caused primarily by **wind stress piling up water in the direction of the storm's movement** and secondarily by the **inverse barometer effect (low central pressure allows sea surface to rise).** Storm surges can reach **5-10 m or more** in the most extreme cyclones — far more deadly than wind or rain. The 1970 Bhola Cyclone (Bangladesh) killed **~300,000-500,000 people** primarily from storm surge that inundated the delta, making it **the deadliest cyclone in recorded history.**

Storm Surge Factor	How It Amplifies Surge
Shallow water	Surge height = (wave energy) / (water depth); shallower water = higher surge; Bay of Bengal shelf = major amplifier

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Coastal geometry	Funnel-shaped coastlines (Bay of Bengal) concentrate surge energy; concave coasts amplify, convex coasts dissipate
Cyclone track angle	Cyclone making landfall perpendicular to coast pushes maximum water onshore; oblique tracks are less dangerous
Cyclone speed	Slow-moving cyclones push water longer in one direction → higher surge; fast-moving cyclones have less time
Tide level at landfall	Surge coinciding with high tide = compounding; the 2020 Amphan surge of ~5 m coincided with high tide at Sundarbans → 10+ m total water level in some areas

MAJOR CYCLONES IN INDIA — HISTORICAL AND RECENT

Cyclone	*Year*	*Category / Wind*	*Landfall / Track*	*Deaths*	*Economic Loss / Notes*
Bhola (Bangladesh)	1970	Cat 3+ (wind ~185 km/h)	Bengal delta (now Bangladesh)	~300,000-500,000 (estimates vary enormously)	Deadliest tropical cyclone in recorded history; storm surge 10+ m; no warning system; no evacuation; Bangladesh was East Pakistan then; political context led to Bangladesh liberation war 1971
Andhra Pradesh Cyclone	1977	Severe Cyclonic Storm	Divi Taluq, Krishna delta, AP	~10,000	Major storm surge; affected Krishna-Godavari delta; massive loss of life due to low elevation coastal population
Orissa Supercyclone	1999	Super Cyclonic Storm (~260 km/h; lowest pressure 912 hPa)	Paradip, Odisha (Oct 29, 1999)	~10,000 (official); estimated much higher in Odisha	India's last major mass-casualty cyclone; before NDMA; before Doppler radar network; ~15 million affected; 15 lakh houses destroyed; total crop loss in coastal Odisha; THIS EVENT catalysed India's cyclone preparedness revolution
Gonu	2007	Cat 5 equivalent (Arabian Sea)	Oman (not India landfall)	~50 in Oman	Strongest Arabian Sea cyclone on record at the time; changed understanding of Arabian Sea cyclone potential
Aila	2009	Severe Cyclonic Storm	West Bengal-Bangladesh coast (May 25, 2009)	~190	Sundarbans badly affected; mangrove destruction noted; significant flooding
Phailin	2013	Very Severe Cyclonic Storm (~220 km/h)	Gopalpur, Odisha (Oct 12, 2013)	~45 (despite being stronger than 1999 storm)	A landmark in India's cyclone preparedness: 1 million people pre-emptively evacuated from Odisha coast; death toll dramatically lower than 1999 due to: (1) Doppler radar tracking; (2) NDMA preparedness; (3) community cyclone shelters; (4) IMD

					5-day early warning; Odisha became model for cyclone preparedness
Hudhud	2014	Very Severe Cyclonic Storm (~185 km/h)	Visakhapatnam, AP (Oct 12, 2014)	~124	Devastated Visakhapatnam; total power failure; trees uprooted; ~Rs.21,000 crore loss; AP government criticised for inadequate city preparedness vs Odisha's village preparedness
Vardah	2016	Severe Cyclonic Storm	Chennai, Tamil Nadu (Dec 12, 2016)	~18	Devastated Chennai's tree cover; airport closed; proof that Chennai urban area vulnerable despite being less cyclone-prone than Odisha-AP
Ockhi	2017	Extremely Severe Cyclonic Storm	Formed near Sri Lanka; hit Kerala-Lakshadweep	~245 (mostly fishermen)	Formed very close to shore; fishermen at sea had no warning; highlighted fishing community early warning gap; Lakshadweep and Kerala coast affected; one of the rare cyclones from the southwestern Bay near Sri Lanka
Fani	2019	Extremely Severe Cyclonic Storm (~250 km/h)	Puri, Odisha (May 3, 2019)	~89	One of the strongest cyclones to hit India; 1.2 million people evacuated in 48 hours; only 89 deaths despite 250 km/h winds; cited globally as a model of disaster preparedness; NDRF deployed; community shelters used; India received international recognition
Amphan	2020	Super Cyclonic Storm at peak; VSCS at landfall (~155 km/h)	Sundarbans-Digha, WB-Bangladesh border (May 20, 2020)	~128	The costliest cyclone in Indian history: ~Rs.1 lakh crore (USD 13 billion) economic loss; devastated Sundarbans mangroves; WB-Bangladesh coast; during COVID-19 lockdown (evacuation complicated by pandemic protocols); Kolkata badly damaged
Yaas	2021	Very Severe Cyclonic Storm (~155 km/h)	Balasore-Dhamra coast, Odisha (May 26, 2021)	~19	Odisha again evacuated 1 million+; remarkably low deaths; Odisha model confirmed
Biparjoy	2023	Extremely Severe Cyclonic Storm (~150 km/h at landfall)	Jakhau coast, Gujarat (June 15, 2023)	~2 (India); ~9 total	RARE Gulf of Kutch landfall cyclone; one of the longest-lived pre-monsoon cyclones in Arabian Sea; ~1 lakh people evacuated from Gujarat; NDRF deployed; excellent warning;

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					minimal deaths despite high intensity; Gujarat preparedness praised
Michaung	2023	Severe Cyclonic Storm (~95 km/h)	Andhra Pradesh near Bapatla (Dec 5, 2023)	~17	Caused severe Chennai urban flooding (72-hour rainfall record for December in Chennai); highlighted urban drainage inadequacy; ~Rs.5,000 crore damage

INDIA'S CYCLONE PREPAREDNESS REVOLUTION — FROM 10,000 DEATHS TO 45 DEATHS

The transformation of India's cyclone management from the **1999 Orissa Supercyclone (10,000 deaths)** to **Cyclone Fani 2019 (89 deaths)** and **Cyclone Yaas 2021 (19 deaths)** is one of the world's great examples of **disaster preparedness reducing mortality even as storm intensity increases.**

Element of Preparedness	*Detail*
Doppler Weather Radar network	~40 Doppler radars covering all coastal areas; real-time tracking of cyclone position, intensity and track; gives 5-7 days' warning; IMD now provides 3-day forecast with 100-150 km track error (major improvement from 500+ km error in 1999)
Multi-hazard early warning system	IMD-NDMA-INCOIS joint cyclone warning; colour-coded alerts (Green-Yellow-Orange-Red); SMS to mobile phones in affected districts; All India Radio, Doordarshan dissemination; Doordarshan rural reach
Community cyclone shelters	Odisha has built >850 multipurpose cyclone shelters (MCS) along the coast (post-1999); each can hold 1,000-3,000 people; elevated 5-10 m above ground level; structurally strong enough to withstand 260 km/h winds; has kitchen, water, toilets; WB, AP, TN also building
Pre-emptive mass evacuation	Odisha NDMA/SDMA protocol: mandatory evacuation of all people within 5 km of coast when cyclone warning issued; trucks and buses arranged by district administration; people moved 48-72 hours before landfall; Fani: 1.2 million evacuated in 48 hours; Yaas: 1 million+ evacuated
NDRF deployment	NDRF battalions pre-positioned at predicted landfall zones before cyclone strikes; rescue teams ready for immediate post-landfall response; search and rescue equipment (boats, rope, medical kits)
Mangrove protection (Odisha)	Odisha's Bhitarkanika mangroves and coastal shelter belts dissipate wave energy and reduce surge penetration inland; states now recognise mangroves as infrastructure (not just ecology)
Post-landfall relief	Pre-positioned food, water, medicines; army, navy, coast guard deployed for relief; NDRF + SDRF coordination; Rs.200-500 crore immediate state relief expenditure in major cyclones

IFoS FOCUS

IFoS — MANGROVES AS CYCLONE BUFFERS: Mangrove forests provide critical ECOSYSTEM-BASED ADAPTATION (EbA) to cyclone hazard: (1) Mangrove root systems dissipate wave energy — reducing wave height by ~50-75% within 500-1,500 m of a dense mangrove belt; (2) The dense aerial root architecture slows water flow, trapping sediment and reducing erosion; (3) post-cyclone recovery is faster in areas with intact mangroves. Studies of the 2004 tsunami and 2019 Cyclone Fani showed that villages behind intact Odisha mangrove belts suffered less structural damage than exposed

villages. The 1999 Orissa Supercyclone was particularly devastating partly because decades of aquaculture (shrimp farm) encroachment had destroyed the coastal mangrove belt. Mangrove RESTORATION is thus both a carbon project and a disaster-risk reduction project.

CYCLONE NAMING — HOW INDIA NAMES CYCLONES

The **World Meteorological Organisation (WMO)** coordinates tropical cyclone naming through Regional Specialised Meteorological Centres (RSMCs). **IMD (India Meteorological Department) is the RSMC for the North Indian Ocean** — responsible for naming and tracking cyclones in the Bay of Bengal and Arabian Sea.

- **Since 2004:** IMD began naming cyclones using a pre-agreed list contributed by 8 North Indian Ocean countries (India, Bangladesh, Myanmar, Oman, Pakistan, Sri Lanka, Thailand, Maldives). These names were used sequentially regardless of origin area.
- **Since 2020:** The naming panel expanded to **13 countries** (original 8 + Iran, Qatar, Saudi Arabia, UAE, Yemen); each country contributes 13 names; new list released 2020 with 169 names.
- **India-contributed names:** Gati, Tej, Murasu, Aag, Vyom, Jhar (some used for Arabian Sea; some for Bay of Bengal cyclones); Biparjoy = contributed by Bangladesh (means "disaster" in Bengali).
- **Retirement:** Names of particularly destructive cyclones are retired from the list (like hurricane names); e.g., Ockhi and Amphan names retired.

CLIMATE CHANGE AND CYCLONE INTENSIFICATION

Observed / Projected Change	*Evidence / Mechanism*
Rapid Intensification (RI) increasing	RI = wind speed increase of >55 km/h in 24 hours; warming SSTs provide more energy for RI; Cyclone Amphan underwent RI from 65 km/h to 260 km/h in ~36 hours (2020); Cyclone Biparjoy also rapidly intensified
More intense cyclones (Cat 4-5)	Global proportion of Cat 4-5 cyclones increasing; IPCC AR6 confirms this trend; Bay of Bengal seeing more VSCS/ESCS category storms
Poleward migration of cyclone tracks	Cyclones moving to higher latitudes as the tropical warm zone expands; Indian Ocean cyclones potentially reaching Gujarat and Maharashtra more often
Slower-moving cyclones	Cyclones moving more slowly = longer rainfall duration over one area = more flooding; 2017 Harvey in USA = prime example; India has seen similar slow-movers
Higher storm surges	Higher sea levels (20 cm rise by 2100 under moderate scenarios) + intensified storms = higher absolute surge heights
Increasing Arabian Sea cyclone activity	Arabian Sea has warmed faster than Bay; more frequent and intense cyclones; longer seasons; Gonu 2007, Biparjoy 2023 = examples of unprecedented Arabian Sea intensity

15.3 DROUGHTS — TYPES, CAUSES AND INDIA'S DROUGHT GEOGRAPHY

A **drought** is a prolonged period of abnormally low rainfall that leads to **water shortage for agriculture, drinking water and ecosystems.** Unlike floods and cyclones, droughts develop **slowly and insidiously** — earning the label "*creeping disaster*." They affect larger areas, last longer and cause greater cumulative economic damage than any other natural hazard — yet receive less media attention because they do not produce the dramatic images of cyclone destruction or flood inundation.

TYPES OF DROUGHTS

Type	*Definition*	*Indian Example*
Meteorological Drought	Below-normal rainfall sustained over a period; India uses: <75% of Long Period Average (LPA) for	India official: if India-wide monsoon rainfall is <96% of LPA = deficient

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	the region as drought threshold; <50% LPA = severe drought	monsoon; 2002 = 81% LPA; 2009 = 78% LPA
Hydrological Drought	Prolonged rainfall deficiency that leads to depletion of surface water (rivers, reservoirs, lakes) and groundwater below normal levels; may lag meteorological drought by months	Krishna, Godavari flowing at critically low levels in dry years; reservoirs in peninsular India at <25% live storage capacity during 2016 and 2019 droughts
Agricultural / Soil Moisture Drought	Soil moisture deficit that stresses crops; depends on evapotranspiration vs rainfall balance; affected by soil type and crop water requirements; the most economically damaging type for India	Kharif crop failure in Marathwada, Vidarbha, Bundelkhand in drought years; crop failure leads to farmer distress and suicides
Socio-Economic Drought	When drought triggers social and economic impacts: food insecurity, water conflict, migration, livelihood loss, livestock death, health impacts (malnutrition)	Bihar, Jharkhand, Odisha tribal areas; Bundelkhand migration to Delhi/UP cities in 2016 drought; Marathwada farmer suicides
Flash Drought	Rapid onset of drought conditions (within weeks) due to sudden spike in evapotranspiration (heat wave) rather than prolonged rainfall deficiency	Not yet well-documented in India but with increasing heat waves (2022, 2023), flash drought becoming relevant

DROUGHT-PRONE REGIONS OF INDIA

Region	*States*	*Characteristic*
MOST DROUGHT-PRONE (Chronic)	Rajasthan (<250 mm rainfall); Western Gujarat (Kachchh, Saurashtra); and some Himalayan rain-shadow areas	Very low rainfall; high evapotranspiration; poor soil water holding capacity; adapted agriculture (millets, pastoralism)
HIGHLY DROUGHT-PRONE	Marathwada and Vidarbha (MH); Rayalaseema (AP); Telangana plateau; Bundelkhand (MP-UP); southern Karnataka (Bidar, Kalaburagi); eastern Rajasthan	Bi-modal rainfall (SW + retreating monsoon) with high variability; black cotton soil (drains quickly); heavy rain-fed agriculture; high risk of agricultural drought
MODERATELY DROUGHT-PRONE	Parts of MP, Bihar, Jharkhand, Odisha, UP Purvanchal	Dependent on SW monsoon; year-to-year variability; some irrigation buffers
GENERALLY, NOT DROUGHT-PRONE	Kerala, coastal Karnataka, Tamil Nadu (NE monsoon dependent), NE India (Meghalaya, Mizoram, Assam), Uttarakhand hills	High rainfall, perennial rivers, irrigation access; drought possible only in very deficient monsoon years

EL NINO — SOUTHERN OSCILLATION (ENSO) AND INDIAN DROUGHT

The **El Nino — Southern Oscillation (ENSO)** is the most important oceanic-atmospheric driver of India's year-to-year monsoon variability — and by extension, the primary trigger of nationwide droughts. Understanding ENSO is therefore central to understanding Indian drought patterns.

ENSO Phase	*Definition*	*Effect on Indian Monsoon*
NORMAL (La Nina neutral)	Pacific SSTs near normal; Walker Circulation (east-west atmospheric circulation over Pacific) normal	Normal monsoon; LPA rainfall; no systematic bias
EL NINO (warm phase)	Anomalous warming of central-eastern Pacific SSTs; Walker	SUPPRESSES Indian monsoon; reduces SW monsoon rainfall (by disrupting moisture flow);

	Circulation weakens; upwelling off Peru stops; convection shifts to central Pacific from Maritime Continent	majority of El Nino years = below-normal or deficient Indian monsoon; NOT 100% correlation (2019 El Nino but near-normal monsoon due to positive IOD)
LA NINA (cool phase)	Anomalous cooling of central-eastern Pacific SSTs; Walker Circulation strengthens; enhanced upwelling	ENHANCES Indian monsoon; usually above-normal rainfall; flood risk higher in La Nina years
INDIAN OCEAN DIPOLE (IOD)	Positive IOD = western Indian Ocean warmer than east; can COUNTERACT El Nino effect (2019 = El Nino + positive IOD = near-normal monsoon)	Positive IOD = enhances Indian monsoon; negative IOD = suppresses; partially independent of ENSO

Year	*ENSO Phase*	*Indian Monsoon / Drought Outcome*
1987	Strong El Nino	Major all-India drought; SW monsoon 81% of LPA; widespread crop failure; Rajasthan-Gujarat-MP-Maharashtra affected
2002	Strong El Nino	Severe all-India drought; monsoon 81% of LPA; worst since 1987; UP, Rajasthan, Gujarat severely affected; Kharif crop loss ~Rs.45,000 crore
2009	Moderate El Nino	Monsoon 78% of LPA — most deficient since 1972; drought across 60% of country; Bihar, UP, Rajasthan, Gujarat worst; food inflation spiked
2015-16	Very strong El Nino (strongest since 1998)	2015 monsoon ~86% LPA — deficient; 2016 La Nina transition → monsoon recovery; Marathwada, Vidarbha, Bundelkhand worst hit; Latur water train (March 2016 — water trains to drought-hit Latur, Maharashtra)
2019	Weak-moderate El Nino BUT strong positive IOD	Positive IOD counteracted El Nino; MONSOON NEAR-NORMAL despite El Nino (a unique demonstration of IOD-ENSO interaction)
2023-24	Strong El Nino (2023) → La Nina transition (2024)	2023 monsoon slightly below normal (94% LPA) due to El Nino; 2024 monsoon above normal (La Nina boost); peninsular drought in 2023, recovery in 2024

DROUGHT MONITORING AND EARLY WARNING

Tool / Index	*Description / Use*
Long Period Average (LPA)	IMD's 50-year average rainfall (currently 1971-2020 average = 87 cm all-India SW monsoon); used as reference; actual / LPA x 100 = % departure
Standardised Precipitation Index (SPI)	WHO/WMO-recommended drought index; measures rainfall deficiency in terms of standard deviations from mean over different time windows (SPI-3 = 3-month drought; SPI-12 = annual drought); negative SPI = drought
NDVI (Normalised Difference Vegetation Index)	Satellite-based (ISRO, Resourcesat); measures vegetation greenness; sharp NDVI decline = crop stress/agricultural drought; used by Ministry of Agriculture for crop loss assessment
Soil Moisture Operational Product System (SMOPS)	Satellite-based soil moisture monitoring; NASA, ISRO collaboration; near-real-time soil moisture maps
National Drought Risk Mitigation Portal (NDMR)	MoAFW + ISRO; integrates rainfall, NDVI, soil moisture, reservoir data into drought risk assessment maps; used for SDRF/NDRF allocation decisions
IMD Seasonal Forecast (April/June)	IMD issues long-range forecast (LRF) for SW monsoon in April and June each year; crucial for agricultural planning, state government pre-positioning of relief
Crop Cutting Experiments (CCE)	State agriculture departments conduct CCEs to assess actual yield loss; basis for insurance claims under PMFBY; ground-truth for satellite estimates

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DROUGHT IMPACT AND GOVERNMENT RESPONSE

Droughts cascade through multiple systems — from agriculture to rural economy to urban water supply to health:

- **Agricultural impact:** Kharif crop failure (direct rainfall dependence); rabi crop failure if reservoir levels low; livestock death (fodder scarcity); seed loss (farmers eat seed grain in distress); crop damage insurance is critical (PMFBY — PM Fasal Bima Yojana).
- **Water supply crisis:** Drought years deplete reservoirs; urban water supply rationed (Bengaluru 2024 — severe water crisis; Chennai Day Zero 2019 when city reservoirs touched zero); borewells drilled ever deeper.
- **Migration:** Drought-induced distress migration from Bundelkhand to Delhi/UP/MH cities; from Marathwada to Pune/Mumbai; from Rajasthan to Gujarat construction sites; creates pressure on urban infrastructure.
- **Farmer suicides:** Crop failure + loan default + social shame = farmer suicide; Maharashtra, Karnataka, AP most affected in drought years (see Chapter 12 on Agriculture for full treatment).
- **Government response:** Declaration of drought (state government; SDRF and NDRF funds released); MGNREGS expanded (provides labour income); water tanker supply; relief camps; PMFBY crop insurance; agricultural input subsidy.

CURRENT AFFAIRS

Latur Water Train (March 2016) — Symbol of Maharashtra Drought Crisis: In March 2016, during one of Maharashtra's worst droughts (El Nino 2015-16), the government of Maharashtra arranged **special "water special" trains carrying 50 lakh litres** of water every day to Latur city (Marathwada) from Miraj (Sangli, 350 km away). Latur's dams had been at zero for months. This was **the first time in independent India that water was transported by train** to a major city. The water train ran for several months. The Latur drought crisis became the symbol of Maharashtra's agrarian and water crisis, and a powerful argument for structural watershed development, dam repair and groundwater recharge in the region.

15.4 FLOODS — RIVER, FLASH, COASTAL AND URBAN

Floods are India's **most frequently occurring, most geographically widespread and economically most damaging natural disaster** — affecting on average **~30 million people and ~40 million hectares of land annually** and killing **~4,000-5,000 people per year.** India has the world's highest annual economic losses from floods in absolute terms, though losses are still rising as exposure (urban expansion in flood plains, coastal settlement) increases faster than resilience.

TYPES OF FLOODS

Flood Type	*Mechanism*	*Indian Examples*
River Floods (Fluvial)	Rivers overflowing their banks due to excess rainfall in the catchment; the most common type in India; river floods are predictable to some degree and allow evacuation time	Brahmaputra annual floods (Assam); Kosi floods (Bihar — "Sorrow of Bihar"); Mahanadi floods (Odisha); Ganga floods (UP-Bihar)
Flash Floods (Pluvial/Hydrological)	Rapid flooding from intense local rainfall over a small area in a short time; little warning; triggered by cloudburst (very intense convective rain); associated with steep mountain slopes	Kedarnath 2013; Chamoli 2021; Uttarakhand/Himachal Pradesh every monsoon; cloudburst events in Delhi-Gurugram; Leh cloudbursts
Urban Floods	Flooding in cities due to: intense rainfall + impervious surfaces + clogged drainage + built	Mumbai July 26 2005 (944 mm in 24 hours; 1,094 dead; Rs.5,000 crore loss); Chennai

	on floodplains/wetlands; rapid onset; often 2-4 hours of heavy rain = knee-deep water	2015; Bengaluru 2022; Delhi 2023; Hyderabad 2020
Coastal Floods	Sea water inundation due to storm surge (cyclone) or tsunami; affects low-lying coastal areas	Cyclone Amphan 2020 (Sundarbans; 5 m surge); 2004 tsunami (TN, AP, Kerala, A&N); Cyclone Fani 2019 surge
Glacial Lake Outburst Floods (GLOFs)	Sudden release of water from a moraine/ice-dammed glacial lake; catastrophic volume in hours; high sediment load; destroys everything downstream	Chamoli 2021; South Lhonak 2023 (Teesta-III dam destroyed); multiple events each monsoon in Uttarakhand, HP, Sikkim
Dam-induced Floods	Sudden release of water from dams without adequate warning; dam failures; reservoir overflows	Rishiganga dam failure (part of Chamoli 2021); Mahad bridge failure (Maharashtra 2021); Banasura Sagar dam (Kerala 2018 releases during floods)

FLOOD-PRONE REGIONS OF INDIA

Region	*Rivers / System*	*Special Characteristic*
ASSAM and NE India	Brahmaputra and its tributaries (Subansiri, Dibang, Lohit, Manas, Kopili, Beki)	Most flood-prone state in India; Brahmaputra carries extraordinary sediment load from eastern Himalayas → rapid aggradation (raising of river bed) → flooding; flash floods from cloudbursts on NE hills; floods affect ~3.5-4 million ha of Assam every year
BIHAR (Kosi, Gandak, Bagmati, Mahananda)	Kosi River (tributaries originate in Nepal)	Kosi = "Sorrow of Bihar"; extreme sediment load → rapid channel shifting; Kosi avulsion of 2008 (river shifted 100+ km east without warning; ~2.3 million displaced; 500+ dead); Bihar is India's most flood-vulnerable state by proportion of population at risk
UTTAR PRADESH	Ganga, Yamuna, Ghaghra (Saryu), Rapti, Sharda	Eastern UP (Gorakhpur, Bahraich, Lakhimpur Kheri, Deoria, Varanasi) flood annually; Ganga plain is extremely flat → water spreads wide
WEST BENGAL	Damodar, Mayurakshi, Ajoy, Jalangi, Ganga delta channels	Damodar = "Sorrow of Bengal" (before DVC dams); Cyclone storm surge amplifies coastal flooding; Hooghly estuary tidal flooding; Kolkata urban flooding
ODISHA	Mahanadi, Baitarani, Brahmani, Budhabalanga	Delta flooding; cyclone surge on top of river floods; some of India's worst disasters; Mahanadi delta = highly fertile but highly flood-prone
ANDHRA PRADESH	Krishna and Godavari deltas	Deltaic flooding; Godavari is a very large river — major floods in deltas; cyclone surge compounds; Polavaram dam project being built for flood control
COASTAL (CYCLONE SURGE)	All east coast states	Cyclone-induced storm surge = coastal flood; mainly Oct-Nov peak; Andhra + Odisha + WB most affected
URBAN FLOODING	All major Indian cities	Mumbai, Chennai, Bengaluru, Hyderabad, Delhi, Gurugram, Patna; causes: built on floodplains/wetlands; impervious surfaces; inadequate stormwater drains; climate change intensifying rainfall events

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MAJOR FLOODS OF INDIA — CASE STUDIES

Bihar – Kosi Floods (2008) – The Great Avulsion

The **Kosi River (Sanskrit: Kausika)** originates in Nepal (Arun, Tamur and Sun Kosi tributaries), drains the eastern Nepal Himalaya and enters Bihar's North plain — carrying one of the world's highest sediment loads (~170 million tonnes/year; comparable to the Yellow River of China). The Kosi's extraordinary sediment deposition causes rapid **aggradation (raising of the river bed)** and lateral migration. The Kosi has shifted its course **~120 km westward over the past 250 years** — the most rapid and dramatic river migration in history for a river of this size.

On **August 18, 2008,** the Kosi embankment at Kusaha (Nepal) was breached, and the river **avulsed eastward by ~100 km** — abandoning its artificial (embanked) channel and reverting toward its pre-1950 natural course. The **sudden avulsion flooded 4,000+ sq km without any warning;** ~2.3 million people were displaced; ~500+ died; ~3.5 lakh livestock perished; entire villages were submerged; crops destroyed. The **failure of the embankment system** — built to prevent Kosi floods but which had artificially confined the river, leading to faster aggradation and instability — was a landmark lesson in the limits of structural flood management.

Mumbai Floods (July 26, 2005)

On **July 26, 2005**, Mumbai received **944 mm of rainfall in a single 24-hour period** — an unprecedented amount that overwhelmed every drainage system the city had. The north-western suburb of Santacruz (Colaba received 74 mm in the same period — a **localised cloudburst of extraordinary intensity**). Roads became rivers; the railway system (the lifeline of Mumbai) completely failed; 1,094 people died (many drowned in vehicles, underpasses and low-lying homes); ~Rs.5,000 crore in economic losses. The BRIMSTOWAD (Brihanmumbai Stormwater Disposal) project was conceptualised after this disaster — to improve Mumbai's storm drain capacity from 25 mm/hour handling to 50 mm/hour. Progress has been slow.

Kedarnath Flash Flood (June 2013)

The **Kedarnath disaster (June 16-17, 2013)** is India's worst mountain flood disaster in modern times. Exceptionally heavy monsoon rainfall on already saturated soils, combined with the breaching of the Chorabari glacial lake (behind Chorabari Glacier above Kedarnath), sent a **catastrophic debris flow (mixture of water, ice, rock and sediment)** through the Kedarnath valley. The Mandakini River at Kedarnath rose **~6 metres within hours;** the temple town was buried under 15+ feet of debris; **~5,700 people were killed** (with thousands more missing and presumed dead). Over 100,000 pilgrims were stranded in the Char Dham (Kedarnath, Badrinath, Gangotri, Yamunotri) pilgrimage circuit; the Indian Army and Air Force conducted the largest rescue operation in the Himalayas since Independence.

The Kedarnath disaster highlighted the **intersection of tourism growth, climate change, geological vulnerability and inadequate disaster preparedness** in the Himalaya. Construction in the fragile valley floor, destruction of natural flood buffers (riparian vegetation, wetlands), and lack of an early warning system all amplified the tragedy. The Char Dham Highway project (NH-58 widening) was subsequently criticised for further destabilising already sensitive Himalayan slopes.

Chennai Floods (November–December 2015)

The **Chennai floods of November-December 2015** resulted from the convergence of: (1) the **NE monsoon delivering >1,000 mm of rainfall in November** — more than twice the normal amount; (2) **catastrophic loss of Chennai's lake-wetland network** — Pallikaranai marshland reduced from 6,000+ ha to ~600 ha; Chembarambakkam and other lakes filled to capacity; (3) **unplanned urban expansion in natural drainage channels and floodplains** — Adyar river floodplain was built over. When the Chembarambakkam reservoir reached full capacity on December 1, 2015, **12,000 cusecs were released downstream without warning,** flooding multiple neighbourhoods. Over **500 people died;** economic losses exceeded **Rs.15,000 crore;** IT companies in

OMR (Old Mahabalipuram Road) corridor were shut for weeks. The disaster is the definitive Indian case study of **"flood of our own making"** — urbanisation eliminating natural water buffers.

ENV ALERT

Floods We Make — Urban Flooding as a Policy Failure

India's worst modern urban floods — Mumbai 2005, Chennai 2015, Bengaluru 2022 — are all **floods of our own making**, not purely natural disasters. The pattern is consistent: (1) **Wetlands filled for development** (Pallikaranai marsh → OMR tech park; Bengaluru lakes → IT layouts; Delhi Yamuna floodplain → Commonwealth Games Village); (2) **Storm drains built to inadequate capacity** (Delhi drain capacity = 12-15 mm/hour; the city often gets 80+ mm/hour in monsoon convection); (3) **Natural drainage channels (nalas) encroached or blocked**; (4) **Climate change intensifying rainfall extremes**. The structural solution = urban flood management plans, Stormwater Drain Master Plans, Blue-Green Infrastructure (BGeI — using parks, trees, permeable surfaces to absorb urban rainfall), strict enforcement of wetland and floodplain protection. Cities that have adopted this framework (Singapore, Rotterdam) have dramatically reduced urban flooding.

FLOOD MANAGEMENT STRATEGIES

Approach	*Tools / Methods*	*Limitations*
STRUCTURAL — Embankments (Levees/Bunds)	Earthen or concrete walls along riverbanks to contain floodwater; widely used in Assam (Brahmaputra) and Bihar (Kosi, Gandak); total 15,000+ km of embankments in India	Causes faster aggradation (river bed rises faster when constrained → embankments must grow higher → eventually fail catastrophically as in Kosi 2008); embankments protect some areas but flood others when breached; high maintenance cost
STRUCTURAL — Dams and Reservoirs	Storage dams absorb excess floodwater; flood control = one of the multiple objectives of most Indian dams (irrigation + power + flood control); DVC (Damodar Valley Corporation) dams ended Damodar's "Sorrow of Bengal" label	Dams cause their own hazards: sudden release without warning (dam-induced floods); seismic risk; silting (50-year lifespan for flood modulation); dam-break flooding; only effective for catchment-level floods, not coastal or urban
STRUCTURAL — Flood Retention Basins/Retarding Basins	Designated land where floodwater is stored temporarily; natural wetlands serve this function; artificial retention basins in urban areas	Requires large land area; politically difficult to keep undeveloped; best done by protecting existing wetlands from encroachment
NON-STRUCTURAL — Early Warning Systems	IMD flood forecasts; Central Water Commission (CWC) river level monitoring; INCOIS tsunami warnings; SMS alerts to villages	Last-mile warning reach to all vulnerable populations not yet achieved; fishermen at sea still under-warned
NON-STRUCTURAL — Flood Plain Zoning	Legal demarcation of hazard zones; restriction of construction in high-risk zones; Flood Plain Zoning Act (a model bill exists; not adopted by most states)	Political resistance (profitable real estate development on floodplains); no central law; state adoption voluntary and rare
NON-STRUCTURAL — Flood Insurance / Financial Protection	PMFBY (crop insurance); SDRF/NDRF (post-disaster government relief); World Bank disaster risk financing	Post-disaster relief = compensatory not preventive; underinsurance of households and assets

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ECOSYSTEM-BASED — Wetland Protection	Protecting floodplain wetlands, oxbow lakes, marshes = natural flood buffers; mangroves for coastal flooding	Requires political will to prevent encroachment; conflict with agriculture and urbanisation
ECOSYSTEM-BASED — Watershed/Forest management	Increasing forest cover in upper catchment → more infiltration → lower peak flow → lower flood risk; CAMPA funds for forest restoration	Impact is long-term (5-20 years); cannot prevent flood from exceptionally intense rainfall events

NATIONAL FLOOD CONTROL PROGRAMME AND INSTITUTIONS

- **Central Water Commission (CWC):** apex technical body under Ministry of Jal Shakti; responsible for flood forecasting (1,327-gauge stations; forecasts for 400+ sites); dam safety; river development; DISASTER MANAGEMENT: 24x7 flood monitoring during monsoon.
- **National Flood Control Programme (NFCP):** running since 1954; provides central assistance to states for anti-erosion and flood management works.
- **Rashtriya Barh Ayog (National Flood Commission, 1976):** RBA report estimated ~40 million ha flood-prone area; recommended integrated approach; many recommendations still not implemented.
- **Brahmaputra Board:** established 1980 under MoJal Shakti; coordinates flood management on Brahmaputra and Barak rivers; conducts surveys; prepares master plans.
- **SDRF and NDRF:** State Disaster Response Fund (financed by Centre+State) and National Disaster Response Fund used for post-flood relief, rehabilitation, reconstruction.

15.5 LANDSLIDES — HIMALAYAN AND WESTERN GHATS VULNERABILITY

Landslides — the downslope movement of soil, rock and debris — are a major and growing hazard in India's mountain regions. India has the world's largest human population in landslide-prone terrain. **~15% of India's total land area (~0.49 million sq km)** is prone to landslides — covering the Himalaya, Western and Eastern Ghats, Nilgiris and the NE hill states. Landslides kill **~3,000-4,000 people annually** and block strategic roads (NH-44 through J&K, NH-58 through Uttarakhand, NH-108, Rohtang Pass roads) for weeks.

LANDSLIDE-PRONE ZONES OF INDIA

Zone	*States*	*Triggering Factors*
WESTERN HIMALAYAS	J&K, HP, Uttarakhand	Heavy monsoon rain; snowmelt; earthquakes; construction (especially NH widening — Char Dham Highway controversy); deforestation; Uttarakhand particularly vulnerable (young, steep, fragile Tertiary formations)
EASTERN HIMALAYAS (and NE Hills)	Sikkim, Arunachal Pradesh, Meghalaya, Mizoram, Nagaland, Manipur, Assam (hills)	Highest rainfall + steepest slopes + soft Tertiary rocks = world's most landslide-active zone; Jaintia Hills (Meghalaya) rat-hole mining destabilises slopes; Manipur-Mizoram roads blocked seasonally; Sikkim's South Lhonak GLOF (2023) triggered massive downstream landslides
WESTERN GHATS (Southern)	Kerala, Tamil Nadu (Nilgiris), Karnataka	Extreme SW monsoon rainfall (>3,000-5,000 mm); deep laterite soils; deforestation; Munnar-Wayanad-Kodagu area particularly active; 2018 Kerala floods + landslides (Wayanad, Idukki, Malappuram); WAYANAD 2024 LANDSLIDES
KONKAN AND SAHYADRI (North)	Maharashtra (Raigad, Satara, Ratnagiri)	Mumbai-Goa highway; NH-66; heavy monsoonal rainfall; Raigad landslide 2023 (Irshalwadi village; 27 dead); Maharashtra Sahyadri = growing risk

CURRENT AFFAIRS	**Wayanad Landslides (July 30, 2024) — India's Worst Recent Disaster:** In the early hours of July 30, 2024, a series of catastrophic landslides struck the villages of Mundakkai and Chooralmala in Wayanad district, Kerala. Over 400 people were killed (official toll; many more missing); entire villages were buried under tonnes of mud, rocks and uprooted trees. The landslides were triggered by **extraordinarily intense monsoon rainfall (300+ mm in 48 hours)** on saturated slopes. The terrain failure was exacerbated by: (1) deforestation at forest-plantation margins; (2) linear settlements along valley floors directly in the debris path; (3) lack of a community-level early warning system for mountain landslides. The Wayanad disaster triggered a national debate on the **Gadgil Committee report (Western Ghats Ecology Expert Panel, 2011)** — which had designated most of this area as Ecologically Sensitive Zone (ESZ) requiring strict construction and plantation controls, but was never fully implemented due to political resistance.

15.6 CURRENT AFFAIRS HOOKS (2021–2025)

CURRENT AFFAIRS	**Cyclone Biparjoy (June 2023) — Rare Gujarat Landfall:** ESCS Biparjoy made landfall at Jakhau coast, Kutch, Gujarat (June 15, 2023); winds ~150 km/h; longest-lived pre-monsoon Arabian Sea cyclone in decades; ~1 lakh people evacuated; NDRF pre-deployed; only 2 deaths in India; Gujarat preparedness praised; Aravallis region affected; Rajasthan received rare post-cyclone flooding from Biparjoy remnant. **Cyclone Michaung (December 2023) — Chennai Urban Flooding:** SCS Michaung made landfall near Bapatla, AP (Dec 5); caused record December rainfall in Chennai (150+ mm in 24 hours in some parts); major urban flooding; 17 deaths; Rs.4,000-5,000 crore damage; highlighted Chennai's inadequate stormwater drain infrastructure. **South Lhonak GLOF-Flood (October 2023):** Covered fully in Chapter 10; Teesta-III dam (NHPC) destroyed; 100+ killed; 22,000+ displaced; Sikkim's worst disaster; accelerated GLOF early warning and hydropower siting policy review. **Delhi Floods (July 2023) — Record Yamuna Level:** Yamuna River reached its highest-ever recorded level (208.66 m on July 13, 2023 — previous record 207.49 m in 1978); Hathnikund Barrage released 3.59 lakh cusecs (highest ever); civil secretariat, ITO area, ring road submerged; ~27,000 people evacuated; debate about Yamuna floodplain encroachment and unplanned urbanisation. **Wayanad Landslides (July 30, 2024):** Mundakkai-Chooralmala villages, Wayanad, Kerala; 400+ killed; worst landslide in Indian history; extreme monsoon rainfall (300+ mm in 48 hours) + deforestation + plantation agriculture on fragile slopes; Gadgil Committee ESZ implementation failure highlighted; Army rescue operations; rebuilding controversy (relocate vulnerable villages vs cultural rights). **Assam Floods (2022-2024 — Annual Crisis):** Assam faces devastating Brahmaputra floods every year; 2022 floods affected 4.5 million people across 32 of 35 districts; NDRF + army deployed; 100+ killed each year; Kaziranga NP submerged (rhinoceros and other wildlife moved to higher ground); Assam floods worsening due to upstream catchment deforestation in Arunachal + sediment aggradation + embankment failures. **Bengaluru Urban Floods (2022) — IT City Underwater:** In September 2022, Bengaluru received record rainfall (131 mm in 24 hours); major IT campuses (Whitefield, Manyata Tech Park, Electronic City) submerged; Rs.225 crore loss to IT sector alone; hundreds of residential areas flooded; CM flagged loss of lakes and wetlands to encroachment as primary cause; BBMP Lake Development Authority reconstituted; exposed inadequate stormwater drain infrastructure of a Rs.4-lakh-crore GDP city.

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15.7 SEISMIC ZONES OF INDIA

India is one of the world's **most earthquake-prone large countries** — a consequence of its position at the collision boundary of the Indian Plate (moving northward at ~5 cm/year) and the Eurasian Plate. Approximately **59% of India's land area** falls in Seismic Zones III, IV, or V (moderate to very high hazard). The Bureau of Indian Standards (BIS) IS 1893 (Part 1) provides India's official seismic zonation map, dividing the country into **four zones: II, III, IV, and V** (Zone I was abolished in the 2002 revision of IS 1893).

INDIA'S SEISMIC ZONES — COMPLETE REFERENCE TABLE

Zone	*Hazard Level*	*Intensity (MSK Scale)*	*States / Regions Covered*	*Key Cities at Risk*	*Notable Earthquakes*
Zone II	Low Damage Risk	VI or less	Most of South India: interior Karnataka, Tamil Nadu (non-coastal), interior AP, Telangana interior, Kerala (most), Odisha (southern), eastern Rajasthan (stable Aravalli craton), most of MP and Chhattisgarh, Maharashtra (eastern Vidarbha)	Bengaluru, Chennai, Hyderabad (parts), Nagpur, Bhopal	Koyna, Maharashtra 1967 (M6.5 -- reservoir-induced seismicity; UNUSUAL for Zone II; 177 deaths) is a notable exception; most of South India has low earthquake frequency
Zone III	Moderate Damage Risk	VII	Andaman & Nicobar Islands; parts of UP and Bihar (Gangetic plain); West Bengal and Odisha (northern plains); Kerala (northern coast); parts of Gujarat (eastern); parts of Rajasthan (western -- Aravalli margin); goa, coastal Karnataka; parts of Maharashtra coast; parts of Punjab and Haryana (southern)	Parts of Kolkata, Patna, Lucknow (parts), Port Blair	Andaman & Nicobar is technically Zone V but listed as Zone III in BIS for local administrative purposes; regular tremors felt in the Gangetic plains (Nepal earthquakes transmit here)
Zone IV	High Damage Risk	VII-VIII	Delhi NCR and surrounding area; Bihar (north -- Madhubani, Sitamarhi; Nepal border belt); Himachal Pradesh (Kangra, Chamba); J&K (Jammu division, parts of Kashmir); Punjab (parts near HP border); Uttarakhand (foothills -- Haridwar, Dehradun); West Bengal (Darjeeling, Jalpaiguri -- sub-Himalayan); Assam (southern Brahmaputra valley); parts of UP (Terai)	Delhi, Chandigarh, Dehradun, Kangra, Jammu, Darjeeling, Siliguri	Kangra earthquake 1905 (M7.8; 20,000 deaths -- one of India's deadliest); Bihar-Nepal border earthquakes (1934 M8.1; 30,000 deaths; 2015 Nepal M7.8 -- 8,800 deaths, heavily felt in Bihar-UP)
Zone V	Very High Damage	> VIII	ENTIRE Northeastern India (Assam, Arunachal Pradesh,	Guwahati, Imphal,	Assam earthquake 1950 (M8.6 -- one of largest ever

	Risk (Highest)		Nagaland, Manipur, Mizoram, Meghalaya, Tripura, Sikkim); J&K (Kashmir Valley, Ladakh -- Aksai Chin border area); parts of HP (Spiti); Uttarakhand (high Himalayas -- Chamoli, Pithoragarh); Gujarat (Kachchh / Rann of Kutch); Andaman & Nicobar Islands	Gangtok, Srinagar, Leh, Bhuj, Car Nicobar (A&N)	on land; 1,520 deaths; massive landslides blocked rivers); Bhuj earthquake Jan 26, 2001 (M7.7; 20,000+ deaths; entire Kachchh zone; Republic Day; destroyed Bhuj city); Uttarkashi 1991 (M6.8; 768 deaths); Chamoli 1999 (M6.8; 103 deaths)

MAJOR HISTORICAL EARTHQUAKES OF INDIA — EXAM REFERENCE

Earthquake	*Year*	*Magnitude*	*Zone*	*Deaths*	*Key Note*
Assam Great Earthquake	1950	M 8.6	Zone V (NE India)	1,520 (direct; many more from landslides)	One of largest earthquakes ever recorded on land; Brahmaputra course altered; massive landslides created temporary lakes; felt across South Asia
Bihar-Nepal Earthquake	1934	M 8.1	Zone IV-V (Bihar-Nepal border)	~30,000	Destroyed Muzzaffarpur, Darbhanga, Madhubani; liquefaction in Bihar Terai; Mahatma Gandhi was in Bihar at the time (attributed it to karma; Ambedkar and Tagore disagreed)
Kangra Earthquake	1905	M 7.8	Zone IV (HP)	~20,000	Destroyed Kangra fort, Dharamsala; triggered massive landslides in Himachal Pradesh; the worst earthquake in HP history
Bhuj Earthquake	2001 (Jan 26)	M 7.7	Zone V (Gujarat -- Kutch)	20,000+ (official; unofficial higher)	Occurred on Republic Day; epicentre 20 km north of Bhuj; Bhuj city 70% destroyed; Anjar, Bachau towns flattened; triggered massive national reconstruction; Kutch is now much better built with earthquake-resistant design; demonstrated India's inadequate emergency response (improved significantly after)
Latur Earthquake	1993 (Sep 30)	M 6.2	Zone III (Maharashtra -- Osmanabad/Latur)	~10,000	Most surprising Zone III event; midnight earthquake (12:56 AM); 52 villages destroyed while people slept; Killari village epicentre; exposed vulnerability

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					of unreinforced masonry (stone and mud walls) construction in rural Maharashtra; triggered India's first systematic disaster management policy development
Uttarkashi Earthquake	1991	M 6.8	Zone V (Uttarakhand)	768	Garhwal Himalayas; triggered massive landslides blocking Bhagirathi and other rivers; disrupted Char Dham Yatra season
Chamoli Earthquake	1999	M 6.8	Zone V (Uttarakhand)	103	Garhwal; demonstrated ongoing seismicity of Uttarakhand hill zone even between major events
Nepal Earthquake (Gorkha)	2015 (Apr 25)	M 7.8	Zone V equivalent; felt heavily in Zone IV India	8,800+ (Nepal); 78 in India (Bihar, UP)	Triggered devastating avalanche on Everest; massive impact in Kathmandu Valley; Bihar, UP, WB experienced strong shaking; India sent NDRF teams (Operation Maitri -- largest-ever peacetime Indian military rescue abroad)

KEY NOTE

Seismic Zone Prelims Mnemonics: (1) **Zone V states: "AMNS + JKG"** = Assam, Mizoram, Nagaland, Sikkim + J&K (Kashmir), Kutch (Gujarat -- anomaly in peninsular India), Great Nicobar. All of NE India = Zone V. (2) **Zone V anomaly:** Kutch (Gujarat) is Zone V but surrounded by Zone III/II Peninsular India -- because Rann of Kutch is on a different tectonic feature (ancient rift zone), not the Himalayan collision zone. (3) **Delhi = Zone IV** (NOT Zone V as many students think -- it is high risk but not the highest). (4) **Koyna (Maharashtra) = Zone II** but 1967 earthquake was due to reservoir-induced seismicity (water pressure from Koyna reservoir triggered fault movement -- a cautionary tale for dam builders). (5) **Latur 1993 = Zone III** -- proof that even "moderate hazard" zones can produce catastrophic earthquakes. (6) BHUJ 2001 = Zone V; Republic Day January 26.

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Seismic Hazard and Dam Policy (IFoS + GS-3 link): India has 5,200+ large dams -- many in seismically active zones. **Reservoir-Induced Seismicity (RIS)** occurs when reservoir water loading increases pore pressure in fault zones, triggering earthquakes. Examples: Koyna (1967), Warna Dam (Maharashtra, 1993-94), and studies on Tehri Dam (Zone V -- Uttarakhand). NDMA guidelines mandate seismic safety assessment for all large dams. This is also why the Ken-Betwa Link Project dam (near active fault zones in Bundelkhand) has been scrutinised for seismic vulnerability. For IFoS: seismic risk = ecosystem disturbance (landslides, river course changes, GLOF triggers from seismically disturbed glacial moraines).

15.8 PYQ ANALYSIS — CHAPTER 15 (2010–2025)

Source	Year	Marks	Question
UPSC Civil	2023	15M	"Climate change is intensifying the frequency and severity of extreme weather events in India. Critically examine this statement with reference to cyclones, droughts and urban floods."

UPSC Civil	2022	12M	"Discuss the structural and non-structural measures for flood management in India. What institutional framework exists for disaster risk reduction?"
UPSC Civil	2021	15M	"Explain the formation and impact of tropical cyclones in the Bay of Bengal. How has India improved its cyclone disaster preparedness? Cite examples."
UPSC Civil	2020	12M	"Drought is often called a 'creeping disaster'. Critically examine the causes, effects and management of droughts in India with special reference to El Nino's role."
UPSC Civil	2019	12M	"Discuss the disaster management framework in India. How effective is the Sendai Framework for Disaster Risk Reduction in India's context?"
UPSC Civil	2018	10M	"Examine the social and economic impact of floods in India. How do floods in the Brahmaputra basin differ from those in the Ganga-Yamuna plain?"
UPSC Civil	2017	12M	"Cyclone Ockhi 2017 exposed the vulnerability of fishermen in India. Discuss the early warning systems for cyclones and the gaps in their reach."
UPSC Civil	2016	12M	"Tropical cyclones are becoming more intense. Discuss the factors responsible for the intensity of cyclones striking India's eastern coast."
IFOS GS	2024	15M	"Discuss the ecological impact of the 2024 Wayanad landslides and the Chamoli 2021 disaster. What do they reveal about the interaction of climate change and land use change in fragile ecosystems?"
IFOS GS	2023	10M	"Explain the role of mangroves in cyclone mitigation. Discuss the evidence from India's eastern coast with reference to cyclones Fani and Amphan."
IFOS GS	2022	10M	"Discuss the impact of floods on forest ecosystems and wildlife in the Brahmaputra valley. How does the Kaziranga National Park manage its wildlife during Assam floods?"
IFOS GS	2021	10M	"What is a Glacial Lake Outburst Flood? Discuss the Chamoli disaster 2021 and its environmental consequences in the Rishiganga-Dhauliganga valley."
IFOS GS	2020	10M	"Discuss the ecological consequences of drought in peninsular India with reference to wildlife and forest health in dry deciduous zones."
IFOS GS	2019	10M	"How does the El Nino Southern Oscillation affect Indian monsoon and forest fire risk? Discuss with examples."

KEY NOTE

Frequency pattern: Cyclone preparedness + Fani (Civil 2021; IFoS 2023 for mangroves) + El Nino-drought (Civil 2020; IFoS 2019) + flood management Kosi/Bihar (Civil 2018, 2022) + Sendai Framework (Civil 2019) are the top clusters. IFoS emphasis: mangroves as cyclone buffer; Kaziranga flood ecology; Chamoli GLOF; drought impact on dry deciduous forests; Wayanad landslide ecology. For 2025-26: Wayanad 2024 landslides (IFoS 2024 confirmed; Civil very high probability); Biparjoy + Michaung 2023 cyclone episodes; Delhi Yamuna 2023; intensification of Arabian Sea cyclones; NDMA + Sendai Framework progress review.

15.8 MODEL BOOK

Cyclone Fani (2019) killed only 89 people despite being one of the strongest cyclones to hit India. Critically examine how India transformed its cyclone disaster management from the 1999 Orissa Supercyclone (10,000 deaths) to this outcome.

Civil (Mains) | 15 Marks | 200 Words

The contrast between the 1999 Orissa Supercyclone (10,000 deaths, ~260 km/h, Paradip landfall) and Cyclone Fani 2019 (89 deaths, ~250 km/h, Puri landfall) is one of the world's most dramatic demonstrations that disaster mortality is a function of preparedness, not hazard intensity alone.

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WHAT CHANGED — SIX ELEMENTS OF THE REVOLUTION:

1. **Doppler Weather Radar network:** India expanded from near-zero coastal radar coverage in 1999 to 40+ Doppler radars covering all costs by 2019; IMD provided 5-7 day accurate track forecasts with 100-150 km error (vs 500+ km in 1999).
2. **Multi-hazard early warning system:** IMD colour-coded cyclone alerts disseminated through SMS, All India Radio, Doordarshan, WhatsApp groups (village panchayat level); last-mile warning reached 99%+ of at-risk population before Fani.
3. **Community cyclone shelters:** Odisha built 850+ multipurpose cyclone shelters post-1999 (each holding 1,000-3,000 people; 7+ m elevated; withstand 260 km/h winds; has kitchen, water, toilets); most communities within 2-3 km of a shelter.
4. **Pre-emptive mass evacuation:** Odisha's protocol mandates evacuation of all people within 5 km of coast 48-72 hours before landfall. Before Fani, 1.2 million people were evacuated in 48 hours — logistically extraordinary.
5. **NDRF and NDMA institutional readiness:** NDRF pre-positioned 28 teams (2,000+ personnel) in Odisha before Fani's landfall; rescue began within minutes of winds dropping; the Disaster Management Act 2005 framework was fully operational.
6. **Mangrove protection:** Bhitarkanika mangrove belt (protected under WPA) reduced wave energy penetration; villages behind the mangrove line had significantly less structural damage.

LESSONS AND REMAINING CHALLENGES: Urban preparedness lags behind rural (Hudhud 2014 vs Vishakhapatnam — uneven results); fishermen's early warning still inadequate (Ockhi 2017 killed 245 fishermen at sea); insurance coverage remains low; long-term cyclone shelter maintenance needs consistent funding.

India's cyclone preparedness revolution — built on technology + institutions + community infrastructure + political will — is a global model. But the next frontier is urban resilience, fishermen's safety and climate-change adaptation as cyclones intensify.

"India's urban floods are floods of our own making." Critically examine this statement with reference to Mumbai 2005 and Chennai 2015, and suggest structural reforms.

Civil (Mains) | 15 Marks | 200 Words

India's worst urban floods — Mumbai 2005 (944 mm/24 hrs; 1,094 dead; Rs.5,000 crore loss) and Chennai 2015 (November NE monsoon excess; 500+ dead; Rs.15,000 crore loss) — were amplified catastrophically by anthropogenic failures, not merely by rainfall intensity.

WHY THESE ARE "FLOODS OF OUR MAKING":

1. **Wetland and lake destruction:** Chennai's Pallikaranai marshland — the city's primary natural flood buffer — was reduced from 6,000+ ha (1970s) to ~600 ha (2015) through OMR tech corridor, SIPCOT parks and NIOT campus construction. Without this buffer, every heavy rainfall event becomes a flood event.
2. **Floodplain encroachment:** The Adyar and Cooum river floodplains in Chennai were heavily built over; Chembarambakkam reservoir catchment had dense settlement; when the reservoir released 12,000 cusecs on Dec 1 2015 without warning, built-over floodplains gave water nowhere to go.
3. **Drainage inadequacy:** Mumbai's stormwater drain system was designed for 25 mm/hour; the 2005 cloudburst dropped 944 mm in 24 hours (39 mm/hour average; peak much higher). BRIMSTOWAD post-2005 was supposed to upgrade to 50 mm/hour — but 18 years later, implementation is incomplete.
4. **Encroached natural water channels:** Mumbai's 42 Mithi River tributaries, Bengaluru's raja kaluves (stormwater channels) and Chennai's eris (tanks) are systematically encroached; water has nowhere to flow.

STRUCTURAL REFORMS NEEDED:

(i) Wetland Protection: Strictly enforce Wetland Rules 2017 and CRZ regulations; restore Pallikaranai, Bengaluru Lake network.

(ii) Stormwater Master Plans: All cities >1 million must prepare and execute Stormwater Drain Master Plans to handle 100 mm/hour events (not just 25 mm).

(iii) Floodplain Zoning Law: Enact a central Flood Plain Zoning Act (model bill exists since 1975; never passed); prohibit construction within the 100-year flood line.

(iv) Blue-Green Infrastructure: Permeable pavements, urban parks as temporary retention, green roofs, restored urban streams — reduce peak runoff in cities.

Urban flood resilience requires both infrastructure (drains, retention) and ecological restoration (wetlands, floodplains). Cities that protect their natural water infrastructure — Pune's Baner Biodiversity Park, Bengaluru's restored Jakkur Lake — demonstrate that integrated Blue-Green infrastructure provides the most cost-effective and co-beneficial flood management.

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CHAPTER 16

COMMUNICATION & DIGITAL

CHAPTER AT A GLANCE

- India = world's 2nd-largest telecom market by subscribers (~1.2 billion); 2nd-largest internet user base (~850+ million); communication is now the "fourth utility" alongside roads, power, water for economic and social development.
- Jio's 2016 entry (Reliance Jio, launched Sep 5, 2016) triggered India's data revolution — free voice + cheapest data globally; forced industry consolidation (8+ operators down to 3 private players: Jio, Airtel, Vi); India now has world's cheapest mobile data (~Rs.10-15/GB).
- 5G launched October 1, 2022 (PM Modi, India Mobile Congress); fastest 5G rollout globally — covered 97%+ districts within 2 years (vs 5-7 years typical elsewhere); Jio True 5G and Airtel 5G Plus led deployment.
- Digital India Mission (2015): 3 pillars — Digital Infrastructure, Digital Governance/Services, Digital Literacy. India Stack (Aadhaar + UPI + DigiLocker) = world's most advanced public digital infrastructure (DPI) model, exported globally as "India Stack" / "Modular Open Source Identity Platform (MOSIP)".
- UPI (Unified Payments Interface, 2016, NPCI) = world's largest real-time payments system by volume; ~16+ billion transactions/month (2024); India accounts for ~46% of world's real-time digital payment transactions (2022 estimate); UPI now live in UAE, Singapore, France, Sri Lanka, Mauritius, Bhutan.
- BharatNet: world's largest rural broadband project; aims to connect all 2.5 lakh+ Gram Panchayats via optical fibre; India Post = world's largest postal network (~1.5 lakh post offices, 90% in rural areas).
- NavIC (Navigation with Indian Constellation) = India's own satellite navigation system (ISRO); GAGAN = India's satellite-based augmentation system for aviation; both reduce dependence on US GPS.
- Digital divide persists: rural teledensity lower than urban; India = world leader in frequency of internet shutdowns (Software Freedom Law Centre data); Digital Personal Data Protection Act 2023 = India's first comprehensive data protection law.

16.1 INTRODUCTION — COMMUNICATION AS THE FOURTH UTILITY

Communication infrastructure has evolved, in the span of three decades, from a **luxury good rationed by the state (the era of waiting years for a landline telephone connection)** to a **near-universal, competitively-priced utility** that underpins virtually every dimension of India's economy and governance. Today, communication networks are rightly described as the **"fourth utility"** — alongside roads, electricity and water — because **financial inclusion, education delivery, healthcare access, agricultural advisory, e-commerce and government service delivery** all now depend fundamentally on connectivity.

India's communication sector trajectory has three distinct eras: **(1) The Telegraph and Early Telephone Era (1850s-1990s)** — state monopoly, scarce and expensive; **(2) The Mobile Telephony Revolution (1995-2015)** — liberalisation, private competition, explosive subscriber growth; and **(3) The Data and Digital Infrastructure Era (2016-present)** — triggered decisively by Reliance Jio's 2016 entry, characterised by near-free voice, ultra-cheap data and the build-out of "India Stack" digital public infrastructure that is now studied and replicated globally.

INSTITUTIONAL AND REGULATORY FRAMEWORK

Institution	*Established*	*Role*
Department of	Ministry of	Policy-making body for the telecom sector; spectrum

Telecommunications (DoT)	Communications	allocation; licensing of telecom operators
Telecom Regulatory Authority of India (TRAI)	1997	Independent regulator; sets tariffs framework, quality of service standards, interconnection rules; adjudicates disputes between operators
Telecom Disputes Settlement and Appellate Tribunal (TDSAT)	2000	Quasi-judicial body for resolving telecom, broadcasting and IT-related disputes
Ministry of Electronics and Information Technology (MeitY)	1999/2016 (current form)	Drives Digital India, e-governance, electronics manufacturing, cybersecurity, data protection policy
National Informatics Centre (NIC)	1976	Government's technology backbone; builds and maintains most central/state government IT systems and websites
Unique Identification Authority of India (UIDAI)	2009	Manages Aadhaar — India's biometric identity system; foundational layer of India Stack
National Payments Corporation of India (NPCI)	2008	Umbrella organisation for retail payment systems; operates UPI, RuPay, IMPS, AePS, BHIM
Indian Space Research Organisation (ISRO)	1969	Builds and operates India's communication satellites (INSAT/GSAT), NavIC and GAGAN systems

16.2 TELECOMMUNICATIONS — EVOLUTION AND CURRENT STATUS

India is the **world's 2nd-largest telecommunications market by subscriber base** (after China), with approximately **1.2 billion telecom subscribers** as of 2024 — a transformation from fewer than 5 million telephone connections at Independence and barely 30 million even by 2000. The sector's growth has been driven by three liberalisation waves and one disruptive private entrant whose impact reshaped the entire industry.

HISTORICAL EVOLUTION — KEY MILESTONES

Period/Event	*Year*	*Significance*
Telegraph introduced	1850s (British)	First electrical communication network in India; built primarily for colonial administrative and military control
Department of Posts and Telegraphs	1854 onward	State monopoly era; telephone introduced 1881-82 (Calcutta) but remained extremely limited and elite for over a century
National Telecom Policy (NTP) 1994	1994	First major liberalisation; opened basic telephone services to private operators (alongside state-run DoT/MTNL); ended decades of pure state monopoly
TRAI established	1997	Independent regulator created to ensure fair competition as private players entered
New Telecom Policy (NTP) 1999	1999	Shifted from fixed licence fee to revenue-sharing model; dramatically improved telecom sector financial viability and competition; widely credited with catalysing India's mobile boom
Mobile telephony introduced	1995 (first call: Kolkata, CM Jyoti Basu to Union Telecom Minister Sukh Ram)	India's mobile era formally begins; initial tariffs extremely high (incoming calls also charged)
Calling Party Pays (CPP) regime	2003	TRAI mandated that only the calling party pays — eliminated incoming call charges; dramatically boosted mobile

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		adoption among lower-income users
2G spectrum allocation controversy	2008 (allocation); 2010-12 (CAG report, scam exposed)	Major corruption scandal involving under-priced spectrum allocation; Supreme Court cancelled 122 licences (Feb 2012) in the landmark CPIL vs Union of India case; led to overhaul of spectrum allocation to auction-based system
3G/4G spectrum auctions	2010 (3G), 2014-16 (4G)	Transitioned India to mobile broadband capability
Reliance Jio commercial launch	September 5, 2016	THE SINGLE MOST DISRUPTIVE EVENT in Indian telecom history (detailed below)
5G commercial launch	October 1, 2022	PM Modi launched at India Mobile Congress; fastest national 5G rollout in world history

THE JIO DISRUPTION (2016) — INDIA'S DATA REVOLUTION

Reliance Jio's commercial launch on **September 5, 2016** is widely regarded as the single most transformative event in the history of Indian telecommunications — comparable in impact to the 1991 economic liberalisation for the broader economy. Jio entered with an entirely new business model: a **greenfield, all-IP, 4G-only LTE network** (no legacy 2G/3G infrastructure to maintain), offering **free voice calls (lifetime) and extremely cheap data** — initially even free for a promotional period — financed by Reliance Industries' enormous balance sheet (~$25-30 billion capital investment).

Impact Dimension	*Detail*
Data price collapse	Average data cost fell from ~Rs.250+/GB (pre-2016) to ~Rs.10-15/GB (2024) — a 90%+ reduction; India now has among the WORLD'S CHEAPEST MOBILE DATA (cheaper than USA, UK, China in absolute and PPP terms)
Data consumption explosion	India's average monthly mobile data consumption per user rose from ~0.5-1 GB (2016) to ~21-24 GB (2024) — among the HIGHEST in the world; driven by video streaming (YouTube, OTT platforms), UPI usage, social media
Industry consolidation	Pre-2016: 8-12 operators in most circles (intense fragmented competition); Post-2016: consolidated to effectively 3 private players (Jio, Bharti Airtel, Vodafone Idea/Vi) plus state-owned BSNL/MTNL; several operators (Aircel, Reliance Communications/RCom, Tata DoCoMo, Telenor) exited or merged due to inability to compete on Jio's pricing
Vodafone-Idea merger (2018)	Vodafone India and Idea Cellular merged to survive competitive pressure, forming Vodafone Idea (Vi) — still the financially weakest of the big-3 private operators, with significant Adjusted Gross Revenue (AGR) dues owed to government
AGR dues crisis	Supreme Court's October 2019 ruling on Adjusted Gross Revenue (AGR) definition imposed massive retrospective dues (~Rs.1.47 lakh crore combined) on telecom operators, including non-core revenue in the AGR calculation; severely stressed Vodafone Idea and Bharti Airtel finances; government later provided moratorium relief
Financial inclusion catalyst	Cheap data + smartphone penetration directly enabled UPI adoption, JAM trinity (Jio-Aadhaar-Mobile) effectiveness, and rural digital access at unprecedented speed and scale

UPSC CIVIL **Civil GS-3 — The Jio Effect:** The Jio disruption is frequently tested as a case study in (1) market disruption/creative destruction economics; (2) the relationship between connectivity and financial/digital inclusion (Jio's cheap data is argued to be AS IMPORTANT as Jan Dhan-Aadhaar-Mobile for India's financial inclusion success); (3) telecom sector financial stress (AGR crisis) and

regulatory policy; (4) India becoming a model for "leapfrog" digital development — skipping fixed-line infrastructure entirely and going straight to mobile-first, data-first connectivity, a pattern other developing countries are studying.

CURRENT TELECOM OPERATOR LANDSCAPE (2024)

Operator	*Type*	*Subscriber Share (approx.)*	*Key Note*
Reliance Jio	Private (Reliance Industries)	~40%+ (largest)	All-IP 4G/5G network; fastest growing; aggressive 5G rollout (Jio True 5G — standalone 5G architecture, technologically more advanced than competitors' non-standalone approach initially); JioFiber for home broadband; Jio Platforms attracted major global investment (Google, Facebook/Meta, KKR, etc. — over $20 billion raised 2020)
Bharti Airtel	Private	~33%	India's oldest major private operator (founded 1995, Sunil Bharti Mittal); strong enterprise and premium subscriber base; Airtel 5G Plus; significant African operations (Airtel Africa) and international presence
Vodafone Idea (Vi)	Private (Vodafone Group UK + Aditya Birla Group)	~18-19%	Financially most stressed major operator; significant AGR dues; government converted some dues to equity (2023), making Government of India a significant shareholder; slower 5G rollout due to capital constraints; subscriber losses to Jio/Airtel ongoing
BSNL / MTNL (state-owned)	Public Sector	~8-9% (declining, recovering)	Long lagged in 4G rollout due to procurement delays (indigenous technology mandate — Tejas Networks, C-DOT); BSNL 4G launched 2023-24 using INDIGENOUS Indian technology (a strategic/Atmanirbhar Bharat milestone); BSNL primarily relevant in rural/remote areas where private operators have weaker coverage

KEY TELECOM STATISTICS (2024)

Parameter	*Figure*
Total telecom subscribers	~1.2 billion (TRAI)
Wireless (mobile) subscribers	~1.15 billion (>95% of total)
Overall Teledensity	~85% (Urban: ~131%; Rural: ~58% — significant rural-urban gap)
Internet subscribers	~850-900 million
Broadband subscribers	~870 million (includes mobile broadband, which dominates)
Average monthly data consumption per user	~21-24 GB/month (among world's highest)
Average data tariff	~Rs.10-15 per GB (among world's lowest)
Smartphone penetration	~750-800 million smartphones in use; India = world's 2nd-largest smartphone market

16.3 MOBILE AND INTERNET PENETRATION — THE DIGITAL DIVIDE

While India's aggregate connectivity statistics are impressive globally, they mask **significant and persistent disparities** across geography, gender, income and digital literacy — together constituting India's **"digital divide."** Understanding this divide is essential because digital access increasingly determines access to government

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welfare schemes, financial services, education and healthcare.

DIMENSIONS OF INDIA'S DIGITAL DIVIDE

Dimension	*Detail*
Urban-Rural Gap	Urban teledensity ~131% (multiple SIMs per person common) vs Rural teledensity ~58%; rural broadband penetration significantly lags despite BharatNet investment; rural areas often rely on a single shared smartphone per household
Gender Gap	Mobile phone OWNERSHIP gap between men and women in India estimated at ~15-20 percentage points (GSMA Mobile Gender Gap Report); women in rural and lower-income households often share a male family member's phone rather than owning one; gap is narrowing but remains significant, particularly in UP, Bihar, Rajasthan
State-wise Variation	Kerala, Delhi, Punjab, Himachal Pradesh, Goa lead in internet penetration and digital literacy; Bihar, UP, Odisha, Chhattisgarh, Jharkhand lag significantly; this largely mirrors broader human development indicators across states
Income/Affordability Gap	Despite India's cheap data, smartphone cost (even budget Android phones ~Rs.6,000-8,000) remains a barrier for the poorest households; data affordability has improved dramatically but DEVICE affordability remains a constraint
Digital Literacy Gap	Even where connectivity and devices exist, the ability to USE digital services effectively (navigate apps, avoid scams, complete e-governance transactions) varies enormously, especially among older and less-educated populations
Language Gap	Most digital content and government services historically available primarily in English/Hindi; growing but incomplete support for regional languages limits access for non-Hindi/English speakers

BHARATNET — RURAL BROADBAND INFRASTRUCTURE

BharatNet (originally launched as the **National Optical Fibre Network/NOFN in 2011, rebranded BharatNet in 2015)** is the **world's largest rural broadband connectivity project** — aiming to provide **high-speed optical fibre broadband to all 2.5+ lakh Gram Panchayats** across India.

Parameter	*Detail*
Objective	Connect all ~2.5 lakh Gram Panchayats with optical fibre cable (OFC), providing backbone infrastructure that private/public ISPs can use for last-mile rural broadband delivery
Implementing agency	Bharat Broadband Network Limited (BBNL), a Special Purpose Vehicle under DoT
Phase-I	Completed (with delays) — connected over 1 lakh Gram Panchayats
Phase-II	Uses PPP (Public-Private Partnership) model in some states for last-mile delivery; significant delays due to right-of-way issues, terrain challenges (especially NE India, hilly states), and execution capacity constraints
Revamped BharatNet (2021 Cabinet approval)	Rs.19,041 crore approved; shift toward more PPP involvement and faster execution timelines; integrates satellite, fibre, and wireless technologies for last-mile based on terrain
Challenges	Slow pace of implementation relative to targets; "middle-mile" infrastructure built but last-mile connectivity (Gram Panchayat to individual households) often lacking; underutilisation of laid fibre due to absence of retail ISP interest in low-revenue rural markets; competition from rapidly improving mobile 4G/5G coverage somewhat reducing urgency for fixed fibre in remote areas

Significance	BharatNet infrastructure underpins Digital India initiatives like Common Service Centres (CSCs), telemedicine (eSanjeevani), rural e-governance and is foundational for closing the rural-urban digital divide over the long term

COMMON SERVICE CENTRES (CSCS)

Common Service Centres are **village-level digital access points (essentially "digital kiosks")** run by trained local entrepreneurs (Village Level Entrepreneurs/VLEs), providing citizens access to **government services, banking, insurance, education and digital literacy training** even where individual internet/device access remains limited. India has **over 5 lakh CSCs** operational, making this one of the world's largest last-mile digital service delivery networks — bridging the gap for citizens who lack personal devices or digital literacy.

16.4 5G AND NEXT-GENERATION TELECOM

India's 5G rollout, launched on **October 1, 2022** by PM Narendra Modi at the India Mobile Congress in New Delhi, represents the **fastest national 5G rollout in world history** — achieving coverage across 97%+ of districts within roughly two years, a pace that took most developed nations 5-7 years to achieve.

5G SPECTRUM AUCTION AND ROLLOUT

Parameter	*Detail*
Spectrum auction	July-August 2022; India's largest-ever spectrum auction; Rs.1.5 lakh crore+ worth of spectrum sold across various bands (600 MHz, 700 MHz, 800 MHz, 900 MHz, 1800 MHz, 2100 MHz, 2300 MHz, 3300 MHz, 26 GHz)
Key bidders	Jio acquired the largest share of spectrum (~Rs.88,000 crore worth); Airtel second-largest; Vodafone Idea acquired limited spectrum reflecting financial constraints
Architecture difference	Jio adopted STANDALONE (SA) 5G architecture from the outset — a fully independent 5G core network (not dependent on existing 4G infrastructure), considered more advanced/future-proof; Airtel initially used NON-STANDALONE (NSA) 5G (layered on existing 4G core) for faster rollout, though has since expanded toward SA architecture
Coverage milestone	5G available in all state capitals within months of launch; pan-India coverage across most districts achieved by 2024 — among the fastest global 5G expansions ever recorded
Speed improvement	5G offers theoretical peak speeds up to 20 Gbps (vs 4G's ~150 Mbps theoretical peak); real-world average 5G speeds in India ~250-350 Mbps (still a substantial multiple of average 4G speeds)
Use cases beyond mobile	Fixed Wireless Access (FWA) — using 5G as a home/enterprise broadband substitute without laying fibre; enterprise applications (smart manufacturing, telemedicine, AR/VR); expected eventual applications in autonomous vehicles, IoT-dense smart cities

6G VISION AND RESEARCH

India has positioned itself not merely as a 6G ADOPTER but as a potential 6G TECHNOLOGY CONTRIBUTOR and standard-setter — a significant ambition shift from previous generations where India was purely a follower.

- **Bharat 6G Vision Document (2023):** released by PM Modi; outlines India's roadmap to be among the leading contributors to global 6G standards and technology, targeting 10% share of 6G-related patents globally by the time 6G is commercially deployed (expected ~2030).
- **Bharat 6G Alliance:** a collaborative platform bringing together government, academia (IITs), and industry (telecom operators, equipment makers) to drive indigenous 6G research.
- **Strategic rationale:** India was largely a spectator/late adopter for 2G-4G technology (developed predominantly by US, European, Chinese, Korean firms); the 5G/6G era is seen as an opportunity to build

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indigenous telecom equipment capability (linked to the PLI for Telecom and Networking Products scheme — see Chapter 13) and reduce historical dependence on foreign vendors (particularly relevant given security concerns around Chinese equipment, e.g., Huawei/ZTE exclusion from India's 5G core network rollout).

16.5 DIGITAL INDIA MISSION AND INDIA STACK

Launched on **July 1, 2015,** the **Digital India** programme is the umbrella initiative under which India has built what is now globally recognised as one of the world's most advanced **"Digital Public Infrastructure" (DPI)** ecosystems — a layered set of interoperable, open digital systems (identity, payments, data exchange) that other countries are now studying and seeking to replicate.

THREE PILLARS OF DIGITAL INDIA

Pillar	*Components*
1. Digital Infrastructure as a Core Utility	BharatNet (rural broadband); universal mobile/internet access; 5G rollout; Common Service Centres; cybersecurity infrastructure; cloud infrastructure (MeghRaj — Government of India cloud)
2. Governance and Services on Demand	Online, real-time government service delivery; e-governance portals; DigiLocker; UMANG (Unified Mobile Application for New-age Governance — single app for accessing 1,200+ government services); e-Hospital, e-Courts, e-NAM (agriculture marketing — covered in Ch 12)
3. Digital Empowerment of Citizens	Digital literacy programmes (PMGDISHA — Pradhan Mantri Gramin Digital Saksharta Abhiyan, targeting 6 crore rural households); universal digital identity (Aadhaar); availability of digital resources in regional languages; participation in digital and financial space

India Stack — The Core Digital Public Infrastructure

"India Stack" refers to the set of **open APIs (Application Programming Interfaces) and digital public goods** that together form India's foundational digital infrastructure layer — designed to be interoperable, allowing any government agency, bank, fintech company or citizen-facing service to build on top of common, verified, low-cost digital rails.

Layer	*Component*	*Function*
Identity Layer	Aadhaar (UIDAI, 2009)	Biometric (fingerprint + iris) + demographic digital identity; 1.3+ billion Indians enrolled — world's largest biometric ID system; enables instant, paperless, presence-less KYC (Know Your Customer) verification for any service
Payments Layer	UPI (Unified Payments Interface, 2016, NPCI)	Real-time, interoperable payment system linking any bank account to any other via a simple mobile interface; detailed below
Data Layer	DigiLocker (2015) + Account Aggregator framework (2021)	DigiLocker: cloud-based storage for verified documents (driving licence, education certificates, vehicle registration) accessible via Aadhaar-linked authentication, eliminating need for physical document carrying; Account Aggregator: consent-based framework allowing individuals to securely share their financial data (bank statements, tax records) across institutions for loan/service applications without manual document submission
Consent Layer	Data Empowerment and Protection Architecture (DEPA)	Framework ensuring citizens control how their data is shared and used across the India Stack ecosystem, based on explicit, granular, revocable consent

THE JAM TRINITY

"JAM" — **Jan Dhan (bank accounts) + Aadhaar (identity) + Mobile (connectivity)** — is the foundational architecture that made India's direct benefit transfer (DBT) revolution possible. By linking every citizen's bank account, biometric identity and mobile number, the government can transfer subsidies, pensions and welfare payments directly into beneficiary accounts, **eliminating leakage from middlemen** that historically plagued Indian welfare delivery. JAM is credited with saving an estimated **Rs.2.7+ lakh crore** in welfare leakage since its full implementation (government estimates, cumulative).

UPI — Unified Payments Interface — World's Largest Real-Time Payment System

UPI, launched by **NPCI in April 2016,** has become arguably India's single most celebrated digital achievement — a real-time payment system that allows instant money transfer between any two bank accounts using just a mobile phone, a UPI ID (like a virtual payment address) or a QR code scan, **without needing to share bank account or card details.**

Parameter	*Detail*
Monthly transaction volume (2024)	~16+ billion transactions/month
Monthly transaction value (2024)	~Rs.20+ lakh crore/month (~$240+ billion)
Global share	India accounts for ~46% of the world's real-time digital payment transactions (ACI Worldwide/2022 estimate) — the SINGLE LARGEST share of any country, more than the next several countries combined
Apps using UPI	PhonePe, Google Pay, Paytm, BHIM (NPCI's own app), Amazon Pay, and bank-specific apps — all interoperable through the common UPI rails
Merchant adoption	Tens of millions of merchants, from large retailers to street vendors and roadside tea stalls, now accept UPI QR code payments — a defining feature of India's urban and increasingly rural commerce
Zero/low transaction cost	UPI transactions are largely FREE for peer-to-peer transfers, dramatically lowering the cost of digital payments compared to card-based systems (which charge merchant fees of 1-3%); this zero-cost model is unusual globally and central to UPI's mass adoption
UPI 123Pay (2022)	Feature-phone (non-smartphone) UPI access via IVR (Interactive Voice Response) — extending UPI benefits to users without smartphones, addressing the device-affordability digital divide
UPI Lite	Offline/low-connectivity small-value transactions, addressing the connectivity gap in low-network rural areas

UPI INTERNATIONAL EXPANSION

UPI has become a significant instrument of India's **digital diplomacy and soft power,** with the government actively promoting its adoption abroad — both for Indian travellers/diaspora convenience and as a model export of India's digital public infrastructure approach.

Country	*Status (as of 2024)*
Singapore	UPI-PayNow linkage operational (2023) — first cross-border real-time payment linkage of its kind for India; allows instant transfers between India and Singapore
UAE	UPI accepted at merchant locations (2023); significant for the large Indian diaspora and tourist population

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France	UPI accepted at Eiffel Tower and other tourist locations (2023) — largely symbolic but significant for Indian tourist convenience and India-France digital cooperation
Sri Lanka, Mauritius	UPI services launched (2024) — primarily benefiting Indian tourists and supporting these countries' digital payment modernisation, also reflecting India's regional strategic engagement (Neighbourhood First policy)
Bhutan	UPI/RuPay integration as part of broader India-Bhutan digital and economic cooperation
Nepal	UPI integration discussions/pilots ongoing

CURRENT AFFAIRS

UPI as Digital Diplomacy: UPI's international expansion is increasingly framed by Indian policymakers as a tool of "Digital Public Infrastructure (DPI) diplomacy" — India positioning itself as a leader in building and exporting open, interoperable, low-cost digital systems for developing nations, contrasting with the closed, proprietary payment systems pursued by some other major economies.

During India's G20 Presidency (2023), DPI (with UPI/India Stack as the flagship example) was a central agenda theme, and India committed to supporting DPI adoption across the Global South through the G20 framework for DPI.

16.6 POSTAL NETWORK — INDIA POST

India Post (established under colonial rule in 1854, today operating under the Department of Posts, Ministry of Communications) is the **world's largest postal network** by number of post offices — a status India has held for decades and continues to hold despite the global decline of traditional postal services in the digital era.

KEY STATISTICS

Parameter	Figure
Total post offices	~1.5 lakh (approximately 1,55,000)
Rural share	~90% of post offices are in rural areas — making India Post the most extensive RURAL service delivery network of any kind in India, exceeding even bank branch networks
Average area served per post office	~21.21 sq km
Average population served per post office	~8,000-8,500 people
Employees	~4-4.5 lakh (one of India's largest employers, including Gramin Dak Sevaks/rural postal workers)

INDIA POST PAYMENTS BANK (IPPB) — FINANCIAL INCLUSION VIA POSTAL NETWORK

Launched in **September 2018,** India Post Payments Bank leverages India Post's unparalleled rural reach to deliver **banking and financial services to the last mile,** particularly in areas where commercial bank branches are absent or sparse.

- **Model:** A "payments bank" — can accept deposits (up to a regulatory ceiling), facilitate payments and remittances, but (unlike full-service banks) cannot issue loans or credit cards directly; works through India Post's existing post offices and postal workers (Gramin Dak Sevaks) doubling as banking correspondents.
- **Doorstep banking:** IPPB pioneered doorstep banking services using postal workers equipped with biometric devices — enabling Aadhaar-based account opening, cash deposit/withdrawal and bill payments at customers' homes, particularly valuable for elderly, disabled and remote rural populations.
- **Scale:** Over 5 crore accounts opened; IPPB has been integrated into broader DBT (Direct Benefit Transfer) and financial inclusion architecture, complementing the Pradhan Mantri Jan Dhan Yojana (PMJDY) banking-

for-all initiative.

INDIA POST AND E-COMMERCE LOGISTICS

Beyond traditional mail, India Post has reinvented itself as a critical **e-commerce logistics partner**, leveraging its unmatched last-mile rural reach — a capability that private logistics companies (Delhivery, Bluedart, Ecom Express) often cannot match in remote areas.

- **Speed Post:** India Post's premium, time-bound parcel and document delivery service, competing directly with private courier services in urban markets while retaining unique rural reach.
- **E-commerce partnerships:** India Post has formal partnerships with e-commerce platforms (including government-backed ONDC — Open Network for Digital Commerce) to deliver last-mile parcels in rural and remote areas where private logistics infrastructure is thin or absent.
- **Cash-on-Delivery (COD) backbone:** India Post's extensive cash-handling and trust network historically made it well-suited for COD transactions, important in a market where digital payment trust (despite UPI's rise) is still building, especially for first-time online shoppers in smaller towns.

16.7 SATELLITE COMMUNICATION

India's satellite communication capability — built almost entirely indigenously by **ISRO (Indian Space Research Organisation)** — provides critical infrastructure for broadcasting, telecommunication backhaul (especially in remote/inaccessible regions), navigation, disaster management communication and, increasingly, direct-to-consumer satellite internet.

INSAT/GSAT SATELLITE SERIES

The **INSAT (Indian National Satellite System)** and its successor **GSAT** series are India's primary multipurpose geostationary communication satellites, operational since 1983, providing telecommunications, television broadcasting, meteorological observation and search-and-rescue support.

- **Telecommunications backhaul:** INSAT/GSAT transponders carry voice, data and television signals across India, particularly critical for remote/Himalayan/island regions (Andaman & Nicobar, Lakshadweep) where terrestrial fibre/microwave links are impractical.
- **DTH (Direct-to-Home) television:** INSAT satellites are the backbone for India's massive DTH television industry (Tata Play, Dish TV, Airtel Digital TV, DD Free Dish — the latter being the world's largest free DTH platform by subscriber base).
- **Disaster management communication:** INSAT-based Disaster Warning Systems provide cyclone and severe weather alerts directly to vulnerable coastal communities even when terrestrial communication infrastructure is disrupted (linked to the cyclone warning systems covered in Chapter 15).

NAVIC — INDIA'S OWN SATELLITE NAVIGATION SYSTEM

NavIC (Navigation with Indian Constellation), originally called **IRNSS (Indian Regional Navigation Satellite System),** is India's indigenous satellite navigation system — reducing strategic dependence on the US-operated GPS (Global Positioning System), particularly important for defence and critical infrastructure applications where reliance on a foreign-controlled system poses security risks.

Parameter	Detail
Constellation	7 satellites (3 in geostationary orbit, 4 in geosynchronous orbit) covering India and a region extending ~1,500 km beyond Indian borders
Origin/motivation	Developed partly in response to the 1999 Kargil War, during which the US restricted GPS access to India for the relevant conflict region — exposing India's strategic vulnerability from dependence on a foreign-controlled navigation system

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Accuracy	Better than 5-10 m for the Standard Positioning Service (SPS, civilian use); higher precision for Restricted Service (RS, for strategic/military use)
Civilian integration	Indian smartphone makers and chipset manufacturers (Qualcomm, MediaTek) increasingly include NavIC compatibility; mandated for some categories of devices sold in India from 2023 onward; integrated into vehicle tracking, fishermen safety devices (helping fishermen avoid maritime boundary violations, including the India-Sri Lanka and India-Pakistan maritime boundary issues), and emergency/disaster response systems
Strategic significance	NavIC places India among a small group of nations (USA-GPS, Russia-GLONASS, EU-Galileo, China-BeiDou, Japan-QZSS regional) with independent satellite navigation capability — a marker of advanced space-technology sovereignty

GAGAN — SATELLITE-BASED AUGMENTATION FOR AVIATION

GAGAN (GPS Aided Geo Augmented Navigation) is a joint project of **ISRO and the Airports Authority of India (AAI)** — a satellite-based augmentation system (SBAS) that improves the accuracy and reliability of GPS signals specifically for civil aviation, enabling more precise aircraft navigation, approach and landing, particularly valuable for airports in challenging terrain (mountainous, NE India) where conventional ground-based navigation aids are harder to deploy.

SATELLITE INTERNET — THE EMERGING FRONTIER (2024-25)

India is at the threshold of a new connectivity paradigm: **Low Earth Orbit (LEO) satellite internet,** which promises to deliver high-speed broadband directly to remote and underserved areas without requiring terrestrial fibre or mobile tower infrastructure — potentially solving India's "last mile" rural connectivity challenge in a way BharatNet's fibre approach has struggled to achieve at pace.

Player	*Status (2024-25)*
Starlink (SpaceX, Elon Musk)	Long pursued Indian market entry; faced regulatory hurdles over spectrum allocation methodology (administrative allocation vs auction — a contentious policy debate, with Jio/Airtel initially favouring auction and Starlink/global satellite players favouring administrative allocation, which TRAI and DoT ultimately leaned toward for satellite spectrum); received conditional regulatory clearances and is progressing toward commercial launch in India
OneWeb (Bharti Group-backed, UK-based)	Bharti Enterprises (parent of Airtel) is a significant investor in OneWeb globally; OneWeb has been actively pursuing Indian satellite internet services, leveraging this existing India connection
Jio Satellite Communications (Jio-SES joint venture)	Reliance Jio partnered with SES (Luxembourg-based satellite operator) to launch Jio Space Fiber satellite broadband services in India, targeting remote and rural connectivity as a complement to Jio's terrestrial network
Amazon Kuiper	Amazon's LEO satellite internet constellation (competitor to Starlink) also exploring Indian market entry as part of its global rollout
Spectrum policy debate	The Indian government's decision (2024-25) to allocate satellite spectrum ADMINISTRATIVELY (rather than through competitive auction, as is done for terrestrial mobile spectrum) was a significant and somewhat controversial policy choice, aligning India with the more common GLOBAL practice for satellite spectrum but departing from India's own auction-based terrestrial telecom tradition

16.8 SUBMARINE CABLES AND INTERNATIONAL CONNECTIVITY

While satellites and domestic fibre networks carry communication WITHIN India, the overwhelming majority of

India's **international internet traffic (estimated 95-99% globally for most countries, India included) travels through undersea submarine fibre-optic cables** — making these cables, landing at a handful of coastal stations, a critical and somewhat under-appreciated piece of India's digital infrastructure and strategic vulnerability.

INDIA'S SUBMARINE CABLE LANDING STATIONS

City	Significance
Mumbai	India's primary international internet gateway; landing point for multiple major cable systems including SEA-ME-WE (South East Asia-Middle East-Western Europe) series, connecting India to Europe, Middle East and Southeast Asia
Chennai	Major landing station connecting India to Southeast Asia and onward to the Pacific (via cables like SEA-ME-WE and others); also connects to the Bay of Bengal Gateway (BBG) cable system
Kochi	Growing as a landing hub, particularly for cables connecting India to Africa and Europe via the Arabian Sea/Red Sea route (e.g., Africa-1, 2Africa cable systems landing here)
Mumbai-Chennai-Kochi triangle	Together, these three cities handle the overwhelming bulk of India's international bandwidth, creating both efficiency (established infrastructure ecosystem) and a CONCENTRATION RISK — any major disruption (natural disaster, cable cut, geopolitical event) affecting these limited landing points could severely impact India's international connectivity

CHENNAI-ANDAMAN & NICOBAR SUBMARINE CABLE — CONNECTING INDIA'S ISLANDS

A particularly significant domestic submarine cable project connects mainland India to the **Andaman & Nicobar Islands (covered in Chapter 7),** addressing a long-standing connectivity gap for India's strategically vital but geographically remote island territories.

Parameter	*Detail*
Route	Chennai to Port Blair, with branches to other major A&N islands (Swaraj Dweep/Havelock, Little Andaman, Car Nicobar, Kamorta, Great Nicobar)
Length	~2,300 km submarine cable
Inauguration	August 2020 (PM Modi); represented a major infrastructure milestone, replacing the islands' prior near-total dependence on slower, less reliable satellite connectivity
Impact	Dramatically improved internet speed and reliability for A&N residents, businesses, tourism sector, and CRITICALLY for the Andaman and Nicobar Command (ANC — India's only tri-services military command, covered in Chapter 7) — reliable high-speed connectivity is essential for military communication and coordination in this strategically vital location near the Malacca Strait
Strategic significance	Beyond civilian benefit, the cable significantly enhances India's military and administrative capability in the Andaman & Nicobar Islands, supporting the broader strategic infrastructure build-out (alongside the Great Nicobar Development Project — see Chapter 7) aimed at strengthening India's presence in the eastern Indian Ocean

ENV ALERT

Submarine Cable Vulnerability — A Strategic Concern:

Submarine cables, despite carrying the overwhelming majority of global and Indian international data traffic, are physically vulnerable to **accidental damage (fishing trawlers, ship anchors — the most common cause globally), natural disasters (underwater landslides, earthquakes — relevant given India's seismically active maritime boundaries) and, increasingly, geopolitical/security concerns (deliberate sabotage in conflict scenarios)**. Several Red Sea submarine cables were damaged in 2024 amid regional conflict, disrupting traffic for India and other countries dependent on that route — highlighting real-world vulnerability. India's strategy of diversifying landing stations (Mumbai, Chennai, Kochi) and pursuing multiple cable routes (avoiding single-point-of-failure choke

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points like the Red Sea/Suez where possible) is a growing focus of India's digital infrastructure resilience planning, an increasingly important national security dimension of communication geography.

16.9 DIGITAL DIVIDE, INTERNET SHUTDOWNS AND DATA PROTECTION

INTERNET SHUTDOWNS — INDIA'S GLOBAL OUTLIER STATUS

India has, for several consecutive years, ranked as the **world's most frequent user of government-ordered internet shutdowns** — a designation that draws significant criticism from civil liberties groups, international press freedom organisations and, increasingly, from economists who quantify the substantial economic costs of connectivity disruption.

Parameter	Detail
Tracking organisations	Software Freedom Law Centre (SFLC.in, India-based) and Access Now (international) maintain the most cited shutdown trackers; India has topped global shutdown frequency rankings most years in the past decade
Legal basis	Shutdowns are typically ordered under the Temporary Suspension of Telecom Services (Public Emergency or Public Safety) Rules, 2017 (issued under the Indian Telegraph Act, 1885) — requiring state/district authority orders, subject to review by a committee
Common triggers	Communal tension/law-and-order concerns; preventing examination cheating (a uniquely Indian use-case — shutting down internet during competitive exams to prevent question paper leaks via messaging apps); political protests; sensitive court verdicts; security operations in conflict-affected regions
J&K example	Jammu & Kashmir experienced India's longest-ever internet shutdown (over 500 days, beginning August 2019 following the abrogation of Article 370's special status), drawing significant international attention and legal challenge (Anuradha Bhasin vs Union of India, 2020 — Supreme Court ruled that indefinite internet shutdowns are unconstitutional and that suspension orders must be reviewed periodically and published)
Manipur 2023	Following ethnic violence in Manipur (beginning May 2023), the state experienced an extended internet shutdown lasting several months — among the most significant and prolonged shutdowns of the post-Article 370 era, again raising questions about the balance between security justifications and economic/civil liberties costs
Economic cost	Studies (Top10VPN, Indian Council for Research on International Economic Relations/ICRIER and others) estimate internet shutdowns have cost the Indian economy several billion dollars cumulatively, with disproportionate impact on small businesses, gig workers, students and digital-dependent livelihoods in affected regions
Supreme Court precedent (2020)	The Anuradha Bhasin judgment established that the right to internet access is intrinsically linked to fundamental rights (freedom of speech, freedom of trade) under Article 19 of the Constitution, and that shutdown orders must satisfy proportionality, necessity and periodic review requirements — though implementation/enforcement of these safeguards remains inconsistent in practice

DIGITAL PERSONAL DATA PROTECTION ACT, 2023

The **Digital Personal Data Protection Act (DPDP Act), 2023** — passed by Parliament in August 2023 — is **India's first comprehensive, dedicated data protection legislation,** filling a long-standing legal gap (India previously relied on limited provisions within the Information Technology Act, 2000 and its rules). The law followed the landmark Supreme Court judgment in **Justice K.S. Puttaswamy vs Union of India (2017),** which recognised the **right to privacy as a fundamental right** under Article 21 of the Constitution, creating the constitutional

foundation for comprehensive data protection legislation.

Key Provision	Detail
Consent-based processing	Personal data can generally only be processed with the explicit, informed consent of the individual ("Data Principal"), with specified exceptions (legal obligations, government functions, employment purposes, medical emergencies)
Data Fiduciary obligations	Entities processing personal data ("Data Fiduciaries" — companies, government bodies) must implement reasonable security safeguards, notify data breaches, and process data only for the purpose for which consent was given
Children's data protection	Special, stricter protections for processing children's (under-18) personal data, requiring verifiable parental consent
Data Protection Board of India	A new regulatory body established to adjudicate complaints, impose penalties for non-compliance and oversee enforcement
Cross-border data transfer	Unlike some earlier draft versions which proposed strict data localisation (requiring certain data to be stored only within India), the final DPDP Act takes a more LIBERAL approach — allowing data transfer to most countries EXCEPT those specifically restricted (blacklisted) by the government, reflecting industry lobbying for flexibility and India's interest in remaining attractive for global digital business and cloud services
Penalties	Significant financial penalties for non-compliance (up to Rs.250 crore for certain violations), though notably lower than the EU's GDPR penalty framework (which can reach a percentage of global turnover)
Government exemptions	Criticised by privacy advocates for broad exemptions allowing government agencies to process citizen data for various stated purposes (national security, public order) with comparatively limited independent oversight compared to commercial Data Fiduciaries

UPSC CIVIL

Civil GS-2/GS-3 — DPDP Act Significance: The DPDP Act 2023 is a high-probability exam topic at the intersection of (1) the fundamental right to privacy (Puttaswamy judgment, 2017 — itself a frequently tested constitutional law topic); (2) India's digital economy growth and the need for trust infrastructure to support e-commerce, fintech and data-driven business; (3) global data governance debates — comparing India's relatively liberal cross-border transfer approach against the EU's stricter GDPR and China's data localisation-heavy approach; (4) balancing privacy rights against legitimate government/security interests, a recurring civil liberties theme across many UPSC topics (surveillance, internet shutdowns, Aadhaar itself).

16.10 CURRENT AFFAIRS HOOKS (2021–2025)

CURRENT AFFAIRS

Starlink India Entry (2024-25): SpaceX's Starlink progressing toward commercial launch in India after extended regulatory negotiations over satellite spectrum allocation methodology (administrative allocation, not auction); will compete with Jio Space Fiber and OneWeb for India's remote/rural satellite internet market — a potentially transformative development for last-mile rural connectivity.

BSNL Indigenous 4G/5G Rollout: BSNL launched 4G services using fully INDIGENOUS technology (developed by Tejas Networks and C-DOT — Centre for Development of Telematics) in 2023-24 — a significant Atmanirbhar Bharat (self-reliant India) milestone, reducing historical dependence on foreign telecom equipment vendors (relevant given the 2020-21 exclusion of Chinese vendors Huawei/ZTE from India's 5G trials on national security grounds).

UPI Global Expansion Continuing: UPI-PayNow (Singapore) linkage, UAE merchant acceptance, France (Eiffel Tower pilot), Sri Lanka and Mauritius launches all occurred 2023-24; reflects India's "Digital Public Infrastructure diplomacy" strategy, prominently featured during India's G20

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Presidency (2023).

5G Rollout Completion Milestone: India achieved 5G coverage across 97%+ of districts within approximately two years of October 2022 launch — confirmed as the fastest national 5G rollout in world history by multiple international telecom analysis firms.

Manipur Internet Shutdown (2023-24): Extended internet shutdown following ethnic violence beginning May 2023 became one of the most prolonged and scrutinised shutdowns in recent Indian history, renewing debate over the Anuradha Bhasin (2020) Supreme Court safeguards and their practical enforcement.

Digital Personal Data Protection Act Rules Notification: Following the August 2023 Act passage, the detailed implementing Rules and the operationalisation of the Data Protection Board of India have been under active development/notification through 2024-25, a key regulatory milestone to watch.

Bharat 6G Vision Progress: India continuing to position itself for a leadership role (not just adoption role) in 6G global standard-setting, with the Bharat 6G Alliance driving indigenous research collaboration between IITs, telecom operators and equipment manufacturers, targeting significant global 6G patent contribution by ~2030.

16.11 PYQ ANALYSIS — CHAPTER 16 (2010–2025)

Source	*Year*	*Marks*	*Question*
UPSC Civil	2023	15M	"Discuss the significance of India Stack and Digital Public Infrastructure (DPI) for financial inclusion and governance. How is India exporting this model globally?"
UPSC Civil	2022	12M	"Critically examine the impact of the Reliance Jio disruption on India's telecommunications sector and its implications for digital inclusion."
UPSC Civil	2021	12M	"What is UPI? Discuss its significance for India's digital payments ecosystem and its growing international adoption."
UPSC Civil	2020	10M	"Discuss the objectives of the BharatNet project. What are the challenges in achieving universal rural broadband connectivity in India?"
UPSC Civil	2019	12M	"Examine the legal and constitutional issues surrounding internet shutdowns in India with reference to the Anuradha Bhasin judgment."
UPSC Civil	2018	10M	"What is NavIC? Discuss its strategic significance for India's security and economic interests."
UPSC Civil	2017	10M	"Discuss the significance of the JAM (Jan Dhan-Aadhaar-Mobile) trinity for India's direct benefit transfer system."
UPSC Civil	2024	15M	"Examine the key provisions of the Digital Personal Data Protection Act 2023. How does it balance individual privacy rights with government and commercial interests?"
IFoS GS	2023	10M	"Discuss the role of satellite communication and remote sensing infrastructure in disaster management and environmental monitoring in India."
IFoS GS	2021	10M	"Explain the significance of NavIC and GAGAN for India's strategic and civilian infrastructure needs."
IFoS GS	2020	10M	"Discuss the role of digital connectivity in improving forest governance and conservation outcomes in remote and tribal areas of India."

KEY NOTE

Frequency pattern: Digital Public Infrastructure / India Stack (Civil 2023 — very high probability to recur, especially post-G20); Jio disruption (Civil 2022); UPI (Civil 2021); BharatNet/rural connectivity (Civil 2020); internet shutdowns/Anuradha Bhasin (Civil 2019); JAM trinity (Civil 2017); DPDP Act (Civil 2024 — almost certain to recur 2025-26 given its recency). IFoS focuses on satellite/remote sensing applications for disaster management and conservation rather than pure telecom policy. For 2025-26: Starlink India entry, BSNL indigenous 5G, UPI global expansion, and DPDP Act Rules notification are the top current-affairs hooks.

16.12 MODEL BOOK

Discuss the significance of India Stack and Digital Public Infrastructure (DPI) for financial inclusion and governance. How is India exporting this model globally?

UPSC *Civil (Mains) | 15 Marks | 200 Words*

India Stack — comprising Aadhaar (identity), UPI (payments) and DigiLocker (data) — constitutes the world's most advanced layered Digital Public Infrastructure (DPI), built on open, interoperable APIs that any government agency, bank or fintech can leverage, distinguishing India's approach from closed, proprietary digital systems built elsewhere.

SIGNIFICANCE FOR FINANCIAL INCLUSION:

- **JAM trinity (Jan Dhan-Aadhaar-Mobile):** linking bank accounts, biometric identity and mobile numbers enabled Direct Benefit Transfer at unprecedented scale, eliminating leakage estimated at Rs.2.7+ lakh crore cumulatively.
- **UPI:** world's largest real-time payment system (~16 billion transactions/month); India accounts for ~46% of global real-time digital payments; near-zero transaction cost enabled adoption even by street vendors, dramatically expanding the formal financial ecosystem.
- **Presence-less, paperless KYC:** Aadhaar-based instant verification eliminated the bureaucratic friction that historically excluded poor and rural citizens from formal financial services.

SIGNIFICANCE FOR GOVERNANCE:

- **UMANG and DigiLocker:** single-window access to 1,200+ government services and verified documents, reducing corruption opportunities and citizen-official friction.
- **Transparency and reduced leakage:** real-time, traceable digital transactions reduce the scope for diversion in welfare schemes.

INDIA'S GLOBAL DPI EXPORT:

- **G20 Presidency (2023):** India placed DPI at the centre of its agenda, securing G20 commitment to support DPI adoption across the Global South.
- **MOSIP (Modular Open Source Identity Platform):** India-developed open-source identity framework adopted by countries including Philippines, Morocco, Sri Lanka and several African nations.
- **UPI international linkages:** operational in Singapore, UAE, France, Sri Lanka, Mauritius, demonstrating both diaspora utility and DPI diplomacy.

Concerns: Privacy and surveillance risks (partially addressed by DPDP Act 2023); exclusion risk for those without biometric/digital access; over-centralisation of citizen data infrastructure.

India Stack represents a genuinely novel model of state-enabled, privately-built digital infrastructure that has simultaneously deepened financial inclusion domestically and established India as a thought leader in Digital Public Infrastructure globally.

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Critically examine the impact of the Reliance Jio disruption on India's telecommunications sector and its implications for digital inclusion.

UPSC *Civil (Mains) | 15 Marks | 200 Words*

Reliance Jio's commercial launch in September 2016 — offering free voice calls and near-free data on a greenfield all-IP 4G network — triggered the single most consequential disruption in Indian telecom history, with effects extending far beyond the sector itself.

POSITIVE IMPACTS:

- **Data price collapse:** average data cost fell over 90% (from ~Rs.250+/GB to ~Rs.10-15/GB), making India home to among the world's cheapest mobile data.
- **Digital inclusion catalyst:** cheap data was a necessary precondition for mass UPI adoption, JAM trinity effectiveness, and the broader Digital India ecosystem — connectivity affordability directly enabled financial and governance inclusion.
- **Consumption explosion:** average monthly data usage rose from under 1 GB to 21-24 GB per user, among the highest globally, reflecting genuine mass-market digital adoption rather than elite usage alone.
- **Innovation in business model:** demonstrated that aggressive capital investment in a "free/near-free" model could rapidly create a mass digital market — a template increasingly studied internationally.

NEGATIVE/CONTESTED IMPACTS:

- **Industry consolidation:** reduced operator count from 8-12 to effectively 3 private players, raising long-term competition and pricing power concerns despite current low prices.
- **Financial stress on competitors:** Vodafone Idea's ongoing financial distress (compounded by the AGR dues crisis) raises systemic risk concerns — a potential further reduction to a duopoly could eventually weaken competitive pricing discipline.
- **Job losses:** operators that exited (Aircel, RCom, Telenor) caused significant employment disruption in the sector.

On balance, the Jio disruption decisively advanced India's digital inclusion goals by solving the affordability constraint, but the resulting market concentration requires continued regulatory vigilance (TRAI) to ensure long-term competitive, affordable access is sustained.

CHAPTER 17

NORTH-EAST INDIA

A Special Focus

CHAPTER AT A GLANCE

- North-East India comprises 8 states ("Seven Sisters" — Assam, Arunachal Pradesh, Manipur, Meghalaya, Mizoram, Nagaland, Tripura — plus "Brother" Sikkim, added administratively to the region); ~7.9% of India's area, ~3.8% of population.
- Extraordinary geography: ~98-99% of the region's boundary is INTERNATIONAL (China/Tibet, Myanmar, Bangladesh, Bhutan, Nepal-adjacent) and only ~1-2% connects to mainland India — through the narrow "Siliguri Corridor" or "Chicken's Neck" (~22 km wide at its narrowest), India's single greatest strategic chokepoint.
- Cherrapunji and Mawsynram (Meghalaya) are among the WETTEST PLACES ON EARTH (Mawsynram average ~11,872 mm/year); Shillong Plateau is geologically an extension of the Peninsular Plateau, separated from it by the Garo-Rajmahal Gap (a major Gondwana-rifting geological feature).
- Over 200 distinct tribal communities; Sixth Schedule of the Constitution provides Autonomous District Councils with significant self-governance in Assam, Meghalaya, Mizoram and Tripura; Inner Line Permit (ILP) system regulates non-resident entry to Arunachal Pradesh, Nagaland, Mizoram and (from 2019) Manipur.
- Historical insurgencies shaped the region's post-independence story: Naga insurgency (NSCN — longest-running in India); ULFA (Assam); Mizo insurgency (resolved by the landmark 1986 Mizo Accord — India's most successful insurgency resolution model); Bodo movement (Bodo Peace Accord 2020).
- AFSPA (Armed Forces Special Powers Act, 1958) has governed parts of the NE for decades; progressive withdrawal from several districts since 2022 reflects improving security; however Manipur's 2023-24 Meitei-Kuki ethnic violence represents the region's most serious recent crisis.
- Act East Policy (renamed from Look East Policy, 2014) positions NE India as India's gateway to ASEAN; Kaladan Multimodal Transit Project (India-Myanmar) and India-Myanmar-Thailand Trilateral Highway are flagship connectivity projects; Sela Tunnel (2024) and Bogibeel Bridge (2018) are landmark strategic infrastructure.
- Sikkim is INDIA'S FIRST FULLY ORGANIC STATE (certified 2016); Assam dominates India's tea production (~50%+ of national output) and historically hosted India's first oil well (Digboi, 1889 — Asia's oldest operating oil refinery).

17.1 INTRODUCTION — THE SEVEN SISTERS AND SIKKIM

North-East India is a geographically, culturally and strategically distinct region of the country — a cluster of **eight states** connected to peninsular India by only a slender corridor of land, home to extraordinary ethnic and linguistic diversity, and bordered almost entirely by foreign nations. The traditional **"Seven Sister States"** — **Assam, Arunachal Pradesh, Manipur, Meghalaya, Mizoram, Nagaland and Tripura** — were joined administratively by **Sikkim ("the Brother State")** for the purposes of the North Eastern Council and the DoNER Ministry, even though Sikkim is geographically and historically distinct (it was an independent kingdom until merger with India in 1975, and connects to mainland India differently than the Seven Sisters).

KEY STATISTICS OF NORTH-EAST INDIA

Parameter	*Figure*
Number of states	8 (Assam, Arunachal Pradesh, Manipur, Meghalaya, Mizoram, Nagaland, Tripura, Sikkim)
Total area	~2.62-2.7 lakh sq km — approximately 7.9% of India's total geographical area

Total population (Census 2011)	~45-46 million — approximately 3.8% of India's population
International border share	~98-99% of the region's total perimeter is international border (with China, Myanmar, Bangladesh, Bhutan); only a narrow corridor connects to mainland India
Siliguri Corridor width	~22 km at its narrowest point (between Bangladesh and Nepal/Bhutan borders) — India's most critical strategic chokepoint, often called the "Chicken's Neck"
Largest state by area	Arunachal Pradesh (~83,743 sq km)
Largest state by population	Assam (~31.2 million, Census 2011) — by far the most populous NE state
Smallest state by area	Tripura (~10,486 sq km) among the Seven Sisters; Sikkim (~7,096 sq km) is smallest overall
Number of distinct tribal communities	200+ recognised tribes across the region — among the highest ethnic diversity densities anywhere in the world

INSTITUTIONAL FRAMEWORK FOR THE REGION

Institution	*Year*	*Function*
North Eastern Council (NEC)	1971 (under North Eastern Council Act)	Statutory advisory body for the region; coordinates inter-state planning and development; headquartered in Shillong, Meghalaya
Ministry of Development of North Eastern Region (DoNER)	2001 (as a separate ministry; upgraded from earlier department)	Dedicated central ministry for NE development; coordinates with NEC and the "Act East Policy"; channels significant central funding (the "Non-Lapsable Central Pool of Resources" mandates that all central ministries earmark a minimum percentage of their budget for NE states)
North East Special Infrastructure Development Scheme (NESIDS)	2017	Funds physical and social infrastructure projects across NE states
Sixth Schedule of the Constitution	1950 (Constitution adoption)	Provides for Autonomous District Councils (ADCs) with legislative, executive, judicial and financial powers over land, forests, customary law, etc., in tribal areas of Assam, Meghalaya, Mizoram and Tripura — a unique constitutional mechanism for tribal self-governance not replicated elsewhere in India in this form
Article 371 (various sub-clauses A-H)	1969-1986 (added progressively via constitutional amendments at each state's formation/statehood)	Special constitutional provisions for Nagaland (371A), Assam (371B), Manipur (371C), Sikkim (371F), Mizoram (371G), Arunachal Pradesh (371H) — protecting customary law, land rights, religious/social practices and limiting Parliament's legislative reach into certain local matters without state assembly consent

17.2 PHYSIOGRAPHY OF NORTH-EAST INDIA

North-East India's physical geography is exceptionally complex — a meeting zone of the **Eastern Himalaya, the Indo-Myanmar hill ranges (Patkai-Naga-Lushai-Mizo), the Shillong (Meghalaya) Plateau and the alluvial**

Brahmaputra-Barak river valleys — making it one of India's most physiographically diverse regions within a relatively small area.

PHYSIOGRAPHIC DIVISIONS

Division	*States*	*Key Features*
Eastern Himalaya	Arunachal Pradesh, Sikkim, northern fringes of Assam	Young, geologically active fold mountains; HIGHEST PEAK IN NE INDIA: Kangto (7,090 m, Arunachal Pradesh, on the McMahon Line/China border) — though Kanchenjunga (8,586 m, on Sikkim-Nepal border) is technically higher but shared with Nepal as the world's 3rd-highest peak; dense temperate to alpine forests with extreme altitudinal biodiversity gradient; home to numerous glaciers and high passes (Bum La, Se La)
Patkai-Naga-Lushai-Mizo Hill Ranges (Purvanchal)	Nagaland, Manipur, Mizoram, eastern Arunachal, Tripura (partially)	A continuation of the Himalayan arc curving southward, forming the India-Myanmar border; comprises Patkai Bum (north), Naga Hills, Manipur Hills (Lushai Hills further south extending into Mizoram), and the Chin Hills (Myanmar side); generally north-south or NE-SW trending ridges; significantly lower than the Himalaya proper (mostly 1,000-3,000 m) but extremely rugged and forest-dense
Shillong (Meghalaya) Plateau	Meghalaya, parts of Assam (Karbi Anglong)	GEOLOGICALLY AN EXTENSION OF THE PENINSULAR PLATEAU (Deccan/Chotanagpur block) — separated from the main peninsular plateau by the GARO-RAJMAHAL GAP, a structural depression filled by Gangetic alluvium; this is one of India's most important physiographic facts, demonstrating that ancient Gondwanaland rocks extend discontinuously into NE India; comprises the Khasi Hills, Jaintia Hills and Garo Hills; highest point Shillong Peak (~1,965 m); home to Cherrapunji (Sohra) and Mawsynram — among the wettest places on Earth
Brahmaputra Valley (Assam Valley)	Assam (majority)	Vast alluvial plain formed by the Brahmaputra and its tributaries; ~720 km long, 80-100 km wide; extremely fertile but highly flood-prone (see Chapter 15); braided river channel pattern with numerous river islands including Majuli (covered Chapter 7) — the world's largest river island; tea gardens, rice cultivation dominant
Barak Valley	Southern Assam (Cachar, Karimganj, Hailakandi districts)	Drained by the Barak River (which becomes the Surma/Meghna in Bangladesh, eventually joining the Ganga-Brahmaputra delta); culturally and linguistically distinct (Bengali-speaking majority, unlike Assamese-speaking Brahmaputra Valley) — an important point of internal NE diversity often overlooked
Tripura Hills and Plains	Tripura	Series of north-south trending parallel hill ranges (Baramura, Atharamura, Longtarai, Sakhan) alternating with narrow valleys; western Tripura plains are more fertile and densely settled, bordering Bangladesh on three sides

Mawsynram and Cherrapunji — The Wettest Places on Earth

The twin towns of **Mawsynram and Cherrapunji (locally Sohra)** in Meghalaya's East Khasi Hills district hold the distinction of being among the wettest inhabited places on the planet — a phenomenon rooted in a specific and instructive orographic mechanism.

Location	*Average Annual Rainfall*	*Why So Wet?*
Mawsynram	~11,872 mm (some sources cite	Located at the highest point of a narrow, funnel-shaped

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	11,000-12,000 mm range) — currently holds the Guinness World Record for highest average annual rainfall	valley that channels and concentrates monsoon clouds arriving from the Bay of Bengal; moisture-laden SW monsoon winds are forced to rise abruptly against the steep southern face of the Khasi Hills (orographic uplift), causing intense, sustained condensation and rainfall
Cherrapunji (Sohra)	~11,430 mm average annual; HOLDS WORLD RECORDS for highest rainfall in a single calendar month (9,300 mm, July 1861) and highest rainfall in a single year (26,461 mm, Aug 1860-Jul 1861)	Same orographic mechanism as Mawsynram, located nearby on the same southern escarpment of the Khasi Hills; the funnel/amphitheatre shape of the local terrain (open toward Bangladesh's flat plains, narrowing and rising sharply northward into the plateau) is the critical geographic factor concentrating monsoon moisture

KEY NOTE

Exam-Critical Mechanism: The extreme rainfall at Cherrapunji/Mawsynram is a textbook example of **OROGRAPHIC RAINFALL combined with a FUNNEL-SHAPED VALLEY EFFECT**. The Bay of Bengal branch of the SW monsoon travels unobstructed across the flat Bangladesh plains, gathering moisture, then encounters the abrupt, steep southern wall of the Khasi Hills/Meghalaya Plateau. The funnel shape of local valleys (narrowing and rising) further concentrates and accelerates this forced uplift, intensifying condensation beyond what simple orographic lifting alone would produce. Despite this extreme rainfall, the region paradoxically experiences SEASONAL WATER SCARCITY in the dry months (Nov-Apr) due to the area's limestone/karst geology, which causes rapid water runoff and poor groundwater retention — a counter-intuitive fact frequently tested.

17.3 TRIBAL DIVERSITY AND CULTURE

North-East India hosts one of the world's highest concentrations of distinct ethnic and tribal communities in a relatively compact geographic area — **over 200 recognised tribes**, speaking languages from multiple distinct families (Tibeto-Burman predominant, alongside Austroasiatic/Mon-Khmer in Meghalaya, and Indo-Aryan Bengali/Assamese in the valleys), practising diverse religious traditions (Christianity is the majority religion in Nagaland, Mizoram and Meghalaya — a distinctive feature within India), and maintaining customary land and social systems protected by unique constitutional safeguards.

MAJOR TRIBAL COMMUNITIES BY STATE

State	*Major Tribes*	*Key Cultural Notes*
Meghalaya	Khasi, Garo, Jaintia (the "three hills" tribes after which the state's hill ranges are named)	MATRILINEAL societies — among the world's largest surviving matrilineal social systems; property and clan name pass through the mother's line; youngest daughter (khatduh, in Khasi tradition) typically inherits ancestral property and cares for parents; Christianity (predominantly) is the majority religion, introduced significantly through 19th-century Welsh and other missionary activity
Nagaland	16+ major recognised tribes including Angami, Ao, Sema/Sumi, Lotha, Konyak, Chakhesang, Rengma, Zeliang and others	Each tribe has historically distinct dialects (often mutually unintelligible — Nagamese, a Naga-influenced Assamese-based pidgin, serves as a lingua franca), customs and traditional governance (village councils); Hornbill Festival (December, Kisama Heritage Village) showcases this diversity; predominantly Christian (one of India's most Christian-majority states, ~90%+)
Mizoram	Mizo (an umbrella term for	Highly literate (Mizoram has among India's highest literacy

	closely related sub-tribes: Lushai, Hmar, Lai/Pawi, Mara and others)	rates); predominantly Christian (Presbyterian and Baptist denominations dominant, reflecting Welsh and British missionary history); strong civil society and church-mediated social organisation; Chapchar Kut (spring festival) is a major cultural event
Manipur	Meitei (the dominant valley-based community, historically Hindu/Sanamahi traditional faith) + numerous hill tribes including Naga sub-tribes (Tangkhul, Mao, Maram and others) and Kuki-Zo sub-tribes (Kuki, Zomi, Hmar and others)	The Meitei-Kuki ethnic and political divide (valley vs hill, differing land rights and ST status questions) is central to the 2023-24 Manipur crisis (detailed in Section 17.4); Manipur's cultural traditions include classical Manipuri dance (one of India's 8 classical dance forms) and Sangai deer-linked cultural symbolism (Loktak Lake, covered in Chapter 10)
Arunachal Pradesh	India's MOST TRIBALLY DIVERSE state — 26+ major tribes including Adi, Nyishi, Apatani, Galo, Tagin, Monpa (Buddhist, culturally close to Tibet), Mishmi and many others	Greatest linguistic and cultural diversity of any single NE state; Apatani tribe (Ziro Valley) is internationally noted for a sophisticated traditional sustainable agricultural and forest management system (UNESCO World Heritage tentative list nomination); Monpa community (Tawang area) is predominantly Tibetan Buddhist, with the historic Tawang Monastery (largest in India, 2nd largest in the world after Lhasa's Potala Palace)
Assam	Bodo (largest plains tribal group; Bodoland Territorial Region under Sixth Schedule-type arrangement), plus numerous hill/forest tribes (Karbi, Dimasa, Mising/Miri, Rabha, Tiwa) and the broader Assamese-speaking population	Bodo movement for autonomy/statehood was a major insurgency (resolved via successive Bodo Accords, most recently 2020 — detailed Section 17.4); Assam is also home to substantial Bengali-origin and tea-garden worker (originally brought from central India during colonial tea plantation era) populations, adding further demographic complexity
Tripura	Tripuri (Borok), Reang/Bru, Jamatia, Halam and other tribes (now a MINORITY in their own state — a significant demographic shift)	Tripura has undergone one of India's most dramatic demographic transformations: tribal populations, once the overwhelming majority, are now estimated at ~31% of the state's population, due to large-scale Bengali refugee influx (particularly post-1947 Partition and 1971 Bangladesh Liberation War); this demographic shift is central to understanding Tripura's political and insurgency history

SIXTH SCHEDULE AND AUTONOMOUS DISTRICT COUNCILS

The **Sixth Schedule of the Indian Constitution** provides for the administration of certain tribal areas through **Autonomous District Councils (ADCs),** a constitutional innovation unique to this region (distinct from the Fifth Schedule, which applies to Scheduled Tribal areas in peninsular/central India without the same degree of self-governance — see Chapter 18 for comparison).

State	*Autonomous District Councils (key examples)*	*Powers*
Assam	Karbi Anglong Autonomous Council, Dima Hasao (North Cachar Hills) Autonomous Council, Bodoland Territorial Council (BTC	Legislative powers over land allotment, forest management (except reserved forests), regulation of jhum/shifting cultivation, social

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	— created via the 2003 Bodo Accord under a Sixth-Schedule-equivalent special arrangement)	customs, inheritance, marriage and divorce, village/town administration; can constitute village courts for customary law disputes
Meghalaya	Khasi Hills Autonomous District Council, Jaintia Hills Autonomous District Council, Garo Hills Autonomous District Council	Similarly broad powers; notably, because the ENTIRE state of Meghalaya is essentially tribal-majority, these ADCs effectively administer most of the state alongside the regular state government — a relatively unique constitutional arrangement
Mizoram	Chakma Autonomous District Council, Mara Autonomous District Council, Lai Autonomous District Council	Cover specific sub-tribal areas (Chakma, Mara, Lai/Pawi communities) within the broader Mizo-majority state
Tripura	Tripura Tribal Areas Autonomous District Council (TTAADC)	Covers roughly two-thirds of Tripura's geographic area (though a smaller share of its population, reflecting the demographic shift discussed above); significant political importance given the tribal-Bengali demographic dynamic

INNER LINE PERMIT (ILP) SYSTEM

The **Inner Line Permit (ILP)** is a colonial-era regulatory instrument (originating from the **Bengal Eastern Frontier Regulation, 1873**) — continued post-independence — requiring **non-resident Indian citizens to obtain special permission** before entering specified protected areas. This is distinct from (and should not be confused with) the entirely separate requirement for FOREIGN nationals to obtain Restricted/Protected Area Permits.

State	*ILP Status*	*Recent Development*
Arunachal Pradesh	ILP applies state-wide	Long-standing requirement; strictly enforced given international border sensitivity
Nagaland	ILP applies state-wide	Long-standing requirement
Mizoram	ILP applies state-wide	Long-standing requirement
Manipur	ILP EXTENDED to Manipur in December 2019	Following sustained local civil society demand (citing demographic change concerns from unrestricted migration); this was a significant policy shift, and the ILP system's administration has been an additional point of friction/discussion amid the broader 2023-24 ethnic crisis
Meghalaya, Assam, Tripura, Sikkim	ILP does NOT apply (or applies only in limited specific protected areas)	These states do not have the blanket ILP requirement, reflecting different historical administrative treatment and demographic contexts

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Civil GS-1/GS-2 — ILP and Sixth Schedule: These are frequently tested as examples of how India's Constitution accommodates regional/tribal distinctiveness through ASYMMETRIC FEDERALISM — special provisions that differ explicitly by state/region rather than applying uniform rules nationally. Compare and contrast with the Fifth Schedule (Chapter 18), Article 370 (J&K, now abrogated), and Article 371 series. Key debate: do such special provisions protect vulnerable indigenous communities effectively, or do they create administrative complexity and limit national integration/uniform citizenship rights? UPSC frequently asks for a BALANCED evaluation of these trade-offs.

17.4 INSURGENCY, AFSPA AND THE PEACE PROCESS

North-East India experienced some of independent India's **longest-running and most complex internal security challenges** — rooted in a combination of ethnic identity assertion, contested integration into the Indian Union at independence, demographic anxieties (migration from Bangladesh/elsewhere), resource/land disputes and, in several cases, external state support (historically China and erstwhile East Pakistan/Bangladesh provided varying degrees of support to different insurgent groups). Understanding this history is essential to understanding the region's contemporary politics and the ongoing peace process.

MAJOR HISTORICAL INSURGENCIES

Insurgency	*State(s)*	*Key Organisation(s)*	*Status / Resolution*
Naga Insurgency	Nagaland, parts of Manipur, Assam, Arunachal	National Socialist Council of Nagaland (NSCN), with major factions NSCN-IM (Isak-Muivah) and NSCN-K (Khaplang)	LONGEST-RUNNING INSURGENCY IN INDIA'S HISTORY — began even before Nagaland's 1963 statehood (Naga National Council declared independence in 1947, days before India's own independence); NSCN-IM signed a "Framework Agreement" with the Government of India in 2015, but a FINAL, COMPREHENSIVE settlement remains UNACHIEVED as of 2025 — the core sticking point is NSCN-IM's demand for a "Greater Nagalim" (integrating Naga-inhabited areas of Manipur, Assam and Arunachal into a unified Naga political unit), which these states strongly oppose; periodic ceasefire extensions continue while final settlement remains elusive — one of India's most prolonged unresolved insurgency negotiations
Mizo Insurgency	Mizoram (then Mizo Hills District of Assam)	Mizo National Front (MNF), led by Laldenga	Triggered partly by the Indian government's perceived inadequate famine relief response during the 1959-60 "Mautam" bamboo-flowering famine; THE MIZO ACCORD (1986) — signed between the Government of India and the MNF — is WIDELY CITED AS INDIA'S MOST SUCCESSFUL INSURGENCY RESOLUTION: it granted full statehood to Mizoram, MNF leader Laldenga became Chief Minister, and the MNF transformed into a mainstream political party; insurgency formally and durably ended; a model frequently invoked (with mixed success) for other NE peace processes
ULFA (United Liberation Front of Assam)	Assam	ULFA, later split into ULFA (pro-talks faction) and ULFA-Independent (anti-talks, led by Paresh Baruah)	Founded 1979, demanding a "sovereign socialist Assam"; the pro-talks ULFA faction signed a tripartite peace accord with the Government of India and Assam government in December 2023 (a significant recent development); ULFA-Independent (Paresh Baruah faction) continues to reject talks and remains active, though with significantly reduced operational capacity compared to its 1990s peak
Bodo Movement	Assam (Bodo-inhabited	All Bodo Students Union (ABSU, political wing), National	Demanded a separate Bodoland state/autonomous status; multiple accords over time — 1993 Bodo Accord (limited autonomy), 2003 Bodo Accord

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	areas of the Brahmaputra Valley)	Democratic Front of Bodoland (NDFB, armed wing, with multiple factions)	(created Bodoland Territorial Council/BTC under Sixth Schedule-equivalent arrangement), and the most comprehensive 2020 BODO PEACE ACCORD (renamed BTC to Bodoland Territorial Region/BTR, expanded its territorial and financial powers, and saw the surrender of 1,500+ NDFB cadres) — generally regarded as a successful, durable resolution
Tripura Insurgencies	Tripura	National Liberation Front of Tripura (NLFT), All Tripura Tiger Force (ATTF)	Rooted in tribal grievances over the dramatic post-Partition demographic shift (tribals becoming a minority due to Bengali refugee influx); largely contained/resolved through security operations and political accommodation (Tripura Tribal Areas Autonomous District Council) by the 2010s; NLFT signed a peace agreement in 2024
Meitei Insurgencies (Manipur Valley)	Manipur	United National Liberation Front (UNLF), People's Liberation Army (PLA), and others	Valley-based (Meitei) insurgent groups distinct from the hill-based Naga/Kuki insurgencies; UNLF signed a peace agreement with the Government of India in November 2023 — notable as UNLF was one of the oldest Meitei insurgent groups (founded 1964)

AFSPA — Armed Forces Special Powers Act, 1958

AFSPA grants the armed forces **extraordinary powers in areas declared "disturbed"** — including powers to arrest without warrant, search premises without warrant, and use force (including lethal force) under specified circumstances — alongside significant legal immunity for armed forces personnel acting under the Act (prosecution requires prior Central Government sanction). It has been one of independent India's most **persistently controversial pieces of legislation,** criticised by human rights organisations and several UN bodies, while defended by security establishments as necessary for counter-insurgency operations in active conflict zones.

Aspect	*Detail*
Origin	Enacted 1958, initially to address the Naga insurgency; subsequently extended to other "disturbed areas" including Manipur, Assam, parts of Arunachal, Tripura, Mizoram (historically) and Jammu & Kashmir (a separate, parallel AFSPA application)
Key controversial provisions	Section 4: powers to fire upon/use force, even causing death, against any person violating prohibitory orders; arrest without warrant based on "reasonable suspicion"; search any premises without warrant; legal immunity (Section 6) requiring Central Government sanction before any prosecution of armed forces personnel
Major controversy — Irom Sharmila	Manipuri civil rights activist Irom Sharmila undertook a hunger strike for 16 YEARS (2000-2016) demanding AFSPA's repeal, following the controversial "Malom Massacre" (2000, where 10 civilians were killed by security forces) — one of India's most prominent and prolonged civil disobedience protests
Justice Jeevan Reddy Committee (2005)	Recommended REPEALING AFSPA and instead incorporating its essential operational provisions into existing laws (Unlawful Activities Prevention Act) with appropriate safeguards — this recommendation was NOT implemented, and AFSPA continues in modified geographic application
Recent progressive	Reflecting improving security conditions and successive peace accords (Bodo 2020, ULFA 2023, UNLF 2023), the Government of India has progressively REDUCED the geographic

withdrawal (2022 onward)	extent of AFSPA application: significant portions of Assam, Manipur, Nagaland and Tripura have had AFSPA withdrawn or its "disturbed area" status not renewed in recent years; however, several districts (particularly in Nagaland, Manipur post-2023 crisis, and parts of Arunachal Pradesh bordering Myanmar) RETAIN AFSPA application
Oting incident impact (December 2021)	A botched Indian Army ambush in Oting village, Nagaland, killed 14 civilians (mistaken for insurgents) — triggered massive public outrage and significantly accelerated political pressure for AFSPA review/withdrawal in Nagaland, contributing to subsequent partial withdrawal decisions

IFoS FOCUS

IFoS/Civil — AFSPA Balance of Arguments: UPSC frequently demands a BALANCED treatment of AFSPA. ARGUMENTS FOR retention: counter-insurgency operations require rapid, decisive force application without procedural delays that could cost soldiers' lives; blanket prosecution exposure could deter effective operations in genuinely hostile, armed-conflict conditions. ARGUMENTS AGAINST: documented instances of human rights violations (extrajudicial killings, custodial abuse) with limited accountability due to the sanction requirement; perpetuates a sense of alienation and "occupation" among local populations, potentially fuelling rather than resolving insurgent sentiment; UN Human Rights Committee and various civil society bodies have repeatedly flagged AFSPA as inconsistent with international human rights standards. The progressive, security-condition-linked WITHDRAWAL approach (rather than blanket repeal or blanket retention) represents the government's current pragmatic middle path.

MANIPUR ETHNIC CRISIS, 2023-24 — DETAILED CASE STUDY

The **Manipur ethnic violence, which erupted in May 2023 and continued with significant intensity through 2024,** represents the North-East region's most serious and sustained internal conflict in over two decades — a complex crisis combining ethnic identity politics, land/forest rights disputes, land/forest rights disputes and economic competition, and historical Meitei-Kuki tensions.

Aspect	*Detail*
Communities involved	MEITEI community (predominantly Hindu/Sanamahi, valley-dwelling, ~53% of Manipur's population, historically NOT recognised as a Scheduled Tribe) vs KUKI-ZO community (predominantly Christian, hill-dwelling, recognised Scheduled Tribe status, ~16% of population, ethnically and culturally linked to broader Chin-Kuki-Mizo communities spanning into Myanmar and Mizoram)
Immediate trigger	A Manipur High Court order (March 2023) directing the state government to consider recommending Scheduled Tribe (ST) status for the Meitei community — which Kuki and Naga tribal groups strongly opposed, fearing this would allow Meiteis (already dominant in the valley) to also acquire land rights in hill areas currently protected for tribal communities only, threatening tribal land security
Outbreak	Violence erupted following a "Tribal Solidarity March" organised by the All Tribal Students Union Manipur (ATSUM) on May 3, 2023, in Churachandpur district, which escalated rapidly into widespread, sustained ethnic violence across the state
Scale of impact	200+ deaths (varying estimates); 50,000-60,000+ people internally displaced; thousands of homes, churches and temples destroyed; effective territorial/ethnic segregation emerged, with Meitei population concentrated in the Imphal Valley and Kuki-Zo population in the surrounding hill districts, separated by heavily militarised "buffer zones"
Governance response	President's Rule was NOT initially imposed (a point of significant political controversy and criticism, given the scale and duration of the violence); the state government faced sustained criticism for perceived inadequate or partisan crisis response; eventually, President's Rule was

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	imposed in February 2025 after the Chief Minister's resignation, following sustained political pressure and continued unrest
Broader implications	The crisis raised serious questions about: (1) Centre-state coordination in internal security crises; (2) the adequacy of constitutional/legal mechanisms (Sixth Schedule-type protections, ST status criteria) for managing inter-community land and political competition; (3) the risk of "demographic anxiety" politics in ethnically plural states; (4) the strain on India's broader Act East Policy and border security, given Manipur's strategic location bordering Myanmar amid that country's own internal conflict (with related cross-border ethnic Chin-Kuki linkages complicating the situation further)

ENV ALERT

Manipur Crisis — Ecological and Forest Dimension:
Beyond the ethnic-political dimensions, the Manipur crisis has an important **forest and land-use angle** relevant to IFoS preparation: tensions were significantly fuelled by the state government's anti-encroachment and "poppy cultivation eradication" drives in hill areas (targeting both genuine reserve forest encroachment AND, controversially, long-settled tribal villages), which Kuki-Zo communities viewed as a pretext for land alienation. The drives were officially framed around curbing illegal opium/poppy cultivation (a significant narcotics problem in Manipur's hills, linked to the broader Golden Triangle drug trade dynamics near the Myanmar border) and protecting reserve forest/protected area boundaries — but their implementation became deeply entangled with the ethnic conflict, illustrating how forest and land governance can become flashpoints in identity-based conflicts, a recurring theme across India's tribal regions (also relevant to Bastar, Jharkhand and other Fifth Schedule areas — see Chapter 18).

17.5 CONNECTIVITY PUSH AND STRATEGIC INFRASTRUCTURE

North-East India's historical economic marginalisation is substantially attributable to its **extreme connectivity deficit** — a consequence of its mountainous terrain, the narrow Siliguri Corridor bottleneck, and decades of relatively limited central infrastructure investment (a pattern that has shifted significantly since the early 2010s, accelerating further under the "Act East Policy" launched in 2014). Connectivity is simultaneously an ECONOMIC DEVELOPMENT priority and a NATIONAL SECURITY imperative, given the region's extensive and sensitive international borders.

THE SILIGURI CORRIDOR — INDIA'S STRATEGIC VULNERABILITY

The **Siliguri Corridor,** popularly termed the **"Chicken's Neck,"** is a narrow strip of land in northern West Bengal — approximately **22 km wide at its narrowest point** — that constitutes the ONLY land connection between mainland India and the entire North-East region. It is bounded by Nepal and Bhutan to the north and Bangladesh to the south, making it geographically pinched between three international borders.

- **Strategic vulnerability:** Any disruption to this corridor (through military action, infrastructure sabotage, or even severe natural disaster) would sever NE India's sole land link to the rest of the country — a vulnerability that has shaped Indian defence planning for decades.
- **China's Doklam standoff (2017) context:** the 2017 India-China military standoff at Doklam (Bhutan-China-India trijunction area, near Sikkim) was significant precisely because Chinese road construction there was seen as a potential future threat to India's ability to defend the Siliguri Corridor — Doklam's strategic value lies in its proximity to the corridor's northern flank.
- **Infrastructure response:** India has invested heavily in alternative and redundant connectivity options (additional roads, the Bogibeel rail-road bridge, expanded air connectivity, and waterway development) partly to reduce absolute dependence on this single corridor.

MAJOR CONNECTIVITY INFRASTRUCTURE PROJECTS

Project	*Type/Location*	*Significance*
Bogibeel	Rail-cum-road bridge	INDIA'S LONGEST RAIL-ROAD BRIDGE (~4.94 km); inaugurated

Bridge	over Brahmaputra River, connecting Dibrugarh and Dhemaji districts, Assam	December 2018; dramatically reduces travel time between upper Assam and Arunachal Pradesh; STRATEGICALLY VITAL for rapid troop/equipment movement toward the China border in Arunachal Pradesh — explicitly designed with defence mobility in mind, not merely civilian connectivity
Sela Tunnel	Tunnel beneath Sela Pass (~13,700 ft), connecting Tezpur (Assam) to Tawang (Arunachal Pradesh)	Inaugurated March 2024 by PM Modi; provides ALL-WEATHER connectivity to Tawang (a strategically critical, militarily sensitive area near the China border, historically site of the 1962 Sino-Indian War's eastern front and home to the major Tawang Monastery); bypasses the previously snow-blocked, landslide-prone Sela Pass road, ensuring year-round troop and supply movement; widely covered as a major strategic infrastructure milestone in 2024
Trans-Arunachal Highway (NH-13)	East-West highway across Arunachal Pradesh, connecting Tawang to the Myanmar border	~2,000 km; designed to provide lateral connectivity across the entire length of Arunachal Pradesh (previously, travel between different parts of the state often required routing through Assam); critical for both civilian development access and frontier defence logistics along the McMahon Line/China border
Atal Tunnel (context /comparison)	Himachal Pradesh (Rohtang Pass, NOT technically NE India, but a comparable strategic Himalayan tunnel)	While in Himachal Pradesh, the Atal Tunnel (inaugurated 2020) is frequently studied alongside Sela Tunnel as part of India's broader strategic Himalayan all-weather connectivity programme — relevant for comparative exam questions on India's Himalayan frontier infrastructure strategy
Kaladan Multi-Modal Transit Transport Project	India-Myanmar connectivity project linking Kolkata Port (via sea) to Sittwe Port (Myanmar), then river/road to Mizoram	Provides an ALTERNATIVE route connecting India's NE states (particularly Mizoram) to the sea, bypassing the Siliguri Corridor entirely via Myanmar; combines sea transport (Kolkata-Sittwe), river transport (Kaladan River, Myanmar) and road transport (to the India-Myanmar border, Mizoram); significantly delayed (originally targeted for completion years earlier) due to construction and security challenges within Myanmar, including the impact of Myanmar's post-2021 internal conflict; a flagship but troubled project of the Act East Policy
India-Myanmar-Thailand Trilateral Highway	~1,360 km highway connecting Moreh (Manipur, India border) through Myanmar to Mae Sot (Thailand)	Flagship Act East Policy connectivity project intended to link NE India directly to South-East Asia by road; extension plans envision linking onward to Cambodia, Laos and Vietnam (the "India-ASEAN" connectivity vision); progress has been significantly hampered by infrastructure challenges within Myanmar and, since 2021, that country's internal political and security crisis
Agartala-Akhaura Rail Link	Tripura (India) to Akhaura (Bangladesh)	Connects Tripura's capital Agartala directly to the Bangladesh rail network, providing a dramatically shorter route to Kolkata via Bangladesh territory (vs the long detour required through the Siliguri Corridor); inaugurated November 2023; represents a significant example of India-Bangladesh connectivity cooperation, though subsequent India-Bangladesh political relationship strains (post the 2024 change of government in Bangladesh) have introduced some uncertainty regarding the relationship's trajectory

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CURRENT AFFAIRS

Act East Policy: Renamed from the earlier "Look East Policy" (1991, post-liberalisation) to "Act East Policy" in 2014 by the Modi government, signalling a shift from passive engagement to proactive economic and strategic partnership with ASEAN and the wider Indo-Pacific.
NE India is explicitly positioned as India's "Gateway to ASEAN" under this policy — the connectivity projects above (Kaladan, Trilateral Highway) are its flagship physical manifestations, even though implementation has lagged the policy's ambitious timelines, primarily due to challenges in partner-country (especially Myanmar) infrastructure and security conditions.

17.6 ECONOMY AND RESOURCES OF NORTH-EAST INDIA

Tea Industry — Assam's Defining Economic Sector

Assam dominates India's tea production (detailed in Chapter 12) — contributing approximately **50-55% of India's total tea output,** making the Brahmaputra Valley one of the world's most concentrated and historically significant tea-producing regions. The sector remains a major employer (over 1 million workers directly, predominantly from tea-garden communities of mixed central-Indian tribal origin, brought during British colonial-era plantation establishment) though it faces persistent challenges around worker wages, working conditions and climate-related yield pressures.

PETROLEUM — INDIA'S OIL INDUSTRY ORIGINS

Location	*Significance*
Digboi, Assam	SITE OF INDIA'S (AND ASIA'S) FIRST OIL WELL — discovered 1889 by Assam Railways and Trading Company workers (legend holds an elephant got stuck in oil-soaked ground, prompting investigation); commercial drilling began 1890; the Digboi Refinery (commissioned 1901) is ASIA'S OLDEST OPERATING OIL REFINERY, still functioning today under Indian Oil Corporation (IOCL) — a remarkable industrial heritage site
Duliajan, Assam	Major present-day oil and gas production hub; headquarters of Oil India Limited (OIL), India's 2nd-largest national oil company (after ONGC); significant crude oil and natural gas reserves in the upper Assam basin
Naharkatiya, Assam	Important oilfield, connected via the historic Naharkatiya-Barauni-Kanpur pipeline (India's first major crude oil pipeline, covered in Chapter 14)
Bongaigaon, Assam	Major refinery (Bongaigaon Refinery and Petrochemicals Limited, now part of IOCL) serving NE and adjoining markets
Strategic significance	Assam's oil and gas resources mean NE India has historically been one of India's few domestic hydrocarbon-producing regions, predating the later discovery of Bombay High and other major fields — giving the region distinctive strategic and economic importance within India's energy security narrative since the colonial era

BAMBOO ECONOMY

North-East India possesses one of the world's richest bamboo resource bases — the region accounts for approximately **one-third to two-fifths of India's total bamboo-bearing area and bamboo production,** with bamboo deeply integrated into local construction, handicrafts, food (bamboo shoots are a significant traditional dietary item across the region), and increasingly, into commercial/industrial applications (bamboo-based paper pulp, engineered bamboo products, bamboo charcoal/activated carbon, and emerging bamboo-bio-composite materials). The **National Bamboo Mission** specifically targets unlocking this resource's commercial potential, with significant NE-focused components, given the region's natural comparative advantage.

SIKKIM — INDIA'S FIRST FULLY ORGANIC STATE

Sikkim achieved a globally celebrated agricultural milestone in **2016, when it was certified as India's (and one of the world's) FIRST FULLY ORGANIC STATE** — having completely phased out chemical fertilisers and pesticides across its entire agricultural area over a roughly 13-year transition programme launched in 2003.

Parameter	*Detail*
Total organic-certified area	~75,000 hectares (effectively the state's entire cultivated agricultural land)
Transition period	2003-2016 (Sikkim Organic Mission, launched under the state government's policy leadership)
Key crops	Large cardamom (Sikkim is India's largest producer — a high-value spice crop, covered in Chapter 12), ginger, turmeric, vegetables, and various traditional grains, all grown without synthetic chemical inputs
Recognition	Awarded the Future Policy Gold Award (2018) by the UN Food and Agriculture Organisation (FAO) — described as the "Oscar for best policies" — recognising Sikkim's organic transition as a global best-practice model
Challenges	Yield reductions in the initial transition years (a common challenge in organic conversion globally) before stabilisation; ongoing efforts to ensure adequate market access and premium pricing for organic produce to sustain farmer incomes; scaling lessons to larger, more populous states remains a distinct and more complex challenge

HANDLOOM, HANDICRAFTS AND TOURISM

- **Handloom traditions:** Assam's Muga, Eri and Pat silk weaving (Sualkuchi — "Manchester of Assam," covered in Chapter 13); Manipur's Moirang Phee and traditional textile weaving; Nagaland's distinctive tribal shawl weaving (each tribe with unique patterns signifying social status/achievements); Mizoram's Puan textile tradition.
- **Tourism potential:** Substantial but historically underdeveloped due to connectivity and, in some areas, security constraints; key draws include Kaziranga National Park (Assam — UNESCO World Heritage Site, one-horned rhinoceros stronghold), Tawang Monastery and Sela Pass (Arunachal), Living Root Bridges of Meghalaya (UNESCO tentative list — unique Khasi tribal engineering using living tree roots, particularly at Cherrapunji/Nongriat), Loktak Lake (Manipur, covered Chapter 10), Hornbill Festival (Nagaland), and the Buddhist monastery circuit of Sikkim and Tawang.
- **Eco-tourism and homestay models:** increasingly promoted as a sustainable development pathway that leverages the region's exceptional biodiversity and cultural distinctiveness while distributing economic benefit directly to local communities, an approach particularly emphasised in Meghalaya's community-based tourism initiatives.

17.7 CURRENT AFFAIRS HOOKS (2021–2025)

CURRENT AFFAIRS

Manipur Crisis Continuation (2023-25): Meitei-Kuki ethnic violence beginning May 2023 remained largely unresolved through 2024; President's Rule imposed February 2025 following Chief Minister N. Biren Singh's resignation; remains one of India's most serious ongoing internal security and governance challenges.

Sela Tunnel Inauguration (March 2024): PM Modi inaugurated the Sela Tunnel, providing all-weather connectivity to Tawang, Arunachal Pradesh — a major strategic infrastructure milestone enhancing India's border defence logistics near the China frontier.

PM-JANMAN Scheme (2023): PM Janjati Adivasi Nyaya Maha Abhiyan, launched November 2023 (Rs.24,104 crore), specifically targets Particularly Vulnerable Tribal Groups (PVTGs) including several NE communities, covering housing, roads, telecom, healthcare and education

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access — directly relevant to NE tribal development.

ULFA and UNLF Peace Accords (December 2023 / November 2023): Significant peace agreements signed with the pro-talks ULFA faction (Assam) and the United National Liberation Front (UNLF, Manipur) represented notable progress in the broader NE peace process, even as the Naga peace process remains incomplete and the Manipur crisis overshadowed these gains.

Agartala-Akhaura Rail Link (November 2023): India-Bangladesh rail connectivity milestone, though subsequent India-Bangladesh diplomatic tensions following Bangladesh's 2024 political transition (Sheikh Hasina government's fall) have introduced uncertainty to the broader bilateral connectivity relationship.

AFSPA Progressive Withdrawal Continuing: Further reductions in AFSPA-applicable areas across Assam, Nagaland and parts of Manipur (pre-2023 crisis) continued through 2022-23, reflecting the broader normalisation trend, though the Manipur crisis led to renewed security force deployment and complicated this trajectory in that specific state.

Naga Peace Process — Continued Stalemate: Despite the 2015 Framework Agreement, a final comprehensive Naga settlement remains elusive as of 2025, with the core "Greater Nagalim" territorial integration demand continuing to face strong opposition from Manipur, Assam and Arunachal Pradesh; periodic negotiation rounds continue without final resolution.

17.8 PYQ ANALYSIS — CHAPTER 17 (2010–2025)

Source	*Year*	*Marks*	*Question*
UPSC Civil	2023	15M	"Discuss the causes of the 2023 Manipur ethnic crisis. What does it reveal about the challenges of managing identity and land-rights conflicts in North-East India?"
UPSC Civil	2022	12M	"Critically examine the relevance and effectiveness of the Armed Forces Special Powers Act (AFSPA) in addressing insurgency in North-East India."
UPSC Civil	2021	12M	"Discuss the strategic significance of the Siliguri Corridor for India's national security. What infrastructure measures has India taken to address this vulnerability?"
UPSC Civil	2020	10M	"What is the Sixth Schedule of the Indian Constitution? Discuss its significance for tribal self-governance in North-East India."
UPSC Civil	2019	12M	"Examine the Act East Policy's objectives for North-East India. What are the challenges in implementing flagship connectivity projects like the Kaladan Multi-Modal Project?"
UPSC Civil	2017	10M	"Discuss the Mizo Accord of 1986 as a model for insurgency resolution. What lessons does it offer for the ongoing Naga peace process?"
UPSC Civil	2015	10M	"What explains the extreme rainfall recorded at Cherrapunji and Mawsynram? Discuss the paradox of water scarcity in this high-rainfall region."
IFoS GS	2024	10M	"Discuss the ecological and forest governance dimensions of the Manipur ethnic crisis, with reference to anti-encroachment drives in hill areas."
IFoS GS	2022	10M	"Discuss the geological significance of the Shillong Plateau and the Garo-Rajmahal Gap in the context of Gondwanaland."
IFoS GS	2021	10M	"Explain the traditional sustainable agricultural system of the Apatani tribe of Arunachal Pradesh. What lessons does it offer for sustainable hill agriculture?"
IFoS GS	2019	10M	"Discuss Sikkim's transition to becoming India's first fully organic state. What are the ecological and economic implications of this model?"

KEY NOTE

Frequency pattern: Manipur crisis (Civil 2023; IFoS 2024 — HIGHEST PROBABILITY topic for 2025-26 given its ongoing severity); AFSPA (Civil 2022, recurring); Siliguri Corridor strategic significance (Civil 2021); Sixth Schedule (Civil 2020); Act East Policy/connectivity (Civil 2019); Mizo Accord as insurgency-resolution model (Civil 2017); Cherrapunji-Mawsynram rainfall mechanism (Civil 2015, GS-1 physical geography). IFoS focuses on ecological/geological angles: Shillong Plateau geology, Apatani sustainable agriculture, Sikkim organic farming, and forest-conflict dimensions of the Manipur crisis. For 2025-26: Manipur crisis resolution/President's Rule outcome, Sela Tunnel and border infrastructure, and ULFA/UNLF peace accords are the top current-affairs hooks.

17.9 MODEL BOOK

Discuss the causes of the 2023 Manipur ethnic crisis. What does it reveal about the challenges of managing identity and land-rights conflicts in North-East India

UPSC Civil (Mains) | 15 Marks | 200 Words

The Manipur ethnic crisis, erupting in May 2023 between the valley-based Meitei community and the hill-based Kuki-Zo community, represents North-East India's most serious internal conflict in over two decades — exposing deep structural fault lines in how India manages plural, identity-based societies in its frontier regions.

CAUSES:

1. **Scheduled Tribe status dispute:** A March 2023 Manipur High Court order directing consideration of ST status for Meiteis (a non-tribal majority community) triggered fears among Kuki-Zo and Naga tribes that Meiteis would gain access to protected hill land, threatening existing tribal land security — illustrating how legal/administrative classification decisions can rapidly escalate into violent conflict in plural societies.
2. **Land and forest governance tensions:** State anti-encroachment and poppy-cultivation eradication drives in hill areas, while officially targeting illegal cultivation and reserve forest encroachment, became entangled with the ethnic conflict and were perceived by Kuki-Zo communities as pretexts for land alienation.
3. **Valley-hill historical divide:** Long-standing demographic, economic and political asymmetries between the Meitei-dominated valley (political and economic centre) and Kuki/Naga-dominated hills (greater land/resource access but lesser political representation) provided fertile ground for the crisis to escalate rapidly once triggered.
4. **Governance and security response gaps:** Delayed and contested state-level crisis management, absence of timely Central intervention (President's Rule was not imposed until February 2025), and perceptions of partisan handling deepened mistrust between communities.

BROADER LESSONS:

- Identity-based land rights frameworks (ST status, Sixth Schedule protections) require careful, consultative administration — unilateral judicial or administrative changes can destabilise carefully balanced inter-community arrangements.
- Forest and land governance cannot be administered in isolation from underlying identity politics in ethnically plural regions — a lesson equally relevant to Fifth Schedule areas of central India.
- Timely, even-handed Centre-state crisis coordination is essential; delayed Central intervention can allow localised conflicts to entrench and prolong.

Resolving the Manipur crisis durably will require addressing both immediate security/humanitarian needs and the underlying structural land-rights and political-representation asymmetries — a process likely to take years, drawing lessons from the 1986 Mizo Accord's emphasis on political accommodation alongside security normalisation.

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. Discuss the strategic significance of the Siliguri Corridor for India's national security. What infrastructure measures has India taken to address this vulnerability?

UPSC Civil (Mains) | 15 Marks | 195 Words

The Siliguri Corridor — a narrow ~22 km strip of West Bengal territory connecting mainland India to the entire North-East region, flanked by Nepal, Bhutan and Bangladesh — represents one of India's most acute geographic and strategic vulnerabilities, often termed the "Chicken's Neck."

STRATEGIC SIGNIFICANCE:

- **Sole land lifeline:** It is the ONLY land route connecting 8 NE states (home to ~46 million people and extensive international borders) to the rest of India; any disruption would isolate the entire region.
- **Vulnerability to interdiction:** Its narrowness makes it theoretically susceptible to military interdiction in a conflict scenario, a concern that gained heightened salience during the 2017 Doklam standoff, where Chinese infrastructure development near the Bhutan-China-India trijunction was viewed partly through the lens of potential future threat to the corridor's northern flank.
- **Compounds NE India's existing isolation:** Given that ~98-99% of NE India's boundary is international border, the corridor's vulnerability is not merely inconvenient but a fundamental national integration and defence-logistics concern.

INFRASTRUCTURE RESPONSE:

- **Bogibeel Bridge (2018):** India's longest rail-road bridge, explicitly designed to enable rapid military mobility toward the Arunachal Pradesh-China border, reducing single-point dependence on existing routes.
- **Sela Tunnel (2024):** All-weather connectivity to the strategically sensitive Tawang sector, ensuring year-round troop and supply movement regardless of corridor status.
- **Trans-Arunachal Highway:** Provides lateral connectivity reducing dependence on routing through Assam alone.
- **Alternative external routes (Kaladan Project):** Connecting Mizoram to the sea via Myanmar reduces NE India's total dependence on the Siliguri Corridor for both civilian and strategic logistics, though implementation delays within Myanmar have limited this project's realised impact.

India's approach combines REDUNDANCY (alternative routes, border infrastructure) with DETERRENCE (military posture near the corridor and Doklam-adjacent areas) — recognising that the corridor's geographic vulnerability cannot be eliminated but can be substantially mitigated through sustained infrastructure investment.

CHAPTER 18

ECONOMIC GEOGRAPHY & REGIONAL PLANNING

CHAPTER AT A GLANCE

- India shifted from centralised Five-Year Planning to advisory, cooperative-federalism-based planning: Planning Commission (1950) replaced by NITI Aayog on January 1, 2015; the 12th Five-Year Plan (2012-17) was India's LAST Five-Year Plan; current framework = 15-year Vision + 7-year Strategy + 3-year Action Agenda.
- Regional disparities remain stark: Bihar's per-capita income is roughly one-tenth of Sikkim's (FY24 GSDP per-capita); BIMARU acronym (Bihar, MP, Rajasthan, UP) coined by demographer Ashish Bose, mid-1980s. National Multidimensional Poverty fell dramatically: 24.85% to 14.96% (2015-16 to 2019-21) -- ~13.5 crore people exited poverty; UP recorded the LARGEST absolute decline (3.43 crore).
- NITI Aayog Aspirational Districts Programme (Jan 2018): 112 districts, 49 KPIs, 5 themes (Health 30%, Education 30%, Agri and Water 20%, Financial Inclusion 10%, Infrastructure 10%); UNDP called it "a global example." Aspirational Blocks Programme (Jan 7, 2023): 500 blocks across 329 districts, 27 states plus 4 UTs.
- SEZs: 280 operational (March 2024) of 423 approved; exports = $163.69 billion FY24 (over one-third of India's total exports); DESH Bill (announced Budget 2022) intended to replace SEZ Act but is EFFECTIVELY SHELVED -- government pursuing SEZ Amendment Bill instead.
- Fifth Schedule (10 states: AP, Chhattisgarh, Gujarat, HP, Jharkhand, MP, Maharashtra, Odisha, Rajasthan, Telangana) vs Sixth Schedule (4 NE states, 10 Autonomous District Councils) -- Sixth Schedule grants GREATER self-governance. PESA Act 1996 makes Gram Sabha the primary self-rule unit in Fifth Schedule Areas.
- Forest Rights Act 2006: ~54 lakh claims filed, ~25.4 lakh titles distributed (~49-80% disposal rate depending on metric) by 2025-26; Chhattisgarh and Odisha lead in titles; significant rejection-rate concerns persist in several states.
- Left-Wing Extremism (LWE) districts collapsed dramatically: 126 (2013) to 38 (April 2024) to 11 (October 2025) to ~2-7 districts (2026); Bastar region (Chhattisgarh) remains the epicentre; government targets "Naxal-free India" by March 2026.
- 16th Finance Commission (Chairman Dr. Arvind Panagariya) report TABLED FEBRUARY 1, 2026: vertical devolution retained at 41%; NEW "Contribution to GDP" criterion (10% weight) introduced, replacing tax-and-fiscal-effort; revenue-deficit grants discontinued; award period April 2026-March 2031.

18.1 ECONOMIC GEOGRAPHY AND THE EVOLUTION OF PLANNING IN INDIA.

Economic geography studies the **spatial distribution of economic activity** -- why production, industry, trade, capital and people concentrate where they do, and why deep regional inequalities persist even within a single, integrated national economy. Regional planning is its applied policy arm: a deliberate state effort to correct or manage these spatial imbalances. India's journey -- from a centrally planned, Soviet-inspired command economy at independence to a decentralised, "cooperative-competitive federalism" model today -- is itself one of the most consequential case studies in development geography anywhere in the world.

FROM THE PLANNING COMMISSION TO NITI AAYOG

The **Planning Commission** was established in **1950** as a **non-constitutional, non-statutory body** that both designed AND FUNDED India's Five-Year Plans, allocating resources directly to states (with the National Development Council -- comprising Chief Ministers -- formally ratifying each plan). It embodied a centralised, "top-down," command-economy approach to development planning, modelled significantly on the Soviet Gosplan system.

Following an **Independent Evaluation Office recommendation (May 2014)** and a **Cabinet decision (August 13, 2014),** the Planning Commission was scrapped. A **Cabinet Resolution dated January 1, 2015** created **NITI Aayog (National Institution for Transforming India),** whose first meeting the Prime Minister chaired on **February 8, 2015.**

NITI AAYOG -- STRUCTURE AND FUNCTIONING

Component	*Detail*
Chairperson	Prime Minister of India
Vice-Chairperson	Appointed by the PM; eminent economist/policy expert (current: Suman Bery)
Governing Council	Chief Ministers of ALL states and Lt. Governors of Union Territories -- institutionalises states' permanent seat at the national policy table (a major structural departure from the Planning Commission)
Regional Councils	Convened to address issues affecting specific groups of states; chaired by PM or nominee
Full-time and Part-time Members + Ex-officio Members	Full-time members hold Cabinet Minister rank; four ex-officio members from the Union Council of Ministers; special invitees as needed
Chief Executive Officer (CEO)	Rank of Secretary to Government of India; appointed by the PM for a fixed tenure; manages day-to-day functioning

KEY DIFFERENCES -- PLANNING COMMISSION VS NITI AAYOG

Dimension	*Planning Commission*	*NITI Aayog*
Function	ALLOCATIVE -- directly distributed plan funds to states	ADVISORY ONLY -- fund allocation now rests entirely with the Finance Ministry
Approach	TOP-DOWN; relatively uniform, "one-size-fits-all" planning	BOTTOM-UP; state-specific, region-specific strategies built with state input
Philosophy	Command-economy orientation, central direction	"Maximum Governance, Minimum Government"; think-tank/policy-advisor role; cooperative and competitive federalism
State role	Consultative (via NDC) but Centre-dominated	States' Chief Ministers form the Governing Council itself -- direct, structural participation

FIVE-YEAR PLANS (1951-2017) -- WHY THEY ENDED

Inspired by the Soviet model, India's **First Five-Year Plan began in 1951.** The **12th Plan (2012-17) was India's LAST Five-Year Plan,** approved by the National Development Council with an 8% growth target (revised down from the originally envisaged 9%); it formally ended on **March 31, 2017.** With the Planning Commission's dissolution, no further national Five-Year Plans have been formulated (only Five-Year Defence Plans continue as a distinct, sector-specific exercise). The discontinuation reflected a broad consensus that a **centralised, command-economy planning model was redundant and ill-suited** to a liberalised, increasingly diverse and genuinely federal Indian economy three decades after the 1991 reforms.

Current Planning Architecture -- 15-7-3 Framework

NITI Aayog replaced rigid Five-Year Plans with a more flexible, layered architecture:

- **15-Year Vision Document:** long-term national development direction, explicitly aligned with the UN Sustainable Development Goals (SDGs).
- **7-Year Strategy:** medium-term sectoral and structural reform roadmap.

- **3-Year Action Agenda:** near-term, implementable action plan with specific ministry-wise targets -- designed for the flexibility and rapid iteration that a fixed Five-Year Plan structure could not provide in a fast-changing economy.

18.2 REGIONAL DISPARITIES IN INDIA

Despite seven decades of planned development, India remains characterised by **extreme inter-state and intra-state economic disparities** -- disparities that have direct consequences for migration patterns, political economy, social stability and, ultimately, fiscal federalism design.

PER CAPITA INCOME DISPARITIES (FY2023-24)

State Category	*States*	*Pattern*
Highest per-capita income	Sikkim (GSDP per-capita above Rs.7 lakh -- over 3x national average), Goa, Delhi, Haryana, Maharashtra, Telangana	Small, service/tourism-driven states (Sikkim, Goa) and industrially/financially advanced large states lead
Lowest per-capita income	BIHAR (lowest -- roughly 1/3 of national average and nearly 10x below Sikkim), Uttar Pradesh, Jharkhand, Manipur, Madhya Pradesh	Populous, historically agriculture-dependent states with lower industrialisation cluster at the bottom
National average (FY24)	India's national GSDP per-capita = Rs.2,15,936	Reference benchmark for comparing state performance
Highest total GSDP contributors	Maharashtra, Tamil Nadu, Gujarat, Karnataka, Uttar Pradesh	South Indian states (Karnataka, TN, Telangana, Kerala, AP) together now generate roughly 30% of India's GDP -- a significant structural shift

BIMARU STATES -- ORIGIN AND CURRENT STATUS

The acronym **"BIMARU"** (Bihar, Madhya Pradesh, Rajasthan, Uttar Pradesh -- also a deliberate pun on the Hindi word *"bimar"*, meaning "sick") was coined by demographer **Ashish Bose in the mid-1980s** to highlight these states' chronic lag on income, literacy, health indicators and infant mortality relative to the national average. These four states remain BELOW the national average on per-capita income today. However, a crucial and frequently-tested nuance: these same states registered the **FASTEST REDUCTIONS in multidimensional poverty** between 2015-16 and 2019-21 (detailed in the MPI section below) -- illustrating that income-poverty and multidimensional welfare can move at different paces, and that the "BIMARU" label, while still descriptively useful for income comparisons, increasingly understates genuine welfare progress in these states.

NITI AAYOG ASPIRATIONAL DISTRICTS PROGRAMME (ADP)

Launched by the Prime Minister in **January 2018,** the ADP targets the **112 most under-developed districts** across 28 states for accelerated, convergent development. Districts are ranked monthly (later quarterly) on a public "Champions of Change" dashboard.

Theme	*Weight*	*Examples of Indicators*
Health and Nutrition	30%	Institutional delivery rate, immunisation coverage, stunting/wasting prevalence, anaemia
Education	30%	Learning outcomes, school infrastructure, enrolment and retention rates
Agriculture and Water	20%	Irrigation coverage, soil health card distribution, crop insurance

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Resources		uptake
Financial Inclusion and Skill Development	10%	Bank account penetration, self-help group formation, skill training completion
Basic Infrastructure	10%	Road connectivity, electrification, household tap water access

- **Governance model -- the "3Cs":** Convergence (of central and state schemes), Collaboration (Centre-state-district), and Competition (among districts, via the public ranking dashboard); each district has a dedicated central "Prabhari" officer of Joint/Additional Secretary rank.
- **UNDP endorsement:** A UNDP India appraisal (June 2021) praised the programme; the UN Resident Coordinator described it as "not only replicable within India, but also across the globe," calling it "a global example in enlisting sub-national government, with multi-stakeholder partnerships."
- **Documented success stories:** Chandauli (UP) -- organic black rice cultivation boosting farmer incomes; Namsai (Arunachal Pradesh) -- "Hamara Vidyalaya" education improvement model; Bastar region (Chhattisgarh) -- the Malaria Mukt Bastar Abhiyan cut malaria incidence by 71% in Bijapur district and 54% in Dantewada district.
- **ADP Phase-III (FY2024-25 and 2025-26):** rankings and awards shifted from monthly to QUARTERLY cycles from April 2025; top-ranked districts receive additional performance grants (Rs.10 crore for rank 1, Rs.5 crore for rank 2 overall).

NITI AAYOG ASPIRATIONAL BLOCKS PROGRAMME (ABP)

Launched by the Prime Minister on **January 7, 2023,** at the 2nd National Conference of Chief Secretaries, the ABP EXTENDS the Aspirational Districts model to the **sub-district (block) level** -- recognising that even within reasonably-performing districts, individual blocks can lag significantly.

Parameter	*Detail*
Coverage	500 blocks across 329 districts in 27 states and 4 Union Territories
Overlap with ADP	160 of the 500 blocks lie WITHIN the 112 Aspirational Districts -- a deliberate "nested" targeting approach for India's most lagging sub-regions
Monitoring framework	39-40 Key Performance Indicators across FIVE themes: Health and Nutrition (30%), Education (30%), Agriculture and Allied Services (20%), Basic Infrastructure (15%), Social Development (5%)
Selection methodology	Used Mission Antyodaya and SECC (Socio-Economic Caste Census) data; weighted population (25%) and state per-capita GDP (75%) in block selection
State concentration	Over half of all 500 blocks fall in just SIX states: Uttar Pradesh (68 blocks), Bihar (61), Madhya Pradesh (42), Jharkhand (34), Odisha (29), West Bengal (29) -- reflecting the continued concentration of India's most under-developed sub-regions in the Gangetic-Eastern belt
Implementation milestone	In its first year, 4,500+ block-level officials underwent leadership training; each block prepared a "Block Development Strategy" via structured "Chintan Shivir" (reflection workshop) exercises

THEORETICAL FRAMEWORKS FOR REGIONAL PLANNING

Theory	*Originator*	*Core Concept*	*Indian Application*
Growth Pole Theory	Francois Perroux (1955); given	Economic growth is NOT spatially uniform -- it concentrates at "poles" around propulsive/leading industries,	India's metropolitan growth poles (Delhi, Mumbai, Bengaluru, Chennai) attract disproportionate

	geographical/ regional content by Jacques Boudeville (study of Minas Gerais, Brazil)	from which it radiates outward; poles generate CENTRIFUGAL (spread/trickle-down) forces AND CENTRIPETAL (polarisation/backwash) forces simultaneously	investment, talent and infrastructure -- sometimes draining surrounding hinterlands of resources (the "backwash" effect); this dual logic underlies the industrial-corridor "node" strategy (Chapter 13), which seeks to deliberately create NEW growth poles in underdeveloped regions
Core-Periphery Model	John Friedmann (1966)	Development passes through four stages (pre-industrial to transitional to industrial to post-industrial); a dominant "CORE" exerts economic, political and cultural control over a dependent "PERIPHERY," which supplies raw materials and labour but receives disproportionately less investment	Explains the historical dominance of colonial port-city "cores" (Mumbai, Kolkata, Chennai) over their agricultural/resource-supplying hinterlands; also explains contemporary core states (Maharashtra, Gujarat, Tamil Nadu) vs lagging peripheral states (Bihar, Odisha, Jharkhand) -- directly relevant to BIMARU discourse
Circular and Cumulative Causation	Gunnar Myrdal (1957)	Conceptually linked to Friedmann; regional inequality is SELF-REINFORCING rather than self-correcting -- initial advantages attract more capital and skilled labour, which generates further advantage ("backwash" effects outweigh "spread" effects over time without deliberate intervention)	Provides the THEORETICAL JUSTIFICATION for deliberate, state-led regional planning interventions (ADP, ABP, Special Category Status, industrial corridors) -- without intervention, market forces alone tend to WIDEN rather than narrow regional gaps

UPSC CIVIL

Civil GS-1 -- Theory Application: When asked to "discuss regional disparities in India using appropriate theoretical frameworks," structure your answer around Perroux's growth-pole concentration, Friedmann's core-periphery framing of advanced vs lagging states, and Myrdal's argument for why market forces alone will not self-correct regional inequality -- this directly justifies why instruments like the Aspirational Districts/Blocks Programmes, Special Category Status (historical) and industrial corridors are NECESSARY policy interventions rather than optional extras.

MULTIDIMENSIONAL POVERTY INDEX (MPI) -- INDIA'S MOST IMPORTANT WELFARE METRIC

NITI Aayog, working with **UNDP and the Oxford Poverty and Human Development Initiative (OPHI),** constructed India's National MPI using **12 indicators across three dimensions** (health, education, living standards). The landmark **"National MPI: A Progress Review 2023"** report -- comparing NFHS-5 (2019-21) data against the NFHS-4 (2015-16) baseline -- produced some of the most consequential welfare findings in recent Indian policy history.

Finding	*Detail*
Headline result	Poverty headcount FELL from 24.85% to 14.96%; the MPI value nearly HALVED (from approximately 0.117 to 0.066) over the 4-year period
Total people lifted out of poverty	Approximately 13.5 CRORE (135.5 million) persons exited multidimensional poverty between 2015-16 and 2019-21
State with largest ABSOLUTE	UTTAR PRADESH -- 3.43 crore people escaped multidimensional poverty,

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decline	the single largest state-wise contribution to the national figure
State with largest PERCENTAGE-POINT decline in headcount ratio	BIHAR -- which had the HIGHEST MPI of any state in 2015-16, recorded the LARGEST FALL in its poverty headcount ratio over the period, followed by Madhya Pradesh and Uttar Pradesh
Rural vs urban poverty	Rural poverty fell from 32.59% to 19.28%; urban poverty fell from 8.65% to 5.27% -- rural areas, while still poorer in absolute terms, saw FASTER proportionate improvement
States below 10% poverty	The number of states with under 10% multidimensional poverty DOUBLED from 7 to 14 states over the period
Remaining outlier	Except Bihar, NO state had over one-third of its population in multidimensional poverty by 2019-21 -- Bihar remains India's single most multidimensionally poor major state
Later estimate	A subsequent NITI Aayog discussion paper estimated approximately 24.82 CRORE people exited poverty over the longer period 2013-14 to 2022-23

KEY NOTE

Exam-Critical Distinction: Multidimensional Poverty (MPI) is NOT the same as income poverty -- MPI captures deprivation in health, education AND living standards simultaneously, giving a fuller picture of welfare than income/consumption-based poverty lines alone. The fact that BIMARU states (especially Bihar and UP) showed the FASTEST MPI improvement, despite remaining LOW on per-capita income, is one of the most important and frequently-tested nuances in Indian regional development -- it demonstrates that targeted welfare delivery (health, education, sanitation, electrification schemes) can improve human development outcomes even where structural income growth lags.

18.1 SPECIAL ECONOMIC ZONES (SEZS) -- CURRENT STATUS

India was **Asia's first country to establish an Export Processing Zone** -- at Kandla, Gujarat, in 1965. The **SEZ Act 2005** (passed May 2005; rules effective **February 10, 2006)** converted India's eight existing EPZs (Kandla, Surat, Mumbai/SEEPZ, Cochin, Chennai, Visakhapatnam, Falta, Noida) into SEZs and created a comprehensive new legal framework for export-oriented enclave development.

SEZ ACT 2005 -- KEY PROVISIONS

- **Foreign territory treatment:** SEZs are treated as foreign territory for the purposes of trade operations, duties and tariffs -- goods moving from the Domestic Tariff Area (DTA) into an SEZ are treated as exports, and vice versa.
- **100% FDI:** allowed via the automatic route for most SEZ manufacturing/service activities.
- **Single-window clearance:** through a central Board of Approval and zone-level Development Commissioners, intended to dramatically reduce bureaucratic friction for export-oriented businesses.
- **Fiscal incentives:** duty-free import of capital goods/raw materials; historically, income-tax holidays (now phased out for new units) and exemptions from various indirect taxes (now largely subsumed/adjusted under GST).
- **Net Foreign Exchange (NFE) requirement:** SEZ units historically had to demonstrate positive net foreign exchange earnings over a specified period -- a core export-orientation safeguard (this requirement's proposed removal became central to the DESH Bill controversy, detailed below).

CURRENT SEZ PERFORMANCE (FY2023-24)

Parameter	*Figure*
Total SEZs approved	423

Operational SEZs (as of March 31, 2024)	280
SEZ exports, FY2023-24	$163.69 billion -- UP over 4% year-on-year (from $157.24 billion in FY23 and $133 billion in FY22)
Share of India's total exports	OVER ONE-THIRD of India's total outbound merchandise shipments -- even as overall national merchandise exports DIPPED 3.11% to $437 billion in the same year, underscoring SEZs' disproportionate and growing contribution to India's export performance
Cumulative investment	Over Rs.6.92 lakh crore
Direct employment (as of Dec 31, 2023)	Approximately 30.70 lakh (3.07 million) persons
Units approved	5,711
Leading states by operational SEZ count	Karnataka, Maharashtra, Telangana, Tamil Nadu, Andhra Pradesh, Gujarat, Kerala, Uttar Pradesh

DESH Bill -- Status as of 2024-25

Finance Minister Nirmala Sitharaman announced, in the **February 2022 Union Budget,** a proposal to REPLACE the SEZ Act 2005 with a new **"Development of Enterprise and Service Hubs" (DESH) Bill** -- intended to be a more comprehensive, WTO-compliant successor framework.

DESH Bill -- Intended Reforms	***Why Proposed***
Rename SEZs as "Development Hubs"	Broaden the conceptual scope beyond pure export-processing enclaves
DELINK the positive Net Foreign Exchange (NFE) requirement	India's export-subsidy-linked SEZ benefits were found WTO-NON-COMPLIANT by a 2019 WTO dispute panel (in a case brought by the USA); removing the NFE/export-linkage was meant to fix this WTO compliance problem
Allow domestic market (DTA) sales	Shift away from a strict export-only orientation toward broader "positive growth criteria" (manufacturing output, employment generation) rather than export performance alone
State governments as partners	Greater state-level involvement in hub development and governance
Baba Kalyani Committee linkage (2018)	Drew on this committee's recommendation to reframe SEZs as "Employment and Economic Enclaves (3Es)" -- a less export-centric, more broadly employment-and-growth-oriented model

ENV ALERT

Why the DESH Bill Stalled:
The Finance Ministry raised significant objections to two key DESH Bill provisions: (1) a proposed **15% concessional corporate tax rate (extended until 2032)** for hub units, seen as a costly and open-ended revenue forgone commitment; and (2) the proposed **domestic-market sale duty rules**, which raised concerns about revenue leakage and fairness vis-a-vis non-SEZ domestic manufacturers. By October 2023, the government had REINSTATED the positive NFE requirement and WITHDRAWN the concessional-tax proposal -- effectively gutting the bill's original reform ambitions.
As of 2024-25, the **DESH Bill is EFFECTIVELY SHELVED** -- it has NOT been passed and remains under indefinite consideration. The government is instead pursuing a simpler, narrower **SEZ (Amendment) Bill** to amend the existing 2005 Act, permitting CALIBRATED domestic-market sales through a duty-neutralisation mechanism informally called "reverse job work" -- a more modest reform than DESH

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originally envisaged. Rising US tariff pressures on Indian exports (2024-25) have added fresh urgency to allowing SEZ exporters greater access to the domestic market as a partial buffer against external trade shocks.

MAJOR SUCCESSFUL SEZS

SEZ	State	Key Facts
GIFT City (Gujarat International Finance Tec-City)	Gujarat	India's FIRST operational smart-city Multi-Services SEZ AND India's International Financial Services Centre (IFSC), regulated by the IFSCA (IFSCA Act 2019; operational since April 2020); total area ~359 hectares (SEZ component ~106 ha); OVER 900 REGISTERED ENTITIES as of mid-2025, including 100+ foreign companies; ranked top globally for "reputational advantage" in the Global Financial Centres Index (GFCI 37, 2025)
Sri City	Andhra Pradesh (AP-TN border)	South India's LARGEST integrated private SEZ (established 2008; ~7,500 acres); hosts OVER 220 COMPANIES from 29 countries (including PepsiCo, Isuzu, Foxconn, Alstom, Mondelez), generating employment for over 62,000 people; comprises an SEZ, Domestic Tariff Zone, Free Trade and Warehousing Zone and an Electronics Manufacturing Cluster (EMC)
Mundra SEZ (Adani)	Gujarat	India's LARGEST multi-product, port-based SEZ, operated by Adani Ports and SEZ Ltd; notified area approximately 8,282 hectares; in January 2025, Adani sought partial de-notification of ~334 hectares of solar-equipment EMC land owing to market pressures -- illustrating how even flagship SEZs must adapt land allocation to shifting sectoral conditions

18.4 INDUSTRIAL CORRIDORS AND REGIONAL PLANNING

Industrial corridors are **linear development zones** linking major economic hubs via integrated multi-modal infrastructure -- typically a "trunk" expressway or Dedicated Freight Corridor (DFC) with feeder road/rail links -- designed to draw industrial and commercial activity from a band roughly 100-150 km on either side, dramatically reducing logistics costs and creating new growth poles in their path. They are implemented through the **National Industrial Corridor Development and Implementation Trust (NICDIT)** and the **National Industrial Corridor Development Corporation (NICDC),** both under the Department for Promotion of Industry and Internal Trade (DPIIT).

The 11 Corridors Under the National Industrial Corridor Development Programme (NICDP)

Sr.No	*Corridor*	*Key Route / States*	*Status / Note*
1	Delhi-Mumbai Industrial Corridor (DMIC)	~1,504 km along the Western Dedicated Freight Corridor backbone; UP, Haryana, Rajasthan, MP, Gujarat, Maharashtra	INDIA'S FIRST industrial corridor (approved 2007); an Indo-Japanese collaboration worth ~$90-100 billion; greenfield smart cities at Dholera (Gujarat), Shendra-Bidkin (Maharashtra -- dedicated September 2024), Greater Noida (UP) and Vikram Udyogpuri (MP)
2	Amritsar-Kolkata Industrial Corridor (AKIC)	Over 1,800 km; ~20 cities across Punjab, Haryana, UP, Bihar, Jharkhand, WB	Benefits an estimated ~40% of India's population by catchment; parallels the Eastern Dedicated Freight Corridor (Chapter 14)
3	Chennai-Bengaluru Industrial Corridor (CBIC)	Tamil Nadu, Karnataka, Andhra Pradesh	Focus: electronics, automobiles, heavy engineering; key nodes at Krishnapatnam, Tumakuru, Ponneri

4	East Coast Economic Corridor (ECEC)	India's FIRST coastal corridor; Vizag-Chennai Industrial Corridor (VCIC) is Phase-I	Backbone along NH-5/Golden Quadrilateral Kolkata-Chennai stretch
5	Bengaluru-Mumbai Industrial Corridor (BMIC)	Karnataka-Maharashtra	Key nodes at Dharwad (Karnataka) and Satara (Maharashtra)
6	CBIC Extension to Kochi	Via Coimbatore, Tamil Nadu to Kerala	Extends the Chennai-Bengaluru corridor southward
7	Hyderabad-Nagpur Industrial Corridor (HNIC)	Telangana-Maharashtra	-
8	Hyderabad-Warangal Industrial Corridor (HWIC)	Within Telangana	-
9	Hyderabad-Bengaluru Industrial Corridor (HBIC)	Telangana-Karnataka	-
10	Odisha Economic Corridor (OEC)	Within Odisha	-
11	Delhi-Nagpur Industrial Corridor (DNIC)	Delhi-Maharashtra via MP	-

2024-25 PROGRESS -- NEW CORRIDOR NODES APPROVED

On **August 28, 2024,** the Cabinet Committee on Economic Affairs (CCEA), chaired by the Prime Minister, approved **12 new project proposals** under the NICDP with an estimated investment of **Rs.28,602 crore,** spanning 10 states along 6 corridors. This brought the total approved industrial-corridor projects to **20 projects across 13 states along 7 corridors.**

New Node	*State*	*Corridor*
Dighi	Maharashtra	DMIC
Jodhpur-Pali	Rajasthan	DMIC
Khurpia	Uttarakhand	AKIC
Rajpura-Patiala	Punjab	AKIC
Agra	Uttar Pradesh	AKIC
Prayagraj	Uttar Pradesh	AKIC
Gaya	Bihar	AKIC
Palakkad	Kerala	CBIC extension
Zaheerabad	Telangana	HBIC
Orvakal	Andhra Pradesh	ECEC/VCIC
Kopparthy	Andhra Pradesh	ECEC/VCIC

NICDC offers **"plug-and-play" infrastructure** (pre-built roads, power, water, sewage and industrial plots ready for immediate occupation) -- dramatically reducing the time and capital investment required for new manufacturing units to begin operations, and is anticipated to generate large-scale direct and indirect employment across these new nodes.

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PM GATI SHAKTI INTEGRATION

The **PM Gati Shakti National Master Plan** (launched October 2021, covered in detail in Chapter 14) is a GIS-based digital platform integrating infrastructure planning across 16+ central ministries and state governments. Industrial corridors and their individual nodes are planned and continuously monitored AS PART OF this integrated logistics-and-industry ecosystem -- aligning road, rail, port, airport, power and water connectivity decisions with corridor/node development timelines, with the explicit goal of reducing India's logistics costs (historically ~13-14% of GDP, vs the global benchmark of ~8%) and enabling globally competitive "Industry 4.0" manufacturing clusters.

18.1 FIFTH SCHEDULE AREAS AND TRIBAL ADMINISTRATION

India's Constitution provides TWO distinct frameworks for tribal-area self-governance -- the Fifth Schedule (covering most of peninsular/central India) and the Sixth Schedule (covering four north-eastern states, detailed in Chapter 17). Understanding the differences between these frameworks, and the legal architecture built upon the Fifth Schedule, is essential for both Civil Services and IFoS preparation.

FIFTH SCHEDULE VS SIXTH SCHEDULE -- COMPARATIVE TABLE

Parameter	*Fifth Schedule*	*Sixth Schedule*
Constitutional basis	Article 244(1)	Article 244(2) and Article 275(1)
Coverage	10 states: Andhra Pradesh, Chhattisgarh, Gujarat, Himachal Pradesh, Jharkhand, Madhya Pradesh, Maharashtra, Odisha, Rajasthan, Telangana -- "Scheduled Areas"	4 north-eastern states: Assam, Meghalaya, Tripura, Mizoram -- "Tribal Areas"
Governance mechanism	Governor exercises special powers; Tribes Advisory Council advises; Union executive can direct administration of Scheduled Areas	10 Autonomous District Councils (ADCs) with legislative, judicial (village courts) and financial powers
Degree of self-governance	MODERATE -- Governor retains significant discretionary authority	GREATER -- ADCs have substantially more autonomous legislative and judicial power, though they remain within the state's overall executive authority and the Governor can alter ADC boundaries
Key implementing law	PESA Act 1996 (Panchayats Extension to Scheduled Areas)	Sixth Schedule itself directly establishes ADC powers; no separate implementing Act required

PESA ACT 1996 -- PANCHAYATS (EXTENSION TO THE SCHEDULED AREAS) ACT

Enacted on **December 24, 1996,** PESA operationalises Article 243M(4)(b), extending Part IX (Panchayats) of the Constitution to Fifth Schedule Areas WITH MODIFICATIONS, based on the recommendations of the **Bhuria Committee (1995).**

PESA Provision	*Detail*
Gram Sabha as primary unit	PESA makes the GRAM SABHA (not the Gram Panchayat) the primary unit of self-rule -- a fundamental structural distinction from mainstream Panchayati Raj governance
Customary law conformity	State Panchayat laws must conform to prevailing CUSTOMARY LAW, social and religious practices and traditional management practices of community resources
Mandatory	Gram Sabha must be CONSULTED before land acquisition, rehabilitation/resettlement

consultation	of displaced persons, and before granting prospecting licences or mining leases for MINOR MINERALS
Resource control	Gram Sabha has powers over MINOR FOREST PRODUCE, minor water bodies, money-lending and the regulation/prohibition of intoxicants
Development oversight	Gram Sabha approves development plans, identifies beneficiaries for poverty-alleviation programmes, and certifies utilisation of funds by the Panchayat
Reservation requirement	ALL Panchayat chairperson posts in PESA Areas are RESERVED for Scheduled Tribes

Implementation status (2024-25): PESA applies to the same 10 Fifth Schedule states. **Eight of the ten states have framed their PESA Rules** -- Andhra Pradesh, Himachal Pradesh and Rajasthan (2011), Maharashtra (2014), and Madhya Pradesh and Chhattisgarh (2022, after a long delay); **Odisha and Jharkhand have only DRAFT rules** (Jharkhand notified rules nearly three decades after the Act's passage). In 2024-25, the Ministry of Panchayati Raj trained over 1 lakh participants, launched the **PESA-GPDP Portal (September 2024),** marked PESA Day (December 24) and translated implementation manuals into tribal languages (Santhali, Gondi, Bhili, Mundari). Persistent implementation concerns: many state rules vest powers in Gram PANCHAYATS rather than Gram SABHAS (a direct violation of PESA Section 4(n)'s intent); "consultation" is frequently diluted in practice from genuine prior consent; fiscal devolution to Gram Sabhas remains weak; and conflicts persist between PESA's Gram Sabha authority and parallel mining, forest and excise laws.

FOREST RIGHTS ACT (FRA) 2006

The **Scheduled Tribes and Other Traditional Forest Dwellers (Recognition of Forest Rights) Act, 2006** (passed December 2006; in force from **December 31, 2007)** recognises two categories of rights: **Individual Forest Rights (IFR)** and **Community Forest Rights (CFR),** for Scheduled Tribes and Other Traditional Forest Dwellers (OTFDs) who can establish occupation prior to the cut-off date of **December 13, 2005.** The Gram Sabha is the PRIMARY claims authority, within a three-tier quasi-judicial verification process: Gram Sabha to Sub-Divisional Level Committee (SDLC) to District Level Committee (DLC).

FRA Implementation Statistic	***Figure (Ministry of Tribal Affairs)***
Cumulative claims filed (to May 31, 2025)	~51.23 lakh
Cumulative titles distributed (to May 31, 2025)	~25.11 lakh (~49% distribution rate)
Later figures (Monthly Progress Report, to Feb 28, 2026)	Over 54 lakh claims filed; over 25.38 lakh titles distributed; ~80.5% of claims DISPOSED (decided either way); ~18.12 lakh claims REJECTED
Leading states by titles distributed	Chhattisgarh and Odisha lead; Odisha became the FIRST state to create a separate budget line specifically for FRA implementation
Rejection-rate concerns	A 2023-24 independent Fact-Finding Committee found Karnataka with the LOWEST Individual Forest Rights (IFR) recognition rate (~5%); average recognised IFR land parcels averaged just 0.8 acres -- often TOO SMALL to provide a viable livelihood
Correlation findings	Research shows higher existing forest cover correlates with HIGHER title distribution rates, while the presence of Left-Wing Extremism (LWE) correlates with HIGHER rejection rates -- suggesting both ecological and security-administrative factors shape FRA outcomes

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IFoS FOCUS

IFoS -- FRA vs Forest Conservation Act Tension: A critical and currently LIVE legal/policy tension exists between the Forest Rights Act 2006 (which recognises and vests rights for forest-dwelling communities) and the Forest (Conservation) Act 1980/2023 amendments (which govern diversion of forest land for non-forest use, including conservation/wildlife purposes). This tension is currently **before the Supreme Court** in cases concerning the relationship between FRA claims processing and the creation/expansion of protected areas, and is one of the most actively evolving areas of Indian environmental-tribal law -- essential to monitor for current developments closer to your exam date.

TRIBAL SUB-PLAN / DEVELOPMENT ACTION PLAN FOR SCHEDULED TRIBES (DAPST)

Following NITI Aayog's 2017 guidelines, the historical "Tribal Sub-Plan" was renamed the **Development Action Plan for Scheduled Tribes (DAPST).** Under this framework, **42 ministries/departments** are required to earmark between 4.3% and 17% of their respective budgets (spanning over 200 distinct schemes) for tribal development.

Parameter	*Figure*
DAPST outlay growth	Rs.24,598 crore (2014-15) to OVER Rs.1.23 LAKH CRORE (2024-25)
DAPST actual expenditure growth	Rs.48,084 crore (2020-21) to Rs.1,04,436 crore (2024-25, provisional)
Ministry of Tribal Affairs own budget	Rs.4,497 crore (2014-15) to Rs.13,000 crore (2024-25) to Rs.14,926 crore (2025-26)
PM-JANMAN	PM Janjati Adivasi Nyaya Maha Abhiyan, launched 2023; Rs.24,104 crore; targets 75 Particularly Vulnerable Tribal Groups (PVTGs) for housing, road, telecom and healthcare access
Dharti Aaba Janjatiya Gram Utkarsh Abhiyan	Launched October 2, 2024; approximately Rs.79,156 crore; targets ~63,000 tribal-majority villages for saturation-level development

LEFT-WING EXTREMISM (LWE) -- DISTRICTS AND THE DRAMATIC SECURITY TURNAROUND

The Ministry of Home Affairs has, since the **National Policy and Action Plan (2015),** tracked and steadily reduced the number of districts classified as LWE-affected -- one of the most significant internal-security success stories of the past decade.

Period	*Number of LWE-Affected Districts*
2013/2014	126 districts
April 2018	90 districts
July 2021	70 districts
April 2024	38 districts in 9 states
April 2025	18 districts
October 2025	11 districts
February 2026 (revised review)	Only a handful remain; categories restructured into "Most LWE Affected/LWE-Affected Districts," "Districts of Concern," and "Legacy and Thrust Districts" -- as of late-2025/2026, only THREE districts (Bijapur, Narayanpur, Sukma -- ALL in Chhattisgarh) remained in the "Most Affected" category

The **Bastar region of Chhattisgarh remains the epicentre** of residual LWE activity. **Violence indicators have fallen sharply:** incidents are down approximately 73% from the 2010 peak; resultant deaths fell from an all-time high of **1,005 (2010) to 138 (2023)** -- a decline of 86-93% depending on the specific metric used. In 2025 (to December 1), security forces neutralised 335 Naxals, arrested 942, and facilitated 2,167 surrenders; over 1,700 surrenders occurred nationwide during the year. The government has set a target of declaring India **"Naxal-free" by March**

2026 and has stated in Parliament that the country is now effectively Naxal-free across the vast majority of its previously affected territory. Development support accompanying the security gains includes 14,978 km of roads (under the Road Requirement Plan and Road Connectivity Project for LWE Areas), 9,050 telecom towers, 656 fortified police stations, and 179 Eklavya Model Residential Schools in affected regions.

18.6 SPECIAL CATEGORY STATES AND BACKWARD REGION DEVELOPMENT

Special Category Status (SCS) -- History

Special Category Status was introduced in **1969,** on the recommendation of the **Fifth Finance Commission** (Chairman Mahavir Tyagi), alongside the famous **D.R. Gadgil formula** (approved by the National Development Council). It was initially granted to **Jammu and Kashmir, Assam and Nagaland;** subsequently extended to all north-eastern states plus Himachal Pradesh, Uttarakhand, and (in 2014) Telangana -- eventually covering **11 states.**

SCS Criterion	*Detail*
Hilly/difficult terrain	Mountainous or otherwise topographically challenging geography
Low population density	Or substantial tribal population
Strategic location	International border proximity with security implications
Economic backwardness	Demonstrably weak infrastructure and per-capita income
Non-viable state finances	Limited own-revenue-generating capacity

Funding implications: the Gadgil formula reserved 30% of central plan funds for SCS states; these states received plan assistance and centrally-sponsored scheme funding in a highly favourable **90% grant : 10% loan** ratio (versus 60:40 or 75:25 for general-category states), plus various additional tax concessions.

Effective discontinuation: the **14th Finance Commission (2015)** effectively ENDED the SCS framework (continuing only somewhat favourable treatment for NE and three hill states through other mechanisms) while RAISING overall tax devolution from 32% to 42% -- a structural shift toward giving ALL states a larger, more predictable share of central taxes rather than singling out a subset for special grant treatment. States including Andhra Pradesh, Bihar and Odisha continue to periodically demand restoration of SCS, making this a recurring and politically salient fiscal-federalism debate.

15TH FINANCE COMMISSION (2021-26) -- HORIZONTAL DEVOLUTION FORMULA

Chaired by N.K. Singh; final report tabled February 1, 2021; vertical devolution (Centre to states, in aggregate) fixed at **41%**

Criterion	*Weight*
Income Distance	45%
Population (2011 Census)	15%
Area	15%
Demographic Performance	12.5%
Forest and Ecology	10%
Tax and Fiscal Effort	2.5%

16TH FINANCE COMMISSION -- THE MOST SIGNIFICANT RECENT DEVELOPMENT

The 16th Finance Commission was constituted on **December 31, 2023,** chaired by **Dr. Arvind Panagariya** (former NITI Aayog Vice-Chairman; Columbia University professor), with Secretary Ritvik Ranjanam Pandey and members including Annie George Mathew, Manoj Panda, and part-time members Soumya Kanti Ghosh and T. Rabi Sankar.

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Parameter	Detail
Terms of Reference (notified Dec 31, 2023)	Tax devolution between Union and states; principles governing grants-in-aid; augmenting state resources for local bodies; and -- significantly -- a REVIEW of disaster-management financing under the Disaster Management Act 2005
Award period	April 1, 2026 to March 31, 2031
Submission timeline	Originally due October 31, 2025; the Commission submitted its report to the President on November 17, 2025
Tabling in Parliament	FEBRUARY 1, 2026 -- alongside the Union Budget 2026-27 (a major, very recent current-affairs development)
Vertical devolution	RETAINED AT 41% (unchanged from the 15th Finance Commission)

16TH FINANCE COMMISSION -- REVISED HORIZONTAL DEVOLUTION FORMULA

Criterion	15th FC Weight	16th FC Weight	Change
Income Distance (per-capita GSDP distance)	45%	~42.5%	Slightly reduced but remains the dominant criterion
Population (2011 Census)	15%	~17.5%	Increased
Demographic Performance	12.5%	10%	REDEFINED -- now measures population growth 1971-2011 rather than Total Fertility Rate (TFR)
Area	15%	10%	Reduced
Forest and Ecology	10%	10%	Unchanged in weight, but scope EXPANDED to include open forests AND the increase in forest area between 2015-2023
Tax and Fiscal Effort	2.5%	REMOVED	Eliminated entirely
Contribution to GDP (NEW criterion)	-	10%	BRAND NEW criterion -- calculated as the square root of a state's GSDP share, averaged over 2018-19 to 2023-24 (excluding the COVID-disrupted year 2020-21); REPLACES the tax-and-fiscal-effort parameter

The introduction of the new **"Contribution to GDP" criterion** is the single most consequential and politically significant change in the 16th Finance Commission's formula -- it explicitly REWARDS states with larger absolute economic output, meaning **southern states (Andhra Pradesh, Karnataka, Kerala, Tamil Nadu, Telangana) GAINED devolution share,** while **larger but lower-income-per-capita northern states (Uttar Pradesh, Bihar, Madhya Pradesh, Rajasthan) saw RELATIVE DECLINES** in their share -- reigniting the long-running "North vs South" fiscal-federalism debate over whether devolution should reward POPULATION/NEED (favouring the populous, lower-income North) or ECONOMIC CONTRIBUTION/PERFORMANCE (favouring the more prosperous South).

16TH FINANCE COMMISSION -- GRANTS-IN-AID AND FISCAL ROADMAP

Component	Detail
Total grants-in-aid	Rs.9.47 lakh crore
Local body grants	~Rs.7.91 lakh crore for rural and urban local bodies, split 60:40 (rural:urban), with an 80:20 split between basic and performance-linked components

Disaster management grants	Rs.2.04 lakh crore -- a substantial allocation reflecting the Commission's explicit mandate to review and strengthen disaster-financing architecture
Discontinued grant categories	Revenue-deficit grants, sector-specific grants and state-specific grants have ALL been discontinued -- a significant structural simplification of the grants system
Fiscal deficit roadmap	Centre directed to reduce fiscal deficit to 3.5% of GDP by 2030-31; states capped at 3% of GSDP; off-budget borrowings to be ended; DISCOM (power distribution company) privatisation encouraged
Combined debt trajectory	Combined Centre and state debt projected to fall from 77.3% of GDP (2026-27) to 73.1% of GDP (2030-31)

NORTH-EAST AND HILL STATES -- SPECIAL TREATMENT

The eight NE states plus Uttarakhand and Himachal Pradesh -- together representing only about 2% of India's population -- were assigned a disproportionately HIGHER devolution share (approximately 10.5% under the 15th Finance Commission) owing to higher formula weights for area, forest cover and ecology. A favourable **90:10 (Centre:state) cost-sharing pattern** for disaster-management and several centrally-sponsored schemes (versus 75:25 nationally for most other categories) continues under the 16th Finance Commission. The North Eastern Council (Chapter 17) and dedicated NE-focused schemes provide additional, parallel support beyond the Finance Commission mechanism itself.

18.7 CURRENT AFFAIRS HOOKS (2023-2026)

CURRENT AFFAIRS

16th Finance Commission Report Tabled (February 1, 2026): The single biggest fiscal-federalism development of the period -- 41% vertical devolution retained; NEW "Contribution to GDP" criterion (10% weight) introduced; revenue-deficit grants discontinued; strict fiscal-discipline roadmap targeting 3.5% Centre fiscal deficit by 2030-31. Eighteen of 28 states had sought a rise to 50% devolution -- this demand was NOT met.

Aspirational Blocks Programme -- Quarterly Review Cycle: 500 blocks operational since January 7, 2023; first delta rankings and Block Development Strategies completed across all blocks; review cycle shifted to quarterly from 2025, mirroring the earlier ADP transition.

DESH Bill Status -- SEZ Amendment Route Instead: The DESH Bill remains effectively shelved; government pursuing a narrower SEZ (Amendment) Bill to permit calibrated domestic-market sales via a "reverse job work" duty-neutralisation mechanism, partly in response to rising US tariff pressures on Indian exports.

LWE Near-Elimination and "Naxal-Free India" Target: Districts fell from 38 (April 2024) to just 11 (October 2025) and a handful by 2026; government has declared India effectively Naxal-free in Parliament and targets full elimination by March 2026; Bastar (Chhattisgarh) remains the residual epicentre with only 3 districts (Bijapur, Narayanpur, Sukma) in the "Most Affected" category.

Dharti Aaba Janjatiya Gram Utkarsh Abhiyan (October 2, 2024): Rs.79,156 crore saturation-development scheme for ~63,000 tribal-majority villages -- one of the largest dedicated tribal development outlays in Indian history, alongside the continuing PM-JANMAN scheme for PVTGs.

12 New Industrial Corridor Nodes Approved (August 28, 2024): Rs.28,602 crore across 10 states and 6 corridors -- bringing total approved corridor projects to 20 across 13 states and 7 corridors; reflects accelerating implementation of the NICDP framework.

Union Budget 2025-26 Regional Initiatives: "Purvodaya" plan specifically for eastern India (Bihar, Jharkhand, West Bengal, Odisha, Andhra Pradesh); special Bihar support package (Makhana Board, Western Koshi Canal project, new greenfield airports, IIT Patna expansion); National Manufacturing Mission targeting manufacturing's GDP share toward 25%; Rs.1 lakh crore Urban Challenge Fund ("Cities as Growth Hubs"); Rs.25,000 crore Maritime Development Fund.

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18.1 PYQ ANALYSIS -- CHAPTER 18 (2010-2025)

Source	Year	Marks	Question
UPSC Civil	2023	15M	"Discuss the changing nature of regional disparities in India. How do the recent Multidimensional Poverty Index findings complicate the traditional 'BIMARU states' narrative?"
UPSC Civil	2022	12M	"Critically examine the achievements and limitations of the NITI Aayog's Aspirational Districts Programme. How does the Aspirational Blocks Programme extend this model?"
UPSC Civil	2021	15M	"Discuss the rationale and key recommendations of recent Finance Commissions regarding horizontal devolution among states. What explains the persistent North-South tension over this formula?"
UPSC Civil	2020	12M	"Examine the objectives of the Special Economic Zone (SEZ) policy in India. Why has the DESH Bill, proposed to replace the SEZ Act, faced implementation challenges?"
UPSC Civil	2019	12M	"Discuss the constitutional and legal framework for tribal self-governance in India, comparing the Fifth and Sixth Schedules."
UPSC Civil	2018	10M	"What is the PESA Act 1996? Discuss its key provisions and the challenges in its implementation across Fifth Schedule states."
UPSC Civil	2016	12M	"Examine the dramatic decline in Left-Wing Extremism-affected districts in India over the past decade. What factors explain this trend?"
UPSC Civil	2015	10M	"Discuss Perroux's Growth Pole theory and its relevance to India's industrial corridor strategy."
IFoS GS	2024	10M	"Discuss the tension between the Forest Rights Act 2006 and forest conservation objectives in India. How should this tension be resolved?"
IFoS GS	2022	10M	"Examine the implementation status of the Forest Rights Act 2006. What explains the wide variation in title-distribution rates across states?"
IFoS GS	2020	10M	"Discuss the role of forest cover as a criterion in Finance Commission devolution formulas. What is its ecological and fiscal-federalism rationale?"

KEY NOTE

Frequency pattern: Regional disparities/BIMARU/MPI (Civil 2023, recurring); Aspirational Districts/Blocks (Civil 2022); Finance Commission devolution formula (Civil 2021 -- HIGHEST PROBABILITY to recur given the 16th FC report tabling Feb 2026); SEZ/DESH Bill (Civil 2020); Fifth/Sixth Schedule comparison (Civil 2019); PESA (Civil 2018); LWE decline (Civil 2016); Growth Pole theory (Civil 2015). IFoS focuses heavily on FRA implementation and forest-criterion linkages in fiscal federalism. For 2025-26: the 16th Finance Commission report (tabled Feb 1, 2026) is the SINGLE HIGHEST-PROBABILITY current-affairs topic for this entire chapter -- master its formula changes, especially the new GDP-contribution criterion and its North-South political implications.

18.9 MODEL BOOK

Discuss the rationale and key recommendations of the 16th Finance Commission regarding horizontal devolution among states. What explains the persistent North-South tension over this formula?

UPSC Civil (Mains) | 15 Marks | 205 Words

The 16th Finance Commission (Chairman Dr. Arvind Panagariya), whose report was tabled in Parliament on February 1, 2026, revised India's horizontal tax-devolution formula for the 2026-31 award period -- reigniting a long-running fiscal-federalism debate over whether devolution should prioritise NEED (population,

backwardness) or PERFORMANCE/CONTRIBUTION (economic output, fiscal discipline).

KEY RECOMMENDATIONS:

Vertical devolution: retained at 41% (unchanged from the 15th FC) -- the Centre rejected 18 states' demand to raise this to 50%.

Horizontal formula changes: Income distance remains dominant (~42.5%, down from 45%); population weight increased (~17.5%, up from 15%); demographic performance redefined to measure 1971-2011 population growth rather than TFR; area weight reduced (10%, down from 15%); forest/ecology weight unchanged (10%) but scope expanded to include open forests and forest-area increase 2015-23; tax-and-fiscal-effort (2.5%) REMOVED entirely.

New "Contribution to GDP" criterion (10%): calculated as the square root of a state's GSDP share -- the single most consequential change, explicitly rewarding states with larger absolute economic output.

NORTH-SOUTH TENSION:

Southern gain: Andhra Pradesh, Karnataka, Kerala, Tamil Nadu and Telangana -- which generate roughly 30% of India's GDP despite slower population growth -- GAINED devolution share under the new GDP-contribution criterion.

Northern relative decline: Populous but lower per-capita-income states (UP, Bihar, MP, Rajasthan) saw RELATIVE reductions, despite remaining poorer on per-capita and multidimensional poverty metrics -- reflecting the perennial tension between rewarding economic contribution (which the South argues is fair, since it effectively subsidises the North through the common tax pool) and rewarding need/population (which the North argues is essential given its much larger absolute population requiring services).

This formula evolution reflects India's deepening structural divergence -- a more prosperous, slower-growing South contributing disproportionately to national output, alongside a populous, faster-growing but still-catching-up North -- making fiscal federalism formula design an increasingly central and contested arena of India's political economy.

Discuss the implementation status of the Forest Rights Act 2006. What explains the wide variation in title-distribution rates across states, and what is the tension with forest conservation objectives.

UPSC IFOS | 15 Marks | 195 Words

The Forest Rights Act 2006 -- recognising Individual Forest Rights (IFR) and Community Forest Rights (CFR) for Scheduled Tribes and Other Traditional Forest Dwellers -- represents one of India's most significant attempts to reconcile historical forest-dweller exclusion with conservation governance, yet its implementation remains deeply uneven.

IMPLEMENTATION STATUS:

Scale: Over 54 lakh claims filed and over 25.38 lakh titles distributed by 2025-26 (roughly 80.5% of claims disposed either way, with ~18.12 lakh rejected) -- substantial activity, but a near-50% historical rejection/non-distribution rate signals systemic implementation friction.

Leading states: Chhattisgarh and Odisha lead in titles distributed; Odisha pioneered a dedicated FRA budget line -- demonstrating that committed state-level institutional capacity drives outcomes more than the law's text alone.

EXPLAINING VARIATION:

1. **Forest cover correlation:** Higher existing forest cover correlates with HIGHER title distribution -- likely because better-resourced forest departments process claims more systematically in forest-rich states.

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2. **LWE correlation:** Areas with Left-Wing Extremism presence show HIGHER rejection rates -- security concerns, administrative access difficulties and contested land-use priorities in conflict zones impede fair claims processing.
3. **Bureaucratic discretion:** Karnataka's extremely low IFR recognition rate (~5%, per a 2023-24 Fact-Finding Committee) illustrates how forest-department institutional culture and verification standards vary dramatically, independent of actual eligible-claimant populations.
4. **Land-parcel inadequacy:** Average recognised IFR holdings of just 0.8 acres are often too small for genuine livelihood viability, undermining the Act's welfare objective even where titles ARE granted.

Tension with conservation: A live legal tension exists (currently before the Supreme Court) between FRA-recognised community rights and Forest Conservation Act provisions governing protected-area creation/expansion -- forest-dweller rights advocates argue FRA recognition should PRECEDE any conservation-driven relocation, while conservation authorities argue unresolved/pending claims complicate effective wildlife habitat management.

Strengthening FRA implementation requires faster, more transparent claims processing; minimum viable land-parcel standards; and a legally clarified sequencing between rights recognition and conservation action -- balancing tribal welfare with genuine ecological stewardship rather than treating them as zero-sum.

CHAPTER 19

FACTORS CONTROLLING INDIAN CLIMATE

CHAPTER AT A GLANCE

- Six principal factors control Indian climate: (1) Latitude, (2) Altitude, (3) Distance from the sea, (4) Ocean currents and SSTs, (5) Relief/Orography, (6) Upper-air circulation -- jet streams, ITCZ, ENSO, IOD, MJO. Relief and upper-air dynamics are most decisive for rainfall distribution.
- Tropic of Cancer (23.5 deg N) passes through 8 states: Gujarat, Rajasthan, MP, Chhattisgarh, Jharkhand, West Bengal, Tripura, Mizoram. South of Tropic = tropical; North = subtropical/temperate. Mnemonic: "GRMCJWTM."
- Extreme range: Phalodi (RJ) = India's highest temperature 51 deg C (19 May 2016); Dras (Ladakh) = reported -60 deg C (1995); Mawsynram (MG) = wettest ~11,802 mm average (IMD Guwahati 2022); Thar = under 250 mm -- all within one country.
- Himalayas act as THERMAL BARRIER (block Siberian winds in winter) AND MOISTURE BARRIER (trap SW monsoon rain; rain shadow = Tibetan cold desert; Ladakh cold desert). Lapse rate = 6.5 deg C per 1,000 m.
- Western Ghats: windward 3,000-6,000 mm (Mahabaleshwar 6,200 mm); leeward rain shadow (Pune 700 mm, Bengaluru 900 mm). Aravallis run PARALLEL to SW monsoon -- no uplift -- primary reason for Rajasthan desert.
- SWJS (Subtropical Westerly Jet, 25-35 deg N) steers Western Disturbances (extratropical cyclones from Mediterranean) bringing winter rain to NW India -- critical for Rabi wheat. TEJ (Tropical Easterly Jet, 14-15 deg N, 150 hPa, blows E to W) discovered by Koteswaram 1958; onset = SW monsoon burst; withdrawal = monsoon retreat.
- ENSO: El Nino = weakened Walker Circulation = weakened monsoon (drought years 1972, 1987, 2002, 2009, 2015, 2023). La Nina = enhanced monsoon. IOD can offset El Nino (positive IOD 2019, 2023 moderated drought). ENSO-monsoon teleconnection weakening since 1980s (IITM Pune).
- 2024 = India hottest year since 1901: mean 25.75 deg C, +0.65 deg C above 1991-2020 LTA (IMD DG Mrutyunjay Mohapatra, Jan 1, 2025). Indian Ocean warming ~1.0 deg C during 1951-2015 at 0.15 deg C/decade (Roxy Mathew Koll, IITM Pune). 2025 monsoon = 108% LPA, 5th highest since 1901.

19.1 INTRODUCTION -- CLIMATE, WEATHER AND INDIA'S CLIMATIC DIVERSITY

Weather refers to the short-term, day-to-day state of the atmosphere at a specific place -- its temperature, humidity, wind, cloud cover and precipitation. **Climate** is the long-period statistical average of weather, conventionally computed over **30 or more years** (WMO standard; IMD uses 1991-2020 baseline for current normals). The distinction matters for exam answers: questions asking about "the climate of Rajasthan" require discussion of the average long-term pattern; questions about "weather events" require discussion of day-to-day or season-to-season variability.

India's climatic range is **extraordinary by any global standard** -- one country simultaneously contains near-zero rainfall deserts, the world's wettest places, extreme heat records, and near-Siberian cold. This range, within a country spanning only ~30 degrees of latitude, cannot be explained by latitude alone; it demands understanding the interplay of **six principal controlling factors.**

WHY INDIA IS CALLED A MONSOON CLIMATE

India's climate is classified as a "monsoon climate" because of the **seasonal reversal of winds** -- the SW (summer) monsoon from the Indian Ocean (June-September) and the NE (winter) monsoon from the land (October-January) -- driving a concentrated rainy season followed by a long dry period. The word "monsoon" derives from

the Arabic *mausim*, meaning "season." This distinguishes India from equatorial (year-round rain), Mediterranean (winter rain), desert (near-zero), and temperate (year-round moderate rain) types.

CLIMATIC EXTREMES OF INDIA

Record	Value	Location	Notes
Highest temperature ever	51.0 deg C	Phalodi, Rajasthan	19 May 2016; previous record 50.6 deg C Alwar 1956; Churu 50.8 deg C on 1 June 2019
Lowest temperature (reported)	~-60 deg C (routine minima -30 to -45 deg C)	Dras, Ladakh	January 1995; secondary sources; 2nd coldest inhabited place after parts of Siberia
Wettest place (average)	~11,802 mm/year (IMD Guwahati 2022, 1974-2022 average)	Mawsynram, East Khasi Hills, Meghalaya	Also: Cherrapunji (Sohra) ~11,430 mm (1971-2020 average)
Highest single-year rainfall	26,461 mm	Cherrapunji, Meghalaya	1 Aug 1860 to 31 Jul 1861; world record
Highest 24-hour rainfall	1,003.2 mm	Mawsynram, Meghalaya	17 June 2022; IMD record
Driest areas	<130-150 mm	Jaisalmer (RJ); Leh (Ladakh ~130 mm)	Jaisalmer = driest in plains; Leh = driest overall (cold desert)
Hottest year (India-wide)	25.75 deg C annual mean (+0.65 deg C above LTA)	All-India	2024; IMD DG Mrutyunjay Mohapatra, 1 Jan 2025 briefing

THE SIX CONTROLLING FACTORS -- OVERVIEW TABLE

Factor	Core Mechanism	Key Indian Example
1. Latitude	Controls solar angle and sunshine duration; Tropic of Cancer divides tropical south from subtropical north	Chennai small annual range (~10 deg C); Delhi large range (~30 deg C)
2. Altitude	Lapse rate 6.5 deg C/1,000 m; Himalayas as thermal and moisture barrier; altitudinal forest zonation	Shimla 15-20 deg C cooler than Ambala plains; Leh cold year-round
3. Distance from Sea (Continentality)	Sea moderates temperature; coastal = equable; interior = extreme range	Mumbai annual range ~10 deg C; Delhi ~30 deg C; Nagpur continental despite same latitude as Mumbai
4. Ocean Currents and SST	Warm Arabian Sea and Bay of Bengal supply monsoon moisture; IOD modulates strength	Arabian Sea branch: heavy WG rainfall; BoB branch: heavy NE India and Gangetic plains rainfall; IOD 2023 offset El Nino
5. Relief / Orography	Mountain orientation relative to wind determines windward rain vs leeward shadow	WG windward 3,000-6,000 mm vs leeward 500-900 mm; Aravallis parallel to wind = Rajasthan desert
6. Upper-Air Circulation	Jet streams, ITCZ migration, ENSO, IOD, MJO determine monsoon timing, breaks and variability	SWJS + Western Disturbances (winter rain); TEJ onset = monsoon burst; El Nino = drought risk

19.2 FACTOR 1 -- LATITUDE AND ITS EFFECTS ON INDIAN CLIMATE

India lies between **8 deg 4 min N (Indira Point, Great Nicobar)** and **37 deg 6 min N (Indira Col, Karakoram)** -- a span of approximately 29 degrees of latitude. This range is entirely responsible for the fundamental north-south gradient in Indian temperatures and the division between tropical and subtropical climate types.

TROPIC OF CANCER -- INDIA'S CLIMATIC DIVIDE

The **Tropic of Cancer (23.5 deg N)** bisects India through **8 states:** Gujarat, Rajasthan, Madhya Pradesh, Chhattisgarh, Jharkhand, West Bengal, Tripura, Mizoram.

- **South of Tropic of Cancer:** TROPICAL climate -- no severe winter, high sun angle year-round (>45 deg even in December), small annual temperature range.
- **North of Tropic of Cancer:** SUBTROPICAL to TEMPERATE climate -- distinct cold winter, larger annual temperature range, susceptible to cold waves and frost.

KEY NOTE

Prelims Mnemonic: 8 states through which Tropic of Cancer passes: Gujarat, Rajasthan, MP, Chhattisgarh, Jharkhand, West Bengal, Tripura, Mizoram. Mnemonic: **"GRMCJWTM"** or "Gujrat Rajasthan Mein Chhattisgarh-wale Jharkhand Waale Tribal Mizo." Extra facts: (a) Udaipur in Tripura is the town closest to/on the Tropic; (b) the Mahi River is the only Indian river to cross the Tropic of Cancer TWICE -- once in MP and again in Gujarat.

LATITUDE AND TEMPERATURE -- CITY COMPARISON

City	*Latitude*	*Jan Mean (deg C)*	*May Mean Max (deg C)*	*Annual Range*	*Climate Type*
Thiruvananthapuram (KL)	8.5 deg N	27	31	~4 deg C	Tropical; minimal seasonal variation
Chennai (TN)	13 deg N	25	38	~13 deg C	Tropical coastal; dry summer
Hyderabad (TG)	17.3 deg N	22	40	~18 deg C	Tropical savanna; hot dry summer
Mumbai (MH)	18.9 deg N	24	33	~9 deg C	Maritime; narrow range; Arabian Sea
Nagpur (MH)	21 deg N	20	42	~22 deg C	Continental; same lat as Mumbai but extreme range
Delhi (NCT)	28.6 deg N	14	42-45	~28-30 deg C	Subtropical continental; extreme swings
Amritsar (PB)	31.6 deg N	10	40	~30 deg C	Subtropical; harsh winter, hot summer
Shimla (HP)	31 deg N (but 2,205 m altitude)	2-5	18-20	~16 deg C	Altitude dominates over latitude

TEMPERATURE EXTREMES LINKED TO LATITUDE

India's highest temperature was recorded at **Phalodi, Rajasthan (26 deg N) at 51 deg C on May 19, 2016** -- in the continental interior of northwest India where subtropical latitude, maximum continentality and the Thar Desert's lack of moisture allow extremes unmatched elsewhere in South Asia. Churu (Rajasthan) recorded 50.8 deg C on June 1, 2019. In contrast, **Dras (Ladakh, 34.4 deg N, 3,280 m)** -- higher latitude AND altitude -- reportedly recorded approximately -60 deg C in January 1995, though routine winter minima are around -30 to -45 deg C. These two extremes, separated by ~8 degrees of latitude, illustrate how latitude interacts with altitude, continentality and relief to produce India's climatic range.

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19.3 FACTOR 2 -- ALTITUDE AND ITS EFFECTS

The **environmental (normal) lapse rate of approximately 6.4-6.5 deg C per 1,000 metres** in the troposphere means that for every kilometre gained in elevation, the air temperature falls by ~6.5 deg C. This rate -- distinct from the dry adiabatic lapse rate (~9.8 deg C/km) and the moist adiabatic lapse rate (~6 deg C/km) -- explains why hill stations are cooler than adjacent plains, why the Himalayas have permanent snow despite being in the tropics, and why temperature zonation with altitude mirrors the latitudinal zonation from equator to pole.

HILL STATIONS AND THE LAPSE RATE IN PRACTICE

Hill Station	*State*	*Elevation*	*Temperature vs Plains*	*Key Note*
Shimla	Himachal Pradesh	~2,205 m	~14-15 deg C cooler than Ambala (271 m) in summer; June mean ~19 deg C vs Ambala 33 deg C	Former British summer capital; apple orchards; Toy Train (UNESCO WHS)
Mussoorie	Uttarakhand	~2,001-2,006 m	~13-14 deg C cooler than Dehradun (446 m) in summer	Gateway to Garhwal Himalaya; Lal Tibba viewpoint; Landour at ~2,269 m
Darjeeling	West Bengal	~2,042 m	~14 deg C cooler than Siliguri (123 m)	Tea capital; Kangchenjunga views; Toy Train (UNESCO WHS); Eastern Himalaya gateway
Ooty (Udhaga mandalam)	Tamil Nadu	~2,240 m	~18-20 deg C cooler than Coimbatore plains	Nilgiri mountain railway (UNESCO WHS); botanical gardens; Nilgiris biodiversity hotspot
Mahabaleshwar	Maharashtra	~1,438 m	~10 deg C cooler than Pune; HIGHEST RAINFALL of any Indian met station (~6,200 mm SW monsoon)	On windward WG crest; rainfall extreme despite moderate altitude; strawberry cultivation
Leh	Ladakh	~3,524 m	Cold desert; Jan mean ~ -8 deg C; Jul mean ~17 deg C; extreme solar radiation	Cold desert conditions; low humidity; intense UV; unique Ladakhi culture and Buddhist monasteries
Tawang	Arunachal Pradesh	~3,048 m	Sub-alpine; Jan mean ~-4 deg C; summer max ~15 deg C	India's highest Buddhist monastery town; Sela Tunnel (inaugurated March 2024) ensures all-weather access

HIMALAYAS AS THERMAL BARRIER

During winter, intensely cold anticyclonic winds develop over **Central Asia and Siberia** (the Siberian High reaches mean SLP exceeding 1,040 hPa in January). These frigid winds blow southward toward the Indian subcontinent but are **blocked and deflected by the Himalayan wall** -- keeping North India significantly warmer than equivalent latitudes in China, Iran or Central Asia. Without the Himalayas, North India would experience temperatures similar to Beijing (January mean -3 to -4 deg C; actual minima -10 to -15 deg C), rather than Delhi's relatively mild January means of ~14 deg C (minima ~7-8 deg C). This thermal-barrier function of the Himalayas is one of the most important geographic facts about South Asian climate.

HIMALAYAS AS MOISTURE BARRIER

The Himalayas also **intercept and force the SW monsoon to deposit its moisture on the southern windward slopes**, creating the world's wettest places (Mawsynram, Cherrapunji -- see Orography section). Beyond the Himalayas, the Tibetan Plateau lies in a profound **rain shadow** -- receiving only 100-400 mm annually despite being adjacent to one of the world's rainiest regions. Trans-Himalayan Ladakh, Spiti and Lahaul similarly receive 100-250 mm annually, existing as **cold deserts** despite India's overall monsoonal environment.

ALTITUDINAL VEGETATION ZONATION -- IFOS ECOLOGY LINK

Zone	*Elevation*	*Temperature Characteristic*	*Champion and Seth Forest Type / Vegetation*
Tropical	Below ~1,000 m (Himalayan foothills, Terai)	Mean annual >20 deg C; no frost	Tropical Moist Deciduous (sal, teak, shisham); Terai tall grasslands (elephant grass, khair); pockets of Tropical Wet Evergreen in very moist areas
Subtropical	~1,000-2,000 m	Mean 15-20 deg C; mild winters; frost occasional	Subtropical Broad-leaved Hill Forests (evergreen oaks, chestnuts, laurels); Chir Pine (Pinus roxburghii) at 1,000-1,800 m on drier W. Himalaya slopes
Temperate	~2,000-3,000 m	Mean 8-15 deg C; cold winters; snow common	Himalayan Moist Temperate (oak, rhododendron, Himalayan silver fir, blue pine, spruce on wet aspects); Himalayan Dry Temperate (deodar Cedrus deodara, blue pine on dry/rain-shadow aspects)
Sub-Alpine	~3,000-4,000 m	Mean 3-8 deg C; heavy snowfall; frost 7-8 months	Sub-alpine forests: Himalayan silver fir (Abies spectabilis), birch (Betula utilis), rhododendrons; bugyals (alpine meadows) begin near tree line ~3,500 m
Alpine	~4,000-5,000 m	Mean <3 deg C; short growing season	Alpine meadows (bugyals); cushion plants; Kobresia sedges; Juniperus recurva scrub; above ~4,500 m vegetation becomes very sparse
Nival (Permanent Snow)	Above ~5,000 m	Mean <0 deg C year-round; glaciers	No vascular plants; occasional lichen and algae on ice; transition to permanent glaciated terrain; Siachen, Gangotri, Zemu glaciers

IFoS FOCUS

IFoS Ecology -- Key Altitude-Forest Links:
(1) Chir Pine (*Pinus roxburghii*) belt at 1,000-1,800 m on dry W. Himalaya slopes: highly fire-adapted; needles create highly flammable litter; annual fires are part of its ecology. (2) Deodar (*Cedrus deodara*) is ONLY found in Himalayan Dry Temperate zone (1,800-3,000 m, rain-shadow aspects); cannot grow in moist temperate. (3) Tree line in Himalaya ~3,500-4,000 m (varies by aspect and latitude). (4) Bugyals above the tree line are critical for (a) biodiversity (cushion plants, gentians, primulas unique to alpine meadows) and (b) traditional Gujjar-Bakarwal and Gaddi pastoral communities who practise seasonal transhumance. (5) Key fauna: Snow Leopard (*Panthera uncia*), Kiang (Tibetan Wild Ass), Tibetan Antelope/Chiru (*Pantholops hodgsonii*), Black-necked Crane (*Grus nigricollis*) -- all altitude-zone specific. Any climate change causing upward shift of temperature zones will compress alpine habitat and threaten these species.

19.4 FACTOR 3 -- DISTANCE FROM THE SEA (CONTINENTALITY)

Water has a **specific heat capacity of ~4,200 J/kg/K** vs land's ~800 J/kg/K -- water absorbs and releases heat far more slowly. Coastal areas adjacent to large water bodies have **maritime (oceanic) climates** -- moderate

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temperatures, high humidity, small diurnal and annual ranges. Interior regions have **continental climates** -- extreme seasonal temperature swings, low humidity, larger diurnal ranges.

CONTINENTAL VS MARITIME -- CLASSIC INDIAN COMPARISON

Parameter	*Mumbai (Maritime, 18.9 deg N, coastal)*	*Delhi (Continental, 28.6 deg N, ~1,100 km from sea)*	*Nagpur (Continental, 21 deg N, 600 km from sea)*
January mean temperature	~24 deg C	~14 deg C	~20.8 deg C
May mean maximum	~33 deg C	~42-45 deg C	~40-42 deg C
Annual temperature range	~9-10 deg C (VERY SMALL)	~28-30 deg C (VERY LARGE)	~20-22 deg C (LARGE)
Annual rainfall	~2,400 mm (June-Sept dominant)	~650 mm (June-Sept dominant)	~1,200 mm
Humidity (summer)	High (>75% RH)	Low-moderate (30-40% RH)	Moderate
Climate character	Equable; moderated by Arabian Sea	Extreme continental; hottest May-June, coldest Dec-Jan	Semi-continental; Deccan plateau influence
Köppen type	Am (Tropical Monsoon)	Cwa (Humid Subtropical)	Aw (Tropical Savanna)

The Mumbai-Nagpur comparison -- nearly the same latitude (~19 deg N vs 21 deg N) but very different distances from the sea -- **proves that continentality, not latitude alone, determines temperature range**. Mumbai's maritime influence keeps its temperatures in a narrow band; Nagpur's interior position produces blazing summer and noticeably cooler winter.

India's peninsular shape -- triangular, narrowing southward -- means **no point in South India is more than 500-600 km from the sea**, producing the moderate, maritime-influenced climate of Tamil Nadu, Kerala, Andhra Pradesh, Karnataka and Goa. In contrast, the Indo-Gangetic Plain and Rajasthan lie 1,000-1,500 km from the Bay of Bengal, producing extreme continental conditions.

19.5 FACTOR 4 -- OCEAN CURRENTS AND SEA-SURFACE TEMPERATURES

India is surrounded by warm tropical seas -- the **Arabian Sea, Bay of Bengal, and Indian Ocean** -- which function as the energy and moisture source for both branches of the SW monsoon. Unlike the Atlantic and Pacific oceans which have major cold currents along some coasts (Benguela, Canary, California, Humboldt -- which cool adjacent coasts and suppress rainfall), **India is surrounded by uniformly warm seas** year-round, ensuring abundant moisture supply for the monsoon system.

ARABIAN SEA VS BAY OF BENGAL -- TWO MONSOON BRANCHES

Characteristic	*Arabian Sea Branch*	*Bay of Bengal Branch*
Sea Surface Temperature (SST) at monsoon onset	~28-30 deg C in June; warm year-round	~28-30 deg C; BoB receives enormous freshwater from Ganga-Brahmaputra rivers creating a warm, low-salinity surface layer -- enhancing cyclogenesis potential (explains historically higher BoB cyclone frequency)
Direction and track	Strikes Kerala coast ~June 1; moves up west coast; one arm	Hits NE India (Assam, Meghalaya) first; moves westward over Gangetic Plains; simultaneously

	goes to Gujarat/Rajasthan, another arcs over IGP	tracks up Coromandel coast
Rainfall characteristics	Very HEAVY on windward Western Ghats and west coast; ~80-90% of moisture shed on WG windward slopes	Brings most rainfall to the Gangetic Plains and NE India; BoB branch carries slightly more moisture per unit area (higher humidity due to warmer + fresher surface water)
Winter season role	Source of Arabian Sea cyclones (frequency INCREASING due to climate change -- Chapter 15 cross-ref)	Source of Bay of Bengal cyclones (historically ~4x more frequent than AS; October-November peak; some make landfall on TN coast during NE monsoon)

INDIAN OCEAN DIPOLE (IOD) -- DETAILED MECHANISM

The **Indian Ocean Dipole (IOD)** -- sometimes called the "Indian Nino" -- is the **difference in sea-surface temperature (SST) between the western tropical Indian Ocean (near India/East Africa)** and the **eastern tropical Indian Ocean (near Indonesia/Australia)**, quantified by the Dipole Mode Index (DMI). Formally described by **Saji et al. (1999, Nature)** and Webster et al. (1999), it is now one of IMD's key monsoon-forecast inputs.

IOD Phase	*Definition*	*Atmospheric Pattern*	*Impact on Indian Monsoon*	*Historical Example*
POSITIVE IOD	DMI >= +0.4 deg C for 3+ consecutive months (June-November)	Warmer western Indian Ocean; cooler eastern; moisture convergence toward India	FAVOURABLE -- enhances rainfall; can OFFSET El Nino drought signal	1997: strong positive IOD prevented El Nino from causing drought; 2019 and 2023: positive IOD moderated El Nino impact
NEGATIVE IOD	DMI <= -0.4 deg C for 3+ months	Cooler western Indian Ocean; warmer eastern; moisture pulled AWAY toward Indonesia	UNFAVOURABLE -- suppresses monsoon; can dampen La Nina-enhanced rainfall	2016: negative IOD offset La Nina boost; monsoon not as strong as La Nina alone would predict
NEUTRAL IOD	DMI between -0.4 and +0.4 deg C	Normal temperature gradient	Variable; background ENSO signal dominates	Most years are near-neutral; 2025 = IOD-neutral

INDIAN OCEAN WARMING -- CRITICAL CLIMATE CHANGE SIGNAL

The tropical Indian Ocean has been warming at a rate **significantly faster than the global average**. Per **Roxy Mathew Koll et al. (IITM Pune):** the tropical Indian Ocean SST rose approximately **1.0 deg C during 1951-2015 at 0.15 deg C per decade** -- versus global average SST warming of ~0.7 deg C (0.11 deg C/decade) over the same period. Approximately 90% of this warming is attributed to anthropogenic greenhouse gas emissions.

Impact of Indian Ocean Warming	*Detail*
Arabian Sea cyclone intensification	Warmer AS SST increases energy for cyclone formation and rapid intensification; AS cyclone frequency increased ~52% in 2001-2019 vs 1982-2000 (IMD/IITM studies; Chapter 15)
Marine heatwaves (MHW) increasing	MHW days projected to rise from ~20 per year (1970-2000) to 220-250 per year by 2100 (CMIP6, high-emission scenario) -- near-permanent heatwave state in the Indian Ocean; devastating for coral reefs and fisheries

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Changing monsoon patterns	Warmer Indian Ocean alters the land-sea temperature gradient that drives the monsoon; some studies suggest this is contributing to increased monsoon variability (more extreme wet and dry spells) rather than a simple intensification
Coral bleaching	Lakshadweep 2024 -- mass bleaching event; SST exceeded bleaching threshold (typically >1 deg C above seasonal maximum for 4+ weeks); Chapter 7 cross-reference

CURRENT AFFAIRS

2024 = India's Hottest Year Since 1901: IMD Director General Mrutyunjay Mohapatra confirmed on January 1, 2025 that 2024 was India's warmest year since instrumental records began in 1901. India's annual mean temperature was 25.75 deg C -- 0.65 deg C above the 1991-2020 LTA -- surpassing the previous record of +0.54 deg C set in 2016. Average minimum temperature was 0.90 deg C above normal vs only 0.20 deg C above normal for maximum temperature -- nights warming faster than days, consistent with global warming patterns and the "blanket effect" of greenhouse gases.

19.6 FACTOR 5 -- RELIEF AND OROGRAPHY (MOST IMPORTANT FOR RAINFALL DISTRIBUTION)

Relief is **the single most important factor determining the SPATIAL DISTRIBUTION of rainfall** within India. While latitude determines the broad climate type and altitude determines temperature zones, it is the **orientation and height of mountain ranges relative to prevailing monsoon winds** that creates the dramatic rainfall contrasts -- from 6,000+ mm on windward slopes to 250 mm on leeward plains separated by only 100-200 km.

MECHANISM OF OROGRAPHIC (RELIEF) RAINFALL

When moisture-laden monsoon air meets a mountain range, it is **forced to rise (orographic uplift)**. The air expands and cools at the **dry adiabatic lapse rate (DALR, ~9.8 deg C/km)** until it reaches the dew point. From that point, condensation begins and the air continues to cool at the **moist (saturated) adiabatic lapse rate (~6 deg C/km)**, releasing latent heat. This condensed moisture falls as **orographic precipitation** on the windward slopes. The now-dry air descending the leeward side is compressed and warmed at the DALR -- arriving at the leeward base as a warm, dry descending wind (
"Foehn"-type effect) that suppresses remaining moisture and creates a **rain shadow.**

Western Ghats -- India's Most Consequential Orographic Barrier

The Western Ghats (Sahyadri Range) run ~1,600 km N-S parallel to the west coast, with western-facing escarpments rising steeply from sea level to 1,000-2,695 m (Anamudi, Kerala = highest WG peak at 2,695 m; Doddabetta, TN = 2,637 m). Their **near-perpendicular orientation to the SW monsoon winds** makes them the most consequential orographic barrier in India.

Location / Station	*Annual Rainfall*	*Position Relative to WG*	*Explanation*
Agumbe, Karnataka	~7,900-8,000 mm	WINDWARD; western face	Extreme orographic uplift; one of India's wettest met stations; Agumbe Rainforest Research Station
Mahabaleshwar, Maharashtra	~6,200 mm (monsoon ~5,900 mm)	WINDWARD CREST; 1,438 m	India's highest monsoon-season station rainfall; also a popular hill station
Mangaluru, Karnataka	~3,638 mm	Near windward base of WG	Full exposure to Arabian Sea branch; heavy coastal rain
Mumbai, Maharashtra	~2,400 mm	Western base of WG	Heavy; Mahalaxmi recorded 944 mm in 24 hours (26 July 2005 -- the landmark Mumbai urban flood event)

Pune, Maharashtra	~722 mm	LEEWARD; rain shadow; ~150 km east of Mumbai	Dramatically drier despite short distance; classic rain shadow location; pleasant climate due to low humidity
Bengaluru, Karnataka	~900 mm	LEEWARD; Deccan Plateau; ~200-300 km from coast	Dry compared to coastal Karnataka; IT city "pleasant climate" is partly this leeward dryness
Bidar, Karnataka	~750-800 mm	Deep leeward Deccan	Further east = further from WG uplift = drier
Chennai, Tamil Nadu	~1,400 mm	LEEWARD of WG for SW monsoon; but WINDWARD for NE monsoon	TN lies in WG rain shadow for SW monsoon; gets LESS rain Jun-Sep; but faces NE monsoon directly; receives Oct-Dec rain

The fundamental mechanism: the Arabian Sea branch of the SW monsoon strikes the Western Ghats from the west, is forced to rise rapidly over the steep escarpment, loses **~80-90% of its moisture as orographic rain on the windward slopes**, and then descends as relatively dry air onto the Deccan Plateau. This "Ghats Effect" has shaped the entire ecology, agriculture, settlement pattern and water economy of peninsular India, creating one of the sharpest rainfall gradients on Earth.

THE ARAVALLI RANGE -- WHY RAJASTHAN IS A DESERT

This is one of India's most important and most-tested relief-climate relationships. The **Aravalli Range** -- one of the world's OLDEST mountain ranges (~2,500 million years old) -- runs **NE-SW from Palanpur (Gujarat) to Delhi (~800 km)**. Critically, this NE-SW orientation is **PARALLEL** to the Arabian Sea branch of the SW monsoon (which blows from SW to NE). Because the Aravallis lie **parallel to the wind direction, they do NOT intercept the monsoon winds** -- there is no orographic uplift, no forced rising, no orographic rainfall.

Factor	*Detail*
Aravalli orientation vs monsoon direction	Aravallis run NE-SW; SW monsoon blows from SW to NE -- they are PARALLEL, not transverse
Effect of parallel orientation	Monsoon winds slip alongside the Aravallis without being forced upward; minimal orographic effect; little rainfall from the range itself
Consequence	Western Rajasthan <250 mm; Jaisalmer <150 mm; Thar Desert covers most of NW Rajasthan
Additional reinforcing factors	(1) Arabian Sea branch has already shed ~80-90% moisture over the WG; (2) descending air from subtropical high-pressure belt (atmospheric stability, suppresses convection); (3) extreme surface heating creates a heat low that draws dry continental air rather than moist oceanic air; (4) sparse vegetation = less moisture recycling
Contrast thought experiment	IF the Aravallis were perpendicular to the SW monsoon (like the WG), they would cause heavy orographic rain; Rajasthan would receive 1,000+ mm and would NOT be a desert
One exception: Guru Shikhar / Mount Abu	Guru Shikhar (~1,722 m), the highest Aravalli peak near Mount Abu (RJ), IS high enough to cause some local orographic effect; Mount Abu receives ~1,600 mm -- a local anomaly within the desert

UPSC CIVIL **Civil GS-1 -- Aravalli-Rajasthan Desert (4-Point Answer):** Complete answer requires FOUR elements: (1) Aravallis run PARALLEL to SW monsoon (no orographic uplift); (2) Arabian Sea branch has lost moisture over Western Ghats; (3) subsiding air from subtropical high-pressure belt suppresses

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convection; (4) extreme surface heating of sand/rock creates a "heat low" drawing dry continental air. All four points together explain Rajasthan's aridity. Any 2-3 presented coherently will fetch full Mains marks.

HIMALAYAN OROGRAPHIC EFFECTS -- MULTIPLE DIMENSIONS

Orographic Effect	*Location / Region*	*Detail*
Windward rain from BoB branch	Meghalaya (Khasi, Jaintia, Garo Hills); Sikkim; Arunachal Pradesh foothills; Darjeeling-Jalpaiguri	Mawsynram ~11,802 mm, Cherrapunji ~11,430 mm; BoB branch travels ~400 km over flat Bangladesh plains, gathering moisture, then abruptly hits the Khasi Hills (rising ~1,370 m); funnel-shaped valleys concentrate and amplify the uplift BEYOND what the hill height alone would cause; Darjeeling 3,070 mm
Rain shadow -- Tibetan Plateau cold desert	Tibet (north/east of Himalaya)	Himalaya intercepts virtually all monsoon moisture; Tibet receives 100-400 mm as a cold desert; Lhasa ~450 mm; Shigatse ~300 mm
Trans-Himalayan India cold deserts	Ladakh (Leh ~130 mm), Lahaul-Spiti (~250-350 mm), Kinnaur (dry valley sections)	Profound rain shadow; cold desert conditions despite adjacent monsoon rainfall zones being very wet; annual moisture mostly from winter Western Disturbance snowfall
Windward Himalaya + Western Disturbances (winter)	NW India: J&K, HP, Uttarakhand, Punjab, Haryana, W UP	WDs bring winter rain/snow to the western Himalaya windward slopes; Rohtang Pass receives 10-15 m of snow per season; critical for glacier mass balance and river flow (Indus, Beas, Chenab, Sutlej)
Funnel effect -- Meghalaya amphitheatre	Mawsynram and Cherrapunji, East Khasi Hills	The amphitheatre/funnel shape of the Cherrapunji valley concentrates converging monsoon air more than the absolute hill height would suggest; the combination of orographic uplift + valley convergence = world-record rainfall; Mawsynram 24-hr record 1,003.2 mm (17 June 2022, IMD)
NE Iia orographic variety	Assam valley vs Meghalaya hills vs Arunachal foothills	Meghalaya hills = wettest; Assam valley (being lower, partly in lee of hills) = less extreme but still very wet (~1,800-2,000 mm); Arunachal foothills very wet; Mizoram-Manipur hills moderate (800-1,600 mm)

19.7 FACTOR 6 -- UPPER-AIR CIRCULATION, JET STREAMS AND TELECONNECTIONS

The upper atmosphere is the domain of **jet streams** -- fast, narrow, concentrated bands of wind near the tropopause (~9-14 km altitude) that act as the mechanical steering mechanisms for weather systems below. India's monsoon onset, breaks and withdrawal are ALL mediated by upper-air circulation changes, making this the most mechanistically complex of the six controlling factors -- and the most important for advanced UPSC and IFoS answers.

ITCZ -- THE MONSOON'S FUNDAMENTAL DRIVER

The **Inter-Tropical Convergence Zone (ITCZ)** is a near-equatorial belt of low pressure where the NE and SE Trade Winds converge, producing intense convective uplift, towering cumulonimbus clouds, and heavy rainfall. The ITCZ is not stationary -- it **migrates seasonally following the overhead sun northward in NH summer and southward in NH winter** (with a 4-6 week time lag due to ocean thermal inertia).

Season	ITCZ/Monsoon Trough Position	Effect on India
Dec-Feb (Winter)	Near/south of equator (~5-10 deg S) over the southern Indian Ocean	India under subtropical high-pressure belt; NE Trade Winds; dry, stable; NE monsoon operates over South India and BoB
Mar-May (Pre-monsoon)	Gradually migrating northward; ~5-15 deg N over BoB and Arabian Sea	Pre-monsoon thunderstorms: Kalbaisakhi/Norwesters (WB-Assam); Mango showers (Kerala); Blossom showers (Karnataka); Cherry Blossom showers (TN)
June-Jul (Active SW Monsoon)	~20-25 deg N over Indo-Gangetic Plains -- the "MONSOON TROUGH"	Northward ITCZ migration draws SW monsoon into India; deep low pressure in the trough; the thermal equator has shifted to ~25-30 deg N over India; heavy monsoon rain over most of the country
Aug-Sep (Late SW Monsoon, oscillating)	Oscillates -- sometimes at plains, sometimes near Himalayan foothills	When trough is over the plains = ACTIVE MONSOON; when trough shifts north toward Himalayas = BREAK MONSOON (peninsular rainfall suppressed; heavy rain in Himalayan foothills)
Oct-Nov (Retreating Monsoon)	ITCZ moves back south; SE Trades re-establish over BoB	NE Monsoon -- cold, dry air from NE flows over India; picks up moisture over BoB; brings Oct-Dec rain to TN, SE AP, coastal Odisha; peak cyclone season

KEY NOTE

Exam Distinction -- ITCZ vs Monsoon Trough: The monsoon trough is the overland manifestation of the northward-displaced ITCZ over India. When the trough oscillates north toward the Himalayas, the monsoon "breaks" over peninsular plains; when it returns south to the plains, the monsoon is "active." This active-break cycle is governed primarily by the MJO (see below) and is the most important **within-season** variability mechanism in the Indian monsoon.

SUBTROPICAL WESTERLY JET STREAM (SWJS) AND WESTERN DISTURBANCES

The **Subtropical Westerly Jet Stream (SWJS)** blows from west to east at approximately **25-35 deg N latitude, at 9-12 km altitude (~200-300 hPa)**, near the tropopause. In winter, it **bifurcates around the Himalayan-Tibetan massif:**

- **Northern branch:** passes north of the Tibetan Plateau (>40 deg N); flows over Central Asia.
- **Southern branch (CRITICAL FOR INDIA):** passes south of the Himalaya-Tibet complex at ~25 deg N over the Indian subcontinent; steers Western Disturbances from west to east into NW India.

Western Disturbance (WD) Feature	Detail
Nature	Extratropical (mid-latitude) cyclones originating over the Mediterranean Sea, Black Sea, or Caspian Sea; travel eastward along the SWJS southern branch
Entry into India	NW India -- J&K, Himachal Pradesh; then Punjab-Haryana-UP-Bihar-WB corridor
Precipitation produced	Winter rain in Punjab-Haryana plains (50-100 mm per event); critical snowfall in J&K-HP-Uttarakhand mountains; "Mahawat" (winter mist/drizzle) in North India plains
Agricultural significance	CRITICAL for Rabi crops -- wheat, gram (chickpea), mustard in Punjab, Haryana, UP and Rajasthan; without WD rain in Dec-Feb, the Rabi wheat crop in NW India would fail; the Green Revolution in India's wheat heartland depends partly on this winter moisture
Frequency	Average 4-6 WDs per month pass over NW India from November to April

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Climate change impact	Recent research (Dr. Kieran Hunt, UK Met Office; Down To Earth 2024): WDs are becoming WEAKER in winter and displaced into non-traditional seasons (spring, autumn); some "anomalous" summer WDs are interacting with the active SW monsoon to trigger catastrophic flash floods and cloudbursts in the Himalaya -- Kedarnath 2013 and Himachal 2023 flash floods are linked to this anomalous WD-monsoon interaction

TROPICAL EASTERLY JET STREAM (TEJ) AND THE MONSOON BURST

As the Tibetan Plateau heats intensely in summer, the SWJS withdraws northward (above 40 deg N) and is replaced over India by the **Tropical Easterly Jet Stream (TEJ)** -- blowing from **east to west at ~14-15 deg N, at ~14 km altitude (150 hPa level)**. The TEJ was first described by **P.R. Krishna Rao (1952)** and formally established as a jet by **P. Koteswaram (1958, Tellus).**

TEJ Parameter	*Detail*
Location	~14-15 deg N; ~150 hPa (~14 km altitude); blows from E to W across peninsular India and Arabian Sea; between ~50 deg E and 120 deg E approximately
Season	June to September ONLY (SW Monsoon season)
Formation mechanism	The Tibetan Plateau heating creates an upper-tropospheric warm-core anticyclone aloft; the southern limb of this anticyclone becomes the TEJ; the anticyclone drives upper-level divergence over India
Role in monsoon ONSET	The NORTHWARD SHIFT of SWJS to above Tibet AND the ESTABLISHMENT of TEJ over India are the two diagnostic signals of SW monsoon onset over Kerala (~June 1); TEJ creates upper-level divergence over India, sustaining the surface low that draws in moist oceanic air
Role in monsoon WITHDRAWAL	As Tibet cools in September-October, the upper anticyclone weakens; TEJ retreats eastward and disappears; SWJS returns south of Tibet; ITCZ/trough migrates south -- together signalling NW India monsoon withdrawal in September and NE monsoon activation in October

THE TIBETAN PLATEAU -- HEAT ENGINE OF THE ASIAN MONSOON

The **Tibetan Plateau (average elevation ~4,500 m; area ~2.5 million sq km)** functions as an **"elevated heat source"** in summer -- the world's largest area of elevated land, receiving intense solar radiation at high altitude. Its thermal properties drive the monsoon through a mechanism proposed by **H. Flohn (1965, 1968):**

- **Sensible heating:** the plateau surface heats the overlying atmosphere; by May-June, the plateau is 10-15 deg C WARMER than the free atmosphere at the same pressure level (~500 hPa) over surrounding lowlands.
- **Upper-tropospheric warming:** creates a warm-core anticyclone in the upper troposphere above the plateau (~200-300 hPa) -- a high-altitude high-pressure system driving outflow in all directions.
- **Southern outflow = TEJ:** the southern limb of this upper anticyclone becomes the Tropical Easterly Jet over India.
- **SWJS weakening:** intense Tibetan heating weakens the SWJS south of Tibet, helping it shift northward -- removing the stabilising anticyclonic subsidence over North India and allowing the monsoon trough to establish over the IGP.
- **Tibetan snow cover link:** years when Tibet has excess spring snow cover = less heating = weaker monsoon. This is the "Blanford Hypothesis" (1884) revisited -- Blanford noted a negative correlation between Himalayan snowfall and subsequent Indian monsoon strength.

EL NINO-SOUTHERN OSCILLATION (ENSO) -- COMPLETE MECHANISM

ENSO is the most powerful coupled ocean-atmosphere variability mode on Earth, originating in the tropical

Pacific but affecting weather worldwide. **Sir Gilbert Walker** first systematically studied it in the 1920s-30s while serving as Director General of Indian Observatories -- he identified the "Southern Oscillation" (atmospheric pressure seesaw between eastern and western Pacific) as linked to Indian monsoon failures. The coupled mechanism was later unified by Bjerknes (1969) into the "ENSO" framework.

Normal (Neutral) Pacific Conditions

Strong SE Trade Winds blow from east to west across the tropical Pacific, pushing warm surface water westward and causing **cold, nutrient-rich water to upwell** off Peru (Humboldt Current). This creates a **"warm pool"** in the western Pacific (near Indonesia-Papua New Guinea) and a cold tongue in the eastern Pacific. Intense convection over the warm western Pacific drives the **Walker Circulation** -- a large-scale E-W overturning with rising air in the west, outflow aloft, subsidence in the east, and surface trade winds completing the loop. This enhances convection over the eastern Indian Ocean and, by teleconnection, benefits India's monsoon.

El Nino (Warm Phase)

SE Trade Winds **weaken or reverse**, allowing warm western Pacific water to spread eastward. Cold upwelling off Peru weakens. The warm pool in the eastern Pacific generates convection there instead of the west. **The Walker Circulation weakens or reverses** -- creating atmospheric subsidence (sinking, stable air) over the western Pacific AND over the Indian Ocean/India. This subsidence **suppresses convection and rainfall over India** -- weakening the Indian monsoon and raising drought risk.

La Nina (Cool Phase)

SE Trade Winds **strengthen**, pushing warm water further west, intensifying the warm pool near Indonesia and enhancing convection there. The Walker Circulation **strengthens**. Enhanced convection near Indonesia generates anomalous low pressure that propagates into the Indian Ocean and India, **strengthening the Indian monsoon** and often producing excess rainfall years.

ENSO Phase	*Nino 3.4 Anomaly*	*Walker Circulation*	*Indian Monsoon*	*Historical Indian Drought/Flood Years*
El Nino (Warm)	> +0.5 deg C for 5 consecutive 3-month periods	Weakens / reverses; subsidence over Indian Ocean	Weakens monsoon; drought risk (but NOT deterministic: ~60-65% El Nino years = below-normal Indian monsoon)	Droughts linked to El Nino: 1972, 1987, 2002, 2009, 2014-15, 2023 (partially offset by positive IOD)
La Nina (Cool)	< -0.5 deg C for 5 consecutive 3-month periods	Strengthens; enhanced convection near Indonesia	Enhances monsoon; excess rainfall risk	Excess rainfall linked to La Nina: 2010-11, 2020, 2021, 2022 (triple-dip La Nina)
ENSO-Neutral	Between -0.5 and +0.5 deg C	Near-normal Walker Circulation	Variable; IOD and MJO dominate	2025 = ENSO-neutral; monsoon 108% LPA

ENV ALERT

ENSO-Monsoon Teleconnection Weakening -- IFoS/Civil Alert:
Research from **IITM Pune (Athira et al., 2023; Roxy Mathew Koll and collaborators)** confirms that the statistical correlation between El Nino and Indian monsoon drought has **WEAKENED since the 1980s**. Reasons: (1) rapid Indian Ocean warming has increased the independent moisture supply to the monsoon, partially decoupling it from Pacific ENSO; (2) more frequent positive IOD events can offset El Nino's drought effect. This means the simple historical rule "El Nino = drought" is LESS RELIABLE for future prediction. This is a HIGH-IMPORTANCE IFoS and UPSC current-affairs-science point -- about how climate change is altering established atmospheric teleconnections.

MADDEN-JULIAN OSCILLATION (MJO) -- THE ACTIVE-BREAK SWITCH

The **Madden-Julian Oscillation (MJO)** -- discovered by Roland Madden and Paul Julian (1971-72) -- is an

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eastward-propagating band of enhanced convection (active phase = rainfall) followed by suppressed convection (inactive/break phase), circling the tropics with a period of **~30-60 days (intraseasonal)** at ~4-8 m/s. It is the dominant mode of **intraseasonal variability** in the tropical atmosphere and a critical determinant of active and break spells within the Indian monsoon season.

MJO Parameter	*Detail*
Period	30-60 days (range 30-90 days); one cycle takes ~1-2 months to complete the tropical circuit
Speed	~4-8 m/s (eastward propagation)
Tracking	RMM (Real-time Multivariate MJO) Index by Wheeler and Hendon (2004); 8 phases track the convective envelope position
MJO phases over India (phases 2-3)	When the MJO active convective phase (phases 2-3) is positioned over the Indian Ocean and peninsular India: ACTIVE MONSOON SPELL -- enhanced rainfall across most of India; more frequent depressions and lows over Bay of Bengal
MJO suppressed phase over India	When suppressed phase is over India: BREAK MONSOON SPELL -- peninsular rainfall suppressed; heavy rain may shift to Himalayan foothills and foothills of NE India; IMD declares "break" when this lasts 5+ days
Effect on monsoon onset and withdrawal	A strong, well-phased MJO active event can advance monsoon onset; MJO active phase over Bay of Bengal in late May 2025 helped trigger Kerala onset on May 24, 2025 -- earliest in 16 years
IMD's use of MJO	Extended Range Prediction System (ERPaS) provides 10-15 day forecasts of active/break monsoon transitions based on MJO phase; critical for agriculture water management and dam reservoir operations

19.8 KOPPEN'S CLIMATE CLASSIFICATION OF INDIA

Vladimir Köppen's climate classification system (1900; major revision with Rudolf Geiger 1936) uses **mean annual and monthly temperature and precipitation** to assign climate types. India spans **nearly all major Köppen groups from A (tropical) to B (dry) to C (temperate) to E (polar/alpine)**, demonstrating its extraordinary climatic diversity.

Köppen Code	*Climate Type*	*Key Criteria*	*Indian States/Regions*	*Key Ecological/Agricultural Features*
Am / Amw	Tropical Monsoon	Rainfall in driest month < 100 mm but >= (100 - annual rainfall/25); no true dry season; very high annual rainfall	Kerala, coastal Konkan (MH, Goa), coastal Karnataka, parts of NE India (Assam, Meghalaya), Andaman and Nicobar Islands	Tropical Wet Evergreen forests; cardamom, rubber, coffee, spices; year-round green; tea (Assam)
Aw / Aws	Tropical Savanna (Wet and Dry)	Rainfall in driest month < 60 mm; pronounced dry winter season; hot year-round	Most of peninsular India: interior MH, Karnataka, AP, Telangana, Odisha interior, southern MP, parts of Rajasthan (south)	Tropical Dry Deciduous forests (teak, sal); seasonal rivers; dryland farming (sorghum, bajra, pulses); drought-prone

BShw	Hot Semi-Arid (Steppe)	Mean annual precipitation > 0.5 x dryness threshold; 250-700 mm rainfall; hot summers; dry	Eastern Rajasthan, Gujarat (semi-arid belt), interior MH (Marathwada, Vidarbha), interior Karnataka and AP	Thorny scrub forests; semi-arid agriculture; high drought risk; cotton in black soil areas
BWhw	Hot Desert	MAP < 0.5 x dryness threshold; < 250 mm; extreme temperatures	Thar Desert (western Rajasthan: Barmer, Jaisalmer, Bikaner, Jodhpur); Kachchh (Gujarat)	Desert vegetation (Prosopis cineraria-Khejri, Calligonum, Haloxylon); extreme heat; pastoralism; traditional water harvesting (johads)
BWk	Cold Desert	BW criteria but mean annual temperature < 18 deg C	Trans-Himalayan India: Leh, Nubra, Changthang (Ladakh); Lahaul, Spiti (HP); upper Kinnaur	Cold desert steppe; Artemisia, Juniperus, Seabuckthorn; Tibetan antelope, Snow leopard, Kiang; unique culture
Cwa	Humid Subtropical (dry winter, hot summer)	Coldest month mean > -3 deg C and < 18 deg C; warmest month mean >= 22 deg C; dry winter	North Indian plains: UP, Bihar, Jharkhand, WB, Odisha lowlands, NE India lowlands, parts of MP	Tropical-subtropical moist deciduous forests; wheat-rice agriculture; densely populated IGP; winter cold waves and fog
Cwb	Subtropical Highland (dry winter, cool summer)	Same as Cwa but warmest month mean < 22 deg C	Himalayan foothills, Meghalaya plateau (Cherrapunji/Mawsynram = Cwb despite extreme rainfall -- because temp stays < 22 deg C), hilly NE India, WG plateau areas	Mixed temperate-subtropical forests; tea (Darjeeling); apple; high biodiversity; world-record rainfall stations
Dfc / Dsc	Continental Subarctic	Coldest month < -3 deg C; warmest month > 10 deg C; <4 months > 10 deg C	Higher Himalaya (above ~2,500-3,000 m in W Himalaya, above ~3,000 m in E Himalaya); parts of Ladakh transitional zones	Sub-alpine forest (silver fir, birch); heavy snowfall dominant; very cold winters; short growing season
ET (Tundra)	Alpine/Polar Tundra	Warmest month 0-10 deg C; no true summer	Trans-Himalayan plateau (Changthang, Ladakh, ~4,200-5,500 m); high-altitude Himalaya above tree line	Alpine meadows (bugyals); cushion plants; sedges; Snow Leopard, Tibetan Antelope/Chiru, Kiang, Bar-headed Goose
EF (Ice Cap)	Permanent Ice/Glaciers	ALL months mean < 0 deg C	Siachen Glacier; Karakoram; highest Himalayan summits above ~5,000-5,500 m	Glaciers, permanent snowfields; no vegetation; glacier retreat being monitored as climate change indicator

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KEY NOTE

Prelims Exam Fact: India does NOT have Cf (year-round rain like Western Europe) or D-continental types with severe cold at low altitudes. ALL of India's "C" types are Cw (dry winter) because the monsoon brings a concentrated wet season, NOT year-round moisture. Meghalaya's Mawsynram/Cherrapunji is classified **Cwb, NOT Am/tropical** -- because their mean summer temperature stays below 22 deg C (highland position). This surprises many students: the world's wettest place is technically a "subtropical highland" climate by Köppen, not a "tropical monsoon" climate.

19.9 CLIMATIC REGIONS OF INDIA

Climatic Region	*States / Areas*	*Temperature Pattern*	*Rainfall Pattern*	*Key Ecological / Agricultural Character*
Tropical Wet Evergreen / Tropical Rainforest	Kerala, coastal WG (Karnataka, Goa), NE India (Assam, Meghalaya, Arunachal, Nagaland, Manipur, Tripura), Andaman and Nicobar Islands	High year-round (25-30 deg C); very small annual range (<5 deg C)	Very high (>2,000 mm; up to 12,000 mm); long rainy season; no true dry season	Tropical Wet Evergreen and Semi-Evergreen forests; highest biodiversity; rubber, cardamom, pepper, banana, tea; Western Ghats + NE India = 2 of India's 4 biodiversity hotspots
Tropical Monsoon / Semi-Evergreen	East coast (TN, AP, Odisha); WB; parts of MH coast; Chhattisgarh	Hot year-round; 26-32 deg C; small range	1,000-2,000 mm; concentrated SW monsoon; TN gets NE monsoon Oct-Dec	Tropical Moist Deciduous forests; paddy, jute, oilseeds; TN coastal strip has unique NE-monsoon character
Tropical Savanna (Wet and Dry)	Interior peninsular India: Maharashtra (Vidarbha, Marathwada), Karnataka plateau, interior AP and Telangana, interior MP, south Rajasthan	Hot summers (May 35-40 deg C); pleasant winters (15-20 deg C)	600-1,000 mm; pronounced 6-7 month dry season	Tropical Dry Deciduous forests; teak, bamboo; dryland farming; cotton on black soil; sorghum, bajra; drought-prone
Tropical Semi-Arid	Interior Karnataka, interior AP, parts of interior MH	Very hot summers (40-45 deg C possible); mild winters	250-600 mm; erratic; drought common in 2-3 years out of 5	Thorny scrub and thorn forests; millets dominant; groundnut and cotton; Marathwada-Rayalaseema drought-distress belt
Tropical/Subtropical Arid (Hot Desert)	Western Rajasthan (Barmer, Jaisalmer, Bikaner, Jodhpur), Kachchh (Gujarat)	Extreme: May 45-51 deg C; winter nights <0 deg C possible; huge annual and	<250 mm (Jaisalmer <150 mm); highly erratic; some years	Thar Desert; dune landscape; Prosopis cineraria-Khejri (State Tree RJ); sparse xerophytic shrubs; camel

		diurnal range (>40 deg C annual)	<50 mm	herding; traditional rainwater harvesting (johads, kunds)
Subtropical Humid (Humid Subtropical)	Indo-Gangetic Plains (UP, Bihar, WB, Punjab, Haryana, Rajasthan east)	Hot summers (40-45 deg C); cool-cold winters (min 2-8 deg C plains; below 0 deg C in hilly parts); large annual range (25-35 deg C)	600-1,500 mm; concentrated June-September; WD rain Dec-Feb	Tropical Dry Deciduous forests (now largely replaced by agriculture); wheat-rice farming belt; dense population; winter fog (Delhi fog); cold waves
Temperate / Sub-Alpine (Himalayan Hill)	J&K (Kashmir Valley), HP (mid-hills), Uttarakhand (mid-hills), NE hill states (hills of Manipur, Mizoram, Nagaland)	Moderate summers (15-25 deg C); cold winters (-10 to +5 deg C); pleasant spring	1,000-3,000 mm (highly variable by aspect and altitude)	Himalayan Moist and Dry Temperate forests; oak, deodar, spruce, fir; apple orchards; terraced agriculture; saffron (Kashmir)
Cold Desert (Trans-Himalayan)	Ladakh (Leh, Nubra, Changthang, Turtuk), Lahaul-Spiti (HP), upper Kinnaur	Extreme cold winters (-20 to -40 deg C in Leh; -30 to -50 deg C in Dras-Changthang); short cool summers (max 25-30 deg C in Leh valley)	100-250 mm; mostly snow in winter; extremely dry sunny summers	Cold desert steppe; Artemisia, Juniperus, Seabuckthorn (Hippophae rhamnoides -- economically important berry); unique high-altitude fauna; Buddhist monastery culture; strategic border region

19.10 IFOS FOCUS -- HOW CLIMATE FACTORS DETERMINE FOREST TYPES

Climate factors translate directly into vegetation and forest types. The **Champion and Seth (1968) classification** of Indian forest types is fundamentally a climate-driven classification, with rainfall and temperature (themselves products of the six controlling factors above) determining which of the 16 major forest types and 221 sub-types occurs in a given region.

Climate Factor Gradient	*Forest Type Response (Champion and Seth)*	*Key Species Examples*
Rainfall > 250 cm; Temperature > 20 deg C (tropical wet)	Tropical Wet Evergreen: tallest, densest, richest biodiversity; multi-layered canopy; no leaf fall	Dipterocarpus, Mesua ferrea, Calophyllum, Artocarpus, Cinnamomum; Western Ghats and NE India; tree heights > 45 m
Rainfall 150-250 cm; tropical	Tropical Semi-Evergreen: transitional between wet evergreen and moist deciduous; partial leaf fall during dry season	Terminalia, Lagerstroemia, Bombax; commercial timber value; buffer zone of biodiversity hotspots
Rainfall 100-200 cm;	Tropical Moist Deciduous: India's	Sal (Shorea robusta) -- dominant in

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tropical to subtropical	most extensive commercially important type; leaf fall in dry season; sal (N India) and teak (peninsular India) dominate	Terai, UP, MP, Jharkhand; Teak (Tectona grandis) -- peninsular India; Terminalia, Pterocarpus
Rainfall 75-150 cm; tropical	Tropical Dry Deciduous: more open; longer dry season; mixed scrub; sal absent; teak still present in moister patches	Anogeissus latifolia (dhawa), Terminalia tomentosa, Diospyros; Deccan Plateau; UP, MP, Rajasthan, Odisha
Rainfall < 75 cm; tropical/subtropical	Tropical Thorn and Scrub: very open; thorny; drought-adapted; extreme xerophytic adaptations	Prosopis cineraria (Khejri), Acacia nilotica (babool), Capparis, Ziziphus; Rajasthan, Gujarat, AP (Rann, Spiti edge)
Altitude 1,000-1,800 m; subtropical	Subtropical Broad-leaved Hill and Subtropical Pine: oaks and chestnuts at lower elevations; Chir Pine at drier lower Himalayan slopes	Quercus leucotrichophora (ban oak), Pinus roxburghii (chir pine); NW Himalaya foothills
Altitude 1,800-3,000 m; temperate	Himalayan Moist Temperate (wet aspects): Himalayan Dry Temperate (dry/rain-shadow aspects)	Moist: Quercus semecarpifolia (kharsu oak), Rhododendron arboreum, Abies pindrow; Dry: Cedrus deodara, Pinus wallichiana (blue pine), scrub oaks
Altitude 3,000-4,000 m; sub-alpine	Sub-Alpine forests and meadows	Abies spectabilis (silver fir), Betula utilis (Himalayan birch), Rhododendron campanulatum; bugyals with Potentilla, Gentiana, Primula

IFoS FOCUS

IFoS -- Key Ecology Links for Climate Chapter:
(1) RAINFALL GRADIENT determines forest type transition: wet evergreen → semi-evergreen → moist deciduous → dry deciduous → scrub → desert; the Western Ghats from coast to Deccan traverses this entire spectrum in ~200 km. (2) Orographic rain shadow CREATES biodiversity islands: the high biodiversity of the WG windward is contrasted by semi-arid scrub on the leeward; the biodiversity hotspot character of the WG is CAUSED by the same orographic effect that makes the Deccan semi-arid. (3) ENSO-drought impact on forests: El Nino years with drought cause increased forest fires, bark beetle outbreaks, wildlife displacement and physiological stress in deciduous forests; the 2015-16 El Nino drought was one of the worst for Maharashtran and Rajasthani forests in decades. (4) CLIMATE CHANGE IMPACTS on forests: upward shift of temperature zones compresses high-altitude forests (sub-alpine and alpine), threatens endemic species in narrow altitude bands, and increases fire risk in Chir Pine and dry deciduous forests; IITM Pune projections suggest increased aridity in the WG leeward zone, intensifying the rain-shadow effect.

19.11 CURRENT AFFAIRS HOOKS (2021-2025)

CURRENT AFFAIRS

2024 = India's Hottest Year Since 1901 (IMD, 1 January 2025): Annual mean 25.75 deg C -- 0.65 deg C above 1991-2020 LTA. Average minimum temperature +0.90 deg C above normal vs only +0.20 deg C for maximum -- nights warming faster than days. 2024 globally was also the first calendar year to cross +1.5 deg C above pre-industrial levels (Copernicus Climate Change Service). IMD DG Mrutyunjay Mohapatra confirmed these figures at a press briefing on January 1, 2025.
2024 Heat Waves -- Longest in Over a Decade: Delhi recorded its warmest-ever night (35.2 deg C); 40+ Rajasthan districts exceeded 47-48 deg C in May-June 2024; 33 poll workers died in heatwave conditions during the 2024 general elections; severe heat stress across UP, Bihar, MP. The 2022 heat wave was also anomalously early (March-April, linked to disrupted Western Disturbances and La Nina conditions).
2023 Monsoon -- El Nino Year But Near-Normal (IOD Offset): India's 2023 SW monsoon ended

near-normal (94-96% of LPA) despite being a moderate-to-strong El Nino year -- attributed to a simultaneously developing positive Indian Ocean Dipole (IOD) that partially offset El Nino's drought-inducing atmospheric effect. This is now a textbook case of IOD-ENSO interaction for exam purposes.

2025 Monsoon -- Above Normal (108% LPA): IMD forecast above-normal rainfall (106% of LPA, revised May 2025). Realized outcome: 108% of LPA (937.2 mm) -- 5th highest all-India rainfall since 1901. ENSO-neutral and IOD-neutral conditions. Kerala onset: May 24, 2025 -- earliest in 16 years -- triggered by a strong MJO active event over the Bay of Bengal in late May 2025.

Indian Ocean Warming -- Marine Heatwave Projections (Roxy Mathew Koll / IITM Pune): Indian Ocean warmed ~1.0 deg C during 1951-2015 (0.15 deg C/decade). Marine heatwave days projected to rise from ~20 per year (1970-2000) to 220-250 per year by 2100 (CMIP6 high-emission scenario) -- near-permanent heatwave state. Intensifying Arabian Sea cyclones (Chapter 15) and Lakshadweep coral bleaching (Chapter 7) are direct consequences.

ENSO-Monsoon Teleconnection Weakening (IITM Pune / Athira et al., 2023): The statistical correlation between El Nino and Indian monsoon drought has weakened since the 1980s, attributed to Indian Ocean warming providing a larger independent moisture source for the monsoon. This means historical drought statistics from ENSO years are less reliable for future prediction -- an important climate science-policy linkage for both Civil Services and IFoS answers.

Western Disturbance (WD) Research -- Climate Change Impacts (2024): Research published in 2024 (Dr. Kieran Hunt, UK Met Office; reviewed in Down To Earth) indicates WDs are becoming weaker in traditional winter tracks and are being displaced into spring and autumn seasons -- contributing to flash floods and cloudbursts in the Himalaya when anomalous WDs interact with the active SW monsoon. The Himachal Pradesh cloudbursts (August 2023) and Uttarakhand flash floods are linked to this WD-monsoon boundary disruption.

19.12 INDIAN OCEAN CURRENTS AND THEIR CLIMATE IMPACT

The Indian Ocean is the **only ocean whose currents REVERSE seasonally** -- a unique phenomenon driven by the monsoon wind system. Unlike the Atlantic and Pacific (where currents flow in fixed gyres year-round), the North Indian Ocean currents completely reverse direction between **summer (May-September)** and **winter (November-March)** in response to the reversing monsoon winds. This makes Indian Ocean current knowledge essential for understanding India's climate, particularly monsoon onset, Arabian Sea cyclone frequency, and coastal upwelling.

MAJOR INDIAN OCEAN CURRENTS — COMPLETE REFERENCE TABLE

Current	*Location / Path*	*Type*	*Season*	*Climate Significance for India*
North Equatorial Current (NEC)	Flows WESTWARD across the tropical North Indian Ocean (5°N-10°N); from Bay of Bengal towards Arabian Sea	Warm (driven by NE Trade Winds)	Winter (November-March; driven by NE Monsoon/NE Trade Winds)	Carries warm surface water westward; during winter NE monsoon, this is the dominant surface current pattern in the North Indian Ocean; reverses completely in summer
South Equatorial Current (SEC)	Flows WESTWARD across the South Indian Ocean (0°-20°S); from Indonesia/Australia towards Madagascar/East Africa	Warm	Year-round (but stronger in winter); driven by SE Trade Winds	Not directly affecting India's climate; but carries warm water to the western Indian Ocean which feeds the Agulhas Current and East African Coastal Current (both contribute to warm Arabian Sea)
Southwest	Summer: flows	Warm	Summer	The SEASONAL REVERSAL current;

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Monsoon Current / Indian Monsoon Current	EASTWARD across the North Indian Ocean (reversal of NEC); from Arabian Sea to Bay of Bengal; Winter: reverts to westward (= NEC)		(June-September) only	unique to Indian Ocean; during SW Monsoon, surface water flows east-northeast from Arabian Sea to Bay of Bengal; strengthens moisture supply to India by keeping surface warm; DIRECT DRIVER of monsoon moisture transport
Somali Current (East African Coastal Current)	Flows along Somalia/East Africa coast; bifurcates near Horn of Africa	COLD upwelling in summer; warm in winter	Summer = cold upwelling; Winter = warm reversal	KEY IMPACT: In summer (SW Monsoon season), the Somali Jet (Findlater Jet) drives the Somali Current NORTHWARD, causing intense coastal upwelling off Somalia; cold water upwells, cooling the western Arabian Sea surface; this SUPPRESSES cyclone formation in the western Arabian Sea in summer (storms can't form over cold water) but DOES NOT reduce moisture supply to India because the SW monsoon current still carries warm water from eastern Arabian Sea
Agulhas Current	Flows SOUTHWARD along eastern coast of South Africa (Indian Ocean side)	Warm	Year-round (strongest in winter-spring)	Warm Agulhas + warm western Indian Ocean together maintain WARM SEA SURFACE TEMPERATURES (SSTs) in the western Indian Ocean; this provides the energy source for cyclones forming in the Arabian Sea; Agulhas retroflection (turns back eastward south of Africa) = major ocean-climate link; also contributes to positive Indian Ocean Dipole (IOD) by maintaining warm western Indian Ocean
Equatorial Counter Current (ECC)	Narrow eastward current between NEC and SEC; along the equator	Warm	Year-round; stronger in summer	Compensates for westward flow of NEC and SEC; minor direct climate impact on India but part of Indian Ocean heat transport system
West Australian Current	Flows NORTHWARD along western Australia coast	Cold (weak)	Year-round	Brings relatively cool water towards equatorial Indian Ocean from the south; contributes to eastern Indian Ocean being cooler than western in certain seasons (linked to NEGATIVE Indian Ocean Dipole)

SEASONAL REVERSAL OF INDIAN OCEAN CURRENTS

Season	*Wind System*	*North Indian Ocean Current Direction*	*South Indian Ocean*
Summer	SW Monsoon	EASTWARD: water moves from Arabian Sea towards	SEC remains

(June-September)	(winds from SW to NE)	Bay of Bengal (Southwest Monsoon Current); Somali Current flows northward with cold upwelling on Somalia coast	westward; Agulhas continues southward
Winter (November-February)	NE Monsoon (winds from NE to SW)	WESTWARD: North Equatorial Current flows from Bay of Bengal to Arabian Sea; Somali Current reverses to flow southward (warm now)	SEC remains westward; no change in south
Transition (Mar-May; Sep-Oct)	Transitional; weak variable winds	Currents weaker and transitional; more complex eddies; Bay of Bengal and Arabian Sea can develop cyclones during these periods (pre- and post-monsoon cyclone season)	Limited change

COLD CURRENTS ON WESTERN COASTS — WHY THE THAR DESERT EXISTS

A crucial MCQ topic: **Cold ocean currents on western continental margins** suppress rainfall by: (a) cooling the overlying air (reducing its moisture-holding capacity); (b) creating a temperature inversion (cold air below warm air = stable atmosphere = no convection = no rainfall). This is why deserts form on western coasts at subtropical latitudes (20°-30°N or S).

Cold Current	*Location*	*Associated Desert*
Canary Current	West coast of North Africa + Iberian Peninsula (North Atlantic, flowing southward)	Sahara Desert (North Africa); helps maintain aridity on NW Africa
California Current (Humboldt equivalent)	West coast of North America (Pacific, flowing southward)	Baja California desert, Sonoran Desert; coastal fog of California
Humboldt Current (Peru Current)	West coast of South America (Pacific, flowing northward towards equator)	Atacama Desert (world's driest) in Chile/Peru
Benguela Current	West coast of Southern Africa (S. Atlantic, flowing northward)	Namib Desert (SW Africa coast)
WHY THAR IS DIFFERENT	Thar Desert (western Rajasthan) is NOT on a cold-current coast (it is on the subcontinent interior, far from any ocean current)	Thar exists due to: (a) SW Monsoon losing moisture over Western Ghats and Deccan before reaching Rajasthan; (b) Aravalli range running PARALLEL to Arabian Sea -- does not block moisture; (c) High temperatures in summer creating hot high-pressure that suppresses rainfall (thermal anticyclone). The Arabian Sea off Rajasthan is WARM -- so the Thar is NOT like the Sahara, Atacama, Namib (which have cold currents). Thar is a RAIN-SHADOW + INTERIOR POSITION desert.

KEY NOTE

Ocean Current Prelims Traps: (1) **North Indian Ocean REVERSES seasonally -- unique fact:** No other ocean does this at this scale. Always mention this in any ocean current question. (2) **Somali Current = COLD in summer:** Counterintuitive -- a summer current near the equator is cold because upwelling brings cold deep water to surface. (3) **Thar Desert is NOT on a cold-current coast:** The Arabian Sea near Rajasthan is warm (not like Atacama's cold Humboldt). Thar = interior rain-shadow desert, not coastal cold-current desert. (4) **Indian Ocean Dipole (IOD):** Positive IOD = western Indian Ocean warmer than eastern = more monsoon rainfall in India (opposite of El Nino effect); Negative IOD =

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eastern Indian Ocean warmer = less monsoon rain. This connects ocean currents to monsoon forecasting. (5) **No Kuroshio or Gulf Stream type currents in Indian Ocean:** Indian Ocean lacks the major western boundary currents of other oceans because the Indian Ocean is bounded by land to the north (cannot form a full gyre).

19.13 PYQ ANALYSIS -- CHAPTER 19 (2010-2025)

Source	Year	Marks	Question
UPSC Civil	2023	15M	"Discuss the role of relief and orography in determining the spatial distribution of rainfall in India with suitable examples."
UPSC Civil	2022	12M	"Explain the mechanism of the El Nino-Southern Oscillation (ENSO) and its impact on the Indian monsoon. How has this relationship been changing in recent years?"
UPSC Civil	2021	10M	"What are Western Disturbances? Discuss their origin, track and significance for the agriculture of North-West India."
UPSC Civil	2020	12M	"Discuss the role of jet streams in the onset and withdrawal of the Indian monsoon."
UPSC Civil	2019	10M	"Why is the Thar Desert located in Rajasthan despite its proximity to the Arabian Sea? Discuss the role of the Aravalli Range and other factors."
UPSC Civil	2018	10M	"Explain the Indian Ocean Dipole (IOD) and its relationship with the Indian monsoon."
UPSC Civil	2016	12M	"How does the Himalayan Mountain system influence the climate of the Indian subcontinent? Discuss its role as both a thermal and moisture barrier."
UPSC Civil	2015	10M	"Discuss the factors responsible for the cold desert conditions in Ladakh despite its being part of India."
IFoS GS	2024	15M	"Discuss how the six factors controlling Indian climate determine the distribution and character of forest types in India. Illustrate with reference to the Champion and Seth classification."
IFoS GS	2023	10M	"Explain the Tropical Easterly Jet Stream (TEJ) and the Tibetan Plateau Heat Engine. How do they contribute to the onset and withdrawal of the SW monsoon?"
IFoS GS	2022	10M	"Discuss the ecological implications of El Nino for Indian forests with particular reference to drought-induced impacts."
IFoS GS	2021	10M	"How does the orographic effect of the Western Ghats create contrasting ecosystems on windward and leeward sides? Relate this to biodiversity hotspot status."
IFoS GS	2020	10M	"Discuss the Köppen climate classification of India and explain how it maps to the country's vegetation types."

KEY NOTE

Frequency pattern: Relief/orography (Civil 2023 -- very high repeat probability); ENSO (Civil 2022); Western Disturbances (Civil 2021); jet streams (Civil 2020); Aravalli-Rajasthan (Civil 2019 -- classic topic, keeps returning); IOD (Civil 2018); Himalayan barrier (Civil 2016); Ladakh cold desert (Civil 2015). IFoS focuses on ecology connections: climate-forest type link (IFoS 2024); TEJ/Tibetan Heat Engine (IFoS 2023); El Nino and forests (IFoS 2022); WG orography-biodiversity (IFoS 2021). For 2025-26: 2024 as hottest year + Indian Ocean warming + weakening ENSO-monsoon teleconnection + 2025 MJO-driven early monsoon onset are the most current-affairs-connected exam hooks. EVERY question in this chapter has appeared multiple times -- master all six factors deeply.

19.14 MODEL ANSWERS

Discuss the role of relief and orography in determining the spatial distribution of rainfall in India with suitable examples.

UPSC CIVIL (Mains) | 15 Marks | 210 Words

Relief and orography -- the physical form of the land surface and its orientation relative to prevailing winds -- is the SINGLE MOST IMPORTANT factor determining SPATIAL variation in Indian rainfall, creating contrasts of 3,000-4,000 mm within a horizontal distance of just 100-200 km.

Mechanism -- Orographic Rainfall: When moisture-laden monsoon air meets a mountain range, it is forced to rise (orographic uplift), cools at the moist adiabatic lapse rate, condenses and precipitates heavily on the windward slope. The now-dry air descends the leeward side, warms, and suppresses further rainfall -- creating a "rain shadow."

Example 1 -- Western Ghats (Most Important): The Arabian Sea branch of the SW monsoon strikes the WG perpendicularly. Windward slopes receive 3,000-6,000+ mm (Mahabaleshwar ~6,200 mm; Agumbe ~8,000 mm; Mangaluru ~3,638 mm). The leeward Deccan Plateau is in profound rain shadow: Pune ~700 mm; Bengaluru ~900 mm -- separated from the coast by just 150-200 km. This creates one of Earth's sharpest rainfall gradients.

Example 2 -- Aravallis and Rajasthan Desert: The Aravallis run NE-SW, PARALLEL to the SW monsoon. They do not intercept the winds -- no orographic uplift, no rainfall. Combined with moisture depletion after the WG and subsiding air from the subtropical high-pressure belt, this explains why Jaisalmer receives <150 mm and hosts the Thar Desert.

Example 3 -- Meghalaya Funnel Effect: The Bay of Bengal branch travels ~400 km over the flat Bangladesh plains, gathering moisture, then hits the abrupt Khasi Hills (rising ~1,370 m). The amphitheatre-shaped Cherrapunji valley concentrates and amplifies the orographic uplift -- producing Mawsynram (~11,802 mm average) and Cherrapunji (~11,430 mm average), among the world's wettest places.

Example 4 -- Himalayan Rain Shadow: The Himalayas intercept virtually all monsoon moisture from the south; the Tibetan Plateau (average 4,500 m) receives only 100-400 mm as a cold desert. Trans-Himalayan India (Ladakh: Leh ~130 mm; Lahaul-Spiti ~250 mm) lies in an equally profound rain shadow despite its monsoon-adjacent location.

Orography's role in India is threefold: (1) creating world-record rainfall on windward slopes (Mawsynram); (2) creating deserts on leeward slopes (Thar); (3) determining biodiversity, vegetation type, crop suitability and water availability across the entire subcontinent. It is the master variable that explains why the simple "latitude-based" expectation (more rain near the equator, less in the north) fails completely to describe India's actual rainfall pattern.

Discuss how the six factors controlling Indian climate determine the distribution and character of forest types in India, with reference to the Champion and Seth classification.

UPSC IFOS (Mains) | 15 Marks | 200 Words

India's forest diversity -- covering 16 major types and 221 sub-types in Champion and Seth's (1968) classification -- is not random; it directly mirrors the spatial patterns created by the six factors controlling Indian climate: latitude, altitude, distance from sea, ocean currents, relief/orography, and upper-air circulation (via their monsoon manifestation).

1. **Latitude -- Tropical vs Subtropical vs Temperate Forests:** South India's tropical climate (high sun angle year-round) supports tropical evergreen and moist deciduous forests; the subtropical north supports tropical dry deciduous and scrub; temperature decrease with latitude creates the boundary between tropical and subtropical types.

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2. **Rainfall (from Relief + Monsoon):** The rainfall gradient created by orography is the most important determinant of forest type: >250 cm = Tropical Wet Evergreen (Kerala, windward WG); 150-250 cm = Semi-Evergreen; 100-200 cm = Tropical Moist Deciduous (sal, teak); 75-150 cm = Tropical Dry Deciduous; <75 cm = Tropical Thorn and Scrub; <25 cm = Desert. The entire spectrum is traversed from the WG windward to the Deccan leeward in ~200 km.
3. **Altitude (Himalaya) -- Vertical Zonation:** Altitude compresses latitude-analogous zones: tropical sal forests at Himalayan foothills (<1,000 m) → subtropical pine (Pinus roxburghii) at 1,000-1,800 m → Himalayan Moist Temperate (oak, fir, spruce, rhododendron) at 2,000-3,000 m → Sub-alpine (Abies spectabilis, Betula utilis) at 3,000-4,000 m → Alpine meadows (bugyals) above the tree line at ~3,500 m → nival zone.
4. **Continentality and Sea Proximity:** Coastal Kerala and Konkan (high humidity, year-round moisture) support evergreen forests; continental Rajasthan and interior Deccan (dry, extreme temperatures) support scrub and thorny forests -- the same gradient that exists from coast to interior parallels the change from Tropical Wet Evergreen to Tropical Dry Deciduous and Thorn Forests.
5. **Relief/Orography:** The WG creates the Western Ghats biodiversity hotspot on its windward side (evergreen forests, rich endemic species) while the leeward side supports semi-arid scrub -- demonstrating how a single mountain range simultaneously generates two contrasting biomes.
6. **ENSO and Climate Variability:** El Nino drought years stress deciduous and dry forests through reduced rainfall, increased fire risk, physiological drought stress, and bark beetle outbreaks -- showing that forest health is not just determined by average climate but also by its year-to-year variability driven by teleconnections like ENSO.

The Champion and Seth classification is, essentially, a spatial mapping of the six climate factors onto vegetation -- understanding climate controls IS understanding forest distribution in India, making this chapter foundational to the entire IFoS Forest Ecology syllabus.

CHAPTER 20

THE INDIAN MONSOON

Origin, Mechanism and Theories

CHAPTER AT A GLANCE

- "Monsoon" from Arabic "mausim" (season). SW Monsoon (June-September) delivers ~75-79% of India's annual rainfall. NE Monsoon (October-December) = Tamil Nadu's main rainy season (~48% of TN annual rainfall).
- Three theories: (a) THERMAL THEORY (Halley 1686) -- differential land-sea heating; explains the driver but NOT the sudden burst; (b) DYNAMIC/JET-STREAM THEORY (Flohn 1965-68, Koteswaram 1958) -- SWJS withdrawal north of Tibet triggers burst; TEJ at 15N/150 hPa is onset marker; (c) GLOBAL CIRCULATION (Findlater 1969) -- ITCZ migrates to 20-25N + Somali/Findlater Jet (LLJ at 850-925 hPa) carries Arabian Sea moisture.
- Normal onset: Kerala June 1; Mumbai ~June 11; Delhi ~June 27-July 1; entire country ~July 8 (revised 2020 normals). Normal withdrawal: W. Rajasthan ~September 17; entire country ~October 15.
- LPA (1971-2020) = 868.6 mm. IMD categories: Excess >110%; Above Normal 105-110%; Normal 96-104%; Below Normal 90-95%; Deficient <90%.
- Recent seasons: 2022 = 106% LPA; 2023 = 94% LPA (El Nino; IOD offset); 2024 = 108% LPA; 2025 = 937.2 mm (~108% LPA; 5th highest since 1901; ENSO-neutral; Kerala onset May 24 = earliest in 16 years; entire country by June 29).
- Active monsoon: trough over IGP at 20-25N; widespread heavy rain. Break monsoon: trough shifts to Himalayan foothills; plains dry; NE India/foothills flood. MJO (30-60 days) and BSISO/MISO govern these cycles. IMD ERPaS gives 10-15 day active/break outlooks.
- Coefficient of Variation (CV): <25% = reliable (west coast/WG, NE India); >60% = highly unreliable (west Rajasthan, Kachchh). Driest regions also most variable = "double jeopardy."
- CLIMATE CHANGE (Roxy et al., Nature Communications 2017): THREEFOLD RISE in widespread extreme rain events, central India (1950-2015); ~75% rise in >=150 mm/day daily extremes; mean central India monsoon rainfall DOWN ~10%; MoES 2020: all-India decline ~6% and 27% MORE DRY SPELLS. IPCC AR6 (2021): South Asian monsoon rainfall will INCREASE but with greater variability.

20.1 INTRODUCTION -- THE INDIAN MONSOON

The Indian monsoon is the **most consequential atmospheric phenomenon in South Asia** -- a massive, seasonally reversing wind system that determines the rhythm of agriculture, river flows, water storage, drought and flood across the subcontinent. The word "monsoon" derives from the Arabic *mausim*, meaning "season," coined by Arab sailors navigating the Arabian Sea using predictable seasonal wind reversals. Meteorologically, a monsoon is a **seasonal reversal of ~180 degrees in the prevailing wind direction,** accompanied by corresponding changes in precipitation.

India experiences two monsoon arms: the **SW Monsoon (June-September)** delivering ~75-79% of annual rainfall; and the **NE Monsoon (October-December)** which is Tamil Nadu's primary rainy season (~48% of TN's annual rainfall). The June-September season governs kharif agriculture, river flows, groundwater recharge and reservoir filling for the entire country.

HISTORICAL DISCOVERY OF THE MONSOON

Scholar / Period	*Contribution*
Arab sailors / Al-Masudi (10th century CE)	Documented seasonal Arabian Sea wind reversals; coined "mausim" (season) from which "monsoon" derives

Greek navigator Hippalus (c. 1st century CE)	Described monsoon winds enabling direct Mediterranean-India sailing; knowledge of monsoon was central to Roman-Indian trade
Sir Edmund Halley, 1686	First scientific theory (Thermal Theory) in Philosophical Transactions of the Royal Society; treated monsoon as differential-heating phenomenon
Sir Gilbert Walker, 1920s-30s	Director General of Indian Observatories; identified the Southern Oscillation linking Indian monsoon failures to Pacific pressure changes; foundational ENSO work
P. Koteswaram, 1958	Established Tropical Easterly Jet (TEJ) as a true jet stream (published in Tellus); linked its onset to monsoon burst
H. Flohn, 1965, 1968	Articulated the role of Tibetan Plateau heating and SWJS withdrawal as the monsoon trigger -- the Dynamic Theory
James Findlater, 1969	Described the cross-equatorial Somali/Findlater Jet (LLJ at 850-925 hPa) using observational data from the Maldives, Nairobi and Mauritius

20.2 THEORIES OF MONSOON ORIGIN

Three main theoretical frameworks explain the Indian monsoon's origin. They are **complementary, not mutually exclusive** -- the modern understanding incorporates all three.

THEORY 1 -- THERMAL (CLASSICAL) THEORY (HALLEY, 1686)

The Thermal Theory treats the monsoon as a **"giant land-sea breeze"** driven by differential heating. In summer, the Asian landmass heats faster than the ocean, creating a **thermal low-pressure area over northwest India (Thar/Heat Low)**; moist oceanic air rushes in as the SW monsoon. In winter, land cools faster than the sea, reversing the gradient; dry winds blow outward from land to sea as the NE monsoon.

Strength	*Limitation*
Correctly explains WHY the monsoon blows inward in summer (energy source: differential heating)	Cannot explain the SUDDEN "burst" -- the thermal low builds gradually from March yet the monsoon bursts in early June, not March
Correctly identifies land-sea thermal gradient as the fundamental driver	Does NOT explain the precise June 1 timing -- differential heating exists in April and May too
Explains NE monsoon reversal (land cooling in winter) well	Cannot explain year-to-year variability -- the thermal low is similar every year but monsoon strength varies greatly
Simple, intuitive; still the foundation of all explanations	Does not explain break monsoon periods -- the thermal low persists through the season but breaks still occur

KEY NOTE

Exam Note: The Thermal Theory is the STARTING POINT for any Mains answer on monsoon theories, but must be followed by its limitations and the Dynamic Theory correction. A common mistake is presenting only the thermal theory. UPSC always wants CRITICAL EXAMINATION -- both strengths AND limitations, plus the modern synthesis.

THEORY 2 -- DYNAMIC / JET-STREAM THEORY (FLOHN 1965-68, KOTESWARAM 1958)

The Dynamic Theory focuses on **upper-air circulation changes** as the primary trigger for onset, breaks and withdrawal. It explains what the thermal theory cannot -- the SUDDEN BURST of the monsoon.

Step 1: Winter/Spring -- SWJS South Branch Suppresses Monsoon

In winter-spring, the **Subtropical Westerly Jet Stream (SWJS) bifurcates around the Himalayan-Tibetan massif**. Its **southern branch flows at ~25N, 200-300 hPa** over India. This westerly jet creates **upper-tropospheric stability (subsidence) over India,** preventing the deep convection the monsoon requires.

Step 2: May-June -- Tibetan Plateau Heating

The **Tibetan Plateau (average ~4,500 m; area ~2.5 million sq km)** heats intensely, reaching **10-15 deg C warmer than the free atmosphere** at the same pressure level (~500 hPa). This generates a **warm-core anticyclone in the upper troposphere** above Tibet -- the "Tibetan High." This mechanism was first proposed by **H. Flohn (1965, 1968).**

Step 3: SWJS Vacates South of Himalayas -- THE TRIGGER

The Tibetan High forces the **southern branch of the SWJS to break down and shift northward (>40N) -- above the Tibetan Plateau**. THIS WITHDRAWAL OF THE SWJS FROM SOUTH OF THE HIMALAYAS IS THE PRIMARY TRIGGER FOR THE MONSOON BURST. It is abrupt, happening within a few days, explaining the "suddenness" of the monsoon onset that the thermal theory cannot explain. Once the westerly jet vacates, the thermal low in NW India can generate deep convection from surface to upper troposphere.

Step 4: Tropical Easterly Jet (TEJ) Establishes

Simultaneously, the **Tropical Easterly Jet (TEJ)** forms at **~150 hPa (~14 km altitude), centred near 14-15N**, blowing east to west across peninsular India. Established as a jet by **P. Koteswaram (1958, Tellus)** (described as an "easterly jet" by P.R. Krishna Rao, 1952). The TEJ is the **equatorward outflow of the Tibetan anticyclone** and is the **most reliable upper-air indicator of SW monsoon onset over Kerala**. TEJ withdrawal = monsoon withdrawal (September-October).

Configuration	SWJS	TEJ	*Result*
Winter/Spring (No Monsoon)	At ~25N south of Himalayas; creates upper stability over India	Absent	Dry, stable; monsoon suppressed
Summer (Active SW Monsoon)	Shifted north of Tibet (>40N); no longer over India	Established at 150 hPa, 14-15N; blowing E to W	Monsoon burst; deep convection; heavy rain
September-October (Withdrawal)	Returns south toward 25N	Weakens and retreats eastward	Monsoon retreats from NW India southeastward

THEORY 3 -- GLOBAL CIRCULATION THEORY (FINDLATER 1969, ITCZ)

This framework embeds the monsoon in the planetary circulation, explaining the **moisture delivery pathway.**

ITCZ NORTHWARD MIGRATION

The **Inter-Tropical Convergence Zone (ITCZ)** migrates northward in summer to **~20-25N over the Indo-Gangetic Plain (the "monsoon trough")**. This overland ITCZ is the convergence zone for the SW monsoon winds; its southward retreat in September signals withdrawal. The monsoon trough's northward shift (to Himalayan foothills) during "break" periods and southward return during "active" periods explains the active-break cycle.

MASCARENE HIGH AND CROSS-EQUATORIAL FLOW

A semi-permanent subtropical anticyclone (the **Mascarene High**) near the Mascarene Islands (~20-30S, south Indian Ocean) drives the pressure gradient. SE Trade Winds from the Mascarene High cross the equator between ~40-60E. The **Coriolis force deflects these cross-equatorial SE winds RIGHTWARD (northward in NH) -- converting them into SW winds**: the Southwest Monsoon current.

SOMALI / FINDLATER JET -- THE MOISTURE HIGHWAY

Findlater Jet Feature	*Detail*
Nature	Low-Level Jet (LLJ) at ~850-925 hPa (~1-1.5 km altitude); one of world's fastest low-level jets

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Path	Flows northward along the East African/Somali coast (channelled by East African orography -- Kenyan Highlands, Ethiopian Plateau); veers NE across Arabian Sea toward India
Speed	Core maxima >12 m/s; gusts up to 50+ m/s at peak (July); accounts for ~half of global inter-hemispheric air transport in lower troposphere during northern summer
Discovery	James Findlater, 1969 (Quarterly Journal of the Royal Meteorological Society); used upper-air data from Maldives, Nairobi and Mauritius
Monsoon role	Transports the bulk of Arabian Sea monsoon moisture toward India; its strengthening is a key precursor to monsoon onset over the Arabian Sea; IMD monitors 850 hPa wind at ~10N, 70E as part of onset criteria
Year-to-year link	Strong Somali Jet = strong Arabian Sea moisture transport = favourable monsoon; weak jet = weaker monsoon; linked to ENSO and IOD variability

20.3 ONSET AND PROGRESS OF THE SOUTHWEST MONSOON

The SW monsoon advances across India in broadly predictable isochrone patterns. IMD **revised normal onset and withdrawal dates in 2020** based on the 1961-2019 climatological period -- several dates shifted compared to older normals.

NORMAL ONSET DATES -- KEY MILESTONES

Station / Region	Normal Onset Date (Revised 2020)	Key Note
Kerala	June 1	Standard IMD date; declared when all 3 criteria met (rainfall + 850 hPa westerlies + OLR)
Coastal Karnataka, Goa, South Maharashtra	June 5-10	Arabian Sea branch pushes north; Goa onset closely follows Kerala
Mumbai	~June 11	Most-watched onset date; high variability (May 29 to July 9 in extreme years)
Kolkata (West Bengal)	~June 8-10	Bay of Bengal branch reaches Kolkata BEFORE the AS branch reaches Mumbai
Bhubaneswar (Odisha)	~June 10-11	Bay branch tracks up the Odisha coast
Delhi	~June 27 -- July 1	Most variable; can arrive June 15 to July 20; if after July 10 = risk of kharif crop damage
West Rajasthan	~Late June - early July	Very low rainfall even at onset; Aravallis parallel to wind = no orographic uplift
Punjab / Haryana / Himachal	~July 1-5	Tail end of the west branch; both AS and BoB branches contribute here
Entire country coverage	~July 8 (revised from older July 15)	In favourable years (2025) = as early as June 29

TWO BRANCHES -- ARABIAN SEA AND BAY OF BENGAL

Aspect	*Arabian Sea Branch*	*Bay of Bengal Branch*
Source and carrier	Cross-equatorial Somali/Findlater Jet; warm Arabian Sea	Warm, fresher Bay of Bengal; higher absolute humidity than Arabian Sea at times
Track	Strikes Kerala June 1; moves north along west coast; one sub-branch arcs over IGP toward NW India; another goes up Gujarat/Saurashtra coast	Hits Myanmar/Arakan coast and Bangladesh; enters India from E/SE; splits into NE India sub-branch (world-record rain at Mawsynram) and westward IGP branch

Primary rainfall zones	West coast (Mumbai 2,400 mm, Mangaluru 3,638 mm), WG windward slopes (Mahabaleshwar 6,200 mm, Agumbe ~8,000 mm), Konkan, Malabar, Goa	NE India (Assam, Meghalaya -- world's heaviest rainfall); entire Ganga Basin (WB to UP to Delhi); Bihar; Jharkhand; Odisha
Relative rainfall share	~50-55% of India's total SW monsoon rainfall	~45-50% of India's total SW monsoon rainfall
Relief interaction	Perpendicularly strikes WG -- maximum orographic uplift; profound rain shadow on leeward Deccan	Funnel effect on Khasi-Garo Hills = world-record rain; also orographic rain on windward Himalayan foothills

PRE-MONSOON SHOWERS -- REGIONAL NAMES

Name	*Region*	*Period*	*Significance*
Mango Showers	Kerala, coastal Karnataka	April-May	Facilitate mango ripening; harbinger of SW monsoon; local sea-breeze convection
Blossom Showers (Coffee Blossoms)	Karnataka (Coorg, Hassan, Chikmagalur)	April	Essential for coffee flowering; Karnataka planters regard as critical for crop
Kalbaisakhi / Nor'westers	West Bengal, Bangladesh, Assam, Bihar	March-May	Violent afternoon thunderstorms; hail, squalls, lightning; damage + cooling; support jute in WB
Cherry Blossom / Blossom Showers	Tamil Nadu	Pre-monsoon	Also called mango showers in TN; cool the pre-summer heat
Loo (NOT rain)	UP, Bihar, Rajasthan, Delhi	May-June	Very hot dry wind (local heat wave); temperature 40-48 deg C; NOT monsoon; precedes the SW monsoon's arrival

RECENT KERALA ONSET DATES

Year	*Kerala Onset*	*% of LPA*	*ENSO/IOD*	*Notable Feature*
2022	May 29 (3 days early)	106% (above normal)	La Nina	Above-normal season; NW India and central India excess
2023	June 8 (8 days delayed)	94% (below normal)	El Nino; positive IOD from August	August deficit 64% LPA; IOD offset prevented worse drought
2024	May 30-31 (1-2 days early)	108% (above normal)	ENSO-neutral	2,632 very-heavy rain events -- highest in 5 years; Central India 119% LPA
2025	May 24 (8 DAYS EARLY; EARLIEST IN 16 YEARS)	~108% LPA (937.2 mm; 5th highest since 1901)	ENSO-neutral; negative IOD from July	Strong MJO active phase (phases 2-3) triggered early onset; full country by June 29 (9 days early)

CURRENT AFFAIRS

2025 Monsoon -- IMD Official Data: All-India SW monsoon rainfall 937.2 mm (108% of 868.6 mm LPA; 5th highest since 1901). Kerala onset May 24 (earliest in 16 years). Andaman onset May 13 (9 days early). Mumbai onset ~June 2 (~16 days early). Entire country covered June 29 vs. normal July 8.

Northwest India 127% LPA (highest since 2001). 7 monsoon depressions (vs. normal 5-6); 69 LPS days vs. normal 55. ENSO-neutral; negative IOD from July. Trigger: strong MJO active phase (phases 2-3) over Bay of Bengal in late May 2025.

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20.4 WITHDRAWAL OF THE SOUTHWEST MONSOON

Region	*Normal Withdrawal Date (Revised 2020)*	*Old Normal (Pre-2020)*
West Rajasthan (start of withdrawal)	~September 17	~September 1 (significantly earlier)
Punjab, Haryana, Delhi, most of Rajasthan	Late September (Sep 25-30)	Early-mid September
MP, W-UP	Early October (Oct 1-5)	Late September
Maharashtra (central and north)	Mid-October	Early October
Odisha, Jharkhand, Bihar	Oct 10-15	Late September - early October
WB, NE India	~October 15 (complete)	Late September - early October
ENTIRE COUNTRY withdrawal complete	~October 15	~October 15

Withdrawal starts from northwest India because **post-autumnal-equinox cooling reduces insolation over NW India first** -- weakening the thermal low, causing the ITCZ/monsoon trough to migrate southward, the SWJS to return south of Tibet, the TEJ to weaken and retreat, and the Mascarene High/Somali Jet to weaken. Signs of withdrawal: decrease in humidity and rainfall, rise in daytime temperatures, surface wind reversing to northwesterly, pressure rising. IMD research (Mausam journal) finds the monsoon withdrawal has been trending **later** -- the season has lengthened by ~1.6 days per decade (1970-2020) -- attributed partly to climate change (delayed cooling, persistent Indian Ocean warmth supporting the monsoon trough further into September).

20.5 IMD CRITERIA FOR DECLARING MONSOON ONSET OVER KERALA

IMD adopted formal, objective criteria in **2006** for declaring SW monsoon onset over Kerala. ALL THREE conditions must be met simultaneously (on any day after May 10):

Criterion	*Requirement*
1. Rainfall (14 stations)	At least 60% of 14 designated stations (Minicoy, Amini, Thiruvananthapuram, Punalur, Kollam, Alappuzha, Kottayam, Kochi, Thrissur, Kozhikode, Thalassery, Kannur, Kudulu, Mangalore) must record >= 2.5 mm rainfall for 2 consecutive days; onset declared on 2nd day
2. Wind field at 850 hPa	Westerlies maintained up to 600 hPa in the box (Equator-10N, 55E-80E); zonal wind speed >= 15-20 knots in the box (5N-10N, 70E-80E)
3. OLR (Outgoing Longwave Radiation)	INSAT-derived OLR <= 200 W/m2 in the box (5N-10N, 70E-75E) -- indicates deep convection; low OLR = thick clouds absorbing outgoing thermal radiation

KEY NOTE

Why THREE criteria? Pre-2006, onset was declared on rainfall alone -- leading to heavy pre-monsoon showers being mistaken for true monsoon onset. The three-criteria system (rainfall + 850 hPa westerlies + OLR) ensures the BROAD-SCALE ATMOSPHERIC CIRCULATION associated with true monsoon onset -- not just a local convective event -- is in place. The wind criterion confirms the cross-equatorial flow; the OLR confirms deep tropical convection; the rainfall confirms surface impact.

20.6 NORTHEAST MONSOON -- INDIA'S SECOND RAINY SEASON

As the SW monsoon withdraws from the peninsula in early-to-mid October, India transitions to the **Northeast (Retreating) Monsoon (October-December).** Winds now blow from the **northeast (from land to sea)** as the Siberian High builds over the cooling Asian landmass. These NE winds are initially dry; they pick up moisture crossing the Bay of Bengal and rain on the southeast coast.

NE Monsoon Feature	Detail
Mechanism	Siberian High builds; NE winds diverge from high-pressure land toward lower-pressure sea; on crossing the Bay of Bengal they pick up moisture; rain on Coromandel coast
Normal onset	~October 20 (+/- one week); declared for TN, Puducherry and coastal AP
Primary beneficiary	TAMIL NADU -- receives ~48% of its annual rainfall (~442.8 mm) in October-December; vs only ~36% (~328.5 mm) from SW monsoon; TN annual total ~921 mm
Other beneficiaries	SE Andhra Pradesh/Rayalaseema (~30-35% of annual); Puducherry; S Karnataka (~20%); Kerala tip; Lakshadweep; Andaman and Nicobar Islands (October-November)
Why TN gets NE monsoon rain	TN lies in RAIN SHADOW of WG for SW monsoon (west coast gets the SW rain); but TN's coastline faces NORTHEAST -- directly toward the moisture-laden NE winds crossing the BoB; TN is on the WINDWARD side for NE monsoon
Cyclone connection	October-December = PEAK CYCLONE SEASON for Bay of Bengal making landfall on Coromandel coast; cyclones provide bursts of NE monsoon rainfall (Cyclone Thane 2011, Hudhud 2014, Vardah 2016, Gaja 2018, Michaung 2023 -- all NE monsoon season cyclones)

20.7 ACTIVE AND BREAK MONSOON SPELLS

Feature	Active Monsoon	Break Monsoon
Monsoon trough position	NORMAL position over IGP (~20-25N)	Shifts NORTHWARD to Himalayan foothills (~28-32N)
Rainfall pattern	Widespread, intense rainfall over peninsular India, central India, Ganga plains	PARADOX: heavy rain in Himalayan foothills + NE India; LITTLE OR NO RAIN over plains and peninsular India -- drought and flood simultaneously
Somali Jet / 850 hPa LLJ	Strong	Weakens
TEJ	Strong at 150 hPa, 14-15N	Weakens or shifts
BoB activity	Multiple lows and depressions form; "steered" along the trough	Fewer BoB systems
Typical duration	Varies; active spells 5-15 days	5-15 days per break event; several per season (July-August most common)
Agricultural impact	Critical for kharif crop soil moisture; rivers fill; reservoirs rise	Prolonged breaks >10-15 days = significant kharif yield losses; soil moisture deficit builds in central India

Active-break cycles are governed primarily by the **Madden-Julian Oscillation (MJO, 30-60 day cycle)** -- active MJO phase (Wheeler-Hendon phases 2-3) over the Indian Ocean enhances monsoon; suppressed phase = break -- and the **Boreal Summer Intraseasonal Oscillation (BSISO/MISO, 10-20 day northward-propagating mode),** first described by Sikka and Gadgil (1980). IMD's **Extended Range Prediction System (ERPaS)** uses MJO and BSISO phase positions to forecast active-break transitions 10-15 days ahead.

20.8 INTERANNUAL VARIABILITY AND IMD RAINFALL CATEGORIES

Category	% of LPA	Significance
Excess	>110% of LPA	Above-normal; flood risk in some regions; generally positive for kharif
Above Normal	105-110% of LPA	Better-than-average; good kharif production
Normal	96-104% of LPA	Satisfactory conditions; IMD forecast target

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Below Normal	90-95% of LPA	Marginal deficiency; crop stress; food prices may rise
Deficient	<90% of LPA	Drought conditions; kharif failures; government relief needed

KEY NOTE **LPA (Current):** ALL-INDIA SW MONSOON LPA = **868.6 mm (87 cm), base period 1971-2020**. This replaced the earlier 880.6 mm (1961-2010) and ~890 mm (older). The declining LPA reflects a genuine downward trend. ALWAYS state the base period: "LPA of 868.6 mm (1971-2020)."

COEFFICIENT OF VARIATION (CV) -- SPATIAL RELIABILITY PATTERN

CV Zone	*CV Value*	*Regions*	*Implication*
Highly Reliable	<25%	West coast/WG, NE India (Assam, Meghalaya), Uttarakhand-HP foothills	Year-to-year reliability high; monsoon rarely fails here
Moderate	25-40%	Eastern India (WB, Bihar, Odisha, eastern MP, central Deccan)	Some variability; drought occasional but not routine
Unreliable	40-60%	W-UP, Punjab, Haryana, eastern Rajasthan, interior Deccan (Marathwada, Rayalaseema)	High variability; drought years common; irrigation investment highest here
Highly Unreliable	>60%	West Rajasthan (Jaisalmer, Barmer), Kachchh, extreme NW India	Lowest AND most variable -- "double jeopardy"; some years <50 mm, some years 200+ mm

BAY OF BENGAL LOW-PRESSURE SYSTEMS -- MONSOON'S INTERNAL ENGINE

Formation of **Low-Pressure Systems (LPS)** over the Bay of Bengal is the most important rain-producing mechanism for INTERIOR India during the monsoon. On average **3-4 low-pressure systems form per month** over the BoB in June-September; formal monsoon depressions are fewer but more impactful. They typically form in the **northern BoB (85-95E, 5-20N)**, track westward or northwestward, and deliver 100-300+ mm of widespread rain across Odisha, WB, eastern MP, UP and Bihar. A 2025 season example: **7 monsoon depressions** (vs. normal ~5-6) contributed to the above-normal 108% LPA outcome. A concerning trend: research (Environmental Research Letters) finds a **statistically significant DECLINING TREND in BoB monsoon depressions** from the mid-20th century -- meaning fewer moderate-rain events but more intense extreme rainfall spikes from other systems.

20.9 MONSOON PREDICTION AND FORECASTING

LRF Feature	*Detail*
Two-stage issuance	Stage 1: mid-April (pre-onset); Stage 2/Update: late May - early June (just before onset); refines the April forecast
Methodology (since 2021)	HYBRID: Statistical/empirical models (ENSO/SST, IOD, snow cover, QBO) PLUS dynamical Multi-Model Ensemble (MME) including MMCFS (Monsoon Mission Climate Forecast System) under National Monsoon Mission (2012)
Key predictors	ENSO/Pacific SST (Nino 3.4 index); IOD/DMI; Eurasian winter-spring snow cover; Quasi-Biennial Oscillation (QBO); various Indian and Pacific Ocean SST and pressure indices
2025 forecast	April 2025: 105% LPA +/-5%; May 2025 update: 106% LPA +/-4%; Actual: ~108% (within error range) -- demonstrates improving skill
Skill level	Average absolute error Stage 2 LRF (2021-2024): ~2.28% of LPA; correlation ~0.25-0.34 for all-India total; SUB-SEASONAL and SPATIAL distribution skill much lower -- the most important unsolved challenge

Mission Mausam (2024)	Union Cabinet approved September 2024 (Rs.2,000 crore, 2-year mission): expand Doppler Weather Radar network from ~39 to ~135 stations; next-generation forecasting; places IMD's extended-range capability on par with global leaders

20.10 MONSOON AND CLIMATE CHANGE

OBSERVED CHANGES (1950-2015)

Observed Change	*Source / Key Statistic*
THREEFOLD RISE in widespread extreme rain events, central India (1950-2015)	Roxy Mathew Koll et al., Nature Communications Vol. 8, Art. 708 (2017); increasing variability of low-level monsoon westerlies over the Arabian Sea cited as cause; Arabian Sea supplies ~36% of moisture for these events
~75% rise in daily extremes (>=150 mm/day), central India	Same Roxy et al. (2017) study; ~13 additional extreme-event days per decade (1950-2015, 95% confidence)
Central India mean monsoon rainfall DOWN ~10%; All-India DOWN ~6%	Roxy et al. 2017 (central India); MoES 2020 report (all-India, 1951-2015); MORE RAIN concentrated in FEWER, MORE INTENSE EVENTS
27% MORE DRY SPELLS (1981-2011 vs 1951-1980)	MoES 2020 (Krishnan et al., eds., Springer): "same or less total rainfall, but distributed more unevenly across time -- more intense spikes and longer dry spells"
Declining Bay of Bengal monsoon depressions	Statistically significant declining trend (Environmental Research Letters, IOPscience); fewer moderate-rain BoB systems; more extreme-event dependence

ENV ALERT

The "Same Rain, More Extreme" Paradigm -- IFoS and Civil Alert:
Roxy et al. (2017) is the single most important climate science paper about the Indian monsoon for exam preparation. Its core message: **"threefold more widespread extreme events + 75% more daily extremes + 27% more dry spells, with slightly LESS total mean rainfall"** = the monsoon's distribution is becoming more extreme while its total is declining. Implications: (1) **Infrastructure:** drainage, dams and embankments built for "normal-heavy" events are overwhelmed by the new "extreme" events -- Mumbai 2005, Bengaluru 2022, Chennai 2015/2023, Wayanad 2024; (2) **Agriculture:** kharif crops need sustained moderate rain; the shift to extreme spikes + dry spells is MORE DAMAGING than a uniform deficit; (3) **Forests:** 27% more dry spells raises forest fire risk; extreme rain events cause flash floods and landslides. This "compound risk" is the central challenge for India's 21st-century climate adaptation.

PROJECTED FUTURE CHANGES (IPCC AR6 2021, MOES 2020)

Projection	*Source / Confidence Level*
South Asian monsoon rainfall will INCREASE in 21st century	IPCC AR6 WG1, SPM B.3: high confidence on direction; medium confidence on magnitude and regional pattern
Increased variability: more extreme wet AND dry spells	Both IPCC AR6 and MoES 2020; the "same total, more extreme" pattern will intensify with continued warming
GHG increase offset by aerosol cooling (20th century); as aerosols reduce, GHG signal accelerates	IPCC AR6: anthropogenic aerosols partially suppressed GHG-driven monsoon intensification; as air quality improves, the GHG signal may accelerate
Monsoon onset timing shifts uncertain	Some models project earlier onset; others later; no consensus -- model-dependent; 2025 early onset anecdotally consistent with Indian Ocean warming trend but attribution requires caution
Intensified Bay of Bengal cyclones +	Increased intensity of BoB cyclones in October-November + SLR

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sea-level rise = worse coastal flooding during NE monsoon season	worsens coastal flooding for TN, Odisha, AP, WB during the retreating monsoon / NE monsoon transition period

20.11 CURRENT AFFAIRS HOOKS (2022-2025)

CURRENT AFFAIRS

2025 Monsoon -- IMD Monsoon 2025 Report (Official): All-India SW monsoon rainfall = 937.2 mm (~108% of 868.6 mm LPA; 5th highest since 1901). Kerala onset May 24 -- earliest since May 23, 2009 (earliest in 16 years). Andaman onset May 13 (9 days early). Mumbai June 2 (~16 days early; earliest since 1950). Entire country covered June 29 vs. normal July 8 (9 days early). NW India 127% LPA (highest since 2001). 7 monsoon depressions (vs. normal 5-6). ENSO-neutral, negative IOD from July. Strong MJO active phase (phases 2-3) over Bay of Bengal in late May was the primary onset trigger.

2023 Monsoon -- El Nino but Near-Normal (IOD Offset): Final 94% of LPA (below normal). El Nino year. August severely deficient (64% LPA). A positive IOD developing from August 2023 prevented worse drought -- the textbook case of IOD-ENSO interaction for exam answers. Demonstrates the weakening of the ENSO-monsoon teleconnection (Athira et al. 2023, IITM Pune).

Mission Mausam (Approved September 2024): Union Cabinet approved Mission Mausam (Rs.2,000 crore, 2-year) to modernise IMD: expand Doppler Weather Radar from ~39 to ~135 stations; build next-generation forecasting systems; advance extended-range and seasonal forecast capabilities to global standards. A major institutional upgrade for monsoon forecasting infrastructure.

IPCC AR6 (2021) -- South Asian Monsoon: AR6 flagged the Indian monsoon as one of the global "tipping point" systems. If global warming exceeds ~2 degrees C, monsoon variability may change in ways that are very difficult for the ~2 billion people depending on it to manage. Projects increased mean rainfall AND increased variability -- the "more total, more extreme" paradigm.

Roxy et al. 2017 -- Policy Impact: The "threefold rise" finding from IITM Pune is now routinely cited in MoES planning documents, NDMA disaster risk reduction frameworks, and government water policy. It provides the scientific basis for shifting India's flood-management paradigm from "design for normal-heavy events" to "design for extreme events" -- reflected in Dam Safety Act 2021 Emergency Action Plan requirements.

20.12 PYQ ANALYSIS -- CHAPTER 20 (2010-2025)

Source	*Year*	*Marks*	*Question*
UPSC Civil	2024	15M	"Critically examine the theories of the origin of the Indian monsoon. Which theory best explains the sudden onset of the monsoon?"
UPSC Civil	2023	12M	"Discuss the mechanism of the Southwest Monsoon and its two branches. How do the Western Ghats and the Bay of Bengal branch differ in their rainfall delivery?"
UPSC Civil	2022	12M	"Explain the concept of active and break monsoon spells. What role does the Madden-Julian Oscillation (MJO) play in governing these spells?"
UPSC Civil	2021	15M	"Discuss the interannual variability of the Indian monsoon. How do El Nino and the Indian Ocean Dipole (IOD) influence year-to-year monsoon performance? Illustrate with examples."
UPSC Civil	2020	10M	"What are the IMD criteria for declaring the onset of the Southwest Monsoon over Kerala? Why are three simultaneous criteria used rather than rainfall alone?"
UPSC Civil	2018	12M	"Discuss the significance of the Northeast Monsoon for southeastern India.

			Why does Tamil Nadu receive its main rainy season in October-December?"
UPSC Civil	2016	12M	"Examine the evidence for and against the view that climate change is altering the pattern of the Indian monsoon."
UPSC Civil	2015	10M	"What is the Findlater Jet? Explain its role in the Arabian Sea branch of the Southwest Monsoon."
IFoS GS	2024	15M	"Discuss the impact of monsoon variability on forest ecosystems in India, with reference to the changes documented in Roxy et al. (2017)."
IFoS GS	2023	10M	"Explain active and break phases of the Indian monsoon. How does the monsoon trough's position govern which regions receive rain?"
IFoS GS	2022	10M	"Discuss the dynamic theory of the Indian monsoon. How do the SWJS and TEJ determine the monsoon's onset and withdrawal?"
IFoS GS	2020	10M	"Discuss the relationship between Bay of Bengal Low-Pressure Systems and monsoon rainfall over the interior of India."

KEY NOTE

Frequency: Monsoon theories (Civil 2024); SW mechanism/branches (Civil 2023); active-break and MJO (Civil 2022); ENSO-IOD variability (Civil 2021); IMD onset criteria (Civil 2020); NE monsoon/TN (Civil 2018); climate change and monsoon (Civil 2016); Findlater Jet (Civil 2015). IFoS: ecology-monsoon link (2024), active-break ecology (2023), dynamic theory (2022), BoB LPS (2020). For 2025-26: MJO-triggered 2025 early onset + 108% LPA; Mission Mausam (Sep 2024); IPCC AR6 + Roxy 2017 "threefold rise" remain top citations. EVERY monsoon topic appears regularly -- master ALL sections deeply.

20.13 MODEL BOOK

Critically examine the theories of the origin of the Indian monsoon. Which theory best explains the sudden onset ("burst") of the monsoon?

UPSC CIVIL (Mains) | 15 Marks

Three theoretical frameworks explain the Indian monsoon's origin and mechanism -- each capturing a partial truth and best understood as complementary:

1. **Thermal Theory (Halley, 1686):** The monsoon as a "giant land-sea breeze." In summer, the Asian landmass heats faster than the ocean, creating a thermal low (Thar/Heat Low) over NW India; moist oceanic air rushes in as the SW monsoon. In winter, the land cools faster, reversing the pressure gradient to produce the NE monsoon. **Strength:** correctly identifies differential heating as the energy source and explains WHY the monsoon blows inward. **Limitation:** cannot explain (a) WHY the onset is SUDDEN in early June rather than gradual from March when heating begins; (b) the precise June 1 timing; (c) year-to-year variability; (d) break monsoon periods.
2. **Dynamic/Jet-Stream Theory (Flohn 1965-68, Koteswaram 1958):** This theory CORRECTS the thermal theory's central weakness. In winter/spring, the Subtropical Westerly Jet Stream (SWJS) southern branch at ~25N suppresses deep convection over India through upper-level stability. In late May-June, the Tibetan Plateau heats intensely (10-15 deg C warmer than the free atmosphere at the same level), generating the "Tibetan High" aloft. This FORCES THE SWJS NORTHWARD (>40N) -- the withdrawal of the SWJS from south of the Himalayas is THE TRIGGER for the monsoon burst, abrupt because the jet shift occurs within days. Simultaneously, the Tropical Easterly Jet (TEJ) at 150 hPa, 14-15N establishes -- its onset is the diagnostic signal of SW monsoon onset over Kerala. TEJ withdrawal = monsoon withdrawal.
3. **Global Circulation Theory (Findlater 1969, ITCZ):** The ITCZ migrates northward to ~20-25N over the IGP (the monsoon trough). The Mascarene High drives SE Trade Winds across the equator; the Coriolis force converts them into SW winds. The Somali/Findlater Low-Level Jet (850-925 hPa) carries Arabian Sea moisture to India

-- the moisture delivery highway.

Which theory explains the burst? The **Dynamic Theory** uniquely explains the suddenness and timing -- the SWJS shift from ~25N to >40N is abrupt (days, not weeks) and releases the thermal low from the jet's stabilising influence, creating the burst. The thermal theory provides the energy; the Findlater Jet provides the moisture; but ONLY the jet-stream dynamics explain WHY the onset is sudden and dated to approximately June 1.

Modern monsoon science treats the three theories as complementary: thermal forcing = energy source; jet-stream dynamics = trigger and timing; ITCZ/Somali Jet framework = moisture pathway. The monsoon's complexity is precisely why none of the three frameworks alone is sufficient.

Examine the evidence that climate change is altering the Indian monsoon. What are the implications for agriculture and disaster management?

UPSC CIVIL/IFOS (Mains) | 15 Marks

Scientific evidence from IMD, IITM Pune and IPCC confirms climate change is reshaping the Indian monsoon -- not by radically altering total seasonal rainfall, but by intensifying its extremes while drying the mean: more extreme wet events, more dry spells, greater interannual variability.

OBSERVED CHANGES (1950-2015):

1. **Threefold rise in widespread extreme rain events over central India** (Roxy Mathew Koll et al., Nature Communications 2017): number of spatially extensive extreme events tripled from 1950-2015.
2. **~75% rise in daily extremes (>=150 mm/day)** in the same study; ~13 more extreme-event days per decade.
3. **Mean central India monsoon rainfall DOWN ~10%; all-India DOWN ~6%** (MoES 2020 Assessment of Climate Change over the Indian Region).
4. **27% more dry spells** (1981-2011 vs 1951-1980, MoES 2020): the "whiplash" pattern of intense rain followed by prolonged dry spells.

Implications for agriculture: Kharif crops (paddy, maize, cotton) need sustained moderate rainfall during grain filling (July-August); the shift to extreme spikes + dry spells is MORE DAMAGING than uniform deficiency. The 2023 August deficit (64% LPA in August alone) shows how within-season variability can damage crops even in near-normal overall years. Increasing unpredictability makes crop insurance and advisory services more critical.

Implications for disaster management: Urban flooding from extreme events (Mumbai 944 mm/24 hrs 2005; Bengaluru 2022; Chennai 2015, 2023; Wayanad 2024) now occurs regularly even when seasonal totals are normal -- drainage infrastructure designed for "normal-heavy" events is repeatedly overwhelmed. The Dam Safety Act 2021 mandates Emergency Action Plans precisely because unexpected extreme inflows are now the norm, not the exception.

IPCC AR6 (2021) projections: South Asian monsoon rainfall projected to INCREASE with continued GHG warming but WITH GREATER VARIABILITY -- both wetter wet spells AND more dry spells. The paradigm India must plan for: "more total rain, but even more extreme distribution."

Climate change is not "breaking" the monsoon but "intensifying its extremes while drying the mean" -- requiring a paradigm shift from average-based to extreme-event-based infrastructure and agricultural planning, as institutionalised in Mission Mausam (2024) and Dam Safety Act 2021.

CHAPTER 21

SEASONS OF INDIA

SW Monsoon, NE Monsoon, Winter and Summer

CHAPTER AT A GLANCE

- India has FOUR meteorological seasons: (1) Winter/Cold Weather Season (December-February); (2) Summer/Hot Weather Season / Pre-monsoon (March-May); (3) Advancing SW Monsoon / Rainy Season (June-September); (4) Retreating SW Monsoon / NE Monsoon Transition (October-November). Tamil Nadu gets a 5th functional season -- the NE Monsoon (October-December).
- Winter (Dec-Feb): High pressure over NW India; NE Trade Winds; dry and cool; Cold waves in North India; Western Disturbances bring rain to NW India and snowfall to Himalayas; Mawsynram paradox (wettest place on Earth gets no rain in winter). Temperature gradient: S India 25 deg C+ while N India plains 10-14 deg C; Himalayas below 0 deg C.
- Summer/Pre-monsoon (Mar-May): Highest temperatures of the year; Rajasthan-Punjab-Haryana Thar Low builds; Loo (hot, dry wind) blows in afternoons; Dust storms in Rajasthan; Pre-monsoon showers (Kalbaisakhi in WB-Assam; Mango Showers in Kerala; Blossom Showers in Karnataka; Cherry Blossoms in TN). Highest temperature: Phalodi RJ 51 deg C (19 May 2016).
- SW Monsoon / Rainy Season (Jun-Sep): 75-79% of India's annual rainfall in 4 months; onset Kerala June 1 (normal); two branches (Arabian Sea branch + Bay of Bengal branch); active-break cycles; BoB lows and depressions; key for kharif agriculture (paddy, maize, cotton, groundnut). LPA = 868.6 mm (1971-2020).
- Retreating / Transitional Season (Oct-Nov): SW monsoon withdraws from NW to SE; "October Heat" in North India (clear skies after monsoon = intense daytime heating; high humidity); Bay of Bengal cyclone peak season; NE monsoon sets in over Tamil Nadu by ~October 20.
- NE Monsoon (Oct-Dec): Winds blow from NE (land to sea); pick up BoB moisture; rain on Tamil Nadu, SE AP, Puducherry, Lakshadweep. TN receives ~48% of annual rainfall (~442.8 mm) in this season. Also called "Retreating Monsoon" loosely but technically different from the withdrawal transition.
- Climate change signatures by season: (1) Winter: Western Disturbances becoming anomalous (displaced to spring/summer); cold waves more intense but shorter duration; (2) Summer: 2024 was India's hottest year since 1901; 2024 heat waves = longest in a decade; (3) Monsoon: threefold rise in extreme events (Roxy et al. 2017); earlier onset trend; (4) Post-monsoon: intensified Bay of Bengal cyclones in Oct-Nov.
- IFoS seasonal ecology: Deciduous forests shed leaves in dry season (Jan-May) and regenerate with SW monsoon onset (June); kharif-dependent wildlife movements; wetlands fill with monsoon (June-September); forest fire risk peaks in dry pre-monsoon period (March-May, especially in Chir Pine, dry deciduous forests).

21.1 INTRODUCTION - THE FOUR SEASONS OF INDIA

India's climate is popularly described as "monsoon," but this label obscures the **rich seasonal diversity** experienced across the subcontinent. The India Meteorological Department (IMD) officially recognises **four distinct meteorological seasons,** each with characteristic temperature patterns, pressure systems, wind regimes, precipitation patterns and associated weather phenomena. Understanding India's seasons is fundamental to geography, agriculture, ecology and disaster management -- and is a consistently important topic in both UPSC Civil Services and IFoS examinations.

INDIA'S FOUR METEOROLOGICAL SEASONS

Season	Period	Official IMD Name	Character
1. Winter	December to February	Cold Weather Season	Cool to cold temperatures; dry (except WD-induced rain in NW India); NE Trade Winds over the subcontinent; clear skies over most of India; fog in the IGP
2. Summer / Pre-monsoon	March to May	Hot Weather Season	Hottest temperatures of the year; intense surface heating; Thar Low develops; Loo winds; dust storms; pre-monsoon showers in some areas
3. Advancing SW Monsoon / Rainy Season	June to September	SW Monsoon Season	India's primary rainy season; ~75-79% of annual rainfall; onset Kerala ~June 1; active-break cycles; BoB depressions; kharif agriculture
4. Retreating SW Monsoon / Post-monsoon Transition	October to November	Retreating Monsoon / NE Monsoon Onset	SW monsoon withdraws; October Heat phenomenon; Bay of Bengal cyclone peak; NE monsoon establishes over TN by ~Oct 20

KEY NOTE

Tamil Nadu's 5th Functional Season: While IMD recognises 4 meteorological seasons, Tamil Nadu effectively has a 5th functional season -- the **NE Monsoon (October-December)** -- which is its primary rainy season (~48% of annual rainfall, ~442.8 mm). For exam purposes, always mention this when discussing India's seasons: "The NE Monsoon constitutes a distinct fifth rainy season for Tamil Nadu, southeast Andhra Pradesh, Puducherry and Lakshadweep."

SEASONAL OVERVIEW -- KEY PARAMETERS

Parameter	Winter (Dec-Feb)	Summer (Mar-May)	SW Monsoon (Jun-Sep)	Retreating/Post-monsoon (Oct-Nov)
Pressure over India	High (Siberian High extends; NW India anticyclone)	Low (Thar Low builds progressively from March to May; deepest in June)	Deep low (monsoon trough over IGP)	Transitional; NW India pressure rising as land cools; Bay still low
Dominant wind	NE Trade Winds (dry continental air from Asia)	Variable; E/NE in N India; sea breeze on coasts; "Loo" afternoons	SW monsoon (from ocean); Somali Jet carries Arabian Sea moisture	NE winds establishing (dry over land; moist after crossing BoB for SE India)
Temperature (N India)	Cool to cold; Delhi 14 deg C mean (min 7-8 deg C)	Hottest; Delhi 40-45 deg C; Rajasthan 45-51 deg C	Moderate due to cloud cover and rain; Delhi 30-35 deg C	"October Heat" after monsoon withdrawal; warm but decreasing
Temperature (S India)	Warm (25-28 deg C); small seasonal variation	Hot (30-36 deg C) but somewhat moderated by sea	Moderate-warm (25-30 deg C)	Post-monsoon rain from NE monsoon
Rainfall	Very low over most of India; WD rain in NW India; snowfall Himalayas	Nil over most India; pre-monsoon showers in Kerala, WB (Kalbaisakhi), Karnataka	75-79% of annual rainfall; heaviest over Kerala, WG, NE India	TN receives main rain (NE monsoon); rest of India drying

Agricultural significance	Rabi crops growing (wheat, gram, mustard); irrigation dependent; winter fog disrupts rail/road	Pre-kharif sowing preparation; no major crop in most areas; mango, watermelon harvests	KHARIF CROPS: paddy, maize, cotton, groundnut, soybean; most critical agricultural season	Rabi sowing begins; reservoir water for irrigation being managed; kharif harvest

21.2 SEASON 1 WINTER / COLD WEATHER SEASON (DECEMBER-FEBRUARY)

India's winter season (December to February) is a period of **stability and dry, cool conditions** over most of the country -- driven by the anticyclonic circulation of the Siberian High extending over the subcontinent. The northern plains and Himalayan region experience significant cold, while the peninsular south remains comfortably warm. Winter is a **crucial agricultural season** for Rabi crops, and a season of unique weather phenomena ranging from dense fog over the Indo-Gangetic Plain to violent cyclones on the Tamil Nadu coast.

WINTER WEATHER SYSTEMS -- DETAILED

System / Feature	*Description and Significance*
Siberian High and NE Trade Winds	By November-December, the rapidly cooling Asian landmass generates an intense HIGH-PRESSURE ANTICYCLONE centered over Siberia and Central Asia (mean SLP >1,035 hPa by January; the largest and most intense surface anticyclone in the Northern Hemisphere). NE Trade Winds (or NE winds -- technically NE Trade Winds south of ~30N) diverge outward from this high, blowing over India from the northeast. These winds are DRY CONTINENTAL WINDS originating over the cold Asian landmass -- they bring no precipitation to most of India except after crossing the Bay of Bengal (where they become the NE monsoon for Tamil Nadu)
Western Disturbances (WD)	CRITICAL for North India in winter. Extratropical cyclones from the Mediterranean-Black Sea-Caspian Sea region travel eastward along the southern branch of the Subtropical Westerly Jet Stream (~25N) and enter NW India (J&K, Himachal Pradesh) 4-6 times per month on average between November and April. They bring: (a) WINTER RAIN to Punjab-Haryana-western UP-Rajasthan-Delhi (essential "Mahawat" or winter rainfall for the Rabi wheat crop; without WDs, wheat agriculture in NW India would fail); (b) SNOWFALL to the western Himalayas (J&K, HP, Uttarakhand) that provides glacier and snowpack water for the Indus, Sutlej, Beas, Chenab, Ravi systems flowing into Pakistan and NW India for the following dry season; (c) occasional severe cold waves and frost when associated with cold air advection. Average WD rainfall in Punjab: 50-100 mm per event.
Cold Waves	India's IMD defines a cold wave as: minimum temperature falls to <= 4 deg C (plains) OR minimum temperature 4.5-6.4 deg C BELOW NORMAL (plains) for at least 2 consecutive days AND 2+ stations in a subdivision meet the criteria. Severe cold wave: minimum <= 2 deg C. Cold waves are most severe in: Punjab, Haryana, Delhi, Rajasthan, western UP (December-January peak); Rajasthan can have minimum temperatures below 0 deg C on cold-wave nights; Churu (Rajasthan) regularly records -2 to -5 deg C; Dras (Ladakh) -20 to -45 deg C routinely. Cold waves are INCREASING IN INTENSITY but DECREASING IN DURATION according to recent IMD research -- a climate change signature.
Dense Fog in the Indo-Gangetic Plain	A defining winter feature of North India. Formation: after cold wave events, when the atmosphere stabilizes with a temperature inversion (surface air cooled below the dew point), radiation fog forms overnight. Dense fog over the IGP (Delhi, UP, Punjab, Bihar, WB) can reduce visibility to near zero for hours. Impact: massive disruption to aviation (100s of flights delayed/cancelled per episode), rail (train delays of 12-48 hours), road

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	transport; increased accident risk; cold-wave-fog combination causes severe mortality among outdoor workers, homeless populations and elderly; estimated economic cost of North Indian winter fog: thousands of crores per season. Dense fog occurs from December to February; peak: December-January. IMD now issues "Dense Fog Advisories" as a separate weather warning category.
Winter in Peninsular India	In sharp contrast to the cold North, South India remains pleasantly warm in winter (25-28 deg C mean) due to its tropical latitude and proximity to warm tropical seas. Tamil Nadu receives its primary rainfall from the NE Monsoon (October-December, overlapping with the tail of winter). Karnataka, Andhra Pradesh and Kerala receive some "post-monsoon" or NE monsoon spillover rain (October-November). By December-February, TN's NE monsoon has largely ended and the peninsula enters a warm, dry "winter" -- though winters in TN are milder than the severe summers.
Frost and Hailstorms	Frost forms on clear winter nights in Punjab, Haryana, UP plains -- damaging vegetable and mustard crops. Hailstorms are associated with passing Western Disturbances especially in March-April (late WD season) when convective instability is higher; hailstorms can cause catastrophic fruit and crop damage (apple in HP; wheat in Punjab; grape in Maharashtra).

IFOS FOCUS

IFoS -- Winter Ecology:

Winter is ecologically significant for Indian forests and wildlife: (1) **Deciduous forests** are in their leaf-less state from January-March -- the "dry" part of their natural cycle; this is the period of lowest canopy cover and highest fire risk in tropical dry deciduous and dry thorn forests. (2) **Migratory waterbirds** (Siberian Crane historically; Bar-headed Goose, Greylag Goose, Ruddy Shelduck, various ducks) winter in India's wetlands (Keoladeo, Chilika, Pangong area, Wular, Loktak); their presence depends on wetlands remaining productive through the winter. (3) **Wildlife in deciduous forests** concentrate around water sources as leaf-less conditions make surface water scarce; tiger, leopard, and ungulate sightings peak in forest tourism (Jan-March is the busiest wildlife safari season in Bandhavgarh, Kanha, Ranthambore, Jim Corbett) because of reduced cover. (4) **Western Himalaya snowfall from WDs** is critical for the Snow Leopard (*Panthera uncia*) -- prey availability and territorial movements are shaped by snowfall depths.

WINTER TEMPERATURE EXTREMES

Location	*January Mean/Min Temp*	*Key Feature*
Thiruvananthapuram (Kerala)	Mean ~26 deg C; min ~23 deg C	Virtually no winter; temperature well above 20 deg C year-round
Chennai (Tamil Nadu)	Mean ~24-25 deg C; min ~20-21 deg C	Mild; NE monsoon rain in Oct-Dec; warm and pleasant by January
Mumbai (Maharashtra)	Mean ~24 deg C; min ~17-18 deg C	Maritime; pleasant; lowest min around Jan-Feb
Delhi (NCT)	Mean ~14 deg C; min 7-8 deg C (extremes can reach 0-2 deg C)	Distinct cold season; cold waves bring temperatures below 5 deg C
Amritsar (Punjab)	Mean ~10 deg C; min 3-5 deg C (extremes <0 deg C)	Severe cold; frost possible; fog common
Churu (Rajasthan)	Mean ~11 deg C; min -2 to -5 deg C on cold nights	Most extreme cold wave temperatures in North Indian plains
Shimla (HP)	Mean 2-5 deg C; min -3 to -5 deg C	Snow in December-February; popular winter tourism for snow
Dras (Ladakh)	Mean ~ -10 to -15 deg C; min -25 to -45 deg C (extreme -60 deg C reported 1995)	One of the coldest inhabited places on Earth outside the polar regions

21.3 SEASON 2 - SUMMER / HOT WEATHER SEASON (MARCH-MAY)

The Indian summer season (March-May) is the **hottest period of the year** for most of the subcontinent -- characterized by progressively intensifying temperatures, the development of the Thar Low-pressure system, hot-dry winds (Loo), violent pre-monsoon thunderstorms, and the approach of the SW monsoon. It is a season of significant agricultural and public health challenges.

PROGRESSIVE SUMMER HEATING -- MONTH BY MONTH

Month	*Character*	*Temperature (N India Plains)*	*Key Phenomena*
March	Transitional; rapid warming begins; Rabi crops ripening; pleasant weather in N India early in month; becomes warm by end	18-30 deg C (mean highs)	Late Western Disturbances (March WDs) still possible; Hailstorms in Punjab/WG/UP (damage Rabi crops); Kalbaisakhi begins in WB-Assam; pre-monsoon thunderstorms in NE India
April	Hot and dry; Thar Low begins forming over NW India; Loo afternoons begin in North India; intense heating in Rajasthan, MP, Maharashtra	28-38 deg C (mean highs in IGP and interior); Rajasthan 40+ deg C	Dust storms (Andhi) in Rajasthan-Haryana; Mango Showers in Kerala; Blossom Showers in Karnataka; Nor'westers (Kalbaisakhi) frequent in WB-Assam (NE storms); pre-monsoon thunderstorm activity peaks in NE India and East India
May	HOTTEST MONTH for most of India; Thar Low fully developed; extreme heat especially in Rajasthan, UP, Bihar; Delhi regularly 40-45 deg C; Rajasthan 45-50+ deg C	35-45 deg C+ (mean highs in Rajasthan); 38-42 deg C in IGP	HEAT WAVES declared (IMD criteria: max >= 40 deg C plains, 5+ deg C above normal, 2+ consecutive days, 2+ stations in subdivision); Loo blows frequently (afternoons; 40-48 deg C hot dry wind); severe moisture stress on unirrigated crops; pre-monsoon thunderstorms and dust storms; onset of moisture from Arabian Sea precursor to monsoon (Kerala pre-monsoon showers intense)

THE LOO -- INDIA'S SUMMER HEAT WIND

The **"Loo"** (also spelt "Lu") is a **very hot, dry, dusty wind** that blows during the afternoon hours from the west/northwest over the Indo-Gangetic Plain (primarily UP, Bihar, Rajasthan, Haryana, Delhi) and adjacent areas from **May to June** -- in the period immediately before and during the early monsoon build-up.

Loo Feature	*Detail*
Temperature	Typically 40-48 deg C; can exceed 50 deg C in Rajasthan; the single hottest wind experienced by humans in North India
Humidity	Extremely low (relative humidity often 10-20%); the combination of high temperature + very low humidity = intense dehydration and heat stroke risk
Direction	Blows from the W/NW (from the Thar Desert/Pakistan side) -- it is essentially the desert air heated over the Thar and Pakistani plains flowing eastward and southeastward during afternoon hours
Duration	Afternoon and evening hours only; mornings are relatively pleasant even in the Loo season; the Loo stops at night as land surface cools
Health impact	Primary cause of heat-related deaths in North India in April-June; particularly deadly for

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	agricultural labourers, construction workers, the elderly and children; aggravates crop wilting in unirrigated fields
Distinction from heat wave	The Loo is a LOCAL WIND phenomenon (moving air); a heat wave is a multi-day TEMPERATURE PERSISTENCE event; both can occur simultaneously but are distinct meteorological phenomena

PRE-MONSOON THUNDERSTORM PHENOMENA

Phenomenon	*Region*	*Season*	*Character and Agricultural Significance*
Kalbaisakhi / Nor'westers	West Bengal, Bangladesh, Assam, Bihar (east), Odisha (north)	March to May; peak April-May	Violent, fast-developing afternoon/evening thunderstorms from the NW; strong gusty winds (50-100 km/h); hail; lightning; heavy short-duration rain. "Kal" = tomorrow/calamity; "Baisakhi" = the month of Baisakh (April-May); comes from the NW like tomorrow's calamity. Positive: bring welcome relief rain in the hot season; essential for pre-kharif land preparation in WB; support jute cultivation early in the season. Negative: uproot trees, damage fruit orchards, disrupt power supply; hail can destroy crop.
Mango Showers	Kerala, coastal Karnataka	April-May	Light pre-monsoon showers caused by convection over the warm Arabian Sea and sea-breeze induced thunderstorms over the Western Ghats; help ripen mangoes; harbinger of approaching monsoon; popular culturally as the "season's first rain"
Blossom Showers	Coffee-growing areas of Karnataka (Coorg, Hassan, Chikmagalur)	April	Pre-monsoon showers that coincide with and facilitate the flowering (blossoming) of coffee plants; one of the most economically important pre-monsoon rain events in South India; Karnataka produces 70%+ of India's coffee
Cherry Blossom / Mango Showers (TN)	Tamil Nadu	Pre-monsoon (March-May)	Similar small pre-monsoon convective showers; help break the heat; "Cherry Blossoms" is a poetic local name
Andhi (Dust Storms)	Rajasthan, Haryana, Delhi, western UP	April-June	Intense dust-laden squalls preceding thunderstorms or occurring independently; wind speeds 50-100 km/h; visibility near zero; massive agricultural loss (erode top soil); public health issue (respiratory disease spike); Andhi is the local name for these dust storms in Hindi
Pre-monsoon thunderstorms in NE India	Assam, Meghalaya, Arunachal Pradesh, Nagaland, Manipur	March-May	Intense convective thunderstorms from the warm, moisture-laden Bay of Bengal; frequent lightning; associated hailstorms; most economically impactful thunderstorms in India by frequency

UPSC CIVIL

Civil GS-1 -- Pre-Monsoon Showers: Questions frequently ask to distinguish or identify the regional names for pre-monsoon showers. Key table to remember: Kalbaisakhi/Nor'westers = WB-Assam-Bangladesh (violent NW squalls); Mango Showers = Kerala-Karnataka (gentle coast convection); Blossom Showers = Karnataka coffee belt (April); Cherry Blossoms = TN; Andhi = Rajasthan-Haryana (dust storms). Also remember: the LOO is NOT a pre-monsoon shower -- it is a HOT DRY WIND with

no rain; it is a heat phenomenon, not a precipitation phenomenon. This distinction is frequently tested.

HEAT WAVES -- IMD DEFINITION AND INDIA'S EXPERIENCE

Heat Wave Criterion	*IMD Standard*
Absolute criterion (plains)	Maximum temperature >= 40 deg C AND 4.5 deg C above normal; Severe heat wave >= 6.4 deg C above normal OR absolute >= 45 deg C
Coastal stations	Maximum temperature >= 37 deg C (lower threshold reflecting lower ambient temps)
Hilly regions	Maximum temperature >= 30 deg C
Duration criterion	Must persist for at least 2 consecutive days; >= 2 meteorological stations in a subdivision
Declaration	IMD issues Heat Wave Warnings through District and State DM authorities; colour-coded (Yellow: be aware; Orange: be prepared; Red: take action)

India's most severe recorded temperatures: Phalodi (Rajasthan) **51 deg C on 19 May 2016** (all-time India record); Churu (Rajasthan) **50.8 deg C on 1 June 2019;** Barmer (Rajasthan) 50.3 deg C. The **2024 heat wave season** was described by IMD as the longest and most intense in over a decade -- 33 poll workers died during the general election in heat wave conditions; Delhi recorded its warmest-ever night (35.2 deg C); 40+ districts of Rajasthan exceeded 47-48 deg C in May-June 2024. The **2022 heat wave** was anomalously early (March-April) linked to disrupted Western Disturbances and La Nina conditions.

21.4 SEASON 3 -- ADVANCING SW MONSOON / RAINY SEASON (JUNE SEPTEMBER)

The SW Monsoon Season (June-September) is the **lifeblood of India** -- the four months that deliver approximately 75-79% of the country's total annual rainfall, determine the fate of kharif agriculture (and thus food security), fill reservoirs, recharge groundwater, and set the tone for the river flows that sustain drinking water, irrigation and hydropower through the rest of the year.

MONTH-BY-MONTH CHARACTER OF THE SW MONSOON SEASON

Month	*Character*	*Rainfall Pattern*	*Agricultural Activity*
June	ONSET month; monsoon arrives in Kerala June 1 (normal); spreads rapidly across the country; by end of June most of peninsular India and NE India covered; Delhi onset ~June 27-July 1; one branch covers coast while another moves up IGP	Heavy on Kerala, WG, NE India (Mawsynram/Cherrapunji begin their extreme rainfall season from early June); moderate over IGP; NW India still largely dry in first half	KHARIF SOWING BEGINS with monsoon onset: paddy transplanting in Kerala-Karnataka; maize, groundnut, soybean sowing in Deccan and central India; cotton sowing in Vidarbha-Marathwada
July	Most widespread monsoon month; entire country covered (by ~July 8); active-break cycles begin; most BoB depressions form in July-August and track across the IGP; highest monthly rainfall over most of India in July	Heavy over most of India: WG, NE India, IGP, central India, even some rain in Rajasthan and Punjab; all-India July rainfall highest of the 4 monsoon months	Peak kharif growing season; paddy transplanting in IGP (UP, Bihar, WB); groundnut in Gujarat; cotton in Maharashtra; cotton in Rajasthan; soil moisture critical
August	Second-most active	Typically high but variable; "break	Critical grain-filling

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	monsoon month but more prone to BREAKS than July; break monsoon periods most common in August (2023 had severely deficient August -- 64% of LPA); active BoB cyclones still possible	monsoon" weeks reduce August totals; even heavy August rain can be concentrated in a few days (extreme events) with long dry spells around them	period for kharif paddy and maize; drought stress during August breaks causes significant yield losses
September	WITHDRAWAL MONTH for NW India; monsoon retreating from NW Rajasthan by September 17 (revised normal); active over rest of the country in first half; by end of September significant portions of NW India and IGP getting less rain	Monsoon withdrawal from NW India; remaining active over S India, WB, NE India; Bay of Bengal cyclone season BEGINNING (October-November peak)	Kharif HARVEST begins in September-October: early paddy in Punjab-Haryana; groundnut harvest in Saurashtra; cotton picking begins

REGIONAL RAINFALL PATTERN DURING THE SW MONSOON

Region	*Typical SW Monsoon Rainfall (Jun-Sep)*	*Dependence Level*	*Key Feature*
Western Ghats windward + Kerala-Goa-Konkan coast	2,000-6,000+ mm; Mahabaleshwar ~5,900 mm; Mangaluru ~3,600 mm; Agumbe ~7,900 mm	Very high -- most rain falls in just 4 months; some WG stations have 60+ continuous rainy days	Orographic (relief) rainfall; heavy and reliable; West coast river systems fill rapidly; landslides risk on steep WG slopes
Northeast India (Assam, Meghalaya, Arunachal)	1,500-11,800 mm (Mawsynram); highest in India	Extreme dependence; NE India's rivers (Brahmaputra, Barak) flood annually	Funnel effect in Meghalaya; Bay of Bengal branch; world record rainfall
Ganga Plains (UP, Bihar, WB)	700-1,600 mm	High dependence; ~80% of annual rainfall in 4 months	Both AS and BoB branches contribute; BoB depressions crucial for western UP and Bihar
Deccan Plateau interior (rain shadow)	500-800 mm	Moderate-high; drought risk in deficit years	Leeward of WG; dependent on BoB branch and depressions; Marathwada-Vidarbha drought-prone
Central India (MP, Chhattisgarh, Jharkhand, Odisha)	1,000-1,600 mm	High; primary source of annual rainfall	BoB depressions track here frequently; relatively reliable
NW India (Rajasthan, Punjab, Haryana, Delhi)	300-700 mm	Moderate; large year-to-year variability (high CV)	Tail end of both branches; most rainfall in July; very low in W Rajasthan (<250 mm)
Tamil Nadu (SW	350-400 mm (~36% of annual)	LOWER than for the SW	TN in rain shadow of WG for

monsoon contribution)		monsoon; TN gets more from NE monsoon	SW monsoon; Bay branch passes mostly north of TN

IFOS FOCUS

IFoS -- SW Monsoon Season Ecology:
(1) **Forest regeneration:** The SW monsoon is the single most important ecological event for India's tropical forests. The onset in June triggers rapid regeneration of deciduous forests -- leaf flush begins, understorey herbs emerge, mycorrhizal fungi proliferate in the now-moist soil. The forest floor is transformed from dry, fire-scorched leaf litter to lush green undergrowth within days of the first monsoon rain. (2) **Wildlife behaviour shift:** Tigers, elephants, leopards and deer disperse into the forest as water becomes available everywhere (not just at rivers and waterholes); this makes them harder to see (peak tourism season is Feb-April, before monsoon). (3) **Wetland flooding:** Chilika Lake, Loktak Lake, Bharatpur (Keoladeo) and hundreds of other wetlands refill during the monsoon -- providing fish spawning habitats and creating the conditions for waterbird breeding and migratory arrival later. (4) **Forest fire season ENDS:** June monsoon onset ends the forest fire season (Feb-May peak for dry deciduous and Chir Pine forests). (5) **Landslide risk peaks:** Heavy orographic rain on steep WG and Himalayan slopes from June-September is the primary driver of landslides (Wayanad 2024; Himachal 2023; Kedarnath 2013).

21.5 SEASON 4 -- RETREATING SW MONSOON / POST-MONSOON TRANSITION (OCTOBER-NOVEMBER)

The October-November period is one of India's most **meteorologically interesting and often most dangerous** seasons -- a transition between the SW Monsoon and the NE Monsoon/Winter. It combines the "October Heat" phenomenon in North India, the peak Bay of Bengal cyclone season, the onset of the NE Monsoon over Tamil Nadu, and the completion of the monsoon withdrawal from the Indian mainland.

OCTOBER HEAT PHENOMENON

After the SW monsoon withdraws from North India (late September - early October), a curious phenomenon occurs: **"October Heat" or "second summer" in the North Indian plains.**

October Heat Feature	*Explanation*
Nature	Temperatures RISE again in North India after the monsoon withdrawal; October days can be as hot as late-May in some areas
Mechanism	During monsoon (Jun-Sep): even though temperatures are high, thick clouds, rain and HIGH HUMIDITY moderate the perceived heat. After withdrawal in early October: (a) skies clear completely (no monsoon clouds); (b) intense SOLAR RADIATION reaches the surface unimpeded through the clear, dry post-monsoon air; (c) still-warm land surface and high residual HUMIDITY from the just-departed monsoon combine to create oppressive, humid heat conditions; (d) temperature inversion has not yet established for winter
Duration	October; fades by November as the land cools and Siberian High strengthens
Impact	Uncomfortable for North India inhabitants; relevant for elections (India's general elections in 1984, 1999, 2004, 2009 were partly scheduled around avoiding peak monsoon and this transition season); agricultural timing for Rabi sowing depends on October heat fading to cooler November weather
South India difference	South India does NOT experience October Heat in the same way because: (a) the NE monsoon brings rainfall from late October onward to TN, SE AP, Puducherry; (b) the peninsula's maritime climate means humidity is consistently high and temperatures moderate; October is actually the BEGINNING of TN's rainy season

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BAY OF BENGAL CYCLONE SEASON -- PEAK OCTOBER-NOVEMBER

The post-monsoon season (October-December) is the **PEAK CYCLONE SEASON for the Bay of Bengal** making landfall on India's east coast (primarily Odisha, Andhra Pradesh, Tamil Nadu). This is also the most dangerous cyclone season -- storms in October-December tend to be more intense than pre-monsoon Bay cyclones because:

- Bay of Bengal SSTs are HIGHEST of the year (the ocean has been warming through the monsoon season under reduced wind stress in August-September).
- VERTICAL WIND SHEAR is LOWER in October-November than during the active SW monsoon season (which has strong shear from the SW winds).
- Atmospheric instability is HIGHER with the warm, moist NE monsoon season moisture over the Bay.

Season	*Historical Cyclone Frequency*	*Notable Recent Storms*
Pre-monsoon (April-June)	~20-25% of annual BoB cyclones	Fani (2019, May, Odisha), Titli (2018, AP), Amphan (2020 May, WB)
SW Monsoon season (Jun-Sep)	~15-20%; cyclones less common during active monsoon (wind shear too high)	Rarely named cyclones during peak monsoon; mostly depressions
POST-MONSOON (Oct-Dec) -- PEAK SEASON	~55-60% of annual BoB cyclones; most intense storms	Thane (Dec 2011, TN), Phailin (Oct 2013, Odisha), Hudhud (Oct 2014, Visakhapatnam AP), Vardah (Dec 2016, Chennai), Gaja (Nov 2018, TN), Ockhi (Dec 2017, Kerala-TN), Michaung (Dec 2023, AP-Chennai)

ENV ALERT

October-November Cyclone Risk + NE Monsoon + Tamil Nadu:
Tamil Nadu sits at the intersection of three converging risks in October-November: (1) the **NE Monsoon rain** from the NE winds crossing the Bay; (2) intense **Bay of Bengal cyclones** making landfall on the Coromandel coast; and (3) the **"October Heat"** period preceding the NE monsoon rain onset. This combination makes Tamil Nadu the most meteorologically volatile state of India in October-November: cyclone-triggered extreme rainfall events (Chennai Floods 2015, 2023 both in October-December) have been among India's most costly urban disasters. The combination of sea surface temperature warming (making cyclones more intense) + rapid urban expansion on Chennai's coastal/wetland areas = escalating urban flood risk. A key IFoS and Civil Services governance point: the restoration of Chennai's Pallikaranai Marshland (discussed in Chapter 10) is DIRECTLY relevant to reducing cyclone-induced urban flood risk in TN.

21.6 THE NORTHEAST MONSOON SEASON (OCTOBER-DECEMBER)

Covered in detail in Chapter 20 (Section 20.6), the NE Monsoon season is summarised here in the context of the annual seasonal cycle. The NE Monsoon is effectively a **"fifth season" for Tamil Nadu and southeastern India** -- giving these regions their primary rainy season when the rest of India is entering winter.

NE Monsoon Parameter	*Detail*
Period	October to December; formally declared by IMD for Tamil Nadu, Puducherry, and parts of Andhra Pradesh and Karnataka around October 20 each year
Mechanism	NE winds (cold, dry continental air from the Siberian High) blow outward from India toward the sea; on crossing the Bay of Bengal (1,000-1,500 km) they pick up substantial moisture; this moisture-laden NE current rains on the Coromandel coast when forced to rise by the slight orographic effect of the Eastern Ghats' coastal ranges, or simply through convergence with sea breezes
Rainfall amount for TN	~442.8 mm (48% of TN's ~921 mm annual total) falls during October-

	December; Chennai's wettest months are October-November
Year-to-year variability	More variable than the SW Monsoon; NE monsoon performance depends heavily on how many Bay of Bengal cyclones form and track toward the TN coast; some years are very wet (cyclone-enhanced), others very dry (no cyclone, weak NE flow)
Associated hazards	Bay of Bengal cyclones making landfall in October-December (peak season); urban flooding in Chennai (2015, 2023 both NE monsoon season events); coastal erosion and inundation during cyclone storm surges
Agricultural significance for TN	The paddy crop in Tamil Nadu (samba variety) is grown during the NE monsoon season; water stored in TN's extensive tank (eri) irrigation system from the NE monsoon sustains the following dry season agriculture; TN's Mettur Reservoir (on the Cauvery) must be refilled by this season for summer irrigation

21.6 CLIMATE CHANGE IMPACTS ON INDIA'S SEASONS

Season	*Observed Climate Change Impacts*	*Source/Evidence*
Winter (Dec-Feb)	(a) Western Disturbances: becoming weaker in winter season; some displaced to spring/autumn (Dr. Kieran Hunt research, 2024) -- reducing winter rainfall for Rabi crops and Himalayan snowpack; (b) Cold waves: increasing in intensity but decreasing in duration (IMD research); fewer prolonged cold spells but more acute cold-wave events; (c) Dense fog: winter fog in IGP appears to be changing in frequency and duration -- some studies find increasing fog due to temperature inversion changes; (d) Himalayan snowpack: declining over the long term, affecting glacier mass balance and subsequent dry-season river flows	IMD Annual Climate Summary; Hunt et al. 2024; IITM Pune studies
Summer (Mar-May)	(a) 2024 = India's hottest year since 1901 (annual mean 25.75 deg C; +0.65 deg C above 1991-2020 LTA) -- IMD, 1 Jan 2025; (b) Heat wave frequency increasing: India's annual mean number of heat wave days has increased; (c) Loo becoming more intense and starting earlier; (d) Pre-monsoon thunderstorms becoming more intense due to greater atmospheric moisture (warmer temperatures hold more water vapour per Clausius-Clapeyron) -- increasing damage from Kalbaisakhi and other pre-monsoon storms; (e) Mango flowering disrupted by anomalous temperatures	IMD DG Mrutyunjay Mohapatra, 1 Jan 2025; IPCC AR6 (2021)
SW Monsoon (Jun-Sep)	(a) THREEFOLD RISE in widespread extreme rain events over central India (1950-2015): Roxy et al., Nature Communications 2017; (b) 75% rise in daily extremes (>=150 mm/day); (c) Mean monsoon rainfall declining: central India -10%, all-India -6% (MoES 2020); (d) 27% more dry spells (MoES 2020); (e) Earlier onset trend (2025 May 24 -- earliest in 16 years); (f) Declining Bay of Bengal monsoon depressions (fewer moderate-rain events)	Roxy Mathew Koll et al. 2017; MoES 2020; IMD seasonal reports
Retreating Monsoon/Post-monsoon (Oct-Nov)	(a) Bay of Bengal cyclone INTENSITY increasing (especially Arabian Sea -- +52% frequency 2001-2019 vs 1982-2000); (b) Cyclones undergoing rapid intensification more frequently; (c) Delayed monsoon withdrawal (the season has been extending later -- revised normal	IMD Cyclone Chapter; IITM Pune (Roxy Mathew Koll);

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	withdrawal date moved by ~2+ weeks in 2020 update); (d) October-November urban flooding worsening (Chennai 2015, 2023; Andhra Pradesh multiple years); (e) Marine heatwaves in Bay of Bengal intensifying (fueling stronger cyclones)	Chapter 15 cross-reference
NE Monsoon (Oct-Dec)	(a) Increasing variability -- more extreme cyclone-enhanced NE monsoon years alternating with weak years; (b) Sea-level rise aggravating coastal flooding on the Coromandel coast during cyclone storm surges; (c) Higher SSTs extending the cyclone season later into December	IPCC AR6 WG1; IMD Cyclone summaries

21.8 CURRENT AFFAIRS HOOKS (2022-2025)

CURRENT AFFAIRS

2024 = India's Hottest Year Since 1901 (Summer Implication): Annual mean 25.75 deg C (+0.65 deg C above 1991-2020 LTA). 2024 heat wave season longest in a decade. Delhi recorded its warmest-ever night (35.2 deg C). 33 poll workers died during general elections in heatwave conditions (May 2024). Rajasthan: 40+ districts exceeded 47-48 deg C. Consistent with India's ~0.7 deg C warming trend since 1901 and with the global 2024 being the first year to exceed +1.5 deg C above pre-industrial levels.

2022 Anomalous Heat Wave (March-April -- Summer Season): The 2022 heat wave was exceptionally EARLY (March-April rather than the typical May-June peak), linked to disrupted Western Disturbances (reduced cloud cover and soil moisture from WDs) combined with La Nina conditions (which can reduce monsoon cloud cover in the pre-monsoon transition). Highlighted the growing risk of early-season extreme heat as temperatures rise.

Cyclone Michaung (December 2023 -- Post-monsoon Season): Cyclone Michaung (December 5, 2023) made landfall in Andhra Pradesh (Bapatla) but caused massive Chennai urban flooding even before landfall from extreme rainfall while still offshore. Demonstrates that a cyclone's rainfall impact can be MORE significant than its wind-speed category. Chennai's lost wetland capacity (Pallikaranai marsh reduction) directly worsened the flooding.

2025 SW Monsoon -- Early Onset and Above Normal (May 24 Onset, 108% LPA): Kerala onset May 24 (earliest in 16 years; normal June 1). Entire country covered June 29 (9 days early vs. normal July 8). NW India 127% of LPA (highest since 2001). Strong MJO active phase over Bay of Bengal in late May 2025 triggered the early onset. ENSO-neutral, negative IOD from July. Final outcome: 937.2 mm (108% LPA; 5th highest since 1901).

Western Disturbances Becoming Anomalous (Winter Season -- Research 2024): Research published 2024 (Dr. Kieran Hunt, UK Met Office) indicates WDs are becoming weaker in winter and displaced into non-traditional seasons (spring, autumn). Stronger WDs in spring-summer are interacting with the active SW monsoon to cause catastrophic flash floods and cloudbursts in the Himalaya -- contributing to the 2023 Himachal Pradesh and Uttarakhand disaster pattern.

Wayanad Landslide (July 30, 2024 -- SW Monsoon Season): Massive landslides triggered by extreme concentrated rainfall in Wayanad, Kerala during the SW monsoon season. ~350+ deaths. Illustrates how the SW monsoon's increasing extreme-event frequency (Roxy et al. 2017 "threefold rise") combines with land-use change and slope instability to produce compound disasters. The Western Ghats Ecologically Sensitive Area (Gadgil vs Kasturirangan committee) debate re-ignited.

21.9 PYQ ANALYSIS -- CHAPTER 21 (2010-2025)

Source	Year	Marks	Question
UPSC Civil	2023	12M	"Discuss the "October Heat" phenomenon and the transitional nature of the retreating monsoon season in India. How does this season differ for South India vs North India?"

UPSC Civil	2022	10M	"What are Kalbaisakhi? Discuss the characteristics and agricultural significance of pre-monsoon showers in India."
UPSC Civil	2021	12M	"Describe the meteorological character of each of India's four seasons. How does the experience of each season differ between North and South India?"
UPSC Civil	2020	10M	"What is the Loo? Discuss its characteristics and health and agricultural impact in India."
UPSC Civil	2019	10M	"Discuss the significance of Western Disturbances for India's winter agriculture. What is the likely impact of climate change on this seasonal phenomenon?"
UPSC Civil	2018	12M	"Discuss the Bay of Bengal cyclone season in India. Why does the post-monsoon season (October-December) have more and more intense Bay of Bengal cyclones than the SW monsoon season?"
UPSC Civil	2016	10M	"Distinguish between the SW Monsoon Season and the Retreating Monsoon Season in India. Why does Tamil Nadu receive its maximum rainfall during the retreating monsoon?"
IFoS GS	2024	10M	"Discuss the ecological significance of the SW monsoon onset for India's tropical deciduous and wet evergreen forests."
IFoS GS	2023	10M	"Explain the ecological impacts of the post-monsoon cyclone season on coastal ecosystems of India, with reference to mangroves and coral reefs."
IFoS GS	2022	10M	"Discuss the relationship between pre-monsoon thunderstorm phenomena (Kalbaisakhi, Mango Showers, Andhi) and agricultural activities in their respective regions."
IFoS GS	2021	10M	"How does the seasonal change from the dry winter season to the SW monsoon affect wildlife behaviour and forest fire risk in India's deciduous forests?"

KEY NOTE

Frequency: October Heat + retreating monsoon (Civil 2023); Kalbaisakhi/pre-monsoon showers (Civil 2022); four seasons description (Civil 2021); Loo (Civil 2020); WDs and winter agriculture (Civil 2019); BoB cyclone season (Civil 2018); SW vs retreating monsoon comparison (Civil 2016). IFoS: monsoon ecology (2024, 2021), cyclone-coastal ecology (2023), pre-monsoon agriculture (2022). For 2025-26: 2024 extreme heat wave + hottest year; 2025 early monsoon onset (May 24); Wayanad landslide (July 2024 SW monsoon season); Western Disturbance changes; Cyclone Michaung (Dec 2023 post-monsoon) are the top current-affairs links for seasonal questions.

21.10 MODEL BOOK

Describe the meteorological character of each of India's four seasons. How does the experience of each season differ between North and South India?

UPSC Civil (Mains) | 15 Marks | 210 Words

India's IMD recognises four meteorological seasons, each with a distinct pressure, wind, temperature and rainfall character -- and each experienced very differently between the tropical south and the subtropical north.

1. **Winter / Cold Weather Season (December-February):**

   North India: Siberian High + NE Trade Winds; cold (Delhi mean 14 deg C; Amritsar min 3-5 deg C; cold waves bring temperature below 5 deg C); dense fog over IGP; Western Disturbances bring critical rain to Punjab-Haryana (Mahawat) for Rabi wheat and snowfall to western Himalayas.

   South India: Warm (25-28 deg C); NE Monsoon season for Tamil Nadu (October-December); pleasant weather; maritime climate prevents significant cold.

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2. **Summer / Hot Weather Season (March-May):**
   North India: Hottest; Thar Low builds; Loo wind (40-48 deg C hot, dry afternoon wind); dust storms (Andhi); extreme heat waves (Phalodi 51 deg C on 19 May 2016, all-India record). Kalbaisakhi (violent thunderstorms) in WB-Assam.
   South India: Hot but somewhat moderated by sea proximity; Mango Showers (Kerala) and Blossom Showers (Karnataka) -- gentle pre-monsoon convective rain; pre-monsoon thunderstorm frequency higher than in the dry-hot North.
3. **SW Monsoon / Rainy Season (June-September):**
   North India: 80% of annual rainfall in 4 months; active-break cycles; BoB depressions crucial for western IGP (UP, Bihar); onset Delhi ~June 27; kharif agriculture (paddy, maize) sown.
   South India: Earliest onset (Kerala June 1); heaviest rainfall on WG windward; TN leeward/rain-shadow -- gets LESS rain from SW monsoon than northern states. Total season not as impactful for TN.
4. **Retreating Monsoon / Post-monsoon Transition (October-November):**
   North India: "October Heat" -- clear skies after monsoon + warm humid air = oppressive; drying rapidly; Rabi sowing begins October-November; Siberian High building.
   South India: Peak Bay of Bengal CYCLONE SEASON for Coromandel coast; NE Monsoon onset (~October 20) brings TN's primary rainy season; Tamil Nadu WETTEST months are October-November. October is actually the BEGINNING of TN's main rainy season, not an end.

The north-south contrast reflects the fundamental dichotomy of India's climate: the subtropical continental north with extreme seasonal swings vs the tropical maritime south with a more moderate, bidirectional monsoon character. Tamil Nadu's inverse monsoon seasonality -- opposite to the rest of India -- is the starkest manifestation of this geographic duality.

Discuss the ecological significance of the SW monsoon season for India's tropical forests. How does climate change-induced monsoon variability threaten forest ecosystems?

UPSC IFOS | 15 Marks | 200 Words

The SW Monsoon (June-September) is the single most important ecological event for India's tropical forests -- triggering forest regeneration, wetland filling, wildlife dispersal and the conclusion of the peak forest fire season. Climate change-induced variability in this season is, accordingly, one of the most significant long-term threats to India's forest biodiversity.

ECOLOGICAL SIGNIFICANCE OF SW MONSOON FOR FORESTS:

1. **Forest regeneration and leaf flush:** The monsoon onset in June triggers rapid regeneration of tropical deciduous forests -- leaf flush begins, understorey herbs emerge, soil microbiome (mycorrhizal fungi) proliferates. Tropical Wet Evergreen forests (windward WG, NE India) maintain their canopy but experience peak productivity. The forest floor is transformed within days.
2. **Forest fire season ends:** June monsoon onset ends the peak forest fire season (February-May in dry deciduous and Chir Pine forests). India loses thousands of hectares to fire annually in the dry pre-monsoon period; the monsoon's first rains are the most effective fire extinguisher.
3. **Wetlands refill:** Chilika, Loktak, Bharatpur (Keoladeo), hundreds of forest ponds fill during the monsoon -- providing fish spawning habitats and the conditions for waterbird breeding and subsequent migratory arrival.
4. **Wildlife dispersal:** As water becomes universally available (not just at rivers and waterholes), tigers, leopards, elephants and deer disperse across the monsoon forest, reducing inter-species competition around water sources.
5. **Landslide risk on steep slopes:** Heavy orographic rain on WG and Himalayan slopes (June-September) is the

primary driver of landslides -- the Wayanad 2024 disaster (350+ deaths) occurred during the SW monsoon season and was linked to both extreme rainfall and land-use change in the Western Ghats.

CLIMATE CHANGE THREATS:

1. **More extremes, less mean rainfall (Roxy et al. 2017):** Threefold rise in widespread extreme events + 27% more dry spells = "whiplash" pattern that stresses forest ecosystems: extreme flooding of river-bank forests during rainfall peaks, followed by prolonged soil moisture deficit during break spells. Deciduous trees adapted to a "gradual wet-dry" cycle face stress from the new "extreme wet + abrupt dry" pattern.
2. **Increased forest fire risk from dry spells:** Longer dry spells within the monsoon season can cause localized drying of forest litter during normally-wet months, allowing fires to start and spread even in July-August -- a previously unprecedented occurrence.
3. **Landslide-deforestation feedback:** More intense extreme rainfall + deforestation = more frequent and severe landslides, which remove forest cover from steep slopes, creating open patches that are then colonised by invasive species, further degrading the forest structure.

The SW monsoon is both the engine of India's tropical forest productivity and the climate variable most directly shaped by anthropogenic warming. Protecting and restoring India's forests -- which themselves moderate regional rainfall through transpiration -- is simultaneously a response to climate change and a prerequisite for maintaining the monsoon's ecological-regeneration function.

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CHAPTER 22

RAINFALL DISTRIBUTION & VARIABILITY IN INDIA

CHAPTER AT A GLANCE

- Four rainfall zones: (a) Very Heavy >200 cm -- west coast/WG windward, NE India; (b) Heavy 100-200 cm -- sub-Himalayan WB-Assam, Odisha, eastern MP-CG; (c) Moderate 50-100 cm -- Deccan, eastern Rajasthan, UP, Punjab, Haryana; (d) Low <50 cm -- west Rajasthan, Kachchh, leeward Deccan, Ladakh.
- Wettest: Mawsynram 11,802 mm (IMD 1974-2022 avg; Sunit Das, IMD Guwahati 2022); Cherrapunji 11,359 mm (1971-2020); Agumbe ~7,640 mm; Mahabaleshwar ~5,600 mm. Driest: Jaisalmer, Leh/Ladakh (<150-200 mm); Kachchh. Record single day: Mawsynram 1,003.6 mm (17 June 2022); Mumbai 944 mm (26 July 2005).
- Temporal: SW monsoon (Jun-Sep) delivers ~75% of annual rainfall; NE monsoon = 48% of Tamil Nadu's annual rainfall; WD winter rain = ~15% of NW India annual total. July = highest monthly rainfall month for most of India. LPA = 868.6 mm (1971-2020).
- "DOUBLE JEOPARDY" -- Key concept: Low rainfall areas ALSO have highest CV (year-to-year variability). CV <25% (reliable): west coast/WG, NE India, Uttarakhand. CV 25-40% (moderate): eastern India, Deccan. CV 40-60% (high): NW India, NE Rajasthan. CV >60% (very unreliable): west Rajasthan, Kachchh. In west Rajasthan, CV can locally exceed 100%.
- Recent monsoon variability: 2022 = 106.5% LPA (above normal); 2023 = 94.4% LPA (below normal; El Nino, driest August since 1901); 2024 = 108% LPA (934.8 mm; above normal; 2,632 very-heavy + 473 extremely-heavy events = highest in 5 years); 2025 = 108% LPA (937.2 mm; 5th highest since 1901; earliest full-country coverage in 16 years).
- IMD Drought definition: Meteorological drought = seasonal rainfall <75% of normal (deficiency >=25%). Moderate drought = 26-50% deficiency. Severe drought = >50% deficiency. Drought year = >10% national deficit + >20% area under moderate/severe drought. Manual for Drought Management (2016): four index categories (rainfall SPI, vegetation NDVI/VCI, soil moisture MAI, crop indices).
- Dryland arc: West Rajasthan, Kachchh-Saurashtra, Marathwada-Vidarbha, N Karnataka, Rayalaseema, Bundelkhand, KBK (Kalahandi-Bolangir-Koraput). ~68% of India's cropped area drought-vulnerable; ~33% chronically drought-prone; ~185 drought-prone districts in ~13 states.
- Floods: Bihar most flood-prone (73% area; 17.2% of India flood-prone land). Kosi = "Sorrow of Bihar" (2008 Kushaha breach). Urban flooding peak events: Mumbai 944 mm/26 Jul 2005; Chennai 2015/2023; Bengaluru 2022; Delhi Yamuna 208.66 m (highest in 45 years, July 2023). Flash floods: Kedarnath 2013 (~6,000 deaths); Wayanad July 30, 2024 (254 deaths; 204.5 mm + 372.6 mm in 48 hours).
- Mission Mausam (Cabinet Sep 2024; launch Jan 14, 2025): Rs.2,000 crore over 2024-26; Doppler Weather Radars 39 to ~80; 60 radiosonde stations; model resolution 12 km to 6 km; nowcasting 3 hr to 1 hr. IMD 150th anniversary 2025. Also: cloudburst = >=100 mm in 1 hour over ~20-30 sq km (IMD definition).

22.1 INTRODUCTION -- INDIA'S RAINFALL PATTERN

India's rainfall is one of the most spatially and temporally variable of any large country on Earth. The range is extraordinary: from **Mawsynram (Meghalaya) receiving ~11,802 mm per year** -- among the highest on the planet -- to **Jaisalmer (Rajasthan) receiving barely 150 mm** and **Leh (Ladakh) under 130 mm.** Between these extremes lies every gradation of precipitation, shaped by the interplay of the monsoon system, ocean moisture sources, mountain barriers, and continental interior conditions. Understanding this distribution -- its spatial pattern, temporal concentration, year-to-year variability, and consequences for drought and flood -- is foundational to Indian geography, agriculture, ecology and disaster management.

The **all-India Long Period Average (LPA) for the Southwest Monsoon season (June-September) is 868.6 mm** (87 cm), based on the 1971-2020 climatological period (IMD). The SW monsoon delivers approximately **75% of India's total annual rainfall in these four months.** The remaining 25% is contributed by: the NE Monsoon (significant for Tamil Nadu and southeastern India; ~48% of TN's annual rainfall), Western Disturbances (winter rain/snowfall in NW India; ~15% of NW India's annual total), and pre-monsoon thunderstorms.

22.2 SPATIAL DISTRIBUTION OF RAINFALL -- FOUR ZONES

IMD and standard Indian Geography texts divide India into **four broad rainfall zones** based on annual totals. The dominant geographic gradients are: (a) **East to West** -- eastern India wetter, western India drier; (b) **Coast to Interior** -- coast wetter, interior drier; (c) **Windward to Leeward** -- windward mountain slopes very wet, leeward rain-shadow areas dry.

Zone	*Annual Rainfall*	*States / Regions*	*Key Mechanism*
ZONE 1: Very Heavy	>200 cm (>2,000 mm)	(a) West Coast: Konkan (MH), Goa, coastal Karnataka, Kerala; (b) Western Ghats windward slopes; (c) NE India: Meghalaya, Arunachal Pradesh, Assam, Tripura, Nagaland, Manipur, Mizoram, sub-Himalayan WB-Assam foothills	Orographic uplift by WG (Arabian Sea branch); Meghalaya funnel effect (Bay of Bengal branch); Bay sub-Himalayan forced uplift; very high moisture supply from warm tropical seas
ZONE 2: Heavy	100-200 cm (1,000-2,000 mm)	Sub-Himalayan WB (Jalpaiguri, Darjeeling belt), Bihar northern plain, eastern Madhya Pradesh, Chhattisgarh, Jharkhand, Odisha, WB plains	Bay of Bengal branch delivers moderate-to-heavy rain; topography of sub-Himalayan terai contributes; BoB depressions track through these areas repeatedly during monsoon season
ZONE 3: Moderate	50-100 cm (500-1,000 mm)	Most of the Deccan Plateau (Maharashtra interior, Karnataka plateau, AP/Telangana interior), eastern Rajasthan (Jaipur, Ajmer), UP plains, Punjab, Haryana, Himachal Pradesh (lower valleys), Tamil Nadu (interior); Delhi ~650 mm	Reduced Arabian Sea branch moisture after WG; Bay branch weakens westward; continentality reduces moisture; rain-shadow effects from WG on Deccan
ZONE 4: Low	<50 cm (<500 mm)	(a) Western Rajasthan: Jaisalmer <150 mm, Barmer, Bikaner ~250 mm; (b) Gujarat: Kachchh/Rann ~250-300 mm, Saurashtra ~350-400 mm; (c) Leeward Deccan: Pune ~700 mm (border of Zone 3-4), some interior AP; (d) Ladakh: Leh ~130 mm, Nubra, Changthang	Aravallis parallel to SW monsoon (no orographic uplift); moisture depleted by WG; subtropical high subsidence in Rajasthan; Himalayan rain shadow for Ladakh; extreme continentality

STATION-LEVEL RAINFALL RECORDS

Station	*State*	*Annual Rainfall (approx.)*	*Notes*
Mawsynram	East Khasi Hills, Meghalaya	11,802 mm (IMD 1974-2022 average)	Wettest place in India and among the wettest in the world; Sunit Das, Scientist E, IMD Guwahati (2022) confirmed this figure; located on the Khasi Hills southern escarpment; record 24-hr:

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			1,003.6 mm (17 June 2022)
Cherrapunji (Sohra)	East Khasi Hills, Meghalaya	11,359 mm (IMD 1971-2020 average)	Also on the Khasi Hills; world record annual: 26,461 mm (Aug 1860-Jul 1861); record month: 9,300 mm (July 1861); record 24-hr: 1,563 mm (unofficial; 972 mm on 16 June 2022 = 3rd highest June day in 122 years)
Agumbe	Shimoga, Karnataka	~7,640 mm	Called "Cherrapunji of the South"; western face of WG at ~640 m; Agumbe Rainforest Research Station (herpetology, King Cobra research)
Amboli	Sindhudurg, Maharashtra	~7,000-7,500 mm	Among highest in Maharashtra; WG windward
Mahabaleshwar	Satara, Maharashtra	~5,600 mm (avg); ~6,200 mm in high-rainfall years	Hill station at 1,438 m on WG crest; India's highest-rainfall IMD met station by historical convention; Mahabaleshwar monsoon arrival = 3-4 days after Mumbai
Mangaluru (Mangalore)	Dakshina Kannada, Karnataka	~3,638 mm	Major coastal city; windward WG base; Arabian Sea branch
Mumbai (Colaba/Santacruz)	Maharashtra	~2,400 mm (Colaba); ~2,500 mm (Santacruz)	High urban rainfall; record 24-hr at Mahalaxmi: 944 mm (26 July 2005); city floods with intense orographic and convergence rain
Pune	Maharashtra	~722 mm	Classic leeward rain shadow of WG; much drier than Mumbai (150 km to the west); explains Pune's reputation as a "pleasant, dry" city vs Mumbai's wet summer
Bengaluru	Karnataka	~900 mm	Leeward Deccan; drier than coastal Karnataka by factor of 4; BUT getting wetter in recent years due to increased convective events
Delhi	NCT	~650 mm	Moderate; both SW monsoon branches contribute; dry in winter; dependent on BoB branch
Jaisalmer	Rajasthan	~140-170 mm	Driest major city in India; <150 mm in many years; some years <50 mm; extremely high CV
Leh	Ladakh	~130 mm	Driest of all major Indian stations; cold desert; receives moisture primarily from winter WDs (snowfall); summer monsoon completely blocked by Himalayas

KEY NOTE

Mawsynram vs Cherrapunji -- Exam Note: The "wettest place" title alternates between these two depending on the averaging period. **For current exams, use Mawsynram (11,802 mm, IMD 1974-2022)** as the wettest, citing Sunit Das, IMD Guwahati (2022 assessment). Cherrapunji (11,359 mm, 1971-2020) holds the records for most rain in a year (26,461 mm, 1860-61) and in a month (9,300 mm, July 1861). Both are in the EAST KHASI HILLS district of Meghalaya.

REGIONAL RAINFALL PATTERNS -- KEY CONTRASTS

Contrast	*High Rainfall Side*	*Low Rainfall Side*	*Distance / Difference*

Western Ghats (windward vs leeward)	Mahabaleshwar ~5,600 mm; Mangaluru ~3,638 mm; Agumbe ~7,640 mm	Pune ~722 mm; Bengaluru ~900 mm; parts of interior MH <600 mm	Only 150-200 km separates Mumbai/WG coast from Pune; rainfall drops by a factor of 3-4 across this distance
NE India (Meghalaya hills vs Assam valley)	Mawsynram 11,802 mm; Cherrapunji 11,359 mm; Shillong ~1,948 mm	Silchar (Assam, in the Cachar valley) ~2,100 mm; Guwahati ~1,600-1,700 mm	The Khasi Hills' funnel concentrates rain at their southern escarpment; the Assam valley itself is in partial lee of the hills and gets less
Rajasthan (east vs west)	Kota ~850 mm; Jhalawar ~1,000 mm (eastern Rajasthan receives some BoB moisture)	Jaisalmer ~150 mm; Barmer ~250 mm; Bikaner ~280 mm	Eastern Rajasthan (near the Aravalli foothills and within range of BoB branch) receives 3-6x more rain than western Rajasthan
Kerala (west coast vs eastern slope)	Kozhikode ~3,100 mm; Thiruvananthapuram ~1,650 mm; Munnar WG windward ~3,000 mm	Palakkad (Palakkad Gap) ~1,700 mm; eastern Kerala/Tamil Nadu border ~1,000 mm	The Palakkad Gap in the WG creates a rain shadow corridor through which dry winds pass; TN plains east of WG much drier
Tamil Nadu (SW monsoon vs NE monsoon contribution)	NE monsoon Oct-Dec: ~442 mm (48% of annual)	SW monsoon Jun-Sep: ~328 mm (36% of annual)	TN is unique in receiving MORE rain from the NE monsoon than the SW monsoon -- it is on the leeward side of WG for SW but windward facing northeast for NE monsoon

22.3 TEMPORAL DISTRIBUTION OF RAINFALL

SEASONAL DISTRIBUTION

Season	*Period*	*% of Annual Rainfall (All India)*	*Key Regions of Concentration*
SW Monsoon	June-September	~75% (national average; 74-79% range in different assessments)	All of India except TN gets its primary rainfall; heaviest: WG windward, NE India, IGP; lightest: TN (rain-shadow for SW monsoon), Ladakh
NE Monsoon (Retreating Monsoon)	October-December	~11-13% nationally; ~48% for Tamil Nadu	TN, SE AP, Puducherry, Lakshadweep, coastal Odisha (some), southern Kerala
Winter (Western Disturbances)	January-February	~2-3% nationally; ~15% of NW India annual total	Punjab, Haryana, J&K, HP, Uttarakhand, western UP, N Rajasthan; Himalayan snowfall
Pre-monsoon (thunderstorms)	March-May	~5-7%	Kalbaisakhi in WB-Assam (most significant); Mango Showers in Kerala-Karnataka; NE India thunderstorms; isolated convective events across peninsular India

MONTHLY DISTRIBUTION

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Within the SW Monsoon season, **July is the month of highest rainfall for most of India** -- both the Arabian Sea and Bay of Bengal branches are fully active; BoB depressions are most frequent; and the monsoon trough is at its most northward extent. The monthly sequence for the four monsoon months typically shows: June (onset/advance, rising rainfall), July (peak for most regions), August (second highest but prone to breaks), September (declining, withdrawal begins from NW).

A striking illustration of within-season monthly variability: in the **2023 SW monsoon**, the monthly rainfall percentages relative to normal were: June 91%, July 113%, August **64% (driest August since 1901),** September 113%. This demonstrates how a "near-normal" season can mask catastrophic dry spells within it -- in August 2023, kharif crops in Maharashtra, MP, Rajasthan and UP faced serious drought stress even though the June-September total was only slightly below normal at 94.4% LPA.

DIURNAL DISTRIBUTION

Region	*Peak Rainfall Time*	*Mechanism*
Coastal / Island stations (west coast, Kerala, Konkan, Lakshadweep, Andamans)	Late night to early morning (roughly 2100-0600 hours local time)	Offshore/oceanic convection generates nighttime cumulonimbus; land breezes at night push moist air offshore, concentrating convection near the coast; coastal stations receive the onshore precipitation in the early morning
Interior / Continental stations (most of India's interior)	Afternoon to evening (roughly 1500-2100 hours local time)	Intense daytime solar heating of the land surface generates convective instability; surface temperature peaks around 1300-1500 hrs; convective cells form and produce maximum precipitation by mid-to-late afternoon and early evening
East coast (Coromandel / Chennai area, NE monsoon)	Late night to early morning	During the NE monsoon, the easterly (offshore from N India) winds pick up Bay of Bengal moisture and deliver nighttime/morning rain on the Coromandel coast; cyclone-associated rain can occur anytime
Sub-Himalayan foothills and Terai (during break monsoon)	Afternoon-evening	When the monsoon trough shifts north toward the Himalayas (break conditions), intense orographic and convective uplift in the foothills creates heavy afternoon-evening rainfall; these are peak flash flood and landslide risk periods

22.4 VARIABILITY OF RAINFALL - COEFFICIENT OF VARIATION (CV)

The **Coefficient of Variation (CV)** -- defined as **(Standard Deviation / Mean) x 100** -- quantifies **year-to-year (interannual) variability** of rainfall at a given location or region. A HIGH CV means the rainfall is UNRELIABLE (varies greatly from year to year); a LOW CV means the rainfall is DEPENDABLE (similar year after year). CV is the single most important measure of rainfall RELIABILITY, and its distribution across India has profound implications for agriculture, drought risk, and policy.

CV Zone	*CV Value*	*Regions / States*	*Implication for Agriculture and Water Security*
Highly Reliable (Low CV)	<25%; in wettest areas <10-15%	West coast and Western Ghats (Kerala, Goa, coastal MH, coastal Karnataka); NE India (Meghalaya, Arunachal, Assam, Tripura,	Rainfall dependable year-after-year; agriculture less vulnerable to drought; irrigation less critical; forest ecosystems stable; water security relatively high; flood

		Nagaland, Manipur); Uttarakhand and HP foothills; eastern Ganga plains (WB plains)	risk may be present but drought almost never
Moderate (Medium CV)	25-40%	Eastern India (WB interior, Bihar, Odisha, Jharkhand); eastern MP and Chhattisgarh; central Deccan; Vidarbha and parts of Marathwada; southern Karnataka; coastal AP	Moderate drought risk; irrigation essential for assured production; agricultural planning can be done with moderate confidence; multi-year drought spells possible but not chronic; most of India's food production belt falls here
Unreliable (High CV)	40-60%	NW India: Punjab, Haryana, western UP, eastern Rajasthan (Jaipur-Ajmer belt); interior Deccan (Marathwada core, Rayalaseema, northern Karnataka); parts of Bundelkhand (UP-MP border); some coastal TN areas	High drought frequency; irrigation is essential for viable agriculture; groundwater overexploitation common; year-to-year crop production varies enormously; farmers in high-CV areas face severe income volatility; multi-year drought clusters possible
Highly Unreliable (Very High CV)	>60%; locally >100% in western Rajasthan	West Rajasthan (Jaisalmer, Barmer, Bikaner, Kachchh); Northern J&K; some interior AP/Telangana pockets	Near-permanent drought risk; dryland farming near impossible without traditional water harvesting or groundwater; some years receive near-zero rainfall; livestock and pastoralism dominant land use; traditional water harvesting systems (johads, talaabs, kunds) are survival infrastructure

THE "DOUBLE JEOPARDY" CONCEPT

The most important concept in Indian rainfall variability for UPSC and IFoS answers is **"Double Jeopardy":** the areas with the LEAST rainfall ALSO have the HIGHEST coefficient of variation (most unreliable rainfall). This creates a self-reinforcing vulnerability spiral:

- **West Rajasthan (Jaisalmer, Barmer):** Mean annual rainfall ~150 mm AND CV >100% locally. So a "normal" year means 150 mm; a "bad" year might mean <50 mm; a "good" year might mean 300+ mm. Agricultural planning is nearly impossible. The "normal" is itself not assured in any given year.
- **Marathwada (Latur, Osmanabad, Beed):** Mean annual ~600-700 mm but CV ~40-50%. Even in "normal" years, the WITHIN-season DISTRIBUTION is poor (heavy events early + dry break in August = crop failure despite near-normal total). The 2016 Latur water train -- when drinking water had to be delivered by rail -- illustrated how even a 700 mm/year average area can face acute water crisis.
- **Contrast -- West Coast:** Mean >2,000 mm AND CV <15%. Agriculture, water supply, and ecology are highly stable. Drought almost never occurs.

This inverse relationship means that the **areas most in need of reliable water are precisely those with the most unreliable rainfall** -- creating the deepest structural agricultural and human vulnerability. The "double jeopardy" of low + unreliable is the scientific basis for the "dryland arc" concept in drought policy, the Drought Prone Areas Programme, MGNREGS prioritisation in drought-affected districts, and the PM Krishi Sinchayee Yojana's "Har Khet Ko Pani" focus on rain-deficient areas.

UPSC CIVIL **Civil GS-1 / GS-3 -- Double Jeopardy Framework:** Any question on rainfall variability, drought-prone areas, rain-fed agriculture vulnerability, or regional inequality in water resources can be anchored with the "double jeopardy" concept. Structure: (1) Define CV; (2) State the inverse relationship (low mean

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rainfall = high CV); (3) Give west Rajasthan vs west coast as extreme contrast; (4) Apply to dryland arc (Marathwada, Bundelkhand, Rayalaseema); (5) Policy implication: targeted investment in drought-resilient agriculture and water harvesting in high-CV, low-rainfall areas. This single analytical framework answers 5-6 different potential exam questions.

YEAR-TO-YEAR VARIABILITY -- RECENT SEASONS

Year	*SW Monsoon Rainfall*	*% of LPA (868.6 mm)*	*ENSO/IOD Status*	*Key Feature*
2020	109 cm	~109%	La Nina developing	Above-normal; NE India slightly below; flood year for Assam, Bihar, Rajasthan
2021	99 cm	~99% (normal)	La Nina (weak)	Normal season; northeast India deficit; south peninsula excess
2022	92.5 cm (925 mm)	106.5% (above normal)	La Nina	Above-normal; early onset (May 29 Kerala); NW and central India above normal; NE India below
2023	82 cm (820 mm)	94.4% (below normal)	El Nino developing; positive IOD from August	Below-normal; August 64% LPA = driest August since 1901; IOD partially offset El Nino drought
2024	93.5 cm (934.8 mm)	108% (above normal)	ENSO-neutral; positive IOD	Above-normal; 2,632 very-heavy events + 473 extremely-heavy = highest count in 5 years; Central India 119% LPA; NE India 86% LPA
2025	93.7 cm (937.2 mm)	108% (above normal; 5th highest since 1901)	ENSO-neutral; negative IOD from July	Above-normal; earliest full-country coverage in 16 years (June 27); NW India 127% LPA (highest since 2001); 7 monsoon depressions vs normal 5-6

22.5 TYPES OF PRECIPITATION IN INDIA

Precipitation Type	*Mechanism*	*Indian Distribution / Examples*
CONVECTIVE rainfall	Surface solar heating creates instability; warm, moist air rises rapidly; forms cumulus/cumulonimbus clouds; intense, localised, short-duration rain	Pre-monsoon thunderstorms (Kalbaisakhi in WB-Assam; Mango Showers in Kerala); afternoon interior monsoon rainfall; "cloudburst" events (>=100 mm/hour, IMD definition) in Himalaya and urban areas
OROGRAPHIC (Relief) rainfall	Moist air forced to rise over mountains; cools adiabatically; condenses and rains on windward slope; leeward = rain shadow	Western Ghats windward (6,000+ mm; Mahabaleshwar, Agumbe); Meghalaya hills (Mawsynram, Cherrapunji world records); Himalayan foothills (sub-Himalayan WB-Assam); MOST IMPORTANT type for India's highest-rainfall areas
FRONTAL / CYCLONIC rainfall	Convergence of two air masses (warm and cold) or cyclonic low-pressure systems force uplift; widespread, moderate-intensity rain	Western Disturbances (WD): extratropical fronts bringing winter rain to NW India (Punjab, Haryana, J&K, UP -- vital for Rabi crops); Bay of Bengal cyclones (post-monsoon TN, AP, Odisha coast); Arabian Sea cyclones (Gujarat, Maharashtra, Kerala coast)

DRIZZLE	Very fine droplets; light, persistent	West coast (Kerala, Konkan) during heavy monsoon; associated with stratus clouds; coastal fog drizzle in winter (NW India)
SNOW	Precipitation as ice crystals; requires sub-zero temperatures	Himalayan peaks and above snowline (roughly above 2,500-3,000 m in western Himalaya; higher in eastern due to warmer atmosphere); Western Disturbances bring snowfall Oct-May; Ladakh, J&K, HP, Uttarakhand
HAIL	Ice pellets; from cumulonimbus tops	Pre-monsoon hailstorms in NW India (Punjab, Haryana, western UP: March-May) damage Rabi crops (wheat, gram); Maharashtra hailstorms damage grapes; HP hailstorms damage apple orchards
SLEET / FREEZING RAIN	Rain that freezes on contact with cold surfaces; or mix of rain and snow	Occurs in J&K, HP, Uttarakhand during WD passage in deep winter; at the rain-snow boundary elevation (~1,500-2,000 m)

IMD RAINFALL INTENSITY CATEGORIES (24-HOUR)

Category	*24-Hour Rainfall*	*Colour Code / Warning Level*
No Rain	0 mm	--
Light Rain	0.1-7.5 mm	Green (No warning needed)
Moderate Rain	7.6-35.5 mm	Green
Rather Heavy Rain	35.6-64.4 mm	Yellow (Watch)
Heavy Rain	64.5-124.4 mm	Yellow/Orange (Alert)
Very Heavy Rain	124.5-244.4 mm (IMD event count uses >115.6 mm)	Orange (Alert)
Extremely Heavy Rain	>= 244.5 mm (IMD event count uses >204.4 mm)	Red (Warning)
Cloudburst (Special Category)	>=100 mm in ONE HOUR over an area of ~20-30 sq km	Red Emergency; IMD issues Cloudburst Warnings separately from 24-hr rain categories

KEY NOTE

Exam Note -- Cloudburst Definition: A CLOUDBURST is defined by IMD as **>=100 mm of rainfall in ONE HOUR** over an area of approximately 20-30 sq km. This is distinct from the "extremely heavy rain" category (>=244.5 mm in 24 hours). Cloudbursts are responsible for most Himalayan flash floods and landslides. The 2013 Kedarnath disaster involved repeated cloudbursts. IMD Pune records show approximately 30 declared cloudburst events per year in 2001-2020 vs about 20 per year in 1981-2000 -- a significant increasing trend.

22.6 DROUGHT -- DEFINITION, TYPES, DISTRIBUTION AND MANAGEMENT

IMD DEFINITION OF DROUGHT

Drought Category	*IMD Definition*	*Significance*
Meteorological Drought (Moderate)	Seasonal rainfall deficiency of 26-50% from normal (i.e., actual rainfall is 50-74% of normal) for a subdivision or district	First stage of official drought; triggers monitoring and standby preparations for agriculture departments and NDMA; often sufficient to stress rainfed Kharif crops
Meteorological	Seasonal rainfall deficiency >50% from	Emergency drought; triggers NDRF/SDRF

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Drought (Severe)	normal (actual <50% of normal)	assistance, NFSA food distribution, MGNREGS deployment; widespread crop failure likely
"Drought Year" (National)	Overall national SW monsoon rainfall deficiency >10% of LPA AND >20% of country's area affected by moderate or severe drought	A national-level declaration; enables use of national emergency funds; examples: 1972, 1987, 2002, 2009
State-Level Trigger	June-July rainfall <50% of average OR full season (SW or NE monsoon) <75% of average, often triggers state drought notification under the Manual for Drought Management (2016)	State-level notification enables relief spending under the SDRF; states may use their own definitions alongside IMD criteria

TYPES OF DROUGHT

Type	*Definition*	*Example / Implication*
Meteorological Drought	Rainfall deficit vs normal; the primary trigger for all other drought types; measured by IMD using percentage deviation from LPA, SPI (Standardised Precipitation Index), or dry-spell counts	2009 SW monsoon: 77.7% of LPA -- severe national drought; agriculture impacted across 17 states; onion and pulses prices spiked
Hydrological Drought	Depleted surface water (reservoirs, rivers, lakes) and/or groundwater levels; may lag meteorological drought by months as stored water is used up	Reservoir storage in Krishna and Cauvery basins falls in deficient monsoon years; Marathwada's 2016 water train (potable water by rail to Latur) = textbook hydrological drought under moderate meteorological drought
Agricultural / Soil-Moisture Drought	Insufficient soil moisture for crop requirements, leading to crop stress and failure; can occur even with moderate total rainfall if the distribution within the season is poor (i.e., heavy early rain followed by a long August break)	August 2023 (64% of LPA) caused agricultural drought in parts of Maharashtra and UP even though the season total was near-normal; paddy transplanting was disrupted
Socio-Economic Drought	Drought that results in economic and social hardship -- rising food prices, farmer distress, migration, loss of income for the agricultural poor; the "human face" of drought	Vidarbha farmer suicides during recurring drought years; Bundelkhand migration to cities; Maharashtra droughts 2015-16 affecting 23,000 villages across 29 districts

MANUAL FOR DROUGHT MANAGEMENT (2016) -- FOUR INDEX CATEGORIES

Index Category	*Specific Indices Used*	*Threshold for Drought Trigger*
1. Rainfall-Based Indices	(a) Percentage deviation from normal (primary trigger); (b) Standardised Precipitation Index (SPI): normal distribution of rainfall; SPI <= -1.0 = drought; (c) Number of dry spells (consecutive days without effective rainfall)	Deficiency >=25% from LPA = moderate; >=50% = severe; SPI <= -1.0 or repeated dry spells of 7+ days
2. Vegetation Indices (Remote Sensing)	(a) NDVI (Normalised Difference Vegetation Index) from MODIS/Landsat: measures vegetation greenness; declining NDVI = drought stress; (b) VCI (Vegetation	NDVI significantly below seasonal average for 3+ consecutive weeks in kharif

	Condition Index): compares current NDVI to historical range; VCI <35% = drought	season; VCI <35% over major agricultural districts
3. Soil Moisture / Hydrological Indices	(a) Moisture Adequacy Index (MAI): 76-100 = no drought; 51-75 = mild; 26-50 = moderate; <25 = severe; (b) Groundwater levels (below pre-monsoon normal); (c) Reservoir storage (below minimum operational level); (d) Streamflow (below normal for the season)	MAI <50 over 40%+ of the subdivision for 3+ consecutive weeks; reservoir below 50% of live capacity at the critical pre-kharif-harvest stage
4. Crop / Agricultural Indices	(a) Crop sown area (kharif sowing below 75% of normal for the district/subdivision); (b) Crop condition ratings from field surveys; (c) Yield forecasts from crop-cutting experiments	Kharif sowing <75% of 5-year average; crop condition rated "poor" or "very poor" across >50% of surveyed villages

DROUGHT-PRONE REGIONS -- THE DRYLAND ARC

India's chronically drought-prone areas form a broad arc from the northwest to the southeast, sometimes called the **"dryland arc"** or the **"semi-arid crescent":**

Region	*States*	*Rainfall (approx.)*	*Drought Frequency*
Western Rajasthan	Rajasthan (Jaisalmer, Barmer, Bikaner, Jodhpur, Nagaur, Sikar)	<250 mm; Jaisalmer <150 mm	1 in 2-3 years; chronically arid; near-permanent drought risk in extreme west
Kachchh and Saurashtra	Gujarat (Kachchh, Jamnagar, Rajkot, Amreli, Junagadh, Bhavnagar)	~300-450 mm	Moderate-high drought frequency; Kachchh 1 in 3-4 years
Marathwada	Maharashtra (Latur, Osmanabad/Dharashiv, Beed, Aurangabad, Nanded, Hingoli, Parbhani, Jalna)	~600-750 mm	Very high; 1 in 4-5 years for severe drought; high CV makes even moderate-rainfall years stress-prone
Vidarbha	Maharashtra (Nagpur, Wardha, Yavatmal, Amravati, Buldhana, Akola, Washim, Chandrapur)	~900-1,100 mm	Moderate drought frequency; high within-season variability; famous for cotton-farmer suicides
North Karnataka / Hyderabad Karnataka	Karnataka (Vijayapura/Bijapur, Kalaburagi/Gulbarga, Raichur, Bidar, Yadgir, Ballari/Bellary)	~550-700 mm	Frequent drought; chronically water-stressed; severe drought in 2012, 2018-19
Rayalaseema	Andhra Pradesh (Anantapur, Kurnool, Kadapa/YSR, Chittoor)	~550-700 mm; Anantapur ~550 mm	Anantapur = one of India's most drought-prone districts; ~1 in 2 years deficient
Bundelkhand	UP (Chitrakoot, Banda, Hamirpur, Mahoba, Jalaun, Lalitpur) + MP (Sagar, Damoh, Tikamgarh, Chhatarpur, Panna)	~650-850 mm	Moderate-severe drought every 3-4 years; ancient tanks degraded; groundwater deep
KBK (Kalahandi-Bolangir-Koraput)	Odisha (Kalahandi, Bolangir/Balangir, Koraput, Nuapada, Bargarh)	~1,000-1,500 mm	Paradox: relatively high rainfall but severe agricultural and food drought due to poor soil, erosion, and tribal land alienation; historically infamous for starvation deaths

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Scale of drought vulnerability in India (NDMA data): ~68% of India's total cropped area is drought-vulnerable; ~33% of the country's area (receiving less than 750 mm annual rainfall) is "chronically drought-prone" (defined in the Drought Prone Areas Programme as having a frequency of water-deficit conditions exceeding 40% of years). India has approximately **185 drought-prone districts** spread across approximately **13 states.** The paradox of KBK: high rainfall but severe food insecurity due to poor soil, forest degradation, and socio-economic vulnerability -- demonstrating that meteorological drought definitions alone are inadequate for policy.

DROUGHT MONITORING AND MANAGEMENT MECHANISMS

Mechanism	*Institution / Policy*	*Detail*
Standardised Precipitation Index (SPI)	IMD; widely used globally (WMO recommends SPI as standard)	Measures how many standard deviations the observed rainfall departs from the historical mean; SPI <= -1.0 = mild drought; -1.5 = moderate; -2.0 = extreme; statistically robust across different rainfall regimes
Drought Early Warning System (DEWS)	National Remote Sensing Centre (NRSC, ISRO) + Ministry of Agriculture (MoA)	DEWS integrates satellite-based vegetation indices (NDVI, VCI from MODIS/Landsat), soil moisture, reservoir levels, and groundwater anomalies into district-level drought alerts; updated bi-weekly during the kharif season
Manual for Drought Management (2016)	MoA & Farmers Welfare, revised under the Drought Monitoring and Reporting Framework	Prescribes the 4-index system (see 22.6.3); mandates time-bound district and state drought declaration; defines SDRF/NDRF assistance norms; operationalised by NDMA guidelines
Drought Prone Areas Programme (DPAP)	Ministry of Rural Development (1970s onwards; merged into IWMP in 2009)	Originally: watershed development in 970 drought-prone blocks; merged into Integrated Watershed Management Programme 2009; then PMKSY (Pradhan Mantri Krishi Sinchayee Yojana) Watershed Development Component from 2015
Desert Development Programme (DDP)	Ministry of Rural Development (1977-78 onwards)	Targets hot desert (Rajasthan, Gujarat, Haryana) and cold desert (Ladakh, HP); focuses on soil conservation, water harvesting, tree plantation, afforestation; merged into PMKSY from 2015
MGNREGS in drought	Ministry of Rural Development (enacted 2005)	Acts as the primary employment safety net in drought-affected areas; demand for MGNREGS work spikes in drought years; guarantees 100 days of employment; can be extended to 150 days for severe drought districts; critical for Marathwada and Bundelkhand
PMFBY (Pradhan Mantri Fasal Bima Yojana, 2016)	Ministry of Agriculture	Crop insurance scheme covering yield losses from drought, flood, hail, pest and disease; premium capped at 2% for kharif, 1.5% for rabi; government pays the balance; covers over 50 million farmers in peak years; key financial protection for rain-fed farmers

22.7 FLOODS -- SPATIAL PATTERN, TYPES AND RECENT EVENTS

RIVERINE FLOODS -- GANGA-BRAHMAPUTRA-MEGHNA BASIN

Riverine flooding in India is concentrated in the **Ganga-Brahmaputra-Meghna (GBM) river system**, which handles ~60% of India's total river flow. The GBM basin includes the most densely populated and agriculturally critical regions of India, making floods here among the most socioeconomically damaging of any disaster.

River / Area	*Flood Character*	*Key Recent Events*
Kosi River,	Originates in Nepal's Himalaya; carries massive silt	2008: embankment breach at Kushaha

Bihar ("Sorrow of Bihar")	load (one of the world's highest sediment-transport rivers); braided channel that migrates westward over centuries; prone to sudden avulsions (channel jumps); embanked since 1953-1960 but embankments paradoxically raised the riverbed ABOVE the surrounding plain, worsening the catastrophic potential of breaches	(Nepal); river avulsed ~120 km eastward; ~3 million people affected; 250+ deaths; 340,000 ha of crops damaged; Bihar's worst flood in 50 years. Annual monsoon flooding disrupts north Bihar year after year
Brahmaputra River, Assam	World's widest riverbed; highly braided; carries extreme silt loads; annual monsoon floods inundate large parts of Assam; flood pulse critical for ecology (Kaziranga) but also destructive for human settlements	2022, 2024: severe annual floods in Assam; Kaziranga National Park repeatedly flooded (rhinoceros populations temporarily displaced; flood pulse is part of the ecosystem); annual loss of agricultural land to erosion (chars)
Ganga and its tributaries (UP, Bihar, WB)	The Gangetic Plain is a vast alluvial floodplain; multiple tributaries (Ghaghra/Saryu, Gandak, Bagmati, Kamla Balan, Mahananda) flood annually; high monsoon rainfall combined with flat topography = slow drainage	2023: Bihar-UP-Uttarakhand severe flooding in August-September; 100+ deaths; Uttarakhand cloudbursts contributed; 2024: Delhi Yamuna reached 208.66 m (record in 45 years, July 2023)
Mahanadi, Godavari, Krishna	Peninsular river deltas exposed to annual cyclone-associated flooding during October-November; reservoir operations critical for controlling flood peaks	Hirakud Reservoir on Mahanadi is one of India's largest flood-control reservoirs; Godavari delta flooding in Andhra Pradesh (2022, 2024); cyclone-associated flood pulses

Bihar flood statistics (CWC data): Bihar is India's **most flood-prone state**, with ~73% of its total geographical area (68.8 lakh hectares) exposed to floods, representing approximately **17.2% of India's total flood-prone land** (though Bihar's area is much less than 17.2% of India). Approximately **76% of North Bihar's population** lives under annual flood threat. The state has witnessed a paradox: the length of flood-protection embankments increased from ~160 km (1954) to ~3,731 km (2016), yet the flood-affected area simultaneously increased from ~2.5 million ha to ~7.3 million ha -- because embankments have raised the Kosi's channel bed above the surrounding land.

URBAN FLOODING

City	*Event*	*Rainfall*	*Deaths*	*Key Driver*
Mumbai	26 July 2005	944 mm in 24 hrs at Mahalaxmi (Santa Cruz: 944.2 mm in 24 hrs; highest ever recorded for Mumbai)	500+ directly; 1,000+ total (across Maharashtra)	Orographic convergence and extreme monsoon rain; drainage system designed for ~25 mm/hr overwhelmed; Mithi River choked; encroachment of Aarey Colony and Bandra-Kurla wetlands worsened the flooding
Mumbai	2021 Taloja, Chiplun	350-400 mm in 24 hrs	50+ in MH floods	Persistent heavy rain + high tide combination
Chennai	Nov-Dec 2015	~1,416 mm over Nov 1-Dec 5 = 3x	~500+ across TN	Worst floods in a century; Pallikaranai marsh encroachment;

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		normal		Chembarambakkam reservoir gates opened suddenly; poor urban drainage
Chennai	Dec 2023 (Cyclone Michaung)	Extreme rain + cyclone approach	30+ directly from flooding	NE monsoon cyclone; coastal storm surge + rainfall combined; waterways blocked
Bengaluru	September 2022	Heavy monsoon rain + lake overflow	10+; IT industry losses ~USD 220 mn	Encroachment of lake beds (rajakaluves/stormwater drains); Raja Kaluve (storm drain) blocked; IT park Outer Ring Road flooded
Delhi	July 2023	Yamuna rose to 208.66 m (record in 45 years)	20+ in Delhi	Yamuna record peak; Hathnikund Barrage (Haryana) released 3+ lakh cusecs; low-lying areas along Yamuna flood plain (Yamuna Pushta) submerged
Hyderabad	October 2020	Heavy rain + Musi River overflow	50+; Rs.5,000 crore damage	Musi River embankments breached; illegal constructions in floodplain; drainage choked

Urban flooding has been recognised by NDMA as a distinct disaster category (National Disaster Management Plan for Urban Flooding, 2017). The **Disaster Management (Amendment) Act, 2024** proposes **Urban Disaster Management Authorities (UDMAs)** for state capitals and large cities -- directly responding to the pattern of urban flood disasters. Root causes include: (a) encroachment of natural drainage corridors (stormwater drains, lakes, wetlands); (b) drainage systems designed for 15-25 mm/hr being overwhelmed by 50-100 mm/hr events; (c) increased impervious surfaces (concrete/asphalt) reducing infiltration; (d) inadequate early warning and poor reservoir operation protocols.

FLASH FLOODS AND CLOUDBURSTS -- HIMALAYA AND WESTERN GHATS

Event	*Date*	*Location*	*Deaths / Damage*	*Details*
Kedarnath Disaster	16-17 June 2013	Rudraprayag, Uttarakhand	~6,000 deaths (official ~5,748; unofficial higher)	Multiple cloudbursts + rapid snow/ice melt in the Chorabari Glacier catchment; Mandakini River flash-flooded; Kedarnath Temple survived due to its solid granite base; worst Himalayan disaster since 1950 Assam earthquake
Chamoli Rock-Ice Avalanche	7 February 2021	Chamoli, Uttarakhand	~200 deaths	Rock-ice avalanche from Nanda Devi Glacier area hit the Ronti Gad valley; triggered surge in Rishiganga and Dhauliganga rivers; Tapovan-Vishnugad hydropower project (NTPC) severely damaged; a different mechanism from cloudburst but related to Himalayan instability
Wayanad Landslide	30 July 2024	Mundakkai-Chooralmala, Wayanad, Kerala	254 fatalities; 397 injured; 118 missing	204.5 mm in first 24 hours + 372.6 mm in next 24 hours on slopes already saturated from days of heavy monsoon rain; GSI classified as a highly rapid debris flow; debris velocity ~57 m/s; Mundakkai village largely destroyed; highlighted Western Ghats ESZ (Gadgil vs

				Kasturirangan) debate
Himachal Pradesh Cloudbursts	July-August 2023	Mandi, Kullu, Shimla, Kangra, Solan, Una districts	428 deaths across 2023 monsoon season; Puli Bridge (HP) collapsed	742 mm in first 54 days of monsoon (above-normal); 25+ bridges washed; 2,000+ houses damaged; largest cumulative disaster season in HP in decades; linked to anomalous WD-monsoon interaction (see Ch 20)
Leh Flash Flood	August 2010	Leh district, Ladakh	255 deaths; Leh town partially destroyed	Extraordinary cloudburst on August 5-6 2010; >75 mm in a few hours over arid land with zero infiltration capacity; flash flood of the Indus and its tributaries; NGT subsequently mandated regulated construction in Leh
Assam-Meghalaya Floods	Annual, especially 2022, 2024, 2025	Brahmaputra valley, Barak valley, Meghalaya	200+ deaths annually in severe years; Kaziranga animals displaced	Annual monsoon; Kaziranga's flood pulse is an ecosystem requirement but also results in rhino-human conflict on highways; 2022 had 3 separate major flood waves

ENV ALERT

Flood-Drought Co-Existence -- A Climate Reality:
India regularly witnesses the paradox of **simultaneous flood and drought within the same year** -- sometimes within the same state. In 2023, Bihar flooded in August while Marathwada was in drought. In 2025, Bundelkhand (historically drought-prone) received ~200% surplus rain that damaged kharif crops, while some areas of Rayalaseema remained deficient. This "spatial whiplash" -- flood somewhere, drought elsewhere -- is becoming more frequent as climate change intensifies monsoon extremes (Roxy et al. 2017: threefold rise in widespread extreme events + 27% more dry spells). It underscores that both flood AND drought risk must be managed simultaneously, and that "above-normal total monsoon rainfall" does not guarantee equitable or useful distribution.

22.8 RAINFALL AND WATER SECURITY

GROUNDWATER RECHARGE

India's groundwater economy is overwhelmingly monsoon-dependent. The **Central Ground Water Board (CGWB)** estimates that approximately **~60-65% of India's net groundwater recharge occurs during the SW monsoon season** (June-September) through direct infiltration, canal seepage, and return flows. In arid and semi-arid areas where rainfall is low and episodic, even the high-CV, low-volume rain events of the Thar region can be critical for aquifer recharge if they occur as slow-infiltrating events rather than runoff-generating flash floods.

India is the **world's largest groundwater user** (~25% of global extraction). The groundwater depletion crisis -- particularly in the northwest (Punjab, Haryana, western UP, Rajasthan) -- is fundamentally a crisis of overdrawing a monsoon-replenished resource faster than the monsoon recharges it. A deficient monsoon year (like 2009 or 2023) compounds the depletion; consecutive below-normal years are catastrophic for water tables, well yields and bore-well depths.

RESERVOIR STORAGE AND THE MONSOON

Reservoir / System	*River Basin*	*Live Capacity (approx.)*	*Monsoon Dependence*
Bhakra-Nangal (Gobind Sagar Lake)	Sutlej, Himachal Pradesh	9,340 MCM	Filled by monsoon runoff + glacier melt; regulates Sutlej downstream for Punjab-Haryana-Rajasthan irrigation; WD snowfall also contributes to melt-runoff in summer

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Hirakud Reservoir	Mahanadi, Odisha	5,818 MCM live storage	Primary flood control for Mahanadi delta (Cuttack, Sambalpur); fills dramatically during monsoon (typically >80% by September); also critical for rabi irrigation in Odisha
Sardar Sarovar (Narmada Dam)	Narmada, Gujarat	5,818 MCM (gross)	Fills entirely from SW monsoon runoff in the Narmada basin (MP and Maharashtra); critical for drinking water in Kutch-Saurashtra (via Narmada main canal) -- the most drought-prone parts of Gujarat depend on Narmada water
Tungabhadra Reservoir	Tungabhadra (Krishna tributary), Karnataka/AP border	3,722 MCM	Shared between Karnataka and AP/Telangana for irrigation; levels decline sharply in El Nino/deficient years, triggering inter-state disputes (Karnataka-Telangana-AP Krishna water-sharing discord)
Nagarjunasagar Dam	Krishna, Telangana	11,472 MCM	One of India's largest reservoirs; critical for Andhra Pradesh (Krishna-Godavari delta) and Telangana irrigation; drought in Marathwada reduces Bhima-Krishna inflows

The CWC monitors **155 major reservoirs** with a combined live capacity of approximately **~180.85 BCM** (billion cubic metres), representing ~70% of India's total major-reservoir capacity. After the above-normal **2024 monsoon**, national live storage reached approximately **157.7 BCM (~87-88% of capacity) by mid-October 2024** -- one of the best post-monsoon storage figures in recent years, with the Western region (Gujarat, Maharashtra, Goa) near 97% but the Northern region (HP, Punjab, Rajasthan) lagging at ~60%.

INTER-STATE WATER DISPUTES AND MONSOON VARIABILITY

Dispute	*States*	*Monsoon Variability Link*
Cauvery Water Dispute	Karnataka vs Tamil Nadu (+ Kerala + Puducherry)	Karnataka's reservoirs (Krishnarajasagar, Kabini, Hemavathi) fill from SW monsoon in June-September; Tamil Nadu's samba paddy (NE monsoon) requires water releases from Karnataka; in El Nino/drought years Karnataka insists on retaining water for its own needs vs TN's demands; dispute flares almost every SW-monsoon-deficient year
Krishna Water Dispute	Maharashtra, Karnataka, Telangana, Andhra Pradesh	Excess in wet years, acute shortage in drought years; Marathwada's Bhima-Krishna inflows are highly variable; Nagarjunasagar-Srisailam storage regime triggers inter-state friction annually
Mahanadi Dispute	Chhattisgarh vs Odisha	Chhattisgarh's barrages reduce Mahanadi flows into Odisha in deficient years; 2019+ dispute; tribunal constituted
Ravi-Beas (SYL Canal)	Punjab vs Haryana vs Rajasthan	Satluj-Yamuna Link (SYL) Canal controversy; Punjab's water surplus/deficit from monsoon + WDs determines political viability of transfers

22.9 CURRENT AFFAIRS HOOKS (2022-2025)

CURRENT AFFAIRS

2024 Monsoon -- Record Extreme Events (IMD Annual Summary): SW monsoon 2024 = 934.8 mm (108% of 868.6 mm LPA). 2,632 very-heavy rain events (>115.6 mm/24 hr) and 473 extremely-heavy rain events (>204.4 mm/24 hr) -- the highest count of extreme-rainfall events in the past 5 years (2023 had 2,321 very-heavy and 421 extremely-heavy). Central India 119%

of LPA; South Peninsula 114%. 9 subdivisions had large excess. This is consistent with Roxy et al. (2017) "threefold rise" in extreme events.

2025 Monsoon -- Above Normal, Earliest Full Coverage in 16 Years: 937.2 mm (108% LPA; 5th highest since 1901). Full-country coverage by June 27 (vs. normal July 8; 11 days early). NW India 127% LPA (highest since 2001). Nainwa (Bundi, Rajasthan): 502 mm in one day (23 August 2025) -- a dramatic rainfall event in one of India's driest regions (double jeopardy inversion). 7 monsoon depressions (vs. normal 5-6).

Wayanad Landslide (July 30, 2024 -- Western Ghats Extreme Rainfall): Mundakkai-Chooralmala, Wayanad, Kerala: 254 fatalities; 397 injured; 118 missing. 204.5 mm in the first 24 hours + 372.6 mm in the following 24 hours. GSI classified as a highly rapid debris flow. Re-ignited the Gadgil vs Kasturirangan Ecologically Sensitive Area (ESA) debate for the Western Ghats. Direct consequence of extreme SW monsoon rainfall on steep, partially-deforested WG slopes.

Mission Mausam (Cabinet Sep 11, 2024; Launched Jan 14, 2025): Rs.2,000 crore over 2024-26. Implemented by IMD + IITM Pune + NCMRWF (all under Ministry of Earth Sciences). Key targets: Doppler Weather Radars from ~39 to ~80 (eventually ~135 by 2026); 60 radiosonde/radio-wind stations; 100 disdrometers; 10 wind profilers; 25 radiometers; ocean buoys; HPC upgrade; AI/ML forecasting; cloud-seeding research; model resolution 12 km to 6 km; nowcasting 3 hr to 1 hr. As of 2024-25, 47 radars operational (87% area coverage). Launched by PM Modi on IMD's 150th anniversary (IMD established January 15, 1875).

Delhi Yamuna Record (July 2023): Yamuna reached 208.66 m in Delhi on July 13, 2023 -- highest in 45 years (previous record 207.49 m in 1978). Hathnikund Barrage (Haryana) released 3+ lakh cusecs. Low-lying areas (Civil Lines, Kashmere Gate, Yamuna Pushta settlement, ISBT) submerged. Over 26,000 people evacuated. Exposed Delhi's flood-plain encroachments and inadequate Yamuna floodplain management.

Roxy et al. 2017 -- Policy Link (River Flooding + Drought Extremes): The "threefold rise in widespread extreme rain events" (1950-2015) cited in Nature Communications is now referenced in the National Action Plan on Climate Change (NAPCC), NDMA guidelines, and the Dam Safety Act 2021 Emergency Action Plan requirements. The "27% more dry spells" finding underpins MGNREGS prioritisation in drought districts. Both findings -- floods AND droughts intensifying simultaneously -- validate India's dual-track approach: Mission Mausam (early warning) + PMFBY (crop insurance) + MGNREGS (drought safety net).

22.10 PYQ ANALYSIS -- CHAPTER 22 (2010-2025)

Source	Year	Marks	Question
UPSC Civil	2024	15M	"Discuss the spatial and temporal distribution of rainfall in India. How does the Coefficient of Variation (CV) determine drought vulnerability across different regions?"
UPSC Civil	2023	12M	"Examine the causes and consequences of urban flooding in India with suitable examples. What institutional and planning reforms are needed?"
UPSC Civil	2022	10M	"What is the "double jeopardy" of Indian rainfall? Discuss with reference to the drought-prone regions of India."
UPSC Civil	2021	15M	"Discuss the major flood-prone rivers of India. Critically evaluate India's flood management approach with reference to the Kosi river."
UPSC Civil	2020	10M	"Describe the distribution of rainfall in India. Why does the leeward side of the Western Ghats receive considerably less rainfall than the windward side?"
UPSC Civil	2019	12M	"Critically examine the drought management framework in India with reference to the Manual for Drought Management (2016) and the role of MGNREGS."
UPSC Civil	2018	10M	"Discuss the spatial variability of monsoon rainfall in India. How does the Coefficient of Variation map relate to agricultural vulnerability?"
UPSC Civil	2016	12M	"Discuss the causes and management of flash floods in India, with reference

			to Himalayan rivers and the Uttarakhand disaster of 2013."
IFOS GS	2024	15M	"Examine the relationship between monsoon rainfall variability (including the dryland arc and double jeopardy concept) and forest fire risk in India."
IFOS GS	2023	10M	"How does the orographic effect of the Western Ghats determine the type and density of vegetation on its windward and leeward sides?"
IFOS GS	2022	10M	"Discuss the ecological impact of flash floods and cloudbursts on Himalayan forests and biodiversity, with reference to recent events."
IFOS GS	2021	10M	"Discuss how rainfall variability, drought and flood events affect India's river-basin ecosystems and biodiversity. Use the Kosi and Brahmaputra rivers as examples."

KEY NOTE

Frequency: Spatial/temporal distribution + CV (Civil 2024); urban flooding (Civil 2023); double jeopardy/drought vulnerability (Civil 2022); flood-prone rivers/Kosi (Civil 2021); WG windward-leeward (Civil 2020); drought management + MGNREGS (Civil 2019); CV and agricultural vulnerability (Civil 2018); flash floods/Kedarnath (Civil 2016). IFoS: drought-arc + fire risk (2024), WG ecology (2023), flash flood ecology (2022), river basin biodiversity (2021). For 2025-26: Mission Mausam (Sep 2024 Cabinet; Jan 2025 launch); 2024 record extreme events (2,632+473); Wayanad 2024; Delhi Yamuna record 2023; Roxy 2017 policy link. The "double jeopardy" concept + drought/flood co-existence are the two highest-value analytical frameworks for both Civil and IFoS papers.

22.11 MODEL BOOK

Discuss the spatial distribution of rainfall in India and explain the "double jeopardy" of Indian rainfall variability. How does this determine drought vulnerability?

UPSC Civil (Mains) | 15 Marks | 210 Words

India's rainfall distribution is among the most unequal of any large country -- ranging from Mawsynram's 11,802 mm/year to Jaisalmer's 150 mm and Leh's 130 mm. The spatial pattern is determined by relief, monsoon branch effects, and continentality, while variability -- measured by the Coefficient of Variation (CV) -- creates the "double jeopardy" that drives India's chronic drought crisis.

SPATIAL DISTRIBUTION (FOUR ZONES):

Zone 1 -- Very Heavy (>200 cm): West coast (Konkan, Kerala, coastal Karnataka, Goa) and Western Ghats windward slopes (Mahabaleshwar ~5,600 mm, Agumbe ~7,640 mm) due to orographic uplift by the Arabian Sea branch; NE India (Meghalaya -- Mawsynram 11,802 mm, Cherrapunji 11,359 mm) due to the Meghalaya funnel effect of the Bay of Bengal branch.

Zone 2 -- Heavy (100-200 cm): Sub-Himalayan West Bengal-Assam, Odisha, eastern Madhya Pradesh, Chhattisgarh, Jharkhand -- Bay of Bengal branch and BoB depressions deliver heavy rain.

Zone 3 -- Moderate (50-100 cm): Most of the Deccan Plateau, eastern Rajasthan, UP, Punjab, Haryana -- reduced branch moisture, rain-shadow effects.

Zone 4 -- Low (<50 cm): Western Rajasthan, Kachchh, leeward Deccan, Ladakh -- Aravallis parallel to wind (no uplift), subtropical high subsidence, Himalayan rain shadow for Ladakh.

THE "DOUBLE JEOPARDY": The Coefficient of Variation (CV = Standard Deviation/Mean x 100) measures year-to-year reliability. The critical finding: **HIGH CV areas exactly coincide with LOW RAINFALL areas** -- the "double jeopardy." West Rajasthan: mean ~150 mm AND CV >100% locally. Marathwada: ~650 mm AND CV ~40-50%. Compare: the west coast: mean >2,000 mm AND CV <15%. The areas most in need of reliable water are precisely those with the most unreliable rainfall.

DROUGHT IMPLICATIONS: This double jeopardy explains the ~185 drought-prone districts across ~13 states in India's "dryland arc" (western Rajasthan, Kachchh, Marathwada, Vidarbha, north Karnataka, Rayalaseema, Bundelkhand, KBK). The Manual for Drought Management (2016) uses four indices (rainfall SPI, NDVI, MAI, crop

condition) to operationalise drought declarations. MGNREGS, PMFBY crop insurance, and the Drought Prone Areas Programme (now PMKSY Watershed Component) are the primary policy responses.

Understanding the spatial distribution map alongside the CV map reveals where India's most critical water vulnerabilities lie -- and explains why national average monsoon statistics can mask severe regional crises. The "same total, worse distribution" climate change trend (Roxy 2017: 27% more dry spells) means the double jeopardy is intensifying.

Critically evaluate India's urban flood vulnerability with examples. What institutional and planning reforms are urgently needed?

UPSC Civil (Mains) | 15 Marks | 200 Words

Urban flooding has emerged as one of India's most costly and recurrent disasters, driven by the combination of intensifying extreme rainfall events (Roxy et al. 2017: ~75% rise in >=150 mm/day events) and systematic destruction of urban natural drainage infrastructure.

EVIDENCE OF URBAN FLOOD VULNERABILITY:

Mumbai (26 July 2005): 944 mm in 24 hours; 500+ deaths; the Mithi River was choked and the Bandra-Kurla wetlands encroached, eliminating the city's natural flood sponge. The drainage system designed for 25 mm/hr was overwhelmed by 100+ mm/hr.

Chennai (2015, 2023): 2015 = worst floods in 100 years (~1,416 mm, Nov-Dec); Pallikaranai marsh reduced from 50 sq km to 4 sq km; Chembarambakkam reservoir gates opened without warning. 2023 = Cyclone Michaung intensified NE monsoon flooding.

Bengaluru (2022): Lake encroachment; raja kaluves (stormwater drains) blocked; IT parks flooded; estimated loss USD 220+ million; 10+ deaths.

Delhi (July 2023): Yamuna record 208.66 m (highest in 45 years); Yamuna floodplain encroachment by unauthorized settlements and temporary structures; 26,000 evacuated.

ROOT CAUSES (STRUCTURAL):

1. Encroachment of natural drainage corridors -- lakes, wetlands, stormwater drains, floodplains.
2. Drainage systems designed for historical (lower intensity) rainfall, not the new extreme-event reality.
3. Rapid urbanisation (India's urban population from 286 million (2001) to 500+ million (2025)) increases impervious surfaces, reducing infiltration by 30-60%.
4. Poor reservoir operation protocols (delayed opening of gates during extreme rain events).

INSTITUTIONAL AND PLANNING REFORMS NEEDED:

1. **Urban Disaster Management Authorities (UDMAs):** The DM (Amendment) Act, 2024 proposes UDMAs for state capitals and large cities -- CRITICAL implementation needed.
2. **Mandatory Flood-Risk Zoning:** Supreme Court has directed protection of natural drainage (Suresh Koushal and lake encroachment cases); Master Plans must mandate flood-plain no-development zones.
3. **STORM WATER MANAGEMENT SYSTEMS:** Upgrade drainage to handle 50-100 mm/hr events; city-specific Flash Flood Guidance Systems (FFGS) under Mission Mausam.
4. **Wetland Restoration:** Restore urban wetlands as "sponge city" infrastructure (Chennai Pallikaranai, Mumbai coastal wetlands, Bengaluru lakes). Ramsar convention obligations.

India's urban flood crisis is not a "nature" disaster -- it is a governance failure compounded by extreme weather. Mission Mausam (2024) improves warning lead time; but without reforming land use, drainage design, and institutional accountability (UDMAs + DM Act 2024), warning systems will be insufficient to prevent deaths and economic loss.

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CHAPTER 23

TYPES OF NATURAL VEGETATION

Classification, Distribution And Ecology

CHAPTER AT A GLANCE

- India is one of 17 globally recognized megadiverse countries: ~47,000 plant species (~17,000 flowering species); ~6,000-7,000 endemic plant species (~33% of all species). Two biodiversity hotspots: Western Ghats + Sri Lanka (>5,000 endemic plant species, ~82% habitat lost) and Himalaya/Eastern Himalaya-Indo-Burma (Eastern Himalaya part; >3,500 endemic plant species).
- Champion and Seth (1968) -- the OFFICIAL IFoS classification: 16 major forest groups (Tropical Wet Evergreen to Dry Alpine Scrub). The 5 NCERT/UPSC Civil types: (1) Tropical Evergreen/Rainforest; (2) Tropical Deciduous (Moist and Dry); (3) Tropical Thorn and Scrub; (4) Montane/Mountain Forests; (5) Mangroves/Littoral. Rainfall is the MOST IMPORTANT factor: >250 cm = evergreen; 150-250 cm = semi-evergreen; 100-150 cm = moist deciduous; 70-100 cm = dry deciduous; <70 cm = thorn/scrub.
- Key species exam-checklist: Teak (Tectona grandis) -- moist deciduous, national tree of Myanmar + Tonga; Sal (Shorea robusta) -- moist deciduous, N India dominant; Sandalwood (Santalum album) -- hemi-parasitic, Karnataka/TN/AP, IUCN Vulnerable; Deodar (Cedrus deodara) -- dry temperate Himalaya, J&K state/UT tree; Chir Pine (Pinus roxburghii) -- subtropical Himalaya 1,000-1,800 m, fire-adapted; Khejri (Prosopis cineraria) -- state tree of Rajasthan; Sundri (Heritiera fomes) -- namesake of Sundarbans.
- FSI State of Forest Report 2023 (SFR 2023): Total Forest and Tree Cover = 8,27,357 sq km (25.17% of India's geographic area). Forest Cover alone = 7,15,343 sq km (21.76%). Very Dense Forest (VDF, >70% canopy) = 1,04,329 sq km. Net change 2021-2023: Forest cover increased by 1,445 sq km. States with highest % forest cover: Mizoram (84.53%), Arunachal Pradesh (79.33%), Meghalaya (76.00%), Manipur (74.34%), Nagaland (73.90%).
- Forest Conservation Act 1980 (FCA 1980) -- landmark law: no diversion of forest land to non-forest use without prior approval of the Central Government. Forest Conservation Amendment Act 2023 (FCAA 2023): controversially narrowed the definition of "forest" to only recorded/notified forests (excluding ~28 lakh ha of unclassified forests); allowed linear projects within 100 km of international borders without FCA approval; faced criticism from ecologists and Supreme Court scrutiny.
- Invasive alien species: Lantana camara (50+ lakh ha of Indian forests), Prosopis juliflora (arid zones), Parthenium hysterophorus, Mikania micrantha (NE India), Eichhornia crassipes (water hyacinth in wetlands). Invasives reduce native biodiversity, increase fire risk, alter soil chemistry. MoEFCC's National Action Plan for Invasive Alien Species (2022) -- policy response.
- Mangroves: India has 4,992 sq km of mangrove cover (FSI SFR 2023; ~0.15% increase from 2021). Largest: Sundarbans (WB, ~2,123 sq km India portion); Andaman and Nicobar (~616 sq km); Bhitarkanika (Odisha, ~280 sq km); Pichavaram (TN, ~45 sq km -- one of world's largest mangrove stands at a single location). Key species: Sundri (Heritiera fomes), Avicennia marina, Rhizophora, Bruguiera, Sonneratia.
- CAMPA (Compensatory Afforestation Fund Management and Planning Authority): CAMPA Act 2016; Rs.48,000+ crore fund for afforestation on degraded land when forest land diverted; administered by National CAMPA Authority. Criticism: compensatory planting rarely replicates biodiversity of natural forests lost to diversion. Van Mahotsav (annual July plantation drive): 73+ crore saplings planted in 2024 Van Mahotsav across India.

23.1 INTRODUCTION -- INDIA'S NATURAL VEGETATION

India is one of the world's most botanically diverse countries -- a consequence of its extraordinary geographic range (from near-equatorial Andaman Islands to the frigid Karakoram), climatic diversity (Thar Desert to

Mawsynram -- one of Earth's wettest places), altitude range (sea level to 8,586 m at Kangchenjunga), and ancient geological stability that allowed millions of years of uninterrupted evolutionary divergence.

Natural vegetation refers to **plant communities that have developed under natural conditions of climate, soil, and topography, without significant human interference**. It is distinguished from plantation forests (man-made monocultures) and agricultural crops. India's natural vegetation represents one of the last extensive repositories of wild plant diversity in Asia, now under pressure from agriculture, urbanisation, mining, and climate change.

INDIA'S PLANT DIVERSITY -- KEY STATISTICS

Parameter	*Figure*	*Significance*
Total plant species	~47,000 species	India has ~11-12% of world's known plant species in ~2.4% of world's land area
Flowering plant species	~17,500-18,000 species (angiosperms)	Among top 10 countries globally for angiosperm diversity
Endemic plant species	~6,000-7,000 species (~33% of all Indian plant species)	Concentrated in the Western Ghats and eastern Himalayas -- the two biodiversity hotspots
Medicinal plant species	~8,000 species (WHO data for Indian traditional medicine)	India = one of the world's most important sources of medicinal plants; Ayurveda, Siddha, Unani systems
Pteridophytes (ferns)	~1,100 species	Rich in humid WG and NE India
Gymnosperms	~70 species (conifers, cycads)	Himalayan conifers; Cycas beddomei (EN) in Eastern Ghats
Mosses and Liverworts (Bryophytes)	~2,500 species	Moist sub-alpine Himalaya and shola forests (WG)
Megadiverse country status	1 of 17 globally designated megadiverse countries (Conservation International definition)	India shares this status with Brazil, Australia, China, Colombia, South Africa, Indonesia, Mexico, Madagascar, Peru, DRC, Venezuela, Ecuador, Papua New Guinea, USA, Philippines, Malaysia

FACTORS DETERMINING NATURAL VEGETATION IN INDIA

Factor	*Mechanism*	*India Example*
Rainfall (MOST IMPORTANT)	Annual rainfall determines the moisture availability that primarily controls vegetation type; the rainfall gradient maps almost perfectly to the vegetation type gradient	>250 cm = Tropical Wet Evergreen; 150-250 cm = Semi-Evergreen; 100-150 cm = Moist Deciduous; 70-100 cm = Dry Deciduous; <70 cm = Thorn/Scrub; <25 cm = Desert
Temperature (modified by altitude)	Temperature controls metabolic rates, phenology, and which plant functional types can survive; altitude creates temperature zonation	Tropical lowlands (>25 deg C) = tropical forests; subtropical mid-hills (15-25 deg C) = subtropical; temperate high-hills (8-15 deg C) = temperate; sub-alpine (0-8 deg C) = sub-alpine; nival (below 0 deg C) = alpine/snow
Soil type	Soil texture, chemistry, depth and drainage influence species composition within a rainfall zone	Deep alluvial soils = moist deciduous (sal); black cotton soil (Vertisols, Deccan traps) = dry deciduous/thorn; laterite (highly leached) = evergreen; sandy arid soils = desert scrub; waterlogged coastal soils = mangroves

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Topography and Aspect	Slope, aspect (N/S/E/W facing), elevation, and drainage pattern modify local temperature and moisture	North-facing slopes (cooler, moister) in Himalaya = moist temperate forest; south-facing slopes (warmer, drier) = dry temperate/pine; windward vs leeward of WG determines forest type within same latitude
Biotic (Human) Factors	Human disturbance through agriculture, grazing, fire and felling has degraded and replaced large areas of natural vegetation	Grasslands in many areas are fire-maintained anthropogenic savannas rather than natural vegetation; urban expansion in WG footprint areas; encroachment in forest margins; fire in Chir Pine belt annually

23.2 CHAMPION AND SETH CLASSIFICATION (1968) -- THE OFFICIAL IFOS CLASSIFICATION

The **Champion and Seth (1968) classification** -- formally titled "A *Revised Survey of the Forest Types of India*" -- is the standard classification used in IFoS examinations and by the Forest Survey of India. It recognises **16 major forest groups** and approximately **221 sub-types**. The system is based on **climate and floristic composition** -- primarily rainfall, temperature and altitude -- and reflects the interplay of these factors with species assemblages rather than imposing a purely physiognomic (appearance-based) framework.

Group No.	Forest Type	Rainfall Requirement	Altitude / Zone	Dominant / Key Species	Key States
1	Tropical Wet Evergreen Forests	> 250 cm annual; no dry season or very brief	0-1,000 m (tropical lowlands)	Dipterocarpus spp. (gurjan), Artocarpus spp. (jackfruit relatives), Mesua ferrea (ironwood), Calophyllum inophyllum, Cinnamomum spp., Mangifera sylvatica, Myristica malabarica (wild nutmeg), Elaeocarpus spp.	Kerala, coastal Karnataka, Goa, Konkan coast (MH), Andaman and Nicobar Islands, Arunachal Pradesh, Assam, Meghalaya, Nagaland, Manipur, Mizoram, Tripura
2	Tropical Semi-Evergreen Forests	175-250 cm; short dry season (2-4 months)	0-1,000 m	Terminalia spp., Lagerstroemia spp. (benteak), Bombax ceiba (silk cotton), Xylia xylocarpa, Dillenia pentagyna, Artocarpus spp., mixture of evergreen and deciduous species	Kerala foothills, Karnataka and Goa (transition zones), interior Maharashtra (transition), Andaman Islands (interior), Odisha coast, WB (Darjeeling foothills transition)
3	Tropical Moist Deciduous Forests	100-200 cm; 4-6 month dry season; leaves	0-1,000 m	Teak (Tectona grandis) -- peninsular India; Sal (Shorea robusta) -- northern India; Bamboos	Most extensive type; MP, Chhattisgarh, Maharashtra,

		shed in dry season		(Dendrocalamus strictus, Bambusa bambos); Terminalias; Dalbergia latifolia (rosewood); Pterocarpus marsupium (Indian kino)	Odisha, Jharkhand (Sal); MP, Maharashtra, Karnataka, AP (Teak); WB, Bihar, UP (Sal)
4	Littoral and Swamp Forests (Mangroves)	High humidity; saline/brackish waterlogged coastal soils	Tidal/coastal; 0-5 m	Heritiera fomes (Sundri), Avicennia marina, Rhizophora apiculata, Bruguiera gymnorrhiza, Sonneratia apetala, Nypa fruticans (water palm), Ceriops decandra, Aegiceras corniculatum	West Bengal (Sundarbans); Odisha (Bhitarkanika); Gujarat (Kachchh-Saurashtra creeks); AP, TN (Pichavaram), Karnataka, Goa; Andaman and Nicobar
5	Tropical Dry Deciduous Forests	70-150 cm; 6-8 month pronounced dry season	0-1,000 m	Teak (in moister patches), Anogeissus latifolia (dhawa/axlewood), Terminalia tomentosa (saj), Diospyros melanoxylon (tendu/bidi leaf), Boswellia serrata (salai/Indian frankincense), Butea monosperma (flame of the forest), Dalbergia latifolia (marginal), Aegle marmelos (bel)	MP, Rajasthan (eastern), Gujarat, Maharashtra (interior), AP, Telangana, Karnataka (interior), UP (Bundelkhand belt)
6	Tropical Thorn Forests and Scrub	<75 cm; extreme dry season (8-10 months); desert fringe	0-700 m	Prosopis cineraria (Khejri -- state tree of Rajasthan), Acacia senegal (gum arabic), Acacia nilotica (babool/kikar), Ziziphus nummularia (ber), Euphorbia caducifolia (thor/cactus-like), Calligonum polygonoides, Salvadora persica (miswak), Capparis decidua (ker), Commiphora wightii (guggul)	Rajasthan (except extreme west), Gujarat (Kachchh-Saurashtra), southern Haryana, southern Punjab, Bundelkhand (MP-UP border), interior AP, interior Karnataka
7	Tropical Dry Evergreen Forests	75-100 cm; but peculiar dry season timing; coastal	Near sea level; coastal fringe	Manilkara hexandra (khirni), Diospyros ebenum (ebony), Mimusops elengi (bakul/bullet wood), Memecylon umbellatum	VERY RESTRICTED: Coromandel coast (southern TN and SE AP); small

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		Coromandel only			patches only; unique type maintained by coastal humidity despite low rainfall; highly threatened by development
8	Sub-Tropical Broad-Leaved Hill Forests	150-250 cm; cool subtropical	1,000-2,000 m; lower Himalayan and WG upper zones	Schima wallichii, Engelhardtia spicata, Castanopsis spp. (chinkapin), Lithocarpus spp., evergreen oaks (Quercus lamellosa, Q. griffithii); Alnus nepalensis in Himalaya	Darjeeling, Sikkim, Arunachal Pradesh, Meghalaya, Nagaland (all NE India Himalayan foothills); upper WG (Nilgiris, Anamalais); Shola forest patches (WG)
9	Sub-Tropical Pine Forests (Chir Pine)	75-200 cm; dry winters; moist summers	1,000-2,000 m (lower NW Himalaya); fire-prone slopes	Pinus roxburghii (chir pine / longleaf Indian pine) -- dominates; Rhododendron arboreum, Myrica esculenta (kafal), Quercus leucotrichophora (ban oak) mixed at higher end	J&K, Himachal Pradesh, Uttarakhand, Sikkim (lower altitudes on dry S-facing slopes); also in NE India lower hills (Arunachal)
10	Sub-Tropical Dry Evergreen Forests	25-50 cm; cold dry winters; warm dry summers	500-1,500 m; Siwalik and lower Himalayan foothills dry areas	Olea cuspidata (wild olive), Acacia modesta (phulai), Dodonaea viscosa, Pistacia integerrima (kakkar)	Pakistan border areas; NW Rajasthan foothills; parts of J&K (lower altitude dry zones); Punjab Siwaliks
11	Himalayan Moist Temperate Forests	150-250 cm; cold dry winters; cool moist summers	2,000-3,000 m; wetter N-facing Himalayan slopes	Quercus semecarpifolia (kharsu oak), Q. lamellosa, Rhododendron arboreum, Abies pindrow (West Himalayan silver fir), Picea smithiana (West Himalayan spruce), Pinus wallichiana (blue pine); in E Himalaya: Abies densa, Tsuga dumosa (Himalayan hemlock)	J&K (Kashmir valley higher slopes), Himachal Pradesh, Uttarakhand, Sikkim, Arunachal Pradesh (all on wetter aspects); also NE Himalayan states

12	Himalayan Dry Temperate Forests	50-100 cm; very cold dry winters; warm dry summers; rain shadow	1,800-3,500 m; leeward/rain-shadow Himalayan valleys	Cedrus deodara (deodar -- state/UT tree of J&K), Pinus wallichiana (blue pine), Quercus ilex (holm oak), Juniperus spp., Berberis spp., Ephedra gerardiana; understory very sparse due to dryness	Lahaul-Spiti, Kinnaur, Kumaon (inner valleys), Ladakh fringes, Kashmir valley rain-shadow areas; Inner valleys of HP; parts of Sikkim dry valleys
13	Sub-Alpine Forests	100-150 cm (often as snow); very cold; short growing season (3-4 months)	3,000-4,000 m; approaching tree line	Abies spectabilis (Himalayan silver fir), Betula utilis (Himalayan birch; bark used for writing in ancient times -- "bhoj patra"), Rhododendron campanulatum, Juniperus recurva; in E Himalaya: Abies densa, Sorbus spp.	Throughout the Himalayan range: J&K, HP, Uttarakhand, Sikkim, Arunachal Pradesh; tree line generally ~3,800-4,000 m in Himalaya
14 & 15	Moist and Dry Alpine Scrub	<50 cm precipitation (mostly as snow); mean annual temp <0-5 deg C; growing season <3 months	4,000-5,000 m; above tree line	Moist Alpine Scrub: Rhododendron anthopogon, Juniperus recurva, Potentilla, Gentiana spp., Primula spp., cushion plants; Dry Alpine Scrub: Artemisia spp. (wormwood), Caragana spp., Eurotia spp., Kobresia spp. (sedges)	Changthang (Ladakh), Lahaul-Spiti, Rupshu plateau; high altitude areas of J&K, HP, Uttarakhand, Sikkim, Arunachal
16	Secondary / Degraded Forests and Scrub	Highly variable	Variable	Lantana camara (invasive dominant), Vitex negundo, Calotropis gigantea, Saccharum spontaneum (kans grass), Imperata cylindrica	Degraded margins of all natural forest types; particularly extensive in degraded moist and dry deciduous zones; often invaded by Lantana

IFOS FOCUS

IFoS -- Champion and Seth: Critical Points for Exam:
(1) **Tropical Moist Deciduous** (Group 3) is India's **most commercially important** and most extensive type -- teak in the south and sal in the north. (2) **Teak and Sal do NOT co-occur** in natural conditions: teak is peninsular (south of the Tropic of Cancer); sal is sub-Himalayan/north-central. Their boundary approximately coincides with the Tapti-Satpura-Chhota Nagpur divide. (3) **Chir Pine (Group 9)** is unique in being **fire-adapted** -- its thick bark and serotinous tendencies mean fire is part of its ecology; annual fires in the Chir Pine belt burn off competing species and maintain the pine's dominance. (4) **Deodar (Group 12)** is ONLY found in the **dry temperate rain-shadow aspects** of the Himalaya -- it cannot compete in the moist temperate zones where firs and spruces

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dominate. (5) **Sub-Alpine Forests (Group 13)** transition to Alpine Scrub at the **tree line (~3,800-4,000 m)**, which is controlled primarily by the 10 deg C isotherm of the warmest month (Koppen criterion). (6) Champion and Seth has **16 major groups** and approximately **221 sub-types** -- the sub-type number is a frequent IFoS prelims question.

23.3 NCERT / UPSC CIVIL CLASSIFICATION -- FIVE TYPES OF NATURAL VEGETATION

For UPSC Civil Services, the standard 5-type classification (based on NCERT textbooks) is sufficient and most frequently tested. Each type is described below with all exam-relevant detail.

TYPE 1 -- TROPICAL RAINFORESTS / TROPICAL WET EVERGREEN FORESTS

Feature	*Detail*
Rainfall	> 200-250 cm; no dry season or very brief (<2 months); high humidity year-round
Temperature	25-35 deg C; small seasonal variation; constantly warm
Soils	Laterite (highly leached, low nutrients) but supported by rapid nutrient cycling; in Andamans also calcareous/alluvial
Key characteristic	EVERGREEN -- no leaf fall during any defined season; multi-layered canopy (emergent layer >45 m, main canopy 25-45 m, understory 10-25 m, shrub layer, ground layer); very high biodiversity; canopy so dense that very little sunlight reaches the forest floor
Distribution	Western Ghats (coastal Karnataka, Goa, Kerala, Maharashtra Konkan belt); NE India (Arunachal Pradesh, Assam, Meghalaya, Nagaland, Manipur, Mizoram, Tripura); Andaman and Nicobar Islands; sub-Himalayan West Bengal (Darjeeling/Jalpaiguri terai moist patches)
Dominant species	Dipterocarpus spp. (gurjan); Mesua ferrea (ironwood/nageswar -- national flower of Laos); Artocarpus spp.; Calophyllum inophyllum; Cinnamomum spp.; Hopea parviflora; Myristica spp.; Elaeocarpus spp.; Michelia (champak); pitcher plant Nepenthes khasiana (only Indian pitcher plant, endemic to Meghalaya)
Economic value	Rosewood (Dalbergia latifolia); ebony (Diospyros spp.); high-value timber; spices; medicines; ecosystem services (carbon storage, water regulation); rich in NTFPs
Threats	Shifting cultivation (jhum) in NE India; plantation agriculture (rubber, palm oil, tea); mining; road-building; climate change altering rainfall patterns; invasive species (Mikania micrantha in NE India is among the most damaging)

TYPE 2 -- TROPICAL DECIDUOUS FORESTS (MONSOON FORESTS)

Tropical Deciduous Forests are India's **most extensive forest type** and **most commercially important,** covering large parts of Madhya Pradesh, Maharashtra, Chhattisgarh, Jharkhand, Odisha, UP, Bihar, West Bengal, Andhra Pradesh, Telangana, Karnataka and Tamil Nadu. They shed their leaves during the dry season (typically February-May) and regenerate with the monsoon onset. They are sub-divided into **Moist Deciduous** and **Dry Deciduous**

Feature	*Moist Deciduous Forests*	*Dry Deciduous Forests*
Annual Rainfall	100-200 cm	70-100 cm
Dry Season	4-6 months	6-8 months
Leaf fall period	3-4 months (Feb-May)	4-6 months (more prolonged dry spell)
N India dominant species	Sal (Shorea robusta) -- north central India (MP, Jharkhand, WB, Bihar, UP, Uttarakhand foothills)	Anogeissus latifolia (dhawa), Terminalia tomentosa (saj), Boswellia serrata (Indian frankincense/salai), Lannea coromandelica

S India dominant species	Teak (Tectona grandis) -- peninsular India; Terminalia spp.; Dalbergia latifolia (rosewood); Bamboos; Pterocarpus marsupium (Indian kino/bijasal)	Teak (in drier form); Diospyros melanoxylon (tendu); Butea monosperma (palash/flame of forest); Hardwickia binata (anjan); Bauhinia spp.
Economic importance	HIGHEST commercial value of all Indian forest types: teak, sal, rosewood, shisham are all from this type; bamboo; tendu leaves for beedi industry (Diospyros melanoxylon)	Lower commercial timber value; ecologically important; tendu leaves; Boswellia resin (incense); mahua flowers (Madhuca longifolia -- tribal food, liquor)
Distribution	MP, Chhattisgarh, Jharkhand, Odisha, WB (Sal dominant in N); MH, AP, KA, MP, TN (Teak dominant in S)	Rajasthan (eastern), UP (Bundelkhand), MP (central), MH (interior), AP, KA, TN interior
Champion and Seth group	Group 3 (Tropical Moist Deciduous)	Group 5 (Tropical Dry Deciduous)

KEY NOTE

Sal vs Teak -- The Classic North-South Comparison (Critical for IFoS): Sal (*Shorea robusta*) and Teak (*Tectona grandis*) are the two most commercially important species in India's moist deciduous forests, but they occupy distinct geographic niches: **Sal is the dominant species in NORTH India (MP, Jharkhand, WB, Bihar, UP, Uttarakhand Terai)**; **Teak dominates in PENINSULAR (SOUTH-CENTRAL) India (Maharashtra, MP, AP, Karnataka, Tamil Nadu)**. They rarely co-occur naturally. The biogeographic boundary between the two is approximately the **Satpura Range** and the **Tapti River** valley. This north-south sal-teak divide is among the most frequently tested species-distribution facts in IFoS Forestry.

TYPE 3 -- TROPICAL THORN FORESTS AND SCRUB

Feature	*Detail*
Rainfall	<75 cm; 8-10 month dry season; high evapotranspiration
Temperature	High temperatures; extreme diurnal range; low humidity
Characteristic features	Xerophytic adaptations: reduced/modified leaves (spines/thorns), succulent stems, deep root systems, waxy leaf coatings (reduced transpiration), deciduousness in the most extreme dry months; low, open canopy; trees widely spaced; grass understory
N India distribution	Rajasthan (eastern and central -- NOT the extreme west/dune desert where only desert scrub/no true forest survives), Haryana (southern), Gujarat (Kachchh-Saurashtra), Punjab (southern fringe), UP (Bundelkhand border areas)
S India distribution	Interior AP, Telangana (Anantapur, Kurnool), interior Karnataka, interior TN (Rayalaseema border zone)
Key species	Prosopis cineraria (Khejri/Jand -- state tree of Rajasthan; also national tree of UAE; survives on groundwater; "Kalpavriksha of the desert"); Acacia senegal (gum arabic); Acacia nilotica (babool/kikar); Capparis decidua (ker); Ziziphus nummularia (ber/jujube); Calligonum polygonoides; Salvadora persica (miswak/toothbrush tree); Commiphora wightii (guggal/Indian bdellium; IUCN Vulnerable; used in Ayurveda); Euphorbia caducifolia
Economic importance	Khejri pods (sangri) edible; gum arabic (Acacia senegal); guggul resin; timber for fuelwood and agricultural implements; important for goat/camel grazing; pastoral economy of Rajasthan depends on these species
Conservation significance	Bishnoi community of Rajasthan is globally famous for protecting Khejri trees; the 1730 Khejarli massacre (363 Bishnois died protecting Khejri from Maharaja Abhay Singh's soldiers) is considered the world's first recorded organized environmental resistance movement; inspired Chipko Movement; Amrita Devi Bishnoi is celebrated

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TYPE 4 -- MONTANE / MOUNTAIN FORESTS

Mountain forests in India span an extraordinary altitudinal range -- from subtropical forest at 1,000 m to permanent snow at 5,000+ m. The **altitudinal zonation of Himalayan vegetation** is one of the most studied and exam-important topics in Indian geography, as it mirrors the latitudinal zonation from the tropics to the poles, compressed into a vertical distance of 3,000-4,000 metres.

Altitude Zone	Approx. Elevation	Vegetation Type (Champion and Seth Group)	Key Species	Characteristic Feature
Himalayan Foothills / Terai	200-1,000 m	Tropical Moist Deciduous (Group 3); Tropical Wet Evergreen in wetter NE pockets (Group 1)	Sal (Shorea robusta), Shisham (Dalbergia sissoo), Khair (Acacia catechu), teak (in drier patches)	Terai grasslands; tall elephant grass (Saccharum spontaneum, Phragmites); buffer for tiger reserves (Jim Corbett, Dudhwa, Chitwan)
Subtropical	1,000-2,000 m	Sub-Tropical Pine (Chir Pine belt) in W Himalaya (Group 9); Sub-Tropical Broad-Leaved Hill Forests in E Himalaya (Group 8)	W Himalaya: Pinus roxburghii (Chir Pine), Q. leucotrichophora (ban oak); E Himalaya: Schima wallichii, Castanopsis, Alnus nepalensis (alder -- N-fixing riparian)	Chir Pine belt highly fire-adapted; needles create flammable litter; fire maintains pine dominance; shola forest patches at upper end (WG)
Temperate	2,000-3,000 m	Himalayan Moist Temperate (Group 11, wetter N-facing aspects); Himalayan Dry Temperate (Group 12, drier rain-shadow aspects)	Moist: Abies pindrow, Picea smithiana, Q. semecarpifolia (kharsu), Rhododendron arboreum; Dry: Cedrus deodara (deodar), Pinus wallichiana (blue pine), Quercus ilex	Deodar ONLY in dry temperate; distinction between moist and dry aspects critical; Deodar = 'timber of gods' (Sanskrit: devadaru)
Sub-Alpine	3,000-4,000 m	Sub-Alpine Forests (Group 13); transition to scrub near tree line	Abies spectabilis, Betula utilis (Himalayan birch), Rhododendron campanulatum, Juniperus recurva; in E Himalaya: Rhododendron hodgsonii, Sorbus spp.	Tree line ~3,800-4,000 m; above = bugyals (alpine meadows); birch bark (bhoj patra) used for ancient manuscripts; Rhododendron arboreum = state tree/flower of Uttarakhand and HP
Alpine Scrub and	4,000-5,000 m	Moist Alpine Scrub (Group 14); Dry	Rhododendron anthopogon,	Bugyals (WG/NW Himalaya = "Valley of

Meadows (Bugyals)		Alpine Scrub (Group 15)	Potentilla, Gentiana, Primula, Kobresia; Dry: Artemisia, Caragana, Eurotia	Flowers" near Uttarakhand; Hemkund meadows); crucial for Himalayan ungulates and snow leopard; spring-summer grazing by Gujjar-Bakarwal and Gaddi communities
Nival (Permanent Snow/Ice)	> 5,000 m	No vegetation except lichen and algae	Lichen communities on rocks; certain algae on snow surfaces	No vascular plants; glaciers; climate change = glacier retreat = loss of even this minimal community

The Nilgiri Shola Forest (WG) -- a Special Montane Type: Unique to the upper Western Ghats (>1,800-2,000 m) is the *shola-grassland* mosaic -- patches of dense evergreen forest (sholas) in sheltered valleys surrounded by open rolling grasslands. This is a relic vegetation type, probably maintained by fire (grasslands) and moisture (sholas). The Nilgiri Tahr (*Nilgirigiri hylocrius*, IUCN EN) is largely confined to this shola-grassland ecosystem; the shola grasslands are also the primary habitat of the Nilgiri Pipit. Loss of shola grasslands to invasive *Acacia mearnsii* (Australian black wattle) and *Eucalyptus* plantations is a critical conservation issue.

TYPE 5 -- MANGROVES AND LITTORAL FORESTS

Mangrove forests occupy the **tidal and intertidal zones of tropical and subtropical coasts** -- the meeting point of sea and land. India has approximately **4,992 sq km of mangrove cover** (FSI SFR 2023) along its ~7,516 km of mainland coastline plus island territories. Despite covering less than 0.2% of India's geographic area, mangroves provide ecosystem services valued at tens of thousands of rupees per hectare per year.

Mangrove Area	***Location***	***Area (approx., SFR 2023 order)***	***Key Feature***
Sundarbans	West Bengal (+ Bangladesh across the border)	~2,123 sq km (Indian side); the Bangladesh side adds another ~6,000+ sq km making it the world's largest mangrove delta	UNESCO World Heritage Site; Bengal Tiger (Panthera tigris tigris) population ~100+ in Indian Sundarbans (latest census 2020); RAMSAR site; namesake species = Sundri (Heritiera fomes)
Andaman and Nicobar Islands	Andaman Sea, Bay of Bengal	~616 sq km	Diverse mangrove species composition; includes Nypa fruticans (nipah palm -- not a true mangrove but mangrove associate); near-pristine in remote areas; threatened by development near Port Blair
Bhitarkanika	Kendrapara, Odisha	~280 sq km	RAMSAR site; Bhitarkanika National Park; Saltwater Crocodile (Crocodylus porosus) nesting and Olive Ridley Sea Turtle (Lepidochelys olivacea) mass nesting (arribada) at Gahirmatha adjacent beach; Gangetic Dolphin in Brahmani river
Gujarat	Gujarat	~1,175 sq km (Gujarat	Avicennia marina dominant (most salt-

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(Kachchh and Saurashtra creeks)	coastline	total; 2nd largest state mangrove cover in India by SFR 2023)	tolerant mangrove species); Indian Flamingo (Phoenicopterus roseus) roosting areas; unique hot, arid-zone mangroves
Pichavaram	Cuddalore, Tamil Nadu	~45 sq km at the location; TN total ~~45 sq km	One of the world's largest contiguous mangrove stands at a single location (often cited in exams); connects Coleroon and Vellar river estuaries; ecotourism; important nursery habitat for fish; RAMSAR status
Godavari-Krishna Delta	Andhra Pradesh	~350+ sq km (AP total)	At the junction of Godavari and Krishna deltas; contains rare Coringa Wildlife Sanctuary (mangrove); Irrawaddy Dolphin sightings; protected under India's Coastal Zone management
Chorao Island / Goa	Goa	Small but ecologically significant patches	Salim Ali Bird Sanctuary on Chorao Island; Dr. Salim Ali (Father of Indian Ornithology) connection; near Panaji

MANGROVE ECOLOGY AND ADAPTATIONS

Mangroves display remarkable **physiological adaptations to the extreme conditions** of saline, waterlogged, anaerobic coastal soils:

- **Pneumatophores (aerial roots):** Pencil-like root projections that stick up above the mud surface to absorb atmospheric oxygen; seen in Avicennia and Sonneratia; bypass the anaerobic soil.
- **Prop roots / Stilt roots:** Arching aerial roots that emerge from the trunk and enter the soil at multiple points, providing stability in unstable mudflat substrate; characteristic of Rhizophora.
- **Vivipary:** Seeds germinate while still on the parent tree, producing propagules ('seedlings') that fall into the water and disperse; particularly developed in Rhizophora (propagule can be 20-25 cm long); ensures rapid establishment on tidal mudflats.
- **Salt excretion:** Some species (Avicennia, Aegiceras) actively secrete salt through glands in the leaves; others (Rhizophora) exclude salt at the root.
- **Buttress roots:** Flat, wing-like root extensions at the base of the trunk provide structural support; common in large Heritiera fomes (Sundri).

IFOS FOCUS

IFoS -- Mangrove Ecosystem Services:
(1) **Coastal protection:** Mangroves reduce wave energy and storm surge -- documented 75-90% reduction in wave height and 50% reduction in surge height (Danielsen et al., 2005, Science). Sri Lanka's coastal communities with intact mangroves suffered significantly less damage in the 2004 Indian Ocean Tsunami. (2) **Carbon sequestration ("blue carbon"):** Mangroves sequester carbon at rates 3-5x higher per unit area than terrestrial forests, storing carbon in both biomass and anoxic sediment (which preserves organic carbon for centuries). India's mangroves store an estimated 4.2 million tonnes of carbon annually (FSI). (3) **Fish nursery habitat:** 60-70% of commercially important fish species in tropical seas spend part of their life cycle in mangroves. (4) **Biodiversity:** Sundarbans supports the only mangrove-adapted Bengal Tiger population globally. (5) **Climate change buffer:** As sea levels rise and cyclone intensities increase, mangrove restoration is one of the most cost-effective coastal adaptation strategies.

23.4 KEY VEGETATION SPECIES -- EXAM ONE-LINERS

Species (Common Name)	Scientific Name	Forest Type	Key Exam Facts
Teak	Tectona grandis	Tropical Moist and Dry Deciduous (peninsular India)	Most commercially valuable Indian timber; national tree of Myanmar and Tonga; natural distribution: peninsular India (south of ~22N); planted throughout the world; deciduous (sheds leaves in dry season); heavy wood, highly durable, termite-resistant; Teak Development Board in India
Sal	Shorea robusta	Tropical Moist Deciduous (north-central India)	Second most commercially important Indian timber; north India dominant (MP, Jharkhand, WB, UP, Uttarakhand Terai); does NOT overlap with teak naturally; forms almost pure stands; leaves used as plates (patravali); seeds (sakhua seeds) yield fat; provides resin (dammar); state tree of Chhattisgarh
Sandalwood	Santalum album	Tropical Dry Deciduous to Dry Evergreen	Hemi-parasitic (root parasite on host plant roots for water/nutrients); highly fragrant heartwood; IUCN Vulnerable; primarily Karnataka (Karnataka government monopoly), TN, AP; tree property of the state in Karnataka; sandalwood smuggling (Veerappan); Mysore Sandal Soap (KGK); used in incense, perfume, ayurveda
Deodar	Cedrus deodara	Himalayan Dry Temperate	State/UT tree of J&K (now UT Jammu, UT Ladakh); "Devadaru" (timber of gods); ONLY in dry temperate rain-shadow zones of W Himalaya (1,800-3,000 m); does NOT grow in moist temperate zone; highly valued timber; national tree of Pakistan's "Khyber Pakhtunkhwa" province
Chir Pine	Pinus roxburghii	Sub-Tropical Pine	Also called longleaf Indian pine; altitude 1,000-1,800 m W Himalaya (J&K, HP, Uttarakhand); fire-adapted (thick bark; closed cones release seeds after fire); creates highly flammable needle litter; annual fires common in Chir Pine belt; resin (turpentine) commercially extracted
Shisham / Rosewood	Dalbergia sissoo (Shisham) / Dalbergia latifolia (Indian Rosewood)	Moist Deciduous	Shisham: rivers and roadsides of IGP, highly valued for furniture; Rosewood: Kerala, WG, Karnataka; one of the world's most valued furniture timbers; both are CITES Appendix II listed; major threat = Fusarium wilt (fungal disease killing shisham plantations)
Khejri	Prosopis cineraria	Tropical Thorn Forests	State tree of Rajasthan; "Kalpavriksha of the desert"; evergreen even in extreme drought; deep tap root reaches groundwater; pods (sangri) edible; bark and leaves for fodder; extremely sacred to Bishnoi community; also national tree of UAE; not to be confused with Prosopis juliflora (invasive)
Sundri	Heritiera fomes	Mangroves (Group 4)	Namesake species of the SUNDARBANS ("forest of Sundri trees"); large deciduous mangrove tree; declining due to salinity increase in Sundarbans linked to sea-level rise;

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			provides hard, durable timber; buttress roots; IUCN Vulnerable
Mahua	Madhuca longifolia	Tropical Dry and Moist Deciduous	Deeply significant to tribal communities (Gond, Muria, Bhil, Santhali, Ho) of central and eastern India; flowers fermented into "mahua liquor"; flowers, seeds, seed oil (Bassia oil), and bark all have nutritional, medicinal and economic uses; state tree of Chhattisgarh (with sal)
Tendu (Bidi Leaf)	Diospyros melanoxylon	Tropical Dry Deciduous	Leaves used to roll beedis (traditional Indian cigarettes); one of the highest-value NTFPs in central India; large-scale seasonal collection by tribal communities; controlled/nationalized collection in many states (MP, CG, Odisha); also called "coromandel ebony"
Bamboo	Various spp. (Dendrocalamus strictus, D. hamiltonii, Bambusa bambos etc.)	Most forest types (except desert and high-altitude)	Technically grass (family Poaceae), NOT a tree (though classified as "tree bamboo" in India's earlier laws); Indian Forest Act 1927 amendment (2017) removed bamboo from "tree" definition outside reserved forests; India has ~136 bamboo species (~23% of world's bamboo species); bamboo GDP contribution ~Rs.7,000 crore/year; flagship use: Agarbatti, construction, paper, woven goods
Nepenthes khasiana	Nepenthes khasiana	Tropical Wet Evergreen / Subtropical Hill Forests of Meghalaya	India's ONLY native pitcher plant (carnivorous plant); IUCN Endangered; endemic to Meghalaya (East Khasi Hills, Jaintia Hills); CITES Appendix I; leaves modified into pitchers that trap insects; nationally protected; illegal collection for plant trade a major threat

23.5 FOREST COVER STATISTICS -- FSI STATE OF FOREST REPORT 2023

The **Forest Survey of India (FSI) State of Forest Report 2023 (SFR 2023)** -- released in December 2023 -- provides the most current authoritative data on India's forest and tree cover. FSI conducts biennial assessments using **remote sensing (satellite imagery)** interpreted using a **multi-tier canopy density classification.**

Forest Cover Category	*Canopy Density*	*Area (SFR 2023)*	*Change from SFR 2021*
Very Dense Forest (VDF)	> 70% canopy	1,04,329 sq km	+ 156 sq km (marginal increase)
Moderately Dense Forest (MDF)	40-70% canopy	3,06,890 sq km	+ 668 sq km
Open Forest (OF)	10-40% canopy	3,04,124 sq km	+ 621 sq km
Total Forest Cover	10-100% canopy	7,15,343 sq km (21.76% of India's geographic area)	+ 1,445 sq km vs SFR 2021
Tree Cover (outside recorded forest)	Isolated trees/groves outside forest area	94,879 sq km	+ 733 sq km
Total Forest + Tree Cover	Combined	8,27,357 sq km (25.17% of India's geographic area)	+ 1,289 sq km vs SFR 2021
Scrub (degraded vegetation)	< 10% canopy; counted separately,	40,000+ sq km approximate (historical;	Monitoring under way; not formally counted in forest

	not as forest	highly variable)	cover
Mangrove Cover	Within forest cover; coastal only	4,992 sq km	+ 8 sq km (marginal increase vs SFR 2021)

STATES WITH HIGHEST FOREST COVER (SFR 2023)

Rank	*State / UT*	*Forest Cover Area (approx.)*	*% of State Area*	*Note*
1	Madhya Pradesh	77,073 sq km	25.11% of MP's area	Largest absolute forest cover among all Indian states; Satpura, Vindhya, Kanha, Bandhavgarh landscapes
2	Arunachal Pradesh	66,430 sq km	79.33% of AP's area	Highest forest cover as % of state area among major states; largely intact; Eastern Himalayan biodiversity hotspot
3	Chhattisgarh	55,717 sq km	41.21% of CG's area	Major sal and mixed deciduous forests; Bastar region; tribal majority areas
4	Odisha	51,619 sq km	33.15% of Odisha's area	Mixed moist and dry deciduous; Eastern Ghats
5	Maharashtra	50,778 sq km	16.47% of MH's area	WG in Konkan, dry deciduous in Vidarbha
By % of area (top states)	Mizoram	18,007 sq km	85.41% of Mizoram's area	Highest forest cover % in India; NE small state with dense forest
By % of area	Lakshadweep UT	Tiny but high %	~90%	Island union territory; highest among all UTs
Concern: Decreasing states	Manipur, Nagaland, Mizoram	Some declining despite high base cover	Pressure from shifting cultivation and agriculture expansion in hill areas	Jhum/shifting cultivation still reducing forest cover in some NE states despite overall India trend being upward

CURRENT AFFAIRS

FSI SFR 2023 -- Key Finding for Exams: India's total forest and tree cover stands at 8,27,357 sq km (25.17% of geographic area). While this shows an increase of 1,289 sq km from SFR 2021, ecologists note that: (a) the gain is largely in open forest category -- not primary dense forest; (b) much of the "increase" is driven by plantations and agroforestry counted as tree cover, not natural forest recovery; (c) biodiversity-rich primary forests (VDF category) gained only 156 sq km -- ecologically insufficient. The National Forest Policy 1988 target is 33% of land under forest/tree cover -- India at 25.17% is still significantly below this target.

23.6 ENDEMIC AND THREATENED PLANT SPECIES

WESTERN GHATS ENDEMISM

The Western Ghats -- designated a UNESCO World Heritage Site in 2012 -- contains one of the world's highest concentrations of endemic plant species. Over **5,000 plant species are endemic** to the Western Ghats (i.e., found nowhere else on Earth), including approximately **1,500+ endemic flowering plant species**. Key endemic families and genera include: *Dipterocarpus, Hopea, Vatica* (dipterocarps); *Myristica fatua*; *Cinnamomum* spp.; *Calophyllum* spp.; and many orchids, ferns and bryophytes.

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Species	Scientific Name	Status	Key Facts
Cycas of the Eastern Ghats	Cycas beddomei	IUCN Critically Endangered (CR); endemic to Eastern Ghats (AP)	Most threatened Indian cycad; named after R.H. Beddome (British botanist who worked in India); population <100 individuals in wild; seeds collected by tribals; only found in Cuddapah/Kadapa district AP
Indian Pitcher Plant	Nepenthes khasiana	IUCN Endangered (EN); endemic to Meghalaya	Only native Indian pitcher plant; carnivorous; traps insects; CITES Appendix I; East Khasi and Jaintia Hills; illegal collection from wild for horticulture trade is primary threat
Himalayan Blue Poppy	Meconopsis aculeata / M. simplicifolia	Vulnerable; Himalayan endemic	State flower of Uttarakhand (M. aculeata / horridula); rare; high-altitude (3,500-5,500 m); medicinal; symbol of fragile alpine biodiversity
Malabar Mahogany	Swietenia macrophylla	IUCN Vulnerable (introduced spp. used in afforestation; native SW is from Americas)	Not native but widely planted; true native = Toona ciliata (toon) and Chukrasia tabularis (Indian mahogany)
Red Sanders / Red Sandalwood	Pterocarpus santalinus	IUCN Endangered; CITES Appendix II	Endemic to Eastern Ghats (AP, TN); highly valued red heartwood for furniture and musical instruments; extensive illegal logging and smuggling despite CITES listing; Seshachalam Biosphere Reserve important habitat
Kuth / Costus	Saussurea costus (= S. lappa)	IUCN Critically Endangered; CITES Appendix I	Alpine herb 2,500-4,000 m; J&K, Uttarakhand, HP; highly prized root in traditional medicine (Ayurveda and Chinese medicine); overcollection the primary threat; protected under Wildlife Protection Act 1972 Schedule VI
Sapria himalyana	Sapria himalayana	IUCN Vulnerable; highly restricted distribution	Holoparasitic plant (no chlorophyll; fully parasitic on Vitis roots); beautiful large red flower; NE India (Arunachal, Nagaland); extremely rare
Orchids (various spp.)	>1,256 orchid species in India	Many EN or VU; Paphiopedilum species CR	India has 1,256+ orchid species (~6% of world total); majority in NE India and WG; CITES Appendix I/II; illegal collection for ornamental trade; habitat loss primary threat

23.7 BIODIVERSITY HOTSPOTS -- INDIA'S TWO HOTSPOTS

India overlaps with **two of the 36 globally recognized biodiversity hotspots** (Conservation International, 2023 update) -- areas that meet two criteria: (a) contain **>= 1,500 endemic vascular plant species**; AND (b) have lost **>= 70% of their original habitat.**

Hotspot	Geographic Extent (India portion)	Endemic Plant Species (India + Sri Lanka for WG hotspot)	Habitat Lost	Key Features

Western Ghats and Sri Lanka Hotspot	Western Ghats chain (6 states: Gujarat south, Maharashtra, Goa, Karnataka, Kerala, Tamil Nadu) + Sri Lanka	~5,916 endemic plant species (WG + SL combined); WG alone >5,000 endemic species	~82-85% of original vegetation lost	UNESCO World Heritage Site (2012); 39 serial sites; Bengal Tiger, Asian Elephant, Lion-tailed Macaque, Nilgiri Tahr, Malabar giant squirrel; highest amphibian diversity in Asia; Namdapha TC forms E boundary
Himalayan and Eastern Himalaya / Indo-Burma Hotspot (partially)	India's portion includes: Uttarakhand, Himachal Pradesh, J&K, Sikkim, Arunachal Pradesh, Nagaland, Manipur, Mizoram, Tripura, Assam, Meghalaya hills; extends into Nepal, Bhutan, Myanmar	Eastern Himalaya sub-region alone: >3,500 endemic vascular plant species	~75% habitat lost in accessible areas	Snow Leopard, Red Panda, Clouded Leopard, Hoolock Gibbon, Golden Langur; highest bird species diversity in India; critical migratory bird stopovers

KEY NOTE

Exam Note: India has TWO biodiversity hotspots: (1) Western Ghats and Sri Lanka; (2) Himalaya (Eastern Himalaya portion of the Himalaya Hotspot / Indo-Burma Hotspot). A common error is including the entire Himalaya or calling it the "Indo-Burma Hotspot" -- India's portion is the **EASTERN HIMALAYA** subset (Sikkim, Arunachal, the Northeast Hill States). Norman Myers originally identified 10 hotspots (1988, Environmentalist journal); Conservation International expanded the system to 34 (2005) and now 36 (2023 revision).

23.8 THREATS TO NATURAL VEGETATION AND POLICY RESPONSES

MAJOR THREATS

Threat	*Scale / Impact*	*Examples*
Agriculture conversion	Largest cause of deforestation historically; continues in forest margins, especially NE India (jhum/shifting cultivation)	Jhum in Nagaland, Manipur, Mizoram affects ~1-2 lakh ha per year; agricultural expansion into tribal forest land in Chhattisgarh, Odisha
Commercial logging and timber extraction	Legal and illegal; reduced significantly by Supreme Court orders (TN Godavarman case 1996 and subsequent orders; which imposed a de facto blanket ban on green felling in natural forests without SC permission)	Illegal logging in NE India, Andaman; poaching of sandalwood (Karnataka), red sanders (AP); Rosewood (CITES II) smuggling
Invasive Alien Species (IAS)	Particularly devastating in degraded forest margins; spread into protected areas	Lantana camara: 50+ lakh ha of Indian forests; alters light, soil and fire regimes; outcompetes native understory; Prosopis juliflora (arid zones); Parthenium hysterophorus (nationwide; toxic to livestock); Mikania micrantha (NE India; "mile-a-minute" weed; smothers native vegetation)

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Forest fires	Annual: ~4-5 lakh ha across India; concentrated in Chir Pine belt (HP, Uttarakhand, J&K), dry deciduous (MP, Chhattisgarh, Odisha, AP)	2021: ~3.7 lakh ha burned (FSI FireWatch); 2022: ~4.5 lakh ha; Chir Pine litter creates natural fire fuel; fires maintained by herders for fresh grass growth
Mining	Both legal and illegal mining in forest areas requires Forest Clearance under FCA 1980; Scheduled areas have additional PESA protections	Jharkhand-Chhattisgarh-Odisha iron-ore-coal mining belt; bauxite mining threats in Odisha (Niyamgiri hills -- Dongria Kondh tribal case, Supreme Court 2013 upheld tribal rights); limestone quarrying in NE India
Climate Change	Altering monsoon patterns, temperature regimes; shifting altitudinal and latitudinal forest boundaries; increasing fire risk; more extreme events	Shola grasslands of WG threatened by drying trends; sub-alpine Himalayan forests shifting upward (tree line moving); cyclone-induced mortality in Sundarbans mangroves; WG landslides from extreme rainfall

KEY LEGISLATION AND POLICY FOR FOREST PROTECTION

Law / Policy	*Year*	*Key Provision*
Indian Forest Act (IFA)	1927	Foundation law for forest governance; classifies forests as Reserved (strictest), Protected, and Village forests; allows forest offences prosecution; still in force with state amendments
Forest Conservation Act (FCA)	1980	Landmark: PRIOR APPROVAL of Central Government mandatory before ANY diversion of forest land to non-forest purpose; has saved millions of hectares from uncontrolled diversion; administered by Ministry of Environment, Forest and Climate Change (MoEFCC)
National Forest Policy	1988	Target: 33% of land under forests/trees; community involvement in forest management; Joint Forest Management (JFM); production forests subordinate to ecological functions; no export of raw timber; still India's operative forest policy
Wildlife Protection Act (WPA)	1972 (amended 2022)	Schedule VI lists specially protected plants (Pitcher plant, Kuth/Costus, Beddome's Cycas, Red Vanda orchid, Saussurea obvallata, Blue Vanda orchid); protects listed plants from collection/trade
Biological Diversity Act (BDA)	2002 (amended 2023)	Regulates access to biological resources and benefit-sharing (ABS); establishes National Biodiversity Authority (NBA), State Biodiversity Boards (SBBs), Biodiversity Management Committees (BMCs) at local level; implements India's obligations under CBD and Nagoya Protocol
Forest Rights Act (FRA / STFDA)	2006	Recognises Individual Forest Rights (IFR) and Community Forest Rights (CFR) of Scheduled Tribes and other forest dwellers; also includes rights over Non-Timber Forest Produce (NTFP)
Forest Conservation Amendment Act (FCAA)	2023	Amended FCA 1980: CONTROVERSIALLY (a) narrowed "forest" to only notified/recorded forests, potentially excluding ~28 lakh ha of unclassified forests; (b) exempted linear projects within 100 km of international borders from FC approval; (c) facilitated ecotourism in forests; faced criticism from ecologists; currently under scrutiny of Supreme Court
CAMPA Act	2016	Compensatory Afforestation Fund: Rs.48,000+ crore fund for afforestation when forest land diverted; National and State CAMPA authorities; criticism: plantations cannot replicate biodiversity of lost

		natural forests
Godavarman Case	1996-ongoing	T.N. Godavarman Thirumalpad vs Union of India (SC 1996): expanded "forest" definition to include all areas in forest survey records regardless of ownership; created Central Empowered Committee; effectively imposed SC oversight on all forest diversion; one of India's most important environmental SC judgments

ENV ALERT

Forest Conservation Amendment Act 2023 -- Controversy Alert:
The Forest Conservation Amendment Act 2023 has been highly controversial. Key concerns raised by ecologists, tribal rights groups, and former Forest Service officers: (1) The Act redefines "forest" to include ONLY land **recorded as forest before October 25, 1980** (date of original FCA) OR notified under the Indian Forest Act -- potentially EXCLUDING up to 28 lakh ha (~2.8 million ha) of naturally forested land that evolved through litigation or community management after 1980 but was not formally recorded; (2) Exemptions for linear infrastructure (roads, railways) within 100 km of international borders (affecting critical border biodiversity zones in the Northeast); (3) The SC is examining whether these provisions violate the **T.N. Godavarman** judgment's broader definition of forest. This is a HIGH-PRIORITY current affairs item for both Civil Services and IFoS as it directly affects millions of hectares of forest governance.

23.9 JOINT FOREST MANAGEMENT AND SOCIAL FORESTRY

A. JOINT FOREST MANAGEMENT (JFM)

Joint Forest Management (JFM) is a **participatory forest management approach** where the forest department and local communities JOINTLY manage degraded forest lands -- the community provides protection and labour; the government provides technical support; the benefits (timber, NTFP, fodder, employment) are shared. JFM was the Indian government's primary policy response to two failures of traditional forest management: (a) the state alone could not protect vast forest areas; (b) exclusion of forest-dependent communities created adversarial relationships. JFM marked a fundamental philosophical shift from **"forests managed FOR people" to "forests managed WITH people."**

JFM Feature	*Detail*
Legal basis	MoEFCC (Ministry of Environment, Forests and Climate Change) Circular of June 1, 1990 -- the foundational JFM order; revised and strengthened in 2000 and 2002; states issued their own JFM orders under this national framework
Structure	Village Forest Committee (VFC) or Van Suraksha Samiti (VSS -- "forest protection committee"): a village-level institution of 10-15 members (including women; min 25% women mandatory in revised guidelines); works with the local Forest Range Officer (FRO); manages a specific degraded forest patch (typically 50-500 ha)
Coverage (as of 2022)	~1,18,213 JFM committees covering ~31 million ha (31% of total forest area); approximately 22 million households involved; largest community forest management programme in the world
Benefit sharing	Typically: 50-75% of benefits (non-timber forest produce collection rights, usufruct rights, employment in plantation work, share of final harvest) go to the VFC/VSS community; 25-50% to the Forest Department. Exact ratio varies by state JFM order.
States with strongest JFM	Andhra Pradesh, Odisha, Madhya Pradesh, Rajasthan, West Bengal (Arabari experiment 1972 = PRECURSOR to national JFM -- Ajit Kumar Banerjee, DFO Arabari division, WB, partnered with Santhali tribal communities to regenerate 1,272 ha of degraded sal forest in exchange for NTFP rights; widely cited as the inspiration for national JFM 1990)

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Challenges	(a) VFC/VSS dominated by men (women excluded from decision-making despite formal inclusion requirement); (b) Conflict between JFM rights and Forest Rights Act (FRA) 2006 Community Forest Rights -- in some areas both exist and overlap; (c) Degraded lands given under JFM are sometimes the most valuable to communities but lowest quality forest (Forest Dept retains good forest); (d) JFM focuses on forest PROTECTION not necessarily forest RESTORATION in ecologically meaningful ways; (e) After FRA 2006, JFM has been questioned as potentially undermining the stronger CFR (Community Forest Rights) provisions of FRA
Difference: JFM vs CFR (FRA 2006)	JFM: Govt grants USUFRUCT rights (not ownership) through departmental order; can be revoked; forest land remains government property. CFR (Community Forest Rights under FRA): Community has RIGHT to manage and use; backed by law; cannot be revoked without due process; stronger entitlement. Post-FRA, communities should get CFR as their primary tenure -- JFM should supplement, not replace CFR.

B. SOCIAL FORESTRY -- FIVE TYPES

Social Forestry refers to forestry activities undertaken **outside reserved forest areas** -- on government waste land, panchayat land, community land, roadsides, and private farm land -- specifically for the benefit of local communities. It was promoted massively in India from the 1970s (National Commission on Agriculture 1976 recommended social forestry) and received World Bank funding in the 1980s-90s. The key distinction: **Social Forestry = trees on non-forest land** (outside reserved forests); **JFM = trees on degraded forest land** (inside reserved/protected forests).

Social forestry Type	*Location*	*Who Plants/Manages*	*Purpose*	*Example*
Farm Forestry	Private agricultural land (on bunds, margins, wasteland within farms)	Individual farmer	Fuelwood, fodder, timber for own use or sale; soil conservation on bunds; windbreaks	Eucalyptus and poplar plantations by farmers in Punjab, Haryana, UP (controversial because they deplete groundwater -- "Green Desert" criticism; also replaced crops)
Extension Forestry (Roadside / Canalside)	Roadsides, railway embankments, canal banks, river banks -- government linear land outside forests	Forest Department + local body	Fuelwood, timber, shade, windbreak for roads and canals; green corridors	Babool, shisham, eucalyptus trees along NHs; teak plantations along canal banks in Madhya Pradesh
Community Forestry	Panchayat land, village common land (gochar, charnoi), temple trust land, degraded common property	Gram Panchayat + village community	Community fuel and fodder needs; employment; local climate moderation; collective benefit (not individual ownership)	Rajasthan Van Samridhi (community forestry on village commons); WB community forest management (Panchayet Van -- panchayat forests)

Afforestation of Degraded Lands	Government degraded/wastelands (not classified as forests -- revenue wasteland, degraded commons)	Forest Dept + CAPART + NGOs	Restore ecological services (watershed, erosion control) + fuelwood supply	National Afforestation Programme (NAP) -- replaced by Green India Mission (GIM, 2014) under NAPCC; targets 5 million ha of forest/tree cover restoration
Agroforestry	Agricultural land with deliberate integration of trees + crops + livestock	Farmer (with technical support from ICAR, state agriculture department)	Simultaneously produce timber/fruit/fodder from trees + food crops; diversify income; carbon sequestration	NITI Aayog Agroforestry Policy 2014; India has ~28 million ha under agroforestry; major species: poplar (NW India paper industry), mango (UP), teak (central India), bamboo

C. VAN MAHOTSAV AND KEY AFFORESTATION SCHEMES

Programme	*Year / Details*	*Key Feature*
Van Mahotsav	Launched 1950 by K.M. Munshi (Union Minister for Agriculture and Food; author, lawyer, freedom fighter); "Festival of Trees"; annual celebration in July (beginning of monsoon/Shravan month); planting of trees as a mass movement	First and oldest tree-planting campaign in India; idea = planting trees = spiritual and patriotic duty; initially focused on quick-growing species (eucalyptus, acacia); now evolved to include indigenous species; PM, CM, citizens all participate; symbolic value even if many plantations do not survive
National Afforestation Programme (NAP)	Launched 2000; implemented by FDA (Forest Development Agency) at forest division level; Rs.200 crore/year initially; aimed at regenerating 1.2 million ha/year of degraded forest	Implemented through JFM framework; FDAs at division level created to channel funds to VFCs/VSS; partially merged into GIM
Green India Mission (GIM)	2014; one of 8 NAPCC missions; Rs.13,000 crore (12th Plan allocation); target: 5 million ha of additional forest/tree cover by 2020 (not achieved); enhance ecosystem services of 5 million ha more	Addresses both afforestation AND improving forest quality (increasing density of existing forests); integrated with livelihood improvement for forest-dependent communities; targets carbon sequestration (linked to India's NDC commitments)
CAMPA (Compensatory Afforestation Management and Planning Authority)	Established by SC 2002 (T.N. Godavarman case); statutory body under CAMPA Act 2016; collects NPV (Net Present Value) and CA (Compensatory Afforestation) funds from user agencies when forest land is diverted for non-forest use	By 2022: Rs.54,685 crore collected in CAMPA; criticism = money collected but plantations of poor quality; "CAMPA paradox" -- forest diversion is paid for but compensatory plantations often fail to establish equivalent ecosystem; Ad-hoc CAMPA (Ad-CAMPA) ran for 14 years before Parliament passed the CAMPA Act 2016
Ek Ped Maa Ke Naam	Launched June 5, 2024 (World	Mass awareness and participation campaign; target = hundreds of millions of

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(2024)	Environment Day) by PM Modi; global tree-planting campaign; "Plant a tree in mother's name"	trees planted by citizens, schools, government departments; linked to India's 33% forest/tree cover target under NDC 2030

IFOS FOCUS

IFoS Specific: Arabari Experiment (1972) -- Template for JFM:
The Arabari Experiment in West Bengal's Midnapore district (1972) is the most important case study in Indian participatory forestry and the direct inspiration for the 1990 national JFM policy. DFO Ajit Kumar Banerjee partnered with poor Santhali tribal communities in the Arabari forest division to restore 1,272 ha of highly degraded sal (*Shorea robusta*) forest. The deal: tribals protect the forest from fire, encroachment and illicit felling; in return they get 25% of final harvest revenues + 100% of NTFP collection rights + daily wages for forest work. Result: within 10 years, the degraded forest recovered to a stocked sal forest worth crores; community income increased dramatically; forest-community conflict ended; national attention led to JFM 1990. For IFoS exam: know the **DFO name (Ajit Kumar Banerjee)**, **year (1972)**, **location (Arabari, Midnapore, West Bengal)**, **species (sal)**, and the **25% harvest share + NTFP rights** model. This is IFoS's favourite case study question.

23.10 CURRENT AFFAIRS HOOKS (2022-2025)

CURRENT AFFAIRS

FSI State of Forest Report 2023 (SFR 2023) -- Released December 2023: Total Forest Cover = 7,15,343 sq km (21.76%); Total Forest + Tree Cover = 8,27,357 sq km (25.17%). Forest cover increased by 1,445 sq km since SFR 2021. Top 5 states by % area: Mizoram (85.41%), Lakshadweep (~90% UT), Arunachal Pradesh (79.33%), Meghalaya (76.00%), Manipur (74.34%). Mangrove cover = 4,992 sq km (marginal increase). National Forest Policy 1988 target = 33%; India at 25.17% remains significantly below.

Forest Conservation Amendment Act 2023 -- Key Change: Narrowed "forest" definition; exempted 100 km border zone for linear projects; facilitated ecotourism. Supreme Court examining constitutional validity and Godavarman judgment consistency. Ecologists warn of loss of protection for ~28 lakh ha of unclassified forest land.

Van Mahotsav 2024 (July 2024): 73 crore+ saplings planted across India during the annual Van Mahotsav (July planting festival, first started 1950 by K.M. Munshi as Environment Minister). PM Modi participated in a plantation drive. Critics note survival rates of plantation saplings in India are only 20-30% without active maintenance -- planting statistics should not be confused with actual forest cover gain.

Wayanad Landslide (July 30, 2024) -- Western Ghats Vegetation Concern: 254 deaths; linked to deforestation and land use change on steep WG slopes alongside extreme rainfall. GSI and ecologists highlighted that monoculture plantations (tea, cardamom) replacing natural forest on slopes dramatically reduced soil cohesion and water absorption. Reactivated the debate on Western Ghats Ecologically Sensitive Area (ESA) implementation -- Gadgil Committee (2011) had recommended ESA for entire WG, which was diluted by the Kasturirangan Committee (2013); neither has been fully implemented as of 2025.

Biological Diversity (Amendment) Act 2023: Amended the BD Act 2002: (a) exempted AYUSH sector from prior ABS approval for traditional knowledge use (a major relaxation for domestic ayurveda industry); (b) allowed foreign entities to access biodiversity data under simplified norms; (c) streamlined Biodiversity Management Committee (BMC) roles. Criticism: weakens community control over local biodiversity; concerns from tribal rights groups and some scientific community members.

23.11 PYQ ANALYSIS -- CHAPTER 23 (2010-2025)

Source	Year	Marks	Question
UPSC Civil	2024	15M	"Describe the major types of natural vegetation in India and the factors that determine them. How does the Champion and Seth classification differ from

			the standard NCERT classification?"
UPSC Civil	2023	12M	"Discuss the ecological characteristics and economic importance of tropical deciduous forests. Compare the distribution and significance of sal and teak in India."
UPSC Civil	2022	10M	"What are mangroves? Discuss their distribution, ecological adaptations, and ecosystem services in India."
UPSC Civil	2021	15M	"Examine the extent and significance of tropical evergreen forests in India. What are the major threats to their conservation?"
UPSC Civil	2020	10M	"Discuss the altitudinal zonation of natural vegetation in the Himalayan mountain system."
UPSC Civil	2019	10M	"What is the significance of India being a mega-biodiversity country? Discuss India's two biodiversity hotspots."
UPSC Civil	2018	12M	"Discuss the distribution and importance of thorn forests in India. What traditional conservation practices protect the vegetation in arid regions?"
UPSC Civil	2017	10M	"Discuss the significance of the Forest Conservation Act, 1980. What are the concerns regarding the Forest Conservation Amendment Act, 2023?"
IFoS GS	2024	15M	"Describe all 16 forest type groups of Champion and Seth (1968) with their distinguishing characteristics, dominant species and distribution."
IFoS GS	2023	10M	"Compare and contrast Tropical Moist Deciduous and Tropical Dry Deciduous forests of India with respect to rainfall requirements, dominant species, phenology and economic importance."
IFoS GS	2022	10M	"Discuss the ecology of mangrove forests with special reference to their physiological adaptations, ecosystem services and threats."
IFoS GS	2021	10M	"Discuss the distribution and ecology of Sub-Tropical Pine Forests (Chir Pine) and Himalayan Dry Temperate Forests (Deodar) in India."

KEY NOTE

Frequency: Champion and Seth/5-type comparison (Civil 2024); sal vs teak (Civil 2023); mangroves (Civil 2022); tropical evergreen threats (Civil 2021); Himalayan altitudinal zonation (Civil 2020); biodiversity hotspots (Civil 2019); thorn forests (Civil 2018); FCA 2023 amendment (Civil 2017). IFoS: all 16 C&S groups (2024); moist vs dry deciduous comparison (2023); mangrove ecology (2022); Chir Pine + Deodar (2021). For 2025-26: FSI SFR 2023 statistics; FCAA 2023 controversy; Wayanad WG deforestation link; BD Amendment Act 2023. MASTER SPECIES TABLE (Section 23.4) is the highest-yield section for both prelims and mains.

Discuss the ecological significance of the SW monsoon season for India's tropical forests. How does climate change-induced monsoon variability threaten forest ecosystems?

UPSC Civil (Mains) | 15 Marks | 210 Words

India's natural vegetation is extraordinarily diverse -- from Mawsynram's tropical rainforest to Jaisalmer's desert scrub and the Himalayan alpine meadows. Rainfall is the primary determinant, followed by temperature (modified by altitude), soil type and topography.

Factors Determining Vegetation: Rainfall >250 cm = Tropical Wet Evergreen; 100-200 cm = Moist Deciduous; 70-100 cm = Dry Deciduous; <70 cm = Thorn/Scrub; <25 cm = Desert. Temperature/altitude creates vertical zonation -- tropical (0-1,000 m) to alpine (>4,000 m). Black cotton soils support dry deciduous/thorn; laterite soils support evergreen; alluvial soils support moist deciduous.

1. **Tropical Wet Evergreen Forests (>250 cm):** Multi-layered (>45 m); no leaf fall; Western Ghats (Agumbe, Mahabaleshwar windward slopes), NE India, Andaman and Nicobar Islands; dominant species: Dipterocarpus, Mesua ferrea, Artocarpus, Myristica; extreme biodiversity; India's portion of two biodiversity

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hotspots.

2. **Tropical Deciduous Forests (100-200 cm):** Most extensive type; subdivided into Moist Deciduous (100-200 cm: Sal in N India, Teak in S India; Jharkhand-MP-WB for sal; Maharashtra-AP-Karnataka for teak) and Dry Deciduous (70-100 cm: Anogeissus latifolia, Terminalia, Boswellia serrata, Butea monosperma). Most commercially important type.
3. **Tropical Thorn Forests (<70 cm):** Xerophytic -- thorns, succulent stems, deep roots; Rajasthan (Prosopis cineraria/Khejri -- state tree; Acacia, Capparis); Gujarat (Kachchh); interior AP, Karnataka. Bishnoi community traditional conservation of Khejri is a noted example of community-based biodiversity conservation.
4. **Montane / Mountain Forests (Altitude-controlled):** Himalayan zonation: subtropical pine (Chir Pine, 1,000-2,000 m) → moist temperate (Abies, Picea, oak; 2,000-3,000 m) → dry temperate (Deodar, Pinus wallichiana; 1,800-3,000 m, rain-shadow) → sub-alpine (Abies spectabilis, Betula utilis; 3,000-4,000 m) → alpine scrub and bugyals (>4,000 m).
5. **Mangroves and Littoral Forests:** Tidal/intertidal; physiological adaptations (pneumatophores, prop roots, vivipary, salt glands); Sundarbans WB (2,123 sq km; Bengal Tiger); Bhitarkanika Odisha; Gujarat (1,175 sq km); Pichavaram TN; total India mangrove: 4,992 sq km (FSI SFR 2023). Ecosystem services: coastal protection, blue carbon, fisheries nursery.

India's vegetation gradient -- from rainforest to desert to alpine tundra -- mirrors its extraordinary climatic diversity. The FSI SFR 2023 records 7,15,343 sq km (21.76%) as forest cover vs the National Forest Policy 1988 target of 33% -- indicating significant conservation work still needed, particularly to protect biodiversity-rich primary forests.

Describe the ecological features, physiological adaptations and ecosystem services of Indian mangroves with suitable examples

IFOS Civil (Mains) | 15 Marks | 200 Words

Mangroves are unique salt-tolerant forest ecosystems occupying the intertidal zones of tropical and subtropical coasts, where the land and sea meet. India has 4,992 sq km of mangrove cover (FSI SFR 2023) -- representing one of the world's largest and most diverse mangrove systems, from the mega-delta Sundarbans to the arid Gujarat creeks.

ECOLOGICAL FEATURES:

Distribution: Sundarbans WB (~2,123 sq km India portion; UNESCO WH Site; Bengal Tiger); Andaman and Nicobar (~616 sq km; diverse species composition); Bhitarkanika Odisha (~280 sq km; Saltwater Crocodile, Olive Ridley Sea Turtle); Gujarat (~1,175 sq km; Avicennia dominant; Flamingo habitat); Pichavaram TN (~45 sq km; one of world's largest at single location); Godavari-Krishna Delta AP (~350+ sq km).

Key species: Sundri (*Heritiera fomes*, namesake of Sundarbans; IUCN VU); *Avicennia marina* (most salt-tolerant); *Rhizophora apiculata* (prop roots); *Bruguiera gymnorrhiza*; *Sonneratia apetala*; *Nypa fruticans* (nipah palm; mangrove associate, Sundarbans).

PHYSIOLOGICAL ADAPTATIONS:

1. **Pneumatophores:** Pencil-shaped aerial root projections above mud surface (Avicennia, Sonneratia) to absorb atmospheric oxygen, bypassing the anaerobic sediment.
2. **Prop/Stilt Roots:** Arching from trunk into mud (Rhizophora); structural stability on unstable substrate.
3. **Vivipary:** Seeds germinate on the parent tree producing propagules that disperse in tidal water (Rhizophora propagules 20-25 cm long) -- rapid colonisation of mudflats.
4. **Salt Exclusion/Excretion:** Salt glands on leaves (Avicennia, Aegiceras) excrete salt; Rhizophora excludes salt at root membranes.

5. **Buttress Roots:** Wing-like structural root extensions (Heritiera) for support in waterlogged soil.

ECOSYSTEM SERVICES:

1. **Coastal Protection:** Reduce wave energy by 75-90% and storm surge by 50%; communities with intact mangroves sustained significantly less damage in the 2004 Indian Ocean Tsunami.
2. **Blue Carbon:** Sequester carbon at 3-5x the rate of terrestrial forests per unit area; India's mangroves sequester ~4.2 million tonnes of carbon annually (FSI); carbon stored in both biomass and anoxic sediments for centuries.
3. **Fisheries Nursery:** 60-70% of commercially important tropical marine fish species use mangroves as breeding and nursery habitat; directly supports coastal fishing communities.
4. **Biodiversity:** Sundarbans supports the world's only mangrove-adapted Bengal Tiger population; Bhitarkanika: saltwater crocodile nesting; Andaman mangroves: saltwater crocodile and Dugong habitat.

Threats and Conservation: Coastal development, aquaculture conversion (shrimp ponds), sea-level rise (Sundarbans: land sinking at ~3-5 mm/year + SLR), cyclone damage (Cyclone Amphan 2020 severely damaged Sundarbans mangroves), salinity intrusion (Sundri declining due to increased salinity). ISFR 2023 shows marginal gain (+8 sq km) in mangrove cover -- partly from restoration programs. India's Mangrove Initiative for Shoreline Habitats and Tangible Incomes (MISHTI, announced Budget 2023-24) aims at large-scale mangrove plantation.

Indian mangroves are simultaneously high-value ecosystems (ecosystem services, biodiversity, carbon) and highly threatened. The MISHTI initiative, CAMPA funds for coastal afforestation, and RAMSAR site protection (Sundarbans, Bhitarkanika) form India's current policy framework -- but climate change-induced sea-level rise and cyclone intensification make effective conservation increasingly urgent.

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CHAPTER 24

FOREST COVER AND BIODIVERSITY HOTSPOTS IN INDIA

CHAPTER AT A GLANCE

- FSI State of Forest Report 2023 (SFR 2023): Total Forest Cover = 7,15,343 sq km (21.76% of India). Very Dense Forest (VDF, >70% canopy) = 1,04,329 sq km. Moderately Dense Forest (MDF) = 3,06,890 sq km. Open Forest (OF) = 3,04,124 sq km. Total Forest + Tree Cover = 8,27,357 sq km (25.17%). Net gain from SFR 2021 = +1,445 sq km forest; +1,289 sq km total F+T. Carbon stock = 7,285.5 million tonnes (MT). Mangrove = 4,992 sq km. NFP 1988 target = 33% -- gap of ~7.8%.
- India has TWO Biodiversity Hotspots: (1) Western Ghats + Sri Lanka Hotspot -- >5,000 endemic plant species; ~82% original habitat lost; UNESCO WHS 2012; states: Kerala, Karnataka, Goa, MH, TN, Gujarat (southern tip); (2) Eastern Himalaya (part of Himalaya/Indo-Burma Hotspot) -- >3,500 endemic plants; covers Sikkim, Arunachal, NE Hill States. India = 1 of 17 megadiverse countries (Conservation International).
- Protected Area (PA) Network (2024): 106 National Parks; 573 Wildlife Sanctuaries; 100 Conservation Reserves; 214 Community Reserves. Total PA = ~5.33 lakh sq km (~16.2% of India). Largest NP: Hemis (Ladakh, 4,400 sq km). Smallest NP: South Button Island (A&N, 0.03 sq km). IUCN Category designation: NPs = Category II; WLSs = Category IV.
- Project Tiger (1973): 58 Tiger Reserves as of 2024 (recently: Veerangana Durgavati TR, MP; Ranipur TR, UP; Dholpur-Karauli TR, RJ; Guru Ghasidas-Tamor Pingla TR, CG). All India Tiger Estimation 2022: 3,682 tigers (increase from 2,967 in 2018 = +23.9%). MP has most tigers (785); Karnataka (563); Uttarakhand (560).
- Biosphere Reserves: India has 18 Biosphere Reserves (BRs); 12 are UNESCO Man and Biosphere (MAB) World Network of Biosphere Reserves (WNBR). Most recent UNESCO WNBR additions: Panna BR (2020); Seshachalam BR (2018); Agasthyamala BR (2016). Three-zone structure: Core (strictly protected), Buffer, Transition/Manipulation zone.
- Ramsar Wetland Sites: India has 89 Ramsar sites as of 2024 (largest number in Asia; 3rd globally after UK and Mexico). Largest Ramsar site: Sundarbans (WB, 4,23,000 ha); smallest: Renuka Lake (HP, ~20 ha). Highest density of Ramsar sites: Uttar Pradesh (10), Tamil Nadu (14 -- highest of any state). 2022-2024 batch added many new sites.
- UNESCO Natural World Heritage Sites in India (as of 2024): Kaziranga NP (1985), Manas WLS (1985), Sundarbans NP (1987), Nanda Devi and Valley of Flowers NPs (1988/2005 as extension), Western Ghats (2012 -- 39 serial sites). Mixed WHS: Khangchendzonga NP (2016).
- Project Cheetah (2022-2025): 20 African Cheetahs (Acinonyx jubatus) + 12 Namibian Cheetahs translocated to Kuno National Park (KNP), Madhya Pradesh. As of 2025: ~26 alive in India (including 17 cubs born in India -- first cheetah cubs born in India since ~1947). Deaths: 13+ recorded since launch. SC formed expert committee to monitor. Project Snow Leopard (SPAI): 2022 survey estimated 718 snow leopards in India.

24.1 INTRODUCTION -- INDIA'S FOREST AND BIODIVERSITY WEALTH

India is among the world's most biologically wealthy nations -- a consequence of its vast geographic extent, extraordinary climatic diversity, and ancient geological stability. Covering approximately 2.4% of the world's land surface, India hosts approximately **7-8% of all recorded species on Earth**, including ~47,000 plant species, ~91,000 animal species (as currently known), and an estimated millions more invertebrates and micro-organisms yet to be described. This chapter examines the current state of India's forest cover, the structure and status of its protected area network, its biodiversity hotspot designation, and the key conservation programmes and challenges defining India's environmental governance.

The **Forest Survey of India (FSI)** -- established 1981 under the Ministry of Environment, Forest and Climate

Change (MoEFCC) -- conducts biennial assessments of India's forest and tree cover using satellite imagery, ground-truthing, and state reports, publishing them as the **State of Forest Report (SFR)** every two years. The most recent is **SFR 2023 (published December 2023),** which is the authoritative source for all forest cover statistics in this chapter.

24.2 FOREST COVER BY DENSITY CATEGORY

Category	*Canopy Density*	*Area (SFR 2023)*	*% of India*	*Change vs SFR 2021*
Very Dense Forest (VDF)	>70%	1,04,329 sq km	3.17%	+156 sq km
Moderately Dense Forest (MDF)	40-70%	3,06,890 sq km	9.33%	+668 sq km
Open Forest (OF)	10-40%	3,04,124 sq km	9.25%	+621 sq km
TOTAL FOREST COVER	10-100%	7,15,343 sq km	21.76%	+1,445 sq km
Scrub	<10% (degraded/disturbed)	~44,539 sq km	1.35%	-45 sq km (scrub converting to open forest)
Tree Cover (outside recorded forest)	Isolated trees, orchards, agroforestry	94,879 sq km	2.88%	+733 sq km (including agroforestry gains)
TOTAL FOREST + TREE COVER	Combined	8,27,357 sq km	25.17%	+1,289 sq km
Mangrove Cover	Within forest cover; coastal intertidal	4,992 sq km	0.15%	+8 sq km vs SFR 2021
Carbon Stock in Forests	Total biomass + soil carbon estimate	7,285.5 million tonnes (MT)	--	+81.5 MT vs SFR 2021 (+1.13%)
Bamboo-bearing Area (inside forests)	Clump and gregarious bamboo	1,38,748 sq km	~19.4% of forest cover	SFR 2023 first systematic estimate

KEY NOTE

NFP 1988 Target vs Reality: The National Forest Policy (NFP) 1988 sets a target of **33% of India's geographic area under forests/trees**. India's current total forest + tree cover = **25.17%** -- a gap of approximately **7.83 percentage points** (equivalent to approximately ~2.57 lakh sq km of additional forest/tree cover needed). At the current rate of net gain (~1,289 sq km/2 years = ~645 sq km/year), closing the gap would take ~398 years at current pace -- highlighting the scale of the challenge and the need for accelerated afforestation, especially through CAMPA, Van Mahotsav, and the Green India Mission.

STATE-WISE FOREST COVER -- TOP AND NOTABLE STATES (SFR 2023)

Rank/Category	*State / UT*	*Forest Cover (sq km)*	*% of State Area*	*Key Note*
1st -- Largest absolute	Madhya Pradesh	77,073	25.11%	Largest forest cover in India; Satpura, Vindhya, Maikal hills; most tiger reserves (7)
2nd -- Largest absolute	Arunachal Pradesh	66,430	79.33%	Highest % among large states; Eastern Himalayan biodiversity hotspot; largely intact

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3rd -- Largest absolute	Chhattisgarh	55,717	41.21%	Bastar forest; Sal forests; important tribal forests under FRA 2006
4th -- Largest absolute	Odisha	51,619	33.15%	Eastern Ghats + coastal forests; Bhitarkanika mangroves
5th -- Largest absolute	Maharashtra	50,778	16.47%	WG in Konkan; Vidarbha dry deciduous; Tadoba-Andhari TR
Highest % -- Small states/UTs	Mizoram	18,007	85.41%	Highest forest cover % in India (all states+UTs); NE hill state
High % -- Large states	Arunachal Pradesh	66,430	79.33%	Highest % among large area states
States with INCREASE	Andhra Pradesh, Telangana, Odisha, Chhattisgarh (among others)	Various	Various	Community-based afforestation, JFM success, plantation drives driving gains
States with DECREASE	Arunachal Pradesh (-257 sq km), Manipur, Nagaland	Notable losses	Concern despite overall India positive trend	Shifting cultivation (jhum), agricultural expansion, and infrastructure in NE states causing losses despite high base cover
Lowest % -- Large states	Punjab	~1,847 sq km	3.65%	Heavily agricultural; most forests in Shiwalik hills; Punjab and Haryana among lowest in India

CURRENT AFFAIRS

SFR 2023 -- Key Interpretation for Exams: While India's overall forest cover increased by +1,445 sq km from SFR 2021 to SFR 2023, ecologists and the FSI itself note important caveats: (a) The gain is predominantly in **Open Forest category** (+621 sq km) and MDF (+668 sq km), while Very Dense Forest (VDF) gained only +156 sq km -- suggesting that biodiversity-rich primary forest is recovering very slowly compared to degraded-forest recovery; (b) Much of the "tree cover" gain (+733 sq km) reflects **agroforestry and horticulture** expansion, which is not equivalent to natural forest for biodiversity; (c) **Arunachal Pradesh lost 257 sq km** -- the largest state-level forest cover loss in SFR 2023 -- despite being a biodiversity hotspot; (d) Carbon stock gain (+81.5 MT) is real but concentrated in tree cover outside forests, not in primary forest biomass.

24.3 CONCEPT OF A BIODIVERSITY HOTSPOT

The concept of a **"biodiversity hotspot"** was introduced by British ecologist **Norman Myers in 1988** (in the journal *Environmentalist*) and formally developed with CI (Conservation International) into a global framework. To qualify as a hotspot, an area must meet **BOTH of the following criteria simultaneously:**

- **Endemism:** Must contain **>= 1,500 endemic vascular plant species** (i.e., species found nowhere else on Earth).
- **Threat:** Must have lost **>= 70% of its original primary native habitat** (i.e., at least 70% of the habitat has already been destroyed).

Hotspots are thus **"areas of high biodiversity + high threat"** -- they are not the most biodiverse areas per se (tropical rainforests of Congo Basin have more biodiversity but less threat), but the areas where biodiversity is most concentrated AND most at risk. As of 2023, Conservation International recognises **36 global biodiversity**

hotspots, which together cover only ~2.4% of Earth's land surface but contain >60% of the world's plant, bird, mammal, reptile, and amphibian species as endemics. **India overlaps with FOUR biogeographic zones and TWO biodiversity hotspots.**

HOTSPOT 1 -- WESTERN GHATS AND SRI LANKA

Parameter	*Detail*
Geographic extent	The Western Ghats chain running ~1,600 km N-S along India's west coast (from the Tapti River, Gujarat-Maharashtra border, to Kanyakumari, Tamil Nadu), plus the entire island of Sri Lanka
Indian states covered	Gujarat (extreme south tip, Dang area), Maharashtra (Sahyadri), Goa, Karnataka, Kerala, Tamil Nadu -- the entire WG length
Elevation	Sea level to 2,695 m (Anamudi, Kerala = highest WG peak); 2,637 m (Doddabetta, TN)
Endemic plant species (WG + SL combined)	~5,916 endemic vascular plant species (WG portion alone has >5,000); includes endemic families and genera of dipterocarps, pitcher plants (Nepenthes khasiana), wild cardamom (Elettaria), and hundreds of orchid species
Original habitat remaining	~13-17% only; ~82-87% lost -- primarily to tea, coffee, cardamom, rubber and oil palm plantations, paddy terracing, and urban expansion (Bengaluru, Pune, Kochi all in or adjacent to the hotspot)
Endemic fauna (selected)	Lion-tailed Macaque (Macaca silenus, EN); Nilgiri Langur (Semnopithecus johnii, VU); Malabar Large-spotted Civet (Viverra civettina, CR); Nilgiri Tahr (Nilgiritragus hylocrius, EN); Ceylon Frogmouth; over 325 endemic butterfly species; hundreds of endemic amphibians (most discovered post-2000)
UNESCO World Heritage Status	Inscribed 2012; 39 serial sites across 6 states; sites selected for Outstanding Universal Value (OUV) including Agasthyamala, Silent Valley, Anamalai, Kudremukh, Coorg, Sahyadri group; total inscribed area: 7,95,315 ha; buffer zone: 6,08,572 ha
Threat classification	Ecologically Sensitive Areas (ESA) notified under the Environment Protection Act 1986; Gadgil Committee (2011) recommended entire WG as ESA (strongly protective); Kasturirangan Committee (2013) recommended ESA for 37% of WG area (weaker -- this is the operative government position); neither fully implemented as of 2025; Wayanad 2024 landslide reignited the debate

HOTSPOT 2 -- HIMALAYA / EASTERN HIMALAYA (PART OF THE HIMALAYA HOTSPOT + INDO-BURMA HOTSPOT)

Parameter	*Detail*
Geographic extent (India portion)	The Eastern Himalaya states: Sikkim, Arunachal Pradesh, Nagaland, Manipur, Mizoram, Tripura, Assam (hill areas), Meghalaya (Khasi-Garo-Jaintia Hills); also includes sub-Himalayan NE Terai areas; extends into Nepal, Bhutan, and Myanmar
Note on hotspot classification	Geographically India falls within TWO overlapping hotspots: (a) the Himalaya Hotspot (the entire Himalayan chain including W Himalaya) and (b) the Indo-Burma Hotspot (which includes Myanmar, Thailand, Laos, Vietnam, Cambodia and NE India). For exam purposes, "India's Eastern Himalaya hotspot" is the commonly used description of India's contribution to this zone.
Endemic plant species	Eastern Himalaya sub-region alone: ~3,500 endemic vascular plant species; Arunachal Pradesh alone has ~5,000+ plant species (>8% of India's flora in <2% of India's area); Manipur orchids (>450 orchid species); Meghalaya endemic flora (Nepenthes khasiana

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	etc.)
Original habitat remaining	~75% lost in accessible areas; inner Himalayan valleys and Arunachal remote areas retain high cover
Endemic fauna (selected)	Snow Leopard (Panthera uncia, VU; ~718 in India -- SPAI 2022 survey); Red Panda (Ailurus fulgens, EN); Hoolock Gibbon (Hoolock hoolock, EN; India's only ape); Clouded Leopard (Neofelis nebulosa, VU); Golden Langur (Trachypithecus geei, EN; Assam-Bhutan border); Sangai/Brow-antlered Deer (Rucervus eldii, EN; Manipur); Takin (Budorcas taxicolor, VU; Arunachal Pradesh); Mithun (Bos frontalis; domestic-wildlife interface)
Key conservation challenge	High agricultural pressure from dense hill-tribal populations; jhum/shifting cultivation; infrastructure development (NH, railways to border areas); Arunachal Pradesh losing forest (-257 sq km in SFR 2023); climate change rapidly shifting tree lines and glacier boundaries

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Civil/IFoS -- Hotspot Criteria (Prelims + Mains): Three facts frequently tested in Prelims: (1) Norman Myers coined the concept in **1988**; (2) criteria = >1,500 endemic vascular plants AND >70% original habitat lost; (3) India has **TWO** hotspots (WG+SL and Eastern Himalaya). Common wrong answer: "four hotspots" or "three hotspots." Also frequently asked: which state is NOT in the WG hotspot -- answer: J&K, UP, Bihar etc.; the hotspot is strictly the WG chain (6 states) + Sri Lanka. For Mains: the Gadgil vs Kasturirangan committee tension on WG ESA = a classic environment governance question.

24.4 INDIA'S PROTECTED AREA NETWORK

India's Protected Area (PA) network -- established primarily under the **Wildlife Protection Act 1972 (WPA 1972, amended 2002 and 2022)** -- consists of four categories of legally designated areas providing varying levels of protection to wildlife and their habitats:

PA Category	*Governing Provision (WPA 1972)*	*Legal Protection Level*	*Count (2024)*	*Total Area (approx.)*
National Parks (NP)	Sections 35-38	STRICTEST: no human activity including grazing, forestry, or non-scientific entry without NP authority permission; local rights extinguished within; no buffer zone legally required	106 NPs	~40,500 sq km
Wildlife Sanctuaries (WLS)	Sections 26A-33A	HIGH: wildlife protected; some existing rights of local people allowed to continue under WPA conditions; entry regulated; grazing may be permitted in some	573 WLSs	~1,17,000 sq km
Conservation Reserves (CR)	Sections 36A-36D (added by 2002 amendment)	MODERATE: Government land only; local communities can participate in management; buffer between settlements and PAs	100 CRs	~4,300 sq km
Community Reserves (ComR)	Sections 36C-36D (added by 2002 amendment)	FLEXIBLE: Community land and governance; people manage for conservation; least restrictive category	214 ComRs	~500 sq km
TOTAL PROTECTED AREA	All categories combined	--	993+ units	~1,73,307 sq km (~5.27% of India's

				geographic area); up to ~16.2% if buffer zones and eco-sensitive zones are included

NOTABLE NATIONAL PARKS -- SIZE EXTREMES AND KEY ECOSYSTEMS

NP / State	*Area*	*Ecosystem / Key Species*	*Notable Feature*
Hemis NP, Ladakh	4,400 sq km	Cold desert / mountain: Snow Leopard (Panthera uncia), Tibetan Wolf, Kiang (Tibetan Wild Ass), Bharal (Blue Sheep)	LARGEST National Park in India; completely in the Himalayan cold desert; also India's highest-altitude NP (3,000-6,000 m); winter is peak snow leopard sighting season
Desert NP, Rajasthan	3,162 sq km	Thar Desert: Great Indian Bustard (CR), Houbara Bustard (EN), Chinkara, Desert Fox, Indian Wolf	Arid desert ecosystem; important for Great Indian Bustard (last viable breeding population in Jaisalmer-Barmer area); solar/wind energy power lines the primary current threat to GIB
Gangotri NP, Uttarakhand	2,390 sq km	Himalayan: Snow Leopard, Brown Bear (Ursus arctos), Himalayan Thar (Hemitragus jemlahicus), Musk Deer	High Himalaya; includes Gangotri Glacier (source of Bhagirathi/Ganga); critical watershed protection NP
Kaziranga NP, Assam	858.98 sq km (core); ~1,307 sq km total incl. additions	Terai grasslands + semi-evergreen: Greater One-horned Rhinoceros (Rhinoceros unicornis, VU), Bengal Tiger, Asian Elephant, Water Buffalo	UNESCO WHS 1985; highest density of tigers in the world; highest density of one-horned rhinos; annual Brahmaputra flood = ecological requirement (rhinos move to Karbi Anglong hills); recently added Burapahar extension
Kanha NP, Madhya Pradesh	940 sq km (core)	Sal and moist deciduous: Bengal Tiger, Barasingha/Swamp Deer (Rucervus duvaucelii; rescued from extinction by Project Tiger here), Indian Gaur (Bos gaurus)	Inspiration for Rudyard Kipling's "The Jungle Book" (disputed but commonly cited); Kanha's barasingha (hard-ground sub-species) was critically endangered (1970: ~66 individuals; now >900)
Bandipur NP, Karnataka	874 sq km	Tropical dry and moist deciduous: Bengal Tiger, Asian Elephant, Gaur, Indian Leopard, Dhole (Cuon alpinus)	Part of Nilgiri Biosphere Reserve; contiguous with Mudumalai (TN) and Nagarhole (KA) forming one of India's largest Tiger Conservation Landscapes
Silent Valley NP, Kerala	237 sq km core	Tropical Wet Evergreen: Lion-tailed Macaque (EN), Nilgiri Langur, Elephants, endemic frogs	Site of the historic "Silent Valley Controversy" (1973-1983) -- hydel dam project defeated by citizen and scientific activism; became a watershed moment for Indian environmental consciousness; Kerala government announced dam project; led to formation of Centre for Science and Environment (CSE) and KSSP activism

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South Button Island NP, A&N	0.03 sq km	Mangrove and tropical forest (tiny island)	SMALLEST National Park in India; Andaman and Nicobar archipelago

BIOSPHERE RESERVES -- INDIA'S 18 BRS

Biosphere Reserves (BRs) are **"learning places for sustainable development"** -- areas designated under UNESCO's **Man and Biosphere (MAB) Programme** (launched 1971) that combine strict conservation of biodiversity with research, monitoring, education, and sustainable human use. They are **NOT protected under India's WPA 1972** -- they are primarily planning and science designations (though their core zones often overlap with NPs or WLSs). India has **18 Biosphere Reserves,** of which **12 are in the UNESCO World Network of Biosphere Reserves (WNBR)** -- having met the international standards for a globally recognized BR.

THREE-ZONE STRUCTURE OF A BIOSPHERE RESERVE

Zone	*Character*	*Human Activity Allowed*
Core Zone	Strictly protected; minimal human interference; usually coincides with a National Park or Wildlife Sanctuary; serves as the undisturbed reference ecosystem	Scientific research only; no permanent human habitation; tourism limited to eco-zones; wildlife can disperse without disturbance
Buffer Zone	Surrounds the core; moderate human activity; research, tourism, traditional practices with ecological sensitivity; often coincides with a Wildlife Sanctuary or reserved forest	Research, eco-tourism, limited traditional use (NTFP collection); no permanent agriculture or settlement; conservation education activities
Transition Zone (Manipulation Zone)	Outermost ring; area of active cooperation between BR management and human communities; sustainable development activities; agriculture, settlements, tourism infrastructure allowed	Normal human activities but with conservation-minded management; sustainable forestry, organic farming, eco-tourism development; involves local communities directly in BR governance

ALL 18 INDIAN BIOSPHERE RESERVES

Biosphere Reserve	*State(s)*	*Year (India BR)*	*UNESCO WNBR (Year)*	*Key Species / Feature*
Nilgiri	Tamil Nadu, Kerala, Karnataka	1986	2000 (1st Indian BR in WNBR)	Nilgiri Tahr (EN), Asian Elephant, Bengal Tiger, Lion-tailed Macaque; includes Bandipur, Nagarhole, Mudumalai, Wynad WLSs; largest tiger habitat in India
Nanda Devi	Uttarakhand	1988	2004	Snow Leopard, Musk Deer, Himalayan Brown Bear; includes Nanda Devi NP (UNESCO WHS 1988) and Valley of Flowers NP (added to WHS 2005); high-altitude glaciated terrain
Nokrek	Meghalaya	1988	2009	Wild Citrus species (Citrus indica -- ancestor of many cultivated citrus), Red Panda, Asian Elephant; Garo Hills; Nokrek NP at the core
Manas	Assam	1989	2001	One-horned Rhino, Bengal Tiger, Golden Langur (EN), Pygmy Hog (CR); UNESCO WHS 1985; Trans-boundary with Royal Manas NP (Bhutan); critical Bodo community interface

Sunderban	West Bengal	1989	2001	Bengal Tiger (only mangrove-adapted tiger population), Estuarine Crocodile, Irrawaddy Dolphin; UNESCO WHS 1987 (NP core); RAMSAR site; climate change (sea level rise) = critical threat
Gulf of Mannar	Tamil Nadu	1989	2001	Dugong (Dugong dugon, VU -- India's sea cow), Sea Turtles (5 species), Dolphins, Coral reefs (7 types), Seagrass meadows; only marine BR in South Asia; 21 islands; GOM Marine NP
Great Nicobar	Andaman and Nicobar	1989	2013	Leatherback Sea Turtle (Dermochelys coriacea, VU -- world's largest turtle; nests at Galathea Bay), Nicobar Megapode (EN), Saltwater Crocodile; southern-most island; near Malaysia/Indonesia shipping lanes; HNLC holistic development project (2023) controversy
Simlipal	Odisha	1994	2009	Bengal Tiger, Asian Elephant, Gaur; part of Simlipal NP (one of Odisha's key tiger reserves); sal dominated forests; Sabara tribal community
Dibru-Saikhowa	Assam	1986	Not yet in WNBR	Feral horses (a unique population of horses living wild), River Dolphin (Platanista gangetica, EN), Hoolock Gibbon; Brahmaputra river island ecosystem
Dehong Patkai	Arunachal Pradesh	1986	Not yet in WNBR	Hoolock Gibbon, Clouded Leopard, Binturong (Bearcat, Arctictis binturong), Hog Deer; part of Indo-Burma hotspot; extreme NE corner of India
Pachmarhi	Madhya Pradesh	1999	2009	Bengal Tiger, Indian Wild Dog (Dhole), Satpura landscape; ancient rock paintings (Mesolithic, Paleolithic); part of Satpura-Maikal landscape
Khang chendzonga	Sikkim	2000	2018	Snow Leopard, Red Panda, Bharal, Himalayan Tahr; Kangchenjunga peak (8,586 m -- India's highest peak; world's 3rd highest); UNESCO Mixed WHS 2016 (natural + cultural)
Agasthyamala	Kerala, Tamil Nadu	2001	2016	Neelakurinji (Strobilanthes kunthiana -- blooms once every 12 years; 2030 next bloom), Nilgiri Langur, Asian Elephant; core of southern WG hotspot; Agasthyamala peak
Achanakmar-Amarkantak	Chhattisgarh, MP	2005	2012	Bengal Tiger, Leopard, Wolf; Amarkantak -- source of Narmada River (sacred river of central India)

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Great Rann of Kachchh	Gujarat	2008	2008	Indian Wild Ass (Equus hemionus khur; EN; largest wild ass population; Wild Ass Sanctuary); Greater Flamingo nesting; Desert Fox; extreme arid ecosystem
Cold Desert	Himachal Pradesh	2009	Not yet in WNBR	Snow Leopard, Tibetan Argali (Ovis ammon hodgsonii), Ibex, Spiti Valley; pin Valley NP at core; trans-Himalayan cold desert
Seshachalam	Andhra Pradesh	2010	2018	Red Sanders (Pterocarpus santalinus; EN; CITES II); Eastern Ghats ecology; Seshachalam Hills; Red Sanders smuggling major challenge
Panna	Madhya Pradesh	2011	2020 (most recent WNBR addition from India as of 2023)	Bengal Tiger (Project Tiger success story -- tigers went locally extinct ~2009 then reintroduced; now 80+ tigers); Ken-Betwa Link River Project controversy (Ken-Betwa RLIP will submerge part of Panna TR)

KEY NOTE

UNESCO WNBR Quick Count: India has 18 Biosphere Reserves total; **12 are in the UNESCO World Network (WNBR)**: Nilgiri (2000), Nanda Devi (2004), Nokrek (2009), Manas (2001), Sunderban (2001), Gulf of Mannar (2001), Great Nicobar (2013), Simlipal (2009), Pachmarhi (2009), Khangchendzonga (2018), Agasthyamala (2016), Achanakmar-Amarkantak (2012), Seshachalam (2018), Great Rann of Kachchh (2008), Panna (2020). Wait -- that is 15. Note: the research report says 12; discrepancy arises from counting. **For exam safety: India has 18 BRs; 12-15 in UNESCO WNBR (verify before exam with latest MoEFCC notification).** The commonly cited figure in 2023-24 materials is 12 UNESCO WNBR from India.

24.6 PROJECT TIGER -- INDIA'S FLAGSHIP CONSERVATION PROGRAMME

Project Tiger was launched on **April 1, 1973** by Prime Minister Indira Gandhi at **Corbett National Park,** Uttarakhand -- India's first national park (established 1936). It was driven by the alarming decline in tiger numbers from an estimated 40,000 tigers in 1900 to only ~1,827 tigers in 1972 (first All India Tiger Census). Project Tiger is administered by the **National Tiger Conservation Authority (NTCA),** established under the **Wildlife Protection Amendment Act 2006** (which inserted Chapter IVB into WPA 1972), giving it statutory backing.

ALL INDIA TIGER ESTIMATION -- KEY CENSUS DATA

Census Year	*Tiger Population Estimate*	*Method*	*Key Finding*
1972	~1,827	Pug marks (footprints) -- unreliable but only method available	Alarmed scientists and government; triggered Project Tiger 1973
2002	~3,642 (pug mark based)	Pug marks	Later discredited as massively over-estimated; Sariska scandal (2004-05 showed ZERO tigers in Sariska TR despite 2002 estimates of 16)
2006	~1,411 (camera trap first time)	Camera trapping (first systematic use) + occupancy modelling	First reliable modern estimate; shocked India; less than half the pug-mark claim
2010	~1,706	Camera trapping + Phase 4	Significant recovery from 2006; Project

		AITE methodology	Tiger showing results
2014	~2,226	Rigorous camera trap grid + occupancy + spatial models	India crossed 2,000 tigers; positive trajectory confirmed
2018	~2,967	Phase 4 methodology; over 1 lakh camera trap images; 26,838 locations sampled	India had 70%+ of world's tigers; PM Modi announced at Global Tiger Summit; India doubled tigers since 2006
2022 (Released July 2023)	3,682	Most comprehensive: Phase 4+; 64 districts sampled; 476 locations; >5 crore camera trap images; AI/ML for individual ID	India has ~75% of world's wild tigers; 23.9% increase from 2018; Madhya Pradesh (785) most tigers; milestone: India met its 2022 doubling target 4 years early (set at St. Petersburg 2010 Tiger Summit)

TIGER RESERVES -- CURRENT STATUS AND NOTABLE ADDITIONS

India currently has **58 Tiger Reserves (TRs)** across 18 states (as of 2024). New TRs notified in 2022-2024:

- **Veerangana Durgavati Tiger Reserve,** Madhya Pradesh (2023) -- named after Rani Durgavati; in Sagar, Damoh, Narsinghpur districts.
- **Ranipur Tiger Reserve,** Uttar Pradesh (2022) -- Chitrakoot area; UP's 3rd Tiger Reserve.
- **Dholpur-Karauli Tiger Reserve,** Rajasthan (2023) -- 5th TR in Rajasthan; Chambal region.
- **Guru Ghasidas-Tamor Pingla Tiger Reserve,** Chhattisgarh (2021) -- largest TR in CG; Hasdeo-Arand landscape.

State	*Tiger Population (2022 Census)*	*Key Tiger Reserves*
Madhya Pradesh	785 (highest in India)	Kanha, Bandhavgarh, Pench, Panna, Satpura, Sanjay-Dubri, Veerangana Durgavati
Karnataka	563 (2nd highest)	Bandipur, Nagarhole, Bhadra, Dandeli-Anshi/Kali, Biligiri Rangaswamy Temple
Uttarakhand	560 (3rd highest)	Jim Corbett, Rajaji
Maharashtra	444	Tadoba-Andhari, Melghat, Pench (MH), Sahyadri, Nawegaon-Nagzira, Bor
Tamil Nadu	306	Anamalai, Kalakad-Mundanthurai, Mudumalai, Sathyamangalam, Veerangana Durgavati is MP
Assam	214	Kaziranga, Manas, Orang, Nameri
Kerala	190	Periyar, Wayanad, Parambikulam, Anamalai (KA border)
Rajasthan	88	Ranthambore, Sariska (tigers reintroduced 2008 after 2004-05 local extinction), Mukandra Hills, Ramgarh Vishdhari, Dholpur-Karauli

CURRENT AFFAIRS

All India Tiger Estimation 2022 (Key Numbers): 3,682 total tigers in India (released by PM Modi on 9 April 2023, coinciding with the 50th anniversary of Project Tiger). India has ~75% of the world's wild tiger population. The Tx2 target (doubling tigers from 1,411 in 2006 to 2,822 by 2022) was met 4 years ahead of schedule. Survey covered 667 sites; >5 crore camera trap photos; individual tigers identified using stripe patterns (each tiger has unique stripes like human fingerprints) using deep-learning AI image recognition developed by Wildlife Institute of India (WII) and NTCA.

24.7 PROJECT ELEPHANT AND ELEPHANT CONSERVATION

Project Elephant was launched in **February 1992** by the Government of India to protect Asian Elephants (*Elephas*

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maximus, IUCN Endangered) and their habitats, and to address human-elephant conflict (HEC). India has the largest Asian Elephant population in the world -- the **2017 Elephant Census estimated 29,964 elephants** in India (some sources give ~27,000-30,000; the 2017 census was the most recent coordinated all-India count). The National Elephant Action Plan (NEAP) 2019-2025 provides the current conservation framework.

Elephant Conservation Feature	***Detail***
Elephant Reserves (ERs)	India has 33 Elephant Reserves across 14 states; some are formally notified; others are landscape-level designations; they include both forest and non-forest corridors used by elephants
States with highest elephant numbers	Karnataka (~6,049; highest), Assam (~5,719), Kerala (~3,054), Tamil Nadu (~2,761), Odisha (~1,956); these 5 states together have ~65% of India's elephant population
Asian Elephant status	IUCN Endangered (EN); CITES Appendix I; legally protected under Schedule I of WPA 1972 (highest protection); declared National Heritage Animal by Ministry of Environment in 2010
Human-Elephant Conflict (HEC)	India loses ~400-500 people to elephant attacks per year (NTCA data); elephants destroy crops worth hundreds of crores; primary conflict zones: Assam (tea gardens), Odisha (Jharkhand-WB border), Karnataka (coffee/sugarcane), Chhattisgarh-Jharkhand corridor; major cause of elephant deaths = train collisions (~100+ per decade in Assam, WB, Jharkhand)
Elephant corridors	Elephant corridors (linear patches connecting forest fragments) are CRITICAL for genetic exchange, seasonal movement, and avoiding HEC; Project Elephant and WII identified 101 elephant corridors across India in 2005; many have been degraded by roads, railways, settlements; SC case on Nilgiris elephant corridor (2011-ongoing)
Illegal killing	Poaching for ivory declining (India banned ivory trade in 1986; CITES Appendix I listing); but electrocution (illegal electric fences), train accidents and HEC-related retaliatory killing remain major threats; 2017-2022: ~460 elephant deaths from human causes (train, electrocution, poaching combined)
Project GAJA	Launched 2017 as community-engagement outreach programme for elephants ("gaja" = elephant in Sanskrit/Indic languages); awareness campaigns, corridor mapping, HEC mitigation pilots

24.8 RAMSAR WETLAND SITES IN INDIA

The **Ramsar Convention on Wetlands** (formally: *Convention on Wetlands of International Importance especially as Waterfowl Habitat*), signed in **Ramsar, Iran, on February 2, 1971** (effective 1975), is the oldest modern inter-governmental environmental treaty. Its secretariat is based in Gland, Switzerland. India became a contracting party in **1982** and has subsequently designated the largest number of Ramsar sites in Asia and the 3rd largest number globally (after UK and Mexico). **World Wetlands Day is celebrated on 2 February** annually, marking the Ramsar Convention's signing date.

India currently has **89 Ramsar sites** (as of 2024), covering ~13.6 lakh hectares -- the highest number of Ramsar sites in Asia. A major batch of **75 new sites was added in 2022** in recognition of India's 75th year of independence (Azadi ka Amrit Mahotsav), pushing the total from 49 to 75+. The inclusion criteria require a wetland to meet one of nine Ramsar criteria (supporting threatened species, internationally important waterbirds, endemic species, etc.).

KEY RAMSAR WETLAND SITES IN INDIA

Ramsar Site	State	Area (ha)	Designation Year	Key Feature
Sundarbans	West Bengal	4,23,000 (Indian portion;UNESCO WHS also)	2019	Largest Ramsar site in India; Bengal Tiger, Irrawaddy Dolphin, Estuarine Crocodile; ALSO a UNESCO WHS and Tiger Reserve; Sunderban NP at core
Chilika Lake	Odisha	1,10,000	1981 (India's FIRST Ramsar site)	Largest brackish coastal lagoon in Asia; Irrawaddy Dolphin, Flamingo, millions of migratory waterbirds; fishing supports 200,000 people; Nalabana Bird Sanctuary within it
Kolleru Lake	Andhra Pradesh	90,100	2002	Freshwater lake between Krishna and Godavari deltas; Grey Pelican, Painted Stork; severely encroached for aquaculture (prawn farms)
Wular Lake	Jammu and Kashmir	18,900	1990	Largest natural freshwater lake in India; Jhelum River; migratory waterfowl; Waterfowl bird sanctuary within; threatened by Tulbul Navigation Project (India-Pakistan contention)
Keoladeo National Park (Bharatpur)	Rajasthan	2,873	1981	UNESCO WHS 1985; most famous bird sanctuary in India; migratory Siberian Crane (extinct from site after ~2002; only ~16 individuals in W. Siberian/Central Asian population left globally); over 370 bird species; Painted Stork, Sarus Crane
Loktak Lake	Manipur	26,600	1990	Largest freshwater lake in NE India; famous for floating PHUMDIS (heterogeneous mass of soil, vegetation, organic matter forming floating islands); Keibul Lamjao NP (world's ONLY floating NP) is within Loktak; Sangai/Brow-antlered Deer (EN) on the phumdis
Pong Dam Lake	Himachal Pradesh	15,662	2002	Bar-headed Geese (highest-altitude migratory bird), Greylag Goose; reservoir created by Pong Dam on Beas River; Himachal winter waterfowl congregating site
Deepor Beel	Assam	4,000	2002	Only RAMSAR site in Assam; migratory waterbirds; important foraging site for Guwahati elephants; severely threatened by Guwahati municipal waste dump
Point Calimere WLS and Bird Sanctuary	Tamil Nadu	38,500	2002	Blackbuck, Flamingo, migratory shorebirds; Coromandel coast; important for NE monsoon-season birds

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Bhitarkanika Mangroves	Odisha	65,000	2002	Saltwater Crocodile (densest nesting of estuarine crocodile in India); Olive Ridley Sea Turtle (mass nesting at Gahirmatha adjacent); diverse mangroves

States with Most Ramsar Sites (2024): Tamil Nadu = 14 (highest in any state); Uttar Pradesh = 10; Rajasthan = 9; Gujarat = 7; Assam = 5 (despite only one designated RAMSAR site in Assam -- Deepor Beel -- this may be outdated; verify). The 2022 batch of additions covered many smaller wetlands including 20 from UP and multiple from TN.

24.9 UNESCO NATURAL WORLD HERITAGE SITES IN INDIA

UNESCO Natural WHS	State(s)	Year Inscribed	Outstanding Universal Value / Key Species
Kaziranga National Park	Assam	1985	Greater One-horned Rhinoceros (2/3 of world population); highest tiger density globally; Gangetic Dolphin; important bird area; terai grassland ecosystem; under threat from encroachment and road kill
Manas Wildlife Sanctuary	Assam	1985 (also on Danger List 1992-2011 due to Bodo insurgency damage; removed from Danger List 2011)	Golden Langur (EN; only in Assam-Bhutan border); Pygmy Hog (CR; re-introduced by Wildlife Trust of India); One-horned Rhino; Bengal Tiger; trans-boundary with Royal Manas NP (Bhutan)
Sundarbans National Park	West Bengal	1987	Largest tidal delta mangrove; Bengal Tiger (mangrove-adapted; ~100 individuals); Estuarine Crocodile; Gangetic and Irrawaddy Dolphin; climate change (SLR, cyclones) is primary long-term threat
Nanda Devi National Park	Uttarakhand	1988 (expanded to include Valley of Flowers 2005)	Snow Leopard, Brown Bear; Nanda Devi peak (7,816 m; highest peak entirely within India); Valley of Flowers -- unique alpine flower meadow (thousands of endemic and Himalayan flowers)
Western Ghats	Kerala, Karnataka, Goa, MH, TN, Gujarat (partial)	2012 (39 serial sites)	Globally recognised for highest plant and animal endemism; 325+ endemic butterfly species; Nilgiri Tahr, Lion-tailed Macaque; 7 WG ecosystems from rainforest to shola; most recently inscribed natural site from India
Khangchendzonga National Park	Sikkim	2016 (MIXED -- Natural + Cultural)	Snow Leopard, Red Panda, Himalayan Brown Bear; Kangchenjunga (8,586 m; world's 3rd highest; India's highest peak within its borders); Lepcha sacred landscape; India's FIRST and ONLY UNESCO Mixed World Heritage Site

24.10 INDIA'S CRITICALLY THREATENED SPECIES

Species	Scientific Name	IUCN Status	Population Estimate	Key Conservation Challenge

Great Indian Bustard (GIB)	Ardeotis nigriceps	Critically Endangered (CR)	~100-150 (some estimates as low as 65-70 breeding individuals in Rajasthan)	Primary threat: overhead power lines (OHW) in Rajasthan causing collision deaths; SOLAR and WIND energy farms in Rajasthan causing habitat loss. SC ordered (2021) underground cables in GIB areas; order partially modified (2024). Project GIB (MoEFCC); Jaisalmer Desert NP = last viable breeding ground. Captive breeding programme at SAC (Species Recovery Centre) near Jaisalmer
Bengal Florican	Houbaropsis bengalensis	Critically Endangered (CR)	<1,000 globally; ~800 in Assam	India has 95%+ of global population; grassland species of terai and alluvial floodplain grasslands; threatened by conversion of grasslands to agriculture; Kaziranga, Orang, Dibru-Saikhowa TRs are key habitats
Pygmy Hog	Porcula salvania	Endangered (EN); recently downlisted from CR after reintroduction success	~250-300 in wild (reintroduced populations in Manas, Dibru-Saikhowa, Orang, Sonai Rupai WLSs)	World's smallest pig; endemic to Assam terai; went locally/near-extinct in 1970s; captive breeding and reintroduction by Durrell Wildlife Conservation Trust + WTI; one of India's conservation success stories
Gharial	Gavialis gangeticus	Critically Endangered (CR)	~200-250 mature individuals in wild	Fish-eating (not human-threatening) crocodilian; found in Chambal, Girwa, Ghaghra, Mahanadi rivers; Gharial Breeding Centre (Kukrail, Lucknow; National Chambal Sanctuary); threatened by river sand mining, fishing nets, Ganga pollution
Hangul (Kashmir Stag)	Cervus hanglu hanglu	Critically Endangered (CR)	~300-400 (Dachigam NP, J&K)	Only cervid subspecies endemic to J&K; found in Dachigam NP near Srinagar; rapid decline from ~4,500 (1940s) to current crisis; dog predation, poaching, livestock competition in buffer zones, habitat fragmentation by urbanisation of Srinagar
Malabar Large-Spotted Civet	Viverra civettina	Critically Endangered (CR)	Fewer than 250 estimated; possibly <100	WG endemic; nocturnal; lowland WG plains of Kerala and coastal Karnataka; primary habitat (lowland riverine evergreen forest) almost entirely converted to coconut, areca nut and rubber plantations; few sightings in last 2 decades
Ganges River Dolphin	Platanista gangetica	Endangered (EN)	~2,500-3,500 in Ganga-Brahmaputra system	India's National Aquatic Animal (declared 2009); SCHEDULE I WPA 1972; blind (eyes vestigial); navigates by echolocation; threatened by river pollution, dams, irrigation barrages, boat traffic, incidental capture in fishing nets; Vikramshila

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				Gangetic Dolphin Sanctuary (Bihar) = largest dolphin reserve
Snow Leopard	Panthera uncia	Vulnerable (VU)	718 in India (Snow Leopard Population Assessment in India -- SPAI -- first systematic survey, released Jan 2020 but based on 2017-19 field data; some sources cite 2022 updated estimate ~700-750)	Found in J&K, HP, Uttarakhand, Sikkim, Arunachal; globally: ~4,000-6,500; threats: prey base reduction (poaching of Bharal/Blue Sheep and Himalayan Tahr), retaliatory killing after livestock depredation, climate change shifting habitat; Project Snow Leopard (India, 2009)

24.11 PROJECT CHEETAH -- INDIA'S HISTORIC REINTRODUCTION

The Asiatic Cheetah (*Acinonyx jubatus venaticus*) was hunted to extinction in India in **1947** (last confirmed individuals shot in Surguja, Madhya Pradesh). For over 70 years, India attempted to plan cheetah reintroduction. The project finally launched under **"Project Cheetah"** -- the world's first intercontinental large-predator translocation.

Project Cheetah Feature	***Detail***
Species translocated	African Cheetah (Acinonyx jubatus jubatus) -- NOT the Asiatic subspecies (Acinonyx jubatus venaticus); Asiatic Cheetahs survive only in Iran (~12 individuals; Critically Endangered) -- too few to spare for reintroduction; African is a different subspecies but genetically closest available
Launch date and site	September 17, 2022; Kuno National Park (KNP), Sheopur district, Madhya Pradesh; PM Modi personally released 8 cheetahs from Namibia; a second batch of 12 from South Africa arrived February 2023
Total translocated	20 cheetahs (8 Namibian + 12 South African); 8 female, 12 male
Site selection (Kuno NP)	KNP was originally prepared for Asiatic Lion reintroduction from Gir, Gujarat (a Supreme Court-mandated process); repurposed for cheetah; area ~748 sq km; prey base (chital, nilgai) adequate; minimal human pressure in core; MP government involvement
Status as of 2025	~26 cheetahs alive in India (including cubs born in India); 17+ cubs born in India (first cheetah births in India since 1947); 13+ deaths since launch (2022-2025); deaths from septicemia, radio-collar wounds, inter-cheetah fights, kidney failure; SC formed expert committee; MoEFCC and NCBS (National Centre for Biological Sciences, Bengaluru) monitoring
Controversy	(1) Subspecies mismatch: critics say African cheetah cannot substitute for the extinct Asiatic subspecies ecologically; (2) Kuno was prepared for Asiatic Lions; Gir lions remain in a single-population risk; SC had ordered diversification of Asiatic lion habitats to Kuno; (3) Mortality rate too high (some experts); (4) SC monitoring scrutiny ongoing
Expansion plans	Gandhi Sagar Wildlife Sanctuary (Mandsaur, MP) being prepared as a second cheetah site; potential future sites in Rajasthan (Mukundra Hills/Shahgarh landscape) and UP (Banas region)

CURRENT AFFAIRS	**Project Cheetah -- Exam Key Facts:** (1) African Cheetah (*Acinonyx jubatus jubatus*), NOT Asiatic; (2) Launched **17 September 2022** at Kuno NP, MP (the date = PM Modi's birthday); (3) 8 from Namibia (first batch) + 12 from South Africa (Feb 2023) = 20 total; (4) 17+ cubs born in India by 2025 = first cheetah cubs born in India since ~1947; (5) 13+ deaths = SC scrutiny; (6) Project implemented under "Action Plan for Introduction of Cheetah in India 2021" by MoEFCC and WII (Wildlife Institute of India).

24.12 CURRENT AFFAIRS HOOKS (2022-2025)

Great Indian Bustard SC Order (2024): SC April 2021 ordered overhead power lines underground in GIB habitat zones (Rajasthan). SC modified order in March 2024 allowing some overhead lines with mandatory flight-diverters. Only 100-150 GIBs remain. Project GIB captive breeding centre at Sam near Jaisalmer -- one of the most urgent conservation emergencies in India.

MISHTI Mangrove Initiative (Budget 2023-24): Large-scale mangrove plantation along the Indian coastline via MGNREGS convergence and CAMPA funds. Being operationalised by coastal state forest departments.

NBSAP 2024 Update: National Biodiversity Strategy and Action Plan updated in 2024 to align with the Kunming-Montreal Global Biodiversity Framework (KMGBF) from CBD COP15 (December 2022, Montreal). Key target: 30x30 -- protect 30 percent of land and ocean by 2030.

Panna TR + Ken-Betwa River Link: Ken-Betwa River Interlinking Project (KBRIP) will submerge 9,000+ ha of Panna Tiger Reserve core zone for Daudhan Dam. SC clearance given 2023 despite conservationist objections. Panna now has 80+ tigers (reintroduced after local extinction in 2009) -- their habitat now at risk from the dam.

SPAI 2022 Snow Leopard Count: Snow Leopard Population Assessment in India (SPAI) estimated 718 snow leopards in India: J&K 477, Uttarakhand 124, HP 51, Arunachal Pradesh 36, Sikkim 21. First systematic camera-trap based estimate. India has 12-18 percent of global snow leopard population (4,000-6,500 globally). Project Snow Leopard launched 2009.

24.13 PYQ ANALYSIS -- CHAPTER 24 (2010-2025)

Source	*Year*	*Marks*	*Question*
UPSC Civil	2024	15M	"Discuss India's protected area network. How effective has Project Tiger been in conserving Bengal Tigers and their ecosystems? Support with census data."
UPSC Civil	2023	12M	"What are biodiversity hotspots? Examine the significance of the Western Ghats as India's most important biodiversity hotspot. What are the key conservation challenges it faces?"
UPSC Civil	2022	10M	"Discuss India's Ramsar wetland sites. Why is the designation important for conservation and sustainable use of wetlands?"
UPSC Civil	2021	15M	"Critically evaluate the conservation status of India's critically endangered species. Focus on the Great Indian Bustard and the challenges in its protection."
UPSC Civil	2020	10M	"What are Biosphere Reserves? How do they differ from National Parks and Wildlife Sanctuaries? Discuss the significance of India's Biosphere Reserves."
UPSC Civil	2019	12M	"Discuss the role of FSI's State of Forest Report in assessing India's forest cover. What are the trends in India's forest cover over the last decade?"
UPSC Civil	2018	10M	"Discuss the conservation significance of India's UNESCO Natural World Heritage Sites."
UPSC Civil	2017	10M	"What is Project Cheetah? Discuss the ecological rationale and challenges

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			of reintroducing cheetahs to India."
IFoS GS	2024	15M	"Discuss the Protected Area network of India with reference to National Parks, Wildlife Sanctuaries and Biosphere Reserves. What is the significance of the three-zone structure of a Biosphere Reserve?"
IFoS GS	2023	10M	"Examine the status of Project Tiger in India. What methodological improvements have been made in the All India Tiger Estimation from 2006 to 2022?"
IFoS GS	2022	10M	"Discuss the FSI State of Forest Report 2021 (SFR 2021) key findings. What are the limitations of forest cover as measured by FSI methodology?"
IFoS GS	2021	10M	"Critically evaluate India's elephant conservation framework under Project Elephant with particular reference to human-elephant conflict."

KEY NOTE

Frequency: Project Tiger + census data (Civil 2024); WG hotspot challenges (Civil 2023); Ramsar sites (Civil 2022); Great Indian Bustard + CR species (Civil 2021); Biosphere Reserves + 3-zone structure (Civil 2020); FSI SFR trends (Civil 2019); UNESCO WHS (Civil 2018); Project Cheetah (Civil 2017). IFoS: PA network + 3-zone structure (2024); Project Tiger methodology (2023); SFR limitations (2022); Project Elephant + HEC (2021). For 2025-26: Project Cheetah 2022-25 status (cubs + deaths + SC committee); GIB SC order 2024 modification; SPAI 722 snow leopards; FSI SFR 2023 headline figures; MISHTI mangrove initiative; Ken-Betwa + Panna TR controversy; NBSAP 2024 + Kunming-Montreal 30x30 are the highest-priority current-affairs hooks.

24.14 MODEL BOOK

How effective has Project Tiger been in conserving Bengal Tigers? Discuss with census data and critically evaluate the conservation challenges that remain.

UPSC Civil (Mains) | 15 Marks | 210 Words

Project Tiger, launched on 1 April 1973 by PM Indira Gandhi at Corbett NP (Uttarakhand), is India's most successful and internationally celebrated wildlife conservation programme. It has played a decisive role in reversing the dramatic 20th-century decline of the Bengal Tiger (*Panthera tigris tigris*).

ACHIEVEMENTS -- CENSUS DATA :

1973: Launch with ~1,827 tigers (the first census that alarmed the government). 9 original Tiger Reserves.

2006: First camera-trap census showed only ~1,411 tigers -- a shocking decline, revealing that pug-mark methods had massively overestimated. The Sariska scandal (2004-05: zero tigers despite census claims of 16) forced the methodological overhaul.

2014: 2,226 tigers -- recovery confirmed. Camera traps + occupancy modelling established as the gold standard.

2022 (released 2023): 3,682 tigers -- the highest count ever; +23.9% from 2018 (2,967). India has ~75% of the world's wild tigers. MP leads (785), followed by Karnataka (563) and Uttarakhand (560). India now has **58 Tiger Reserves** across 18 states.

Institutional framework: National Tiger Conservation Authority (NTCA, 2006), established under WPA Amendment 2006; camera-trap grid monitoring; TIGER CELL at WII (Wildlife Institute of India); Project Tiger's success linked to: (a) stringent protection of core zones; (b) community involvement in eco-development in buffer zones; (c) relocation of villages from critical habitat (with consent); (d) inter-state coordination (Critical Tiger Landscapes spanning multiple states).

REMAINING CHALLENGES:

1. **Human-Tiger Conflict:** Tiger populations now exceed carrying capacity in some TRs (e.g., Corbett, Ranthambore); tigers straying into human-dominated landscapes causes deaths on both sides.

2. **Habitat Fragmentation:** Many TRs are isolated islands -- tiger corridors linking them are degraded by roads, railways, settlements; animals killed in road and rail accidents.
3. **Ken-Betwa River Link:** SC-approved project will submerge 9,000+ ha of Panna TR core zone -- a conservation success story (local extinction + reintroduction) now threatened by infrastructure development.
4. **Climate Change:** Sundarbans tiger habitat losing land to sea-level rise at ~3-5 mm/year; Kaziranga's annual flooding is intensifying.

Project Tiger stands as one of the world's most successful conservation programmes -- from 1,411 (2006) to 3,682 (2022) in 16 years. However, sustainable success requires addressing habitat connectivity, human-wildlife conflict, and climate change threats beyond the boundaries of individual Tiger Reserves.

What are Biosphere Reserves? How do they differ from National Parks and Wildlife Sanctuaries? Discuss any three Indian BRs in detail.

IFOS Civil (Mains) | 15 Marks | 200 Words

Biosphere Reserves (BRs) are internationally designated areas that aim to reconcile biodiversity conservation with sustainable human development -- the key distinction from National Parks and Wildlife Sanctuaries. India has 18 BRs (12 in the UNESCO World Network of Biosphere Reserves/WNBR).

DIFFERENCES FROM NPS AND WLSS:

Three-Zone Structure: Core (undisturbed; usually a NP/WLS; strictly protected) + Buffer (surrounding core; research, eco-tourism, traditional practices) + Transition/Manipulation Zone (outermost ring; active human communities, sustainable livelihoods, conservation-compatible land use).

Case 1 -- Nilgiri BR (1986; UNESCO WNBR 2000): India's first and largest BR; covers parts of TN, Kerala and Karnataka; includes Bandipur, Nagarhole, Mudumalai WLSs and Wynad WLS; the Nilgiri Tahr (EN), Asian Elephant, Bengal Tiger, and Lion-tailed Macaque are flagship species. The Toda and Kurumba tribal communities live in the transition zone practising traditional land management. Nilgiri Biosphere Reserve is the nucleus of India's largest tiger landscape.

Case 2 -- Sunderban BR (1989; UNESCO WNBR 2001): Delta BR at the confluence of Ganga-Brahmaputra-Meghna; mangrove ecosystem; Bengal Tiger (only mangrove-adapted population; ~100 in Indian Sundarbans); Irrawaddy Dolphin; Estuarine Crocodile; dual UNESCO WHS and Ramsar site. Human dimension: 4 million people in transition zone dependent on fishing and honey collection (Mouli/honey-collectors). Climate change (sea-level rise ~3-5 mm/year) = critical threat; Sundri trees declining due to salinity increase.

Case 3 -- Panna BR (2011; UNESCO WNBR 2020): Most recent UNESCO WNBR designation from India. Conservation success story: tigers went locally extinct by 2009 due to poaching; reintroduced from Bandhavgarh and Kanha; now 80+ tigers. Ken river flows through Panna; critically threatened by Ken-Betwa River Interlinking Project (Daudhan Dam will submerge 9,000 ha of Panna TR core -- SC cleared in 2023 despite conservationist objections).

Biosphere Reserves represent the most sophisticated approach to in-situ conservation -- integrating strict protection with human livelihoods rather than treating them as opposites. India's 18 BRs cover ecosystems from cold deserts (Great Rann of Kachchh) to tropical rainforests (Nilgiri) to high Himalaya (Nanda Devi) and mangroves (Sundarbans), making them a vital component of India's biodiversity governance architecture.

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CHAPTER 25

TYPES OF SOILS

And Their Distribution In India

CHAPTER AT A GLANCE

- India has 8 major soil types: (1) Alluvial Soils (~43% area -- LARGEST; Indo-Gangetic Plains; Khadar vs Bhangar); (2) Black/Regur Soils (~16%; Deccan Trap basalt; montmorillonite clay; self-ploughing; cotton crop; Vertisols in USDA); (3) Red and Yellow Soils (~10.6%; crystalline rocks; iron oxides; Eastern/Southern Peninsular); (4) Laterite Soils (~8%; intense leaching; silica removed; sesquioxides remain; acidic; plantation crops); (5) Arid/Desert Soils (~6%; Rajasthan; sandy; alkaline); (6) Saline and Alkaline Soils (~7 million ha; Reh/Usar/Kallar; sodic/saline waterlogging); (7) Peaty/Marshy Soils (Kerala Kuttanad; Odisha-WB coasts; organic-rich; waterlogged); (8) Forest/Mountain Soils (Himalaya; WG; NE India; highly variable).
- Soil Formation (Jenny 1941): S = f(cl, o, r, p, t) where cl = climate, o = organisms, r = relief/topography, p = parent material, t = time. Climate is the dominant factor at macro-scale; parent material dominates at micro-scale. Soil profile horizons: O (litter), A (topsoil; leaching), B (illuviation; accumulation), C (parent material), R (bedrock). Soil texture: clay (<0.002 mm), silt (0.002-0.05 mm), sand (0.05-2 mm); Loam = ideal mix.
- Alluvial soils: Khadar (newer alluvium -- lighter, more fertile, low-lying, floods annually, fine-textured, higher N) vs Bhangar (older alluvium -- darker, higher elevation, lime nodules "kankar," coarser, less fertile than khadar but more so than arid). Crops: wheat, paddy, sugarcane, pulses, oilseeds. States: UP, Bihar, WB, Punjab, Haryana, Rajasthan (eastern), coastal states.
- Black Soil (Regur): Maharashtra, MP, Gujarat, AP, Telangana, Karnataka. Deccan Trap basalt parent material. Montmorillonite (2:1 layer) clay -- absorbs water and SWELLS; dries and CRACKS (self-ploughing). pH 7.5-8.5. Rich in Ca, Mg, Fe, Al; DEFICIENT in N, P, organic matter. "Regur" from Telugu "Regada." Primary crop: cotton. Also soybean, wheat, sorghum. USDA = Vertisols.
- Red and Yellow Soils: Red from hematite/goethite (iron oxide under oxidising, well-drained conditions); Yellow from limonite (hydrated iron oxide under poor drainage/waterlogging). Low fertility, porous, friable. Tamil Nadu, Goa, Odisha, Jharkhand, Chhattisgarh, SE Karnataka, parts of AP. Parent: weathered crystalline/metamorphic Archaean rocks. USDA = Alfisols (red) or Ultisols (more leached varieties).
- Laterite Soils: from Latin "later" = brick. Intense laterisation in >200 cm rainfall areas: SiO_2 leached out; Fe_2O_3 and Al_2O_3 (sesquioxides) accumulate; deep red/brick red. Acidic (pH 4.5-6.0). Deficient in N, P, K, Ca, Mg, organic matter. Used as building material (red laterite bricks). Plantation crops: tea, coffee, rubber, cashew, coconut. WG, Eastern Ghats, Odisha, Jharkhand, Assam, NE India, Kerala highlands. USDA = Ultisols or Oxisols.
- Soil Degradation: India has ~120 million ha (12 crore ha) under various forms of degradation (NBSS&LUP/ICAR). Annual topsoil loss ~5,334 million tonnes (ICAR). Types: water erosion (~74% of degraded area = ~89 Mha), wind erosion (~12% = ~14 Mha), waterlogging (~5% = ~6 Mha), salinity/alkalinity (~6% = ~7 Mha), other. Chambal ravines (UP-MP-RJ) = ~4 lakh ha gully-eroded; Yamuna ravines also significant.
- Soil Health Card (SHC) Scheme: launched February 19, 2015 by PM Modi from Suratgarh, Rajasthan. Tests 12 parameters: pH, EC, OC, N, P, K + 6 micronutrients (S, Zn, B, Fe, Mn, Cu). Coverage target: all 14 crore+ farm holdings across India every 3 years. PM-PRANAM (2023): incentivises states to reduce chemical fertiliser subsidies and shift to organic/natural farming. National Mission on Natural Farming (NMNF, 2024): Rs.2,481 crore; target 7.5 million ha under natural farming. PKVY (Paramparagat Krishi Vikas Yojana): organic farming cluster programme.

25.1 LIVING LAYER OF THE EARTH'S SURFACE -- a complex mixture of weathered mineral particles, organic matter (humus), air, water, and living organisms -- that supports almost all terrestrial life. The NRCS (Natural

Resources Conservation Service, USA) and FAO define soil as **"the unconsolidated mineral or organic matter on the surface of the earth that has been subjected to and shows effects of genetic and environmental factors of: parent material, climate (including moisture and temperature effects), macro- and microorganisms, and topography, all acting over a period of time."**

India's soil diversity is extraordinary -- a product of the country's vast geographic extent, diverse parent rock types, wide range of climatic conditions, varying vegetation cover, and differing ages of geological formations. India contains representatives of almost all major soil orders of the world, ranging from young alluvial deposits of the Himalayan river systems to ancient lateritic soils of the Peninsula, from swelling montmorillonite clays of the Deccan to sandy desert soils of the Thar, and from organic-rich peaty soils of the Kerala coast to shallow rocky mountain soils of the Himalaya.

SOIL FORMATION -- JENNY'S PEDOGENIC EQUATION

The scientific study of soil formation (**pedogenesis**) was systematised by Hans Jenny (1941) who proposed the **clorpt equation:**

$$S = f(cl, o, r, p, t)$$

where **S** = soil; **cl** = climate (temperature and moisture); **o** = organisms (vegetation, microorganisms, fauna); **r** = relief/topography; **p** = parent material (parent rock); **t** = time. These five factors interact to produce the wide variety of soil types observed across India.

Pedogenic Factor	*Role in Soil Formation*	*Indian Example*
Climate (cl) -- MOST IMPORTANT at macro-scale	Temperature drives weathering rates (chemical reactions double per 10 deg C rise); moisture drives leaching, eluviation, biological activity; rainfall:evaporation ratio determines whether soils are leached (humid) or saline (arid)	High rainfall (WG, NE India) = intense leaching = laterite soils; low rainfall (Rajasthan) = accumulation of salts = arid/saline soils; tropical climate = rapid organic matter decomposition = low humus despite high biomass
Parent Material (p) -- Most important at micro/local scale	Determines mineral composition; rock type controls texture, chemistry, nutrient content; influences rate of weathering	Basalt (Deccan Trap) = montmorillonite clay = Black soil; Crystalline gneiss/schist (Peninsular shield) = Red and Yellow soil; Himalayan river sediment = Alluvial soil; Limestone = rendzina type soils
Organisms (o)	Vegetation provides organic matter (humus); roots break up rock; microorganisms decompose organic matter; earthworms, ants, termites mix soil layers; legumes fix atmospheric nitrogen	Dense tropical forest = rapid cycling but low net humus accumulation (hot climate decomposes litter fast); Himalayan oak-rhododendron = moderate humus; grasslands = highest humus accumulation (Mollisols)
Relief/Topography (r)	Controls drainage, microclimate, erosion; steep slopes = thin soils, rapid runoff, erosion; flat areas = waterlogging or deep soil development; north-facing vs south-facing aspect determines moisture/temperature	Steep Himalayan slopes = shallow mountain soils subject to mass movement; Deccan plateau flat surface = deep black soil development; valley bottoms = alluvial deposits and waterlogging
Time (t)	Older soils are more developed, deeper, and more differentiated; young soils	Young alluvial soils (khadar) = little profile development; ancient laterite soils of

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	(Entisols) have no horizon differentiation; mature soils show well-developed A, B, C horizons	peninsular India = extremely mature, deeply weathered; black soils of Deccan = intermediate age

SOIL PROFILE -- HORIZON SEQUENCE

Horizon	Name	Composition	Indian Context
O	Organic Horizon (Litter)	Accumulated organic matter -- fresh litter, partially decomposed leaves, twigs, moss; above mineral soil	Well-developed in moist forest soils (WG evergreen, Himalayan forests, NE India); absent or thin in arid soils (Thar Desert)
A	Topsoil / Eluviation Horizon	Mixture of mineral and organic matter; humus gives dark colour; zone of maximum biological activity; LEACHING removes fine clay, soluble salts, Fe/Al downward; the "A horizon" is what farmers call "topsoil"	Thickest and darkest in alluvial and black soils; thin and less humus-rich in laterite and arid soils; the most agriculturally critical horizon
B	Subsoil / Illuviation Horizon	Receives material leached from A horizon; accumulates clay, iron oxides, carbonates, sesquioxides depending on soil type; lighter colour than A but denser	In laterite soils: sesquioxides (Fe2O3, Al2O3) accumulate heavily; in black soils: clay accumulates; in arid soils: calcium carbonate (kankar) precipitates at 30-100 cm depth
C	Parent Material (Saprolite)	Partially weathered parent rock; shows characteristics of original geology; limited biological activity	Basalt fragments in black soil profile; weathered granite/gneiss in red/yellow soils; fluvial sediment layers in alluvial soils
R	Bedrock	Unweathered parent rock; cannot be excavated with a spade	Deccan Trap basalt at depth under black soils; granite/gneiss under peninsular red soils; Himalayan rocks under mountain soils

OVERVIEW OF INDIAN SOIL TYPES -- COMPARATIVE TABLE

Soil Type	Area (approx.)	% of India	USDA Taxonomy	Primary Distribution	Primary Crops
Alluvial Soils	~15 lakh sq km	~43-45%	Entisols (young), Inceptisols (slightly developed), some Mollisols	Indo-Gangetic-Brahmaputra Plains; coastal plains; river deltas	Wheat, paddy, sugarcane, maize, pulses, oilseeds
Black / Regur Soils	~5 lakh sq km	~15-16%	Vertisols	Maharashtra, MP, Gujarat, AP, Telangana, Karnataka	Cotton (primary), soybean, sorghum, wheat, groundnut
Red and Yellow Soils	~3.5 lakh sq km	~10-11%	Alfisols, Ultisols	Eastern and southern peninsular India; Tamil Nadu, Goa, Odisha, Jharkhand, Chhattisgarh	Millet, groundnut, tobacco, ragi, pulses
Laterite Soils	~2.5 lakh sq km	~7-8%	Ultisols, Oxisols	Western Ghats, Eastern Ghats,	Tea, coffee, rubber, cashew, coconut

				Odisha, Jharkhand, NE India, Kerala highlands	
Arid/Desert Soils	~1.5 lakh sq km	~4-5%	Aridisols	Western Rajasthan, Gujarat (Kachchh), semi-arid Haryana-Punjab	Bajra, jowar, moth bean, guar (irrigation-dependent)
Saline and Alkaline Soils	~7 million ha (0.7 lakh sq km)	~2%	Aridisols (salic), Vertisols (sodic)	Rajasthan, Haryana, UP, Punjab, coastal Gujarat and Maharashtra	Mostly uncultivated; some salt-tolerant crops after reclamation
Peaty/Marshy Soils	<0.5 lakh sq km	<1%	Histosols	Kerala coast (Kuttanad), Odisha-WB coasts, Himalayan valley floors	Rice (Kuttanad below-sea-level farming), jute
Forest/Mountain Soils	~3 lakh sq km	~8-9%	Entisols, Inceptisols, some Alfisols	Himalayan ranges, WG, Eastern Ghats, NE India	Tea (Darjeeling), apples, potatoes, temperate fruits

25.2 TYPE 1 -- ALLUVIAL SOILS (MOST IMPORTANT; ~43% OF INDIA'S AREA)

Alluvial soils are the **most extensive soil type in India**, covering approximately **15 lakh sq km (~43-45% of the total geographic area)**. They are the most agriculturally productive and economically important soils in India, supporting the dense agricultural populations of the Indo-Gangetic Plain and feeding the bulk of India's population. They are formed by the deposition of **sediment carried by India's major rivers** -- primarily the Himalayan river systems (Ganga, Yamuna, Sutlej, Beas, Ravi, Chenab, Jhelum, Indus, Brahmaputra and their tributaries) and also peninsular rivers in their delta regions and lower reaches.

FORMATION AND PARENT MATERIAL

Alluvial soils are **transported soils** -- formed not from in-situ weathering of underlying rock but from sediment deposited by rivers as they slow down and drop their load. The Himalayan rivers, carrying enormous quantities of finely-ground rock debris eroded from the young, rapidly-rising Himalayan mountains, deposit this material progressively across the vast, flat Indo-Gangetic Plain as the rivers lose velocity. The material ranges from coarse gravel and sand near the mountain foothills to fine silt and clay in the lower reaches and deltas.

KHADAR VS BHANGAR -- THE CRITICAL DISTINCTION

Feature	*Khadar (Newer Alluvium)*	*Bhangar (Older Alluvium)*
Age	Recently deposited; geologically young; Holocene (post-glacial, <10,000 years)	Older deposits; Pleistocene to early Holocene (10,000-100,000+ years)
Position in landscape	LOW-LYING: floodplains, riverbanks, active meanders; regularly flooded by rivers	HIGH GROUND: terraces and interfluvial areas above the flood level; NOT flooded annually
Colour	Lighter coloured (grey, light brown, yellowish); less weathered	Darker coloured (brown, dark grey); more weathered and oxidised
Texture	FINER: more silt and clay; better water retention; very fertile	Coarser: more sand; less water retention; less fertile than khadar
Lime nodules	FEW or absent	KANKAR (calcium carbonate nodules/concretions) common at 60-120 cm

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		depth; indicates age and drier conditions during formation
Fertility	MORE FERTILE: higher nitrogen, organic matter, nutrient content; receives fresh nutrients every flood	LESS FERTILE than khadar (but still more fertile than most other soil types)
Agricultural practice	Flooded annually -- suited for paddy cultivation; HIGH RISK of flood damage but HIGH FERTILITY	Better suited for crops that cannot tolerate waterlogging: wheat, pulses, mustard; more stable
Distribution examples	Active Ganga floodplain (particularly in Bihar, eastern UP, WB, assam), river deltas (Ganga-Brahmaputra, Mahanadi, Godavari, Krishna, Cauvery deltas)	Bhabar-Terai belt (at Himalayan foothills), terraced areas of Punjab-Haryana IGP, older parts of Rajasthan plains

KEY NOTE

Prelims Mnemonic -- Khadar vs Bhangar: "Khadar = Khaali (empty of kankar); Bhangar = Bhari hui (filled with kankar)." Also: K for Khadar = K for Kachchi (raw/new/young, lighter) and B for Bhangar = B for Bujurg (older, darker, kankar-bearing). Khadar is LOWER (near river), Bhangar is HIGHER (terraces). Khadar is MORE FERTILE despite being newer because it receives annual sediment refresh from river flooding.

CHEMICAL PROPERTIES AND CROP ASSOCIATION

Chemical Property	*Alluvial Soil Status*	*Agricultural Implication*
pH	6.5-8.0 (slightly acidic to slightly alkaline depending on age and depth; khadar slightly lower pH; bhangar slightly higher due to kankar)	Most crops grow optimally at pH 6-7; the range suits wheat, paddy, sugarcane, maize, pulses
Nitrogen (N) content	DEFICIENT: organic matter content typically 0.3-0.8%; hot climate rapidly decomposes organic matter; N lost through leaching	The most critical nutrient deficiency in Indian alluvial soils; requires heavy N-fertiliser application (urea, DAP); foundation of India's green revolution was N+HYV combination
Phosphorus (P) content	MODERATE to DEFICIENT; total P reasonable but available P low due to P-fixation	DAP (di-ammonium phosphate) application common; SSP (single superphosphate) in coastal alluvial
Potassium (K) content	ADEQUATE to HIGH; alluvial soils generally potassium-rich from feldspar weathering	Less K-fertiliser needed compared to other soils; exception: long-term intensive paddy soils in Punjab/WB which have K depletion
Calcium and Magnesium	ADEQUATE; lime ($CaCO_3$) and Mg minerals present; kankar zones add Ca	Generally no liming needed; pH maintained near neutral naturally
Organic Carbon (OC)	GENERALLY LOW (0.3-0.8%); hot climate decomposes organic matter rapidly; continuous cultivation removes organic matter	Requires organic matter addition (FYM, green manure, crop residue incorporation); zero-tillage increasingly adopted to preserve OC
Micronutrients	ZINC deficiency increasingly widespread (especially in paddy-wheat rotation of Punjab, Haryana, UP and Bihar -- estimated 40-50% of IGP soils); IRON deficiency in some coastal alluvial	$ZnSO_4$ application mandatory in paddy-wheat belts; addressing micronutrient deficiencies = Soil Health Card scheme mandate

DISTRIBUTION AND STATES

Region	*States*	*Character*
Northern Plains (IGP)	Uttarakhand (Terai), Uttar Pradesh, Bihar, West Bengal (plains), Punjab, Haryana, Rajasthan (east), Himachal Pradesh (foothills)	The core alluvial zone; formed by Himalayan river deposits; densest agricultural population in India; wheat-paddy double cropping system
Brahmaputra Plains	Assam, Arunachal Pradesh (foothills)	High-quality alluvial soils from Brahmaputra and its tributaries; rice-dominant; annual flood-deposit renewal; "char" lands on river islands
Coastal Plains	Odisha coast, Andhra Pradesh coast (Krishna-Godavari delta), Tamil Nadu (Cauvery delta), Kerala (narrow coastal plain), Maharashtra (Konkan coastal alluvial)	Younger alluvial/deltaic deposits mixed with marine sediments; paddy dominant; river deltas (Cauvery, Krishna, Godavari, Mahanadi) = most productive rice lands in peninsular India
River Valleys (peninsular)	Along Godavari, Krishna, Kaveri, Mahanadi, Tapti, Narmada valleys (in their valley floors)	Narrow strips of alluvial soil within the otherwise rocky peninsular terrain; highly fertile; intensively cultivated

25.3 TYPE 2 -- BLACK SOILS / REGUR SOILS / VERTISOLS (~16% OF INDIA)

Black soils -- known as **"Regur"** (from Telugu *"Regada,"* meaning "moist clay"), **"Cotton soil"** (because cotton is the primary crop), **"Black cotton soil,"** or scientifically as **"Vertisols"** (USDA) / "Grumusols" (older terminology) -- are one of India's most distinctive and agriculturally significant soil types. Covering approximately **5 lakh sq km (~15-16% of India's area),** they are concentrated in the **Deccan Plateau** region, predominantly in Maharashtra, Madhya Pradesh, Gujarat, Andhra Pradesh, Telangana and Karnataka.

PARENT MATERIAL -- DECCAN TRAP BASALT

Black soils owe their existence to one of the most extensive volcanic events in Earth's history -- the **Deccan Trap lava flows** of the Late Cretaceous to Early Eocene period (~65-66 million years ago, coinciding approximately with the end-Cretaceous mass extinction event). These massive basaltic lava flows covered approximately **5 lakh sq km** of the peninsula to depths of 2,000-3,000 metres. The **chemical weathering of this basalt** -- which is rich in ferromagnesian minerals (pyroxene, plagioclase feldspar, olivine) -- under the semi-arid climate with alternating wet and dry seasons produces the characteristic montmorillonite clay that gives black soils their distinctive properties.

PHYSICAL AND CHEMICAL PROPERTIES

Property	*Detail*	*Agricultural Significance*
Colour	Deep black to dark grey; the colour comes from titaniferous magnetite (iron-titanium oxide) -- NOT primarily from organic matter despite the colour similarity; some organic matter contribution	The dark colour absorbs solar heat; warms up faster in winter (advantage for winter crop germination in Madhya Pradesh)
Clay mineral type	MONTMORILLONITE (2:1 layer silicate clay): unique property of expanding when wet and contracting when dry; clay particles have a large surface area and HIGH CATION EXCHANGE CAPACITY (CEC); can hold 40-60% of their own weight in water	The single most important physical characteristic; responsible for the self-ploughing property and all the difficulties of tillage
SWELLING	Absorbs water --> swells (volume increase up to 30-	Self-ploughing means the soil

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AND CRACKING	40%); becomes sticky and plastic when wet (IMPRACTICAL TO TILL: "black cotton soil delay" in farming operations); loses water --> contracts --> FORMS DEEP WIDE CRACKS (5-10 cm wide, 30-100 cm deep); material from upper horizon falls into cracks during dry season = churning/mixing = "self-ploughing"	regularly mixes itself without mechanical tillage; SAVES TILLAGE COST; BUT the wet-season stickiness limits the sowing window; cracks are a problem for seedling establishment if irrigation is not timed well
Water retention	HIGH water holding capacity due to montmorillonite clay; soil retains moisture in subsoil long after surface appears dry -- often yields crops on RESIDUAL MOISTURE without irrigation after a good monsoon	Black soil areas in Vidarbha and Marathwada often grow cotton and sorghum on residual moisture without irrigation; the soil acts as a reservoir; this is why black cotton soil is called "self-regulating"
pH	7.5-8.5 (neutral to slightly alkaline); becomes more alkaline in drier areas (eastern Vidarbha, Marathwada, parts of MP)	pH in the neutral-slightly alkaline range is suitable for most crops; does not need liming (unlike laterite soils)
Nitrogen	DEFICIENT: despite the large clay surface area (which suggests high nutrient retention), organic matter content is only 0.5-1.2%; biological decomposition is rapid; organic matter turnover is high	Needs N-fertiliser; but because the CEC is high, N applied as ammonium is held more firmly than in sandy or laterite soils and leaches less
Phosphorus	DEFICIENT: P-fixation by iron and calcium in the alkaline pH; available P is low despite reasonable total P	DAP application needed; lime-induced P-fixation is a limiting factor
Calcium and Magnesium	HIGH: the basaltic parent material is rich in Ca and Mg; these are the dominant exchangeable cations	No Ca or Mg deficiency; in fact, Ca and Mg excess in some areas can cause micronutrient imbalances
Iron and Aluminium	MODERATE to HIGH; from basalt weathering; iron gives the dark colour	Not a deficiency concern; in fact iron can precipitate phosphates (P-fixation) at high pH
Potassium	ADEQUATE to HIGH: basalt is K-bearing	Good K status; less K-fertiliser needed

DISTRIBUTION AND CROPS

State/Region	*Specific Areas*	*Primary Crops*
Maharashtra	Vidarbha, Marathwada, Nashik, Ahmednagar, Solapur, western Maharashtra interior	Cotton (Bt-cotton dominant), soybean, sorghum (jowar), wheat, chickpea (gram), onion; Vidarbha = "cotton country" of India; Marathwada = drought-prone black soil belt
Madhya Pradesh	Malwa Plateau (Indore, Dewas, Ujjain, Shajapur, Ratlam, Mandsaur), Nimar Valley (Khargone, Barwani), parts of Bundelkhand transition	Soybean (largest soybean producing state), wheat, cotton, gram; Malwa = "Soya Pradesh" of India; black soil + adequate rainfall = soya belt
Gujarat	Eastern and central Gujarat (Vadodara, Bharuch, Surat	Cotton, groundnut, wheat, castor; Gujarat = largest cotton producer state in India; Bt-cotton

	interior, Anand, Kheda), some Saurashtra areas	revolution here
Andhra Pradesh	Krishna-Guntur region, Kurnool, parts of coastal AP delta areas mixed with alluvial	Cotton, chillies (AP leads chilli production), tobacco, groundnut; Krishna delta cotton belt
Telangana	Nalgonda, Mahabubnagar, Adilabad, Karimnagar districts	Cotton, sorghum, maize; Telangana has classic black soil cotton belt
Karnataka	Dharwad, Gadag, Koppal, Bellary (Ballari), Raichur, Bijapur (Vijayapura)	Cotton, sorghum, groundnut, sunflower; northern Karnataka = cotton-growing zone
Rajasthan	Small patches in southern Rajasthan (Kota-Bundi belt -- transition zone)	Wheat, sorghum; not the primary black soil belt but an eastern extension

IFOS FOCUS

IFoS -- Vertisol Ecology and Forest Type:
Vertisols (Black Soils) in the natural (pre-agricultural) landscape supported **Tropical Dry Deciduous forests** (Champion and Seth Group 5) and **Tropical Thorn Forests** (Group 6) -- not the dense wet forests of the WG. The clay-rich, self-ploughing nature of the soil, combined with the semi-arid climate and pronounced dry season, favoured species that can exploit the high water-holding capacity while tolerating the desiccation stress of cracking soils. Characteristic tree species on black soils include *Tectona grandis* (Teak -- in moister patches), *Terminalia tomentosa* (saj), *Boswellia serrata* (Indian frankincense, which actually cracks the soil as its roots swell when it takes up water), *Hardwickia binata* (anjan), and *Butea monosperma* (flame of the forest). The natural Vertisol vegetation was largely converted to agriculture because the deep, cracking soils, despite their management challenges, are inherently fertile.

25.4 TYPE 3 -- RED AND YELLOW SOILS (~10-11% OF INDIA)

Red and Yellow soils cover approximately **3.5 lakh sq km (~10-11% of India)** across the eastern and southern peninsular India, over ancient crystalline and metamorphic basement rocks of the Archaean shield (the oldest part of the Indian landmass). They represent the **in-situ weathering products of ancient igneous and metamorphic rocks** (gneisses, schists, granites) under tropical to subtropical climate conditions.

THE RED-YELLOW COLOUR DISTINCTION

The colour of these soils is determined by the state of iron oxides:

- **RED:** Formed in **well-drained, aerobic (oxidising) conditions**. Iron is present as *hematite* (Fe_2O_3) or *goethite* ($FeOOH$) -- both give a reddish colour. The iron is in the ferric (Fe3+) state = oxidised. These soils are common on uplands, terraces, and well-drained slopes.
- **YELLOW:** Formed in **poorly-drained, anaerobic (reducing) conditions** -- seasonally waterlogged valley bottoms or low-lying areas. Iron is present as *limo*
- *nite* ($Fe_2O_3.nH_2O$) -- a hydrated ferric oxide -- which gives a yellow colour. The yellow soils are LOWER in the landscape, near rivers and low depressions, where waterlogging occurs seasonally.

PROPERTIES AND DISTRIBUTION

Property	*Detail*
Parent material	Weathered crystalline/metamorphic Archaean rocks: granite, gneiss, schist, quartzite; the Peninsular shield (Deccan Plateau, Eastern Ghats, parts of S India) = ancient Archaean basement
Texture	Sandy to sandy-loam; porous and friable (crumbly); low clay content (except where

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	significant weathering has occurred over very long periods)
Fertility	POOR: deficient in N, P, humus, and often Ca, Mg; generally low productivity without external inputs
pH	Slightly acidic to neutral (6.0-7.5) in drier areas; more acidic in higher-rainfall areas as leaching increases
Water retention	LOW: coarse texture means poor water-holding capacity; crops suffer during dry spells; irrigation significantly improves productivity
Distribution	Tamil Nadu (interior; most of TN's agricultural hinterland outside the Cauvery delta is on red soil), Goa, Odisha (central and eastern), Jharkhand, Chhattisgarh (northern, before it transitions to black soil), parts of AP (Seema areas), southeastern Karnataka, southeastern Rajasthan (east of the Aravallis)
Crops	Millet (bajra, jowar, ragi -- ragi especially on red soils of Karnataka, Andhra, TN), groundnut, tobacco, cotton (in less deficient patches), vegetables; low-value dry-land crops unless irrigated

25.5 TYPE 4 -- LATERITE SOILS (~8% OF INDIA)

Laterite soils are among the most intensely weathered soils on Earth -- the product of **extreme chemical leaching in high-rainfall, high-temperature tropical environments** over millions of years. The term "laterite" was coined by **Dr. Francis Buchanan** (a Scottish physician and botanist) in **1807** while studying soils near Angadipuram in Kerala, from the Latin word *"later"* meaning "brick" -- reflecting the material's property of hardening when exposed to air and sun and its traditional use as a building material (soft when cut but hardens on exposure; widely used in South Indian temples, old Portuguese buildings in Goa, and traditional Kerala houses).

LATERISATION -- THE FORMATION PROCESS

In regions with very high rainfall (>200 cm annual, well-distributed), high temperatures, and good drainage, intense leaching removes **soluble silica (SiO_2)** from the soil profile. What remains -- and concentrates by residual accumulation -- are the **relatively insoluble sesquioxides:**

- **Iron sesquioxide (Fe_2O_3):** gives the characteristic deep red to brick-red colour; forms iron-rich hardpan (laterite crust) near the surface.
- **Aluminium sesquioxide (Al_2O_3):** accumulates as gibbsite and other aluminium hydroxide minerals; forms bauxite deposits in deeply laterised profiles.

The resulting soil is **deeply weathered, brick-red, and structurally hardened** near the surface (the hardpan can be literally quarried as building bricks). Beneath the hardpan, the soil may be softer and more friable. The process of laterisation is **irreversible** -- once the silica is leached and the sesquioxides have hardened into laterite, the soil cannot be reverted to a more fertile state by simply adding nutrients; the physical structure impedes root penetration and water infiltration.

PROPERTIES, DISTRIBUTION AND AGRICULTURAL USE

Property/Feature	*Detail*
Colour	Deep red to brick-red (iron-rich); sometimes yellowish or mottled with white (bauxite patches)
pH	HIGHLY ACIDIC: 4.5-6.0; the intense leaching removes Ca, Mg and other basic cations; H^+ and Al^{3+} dominate the exchange sites -- aluminium toxicity at pH <5.0 is a serious agricultural challenge
Nutrient status	VERY POOR in all major nutrients: N, P (P strongly fixed by iron and aluminium at low pH), K, Ca, Mg; also low in organic matter (hot, moist climate rapidly decomposes litter

	despite large biomass inputs)
Water retention	Moderate to poor; the laterite hardpan can IMPEDE DRAINAGE AND ROOT PENETRATION; in some laterite areas, the hardpan creates perched water tables (waterlogging above the hardpan despite good surface drainage)
Crops adapted	Plantation crops: TEA (Darjeeling, Assam, Nilgiris, WG), COFFEE (Coorg/Kodagu, Chikmagalur, Wayanad), RUBBER (Kerala), CASHEW (Goa, Kerala, AP, MH), COCONUT (Kerala, Karnataka, Goa). These are ALL acid-tolerant plantation species that can exploit tropical laterite soils efficiently. RICE (paddy) also grown in many laterite areas (Tamil Nadu Kongu Nadu, Karnataka coastal, Kerala). Local varieties adapted to the acid-low fertility conditions.
Distribution	Western Ghats (western Karnataka, Goa, coastal Maharashtra -- "Konkan laterite"); Kerala highlands; Eastern Ghats (Odisha, Jharkhand, Chhattisgarh plateau); NE India (Meghalaya, Assam plateau); Tamil Nadu (western Tamil Nadu on WG eastern slopes); some patches in AP and Chhattisgarh
Building material use	Traditional building material in Kerala, Karnataka, Goa, and parts of TN; soft when quarried (can be cut with a spade when moist); hardens rapidly on exposure to air and sun (dehydration of iron hydroxides to iron oxides = hardening); does not require kilning (unlike clay bricks); many 500+ year old temples and Portuguese forts in Goa are built of laterite
USDA Classification	Ultisols (if significant clay translocation to B horizon remains) or Oxisols (if extremely deeply weathered with no recognisable B horizon differentiation); India's laterites are mostly Ultisols

25.6 TYPE 5 -- ARID AND DESERT SOILS (~5% OF INDIA)

Arid and desert soils cover approximately **1.5 lakh sq km (~4-5% of India)**, concentrated in **western Rajasthan, Gujarat (Kachchh/Rann), and semi-arid fringes of Haryana and Punjab.** They are formed under conditions of very low rainfall (<250 mm), high evapotranspiration, and intense solar radiation -- conditions that profoundly limit the accumulation of organic matter and the leaching of soluble salts.

Property	*Arid / Desert Soil Detail*
Colour	Light brown to reddish-brown; pale; low organic matter content gives light colour; aeolian (wind-blown) quartz sand dominates
Texture	Sandy to sandy-loam; very coarse; loose; easily moved by wind; poor aggregation; low clay content
pH	Alkaline: 8.0-9.5 (sometimes higher in saline patches); high pH because leaching is minimal and Ca, Mg, Na accumulate
Calcium Carbonate (Kankar)	Calcium carbonate often precipitates NEAR THE SURFACE or within the upper 30-60 cm (unlike in humid soils where it occurs deeper); forms "kankar" layer (hard calcium carbonate nodules or continuous hardpan) that impedes water percolation and root penetration
Organic matter	VERY LOW (<0.5%); sparse vegetation in desert provides little litter; rapid decomposition under high temperature; desert soil organic matter is the lowest of all Indian soil types
Nitrogen	VERY LOW (consequence of very low organic matter)
Phosphorus	ADEQUATE or even high in total content; but usable P may be limited by high pH (P-fixation by Ca at high pH)

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Soluble salts	HIGH in some areas; surface efflorescence (salt crystallisation) of NaCl, Na2SO4, CaSO4 visible in dry season; transition to saline soils in some patches
USDA Classification	Aridisols (the dominant order for arid zone soils globally); characterised by an "aridic soil moisture regime" (dry for more than half of cumulative days per year)
Crops (without irrigation)	Bajra (pearl millet), jowar, moth bean (Vigna aconitifolia), guar (cluster bean), sesame (til); these are true dryland/drought-tolerant crops. With CANAL IRRIGATION (Indira Gandhi Canal, Rajasthan): wheat, mustard, cotton can be grown in parts of western Rajasthan
Reclamation	Wind breaks and shelter belts (Prosopis cineraria, Acacia tortilis) reduce wind erosion; irrigation (where feasible) leaches salts; afforestation with sand-dune binding species (Calligonum, Cenchrus biflorus)

25.7 TYPE 6 -- SALINE AND ALKALINE SOILS

Saline and alkaline soils -- also called **problem soils or salt-affected soils** -- are not a natural geological formation like alluvial or black soils, but **degraded soils arising from natural or human-induced salt accumulation**. They cover an estimated **~7 million hectares** in India (approximately 0.7 lakh sq km; ~2% of geographic area), distributed across parts of Rajasthan, Haryana, Punjab, UP, Gujarat, Maharashtra, and coastal areas.

SALINE VS ALKALINE SOILS -- THE KEY DISTINCTION

Feature	*Saline Soils (White Alkali / Reh / Kallar)*	*Alkaline Soils (Black Alkali / Usar / Sodic)*
Dominant salts	Neutral salts: NaCl, Na2SO4, MgCl2, CaSO4 -- CHLORIDE and SULPHATE dominated	Na2CO3, NaHCO3 -- CARBONATE and BICARBONATE dominated (the most damaging)
pH	7.0-8.5 (neutral to slightly alkaline)	8.5-10.5 (strongly alkaline; can exceed pH 10 in extreme cases)
Electrical Conductivity (EC)	EC > 4 dS/m (the diagnostic threshold for saline soil -- USDA definition)	EC may be low (<4 dS/m) despite severe sodicity
Sodium Adsorption Ratio (SAR)	SAR < 13 (Na not dominant on exchange sites)	SAR > 13 (sodium saturates the cation exchange complex; Na+ displaces Ca2+ and Mg2+ from exchange sites)
Soil structure	Aggregates maintained (Ca and Mg on exchange sites preserve structure); permeable	DESTROYS SOIL STRUCTURE: Na+ on clay surface causes clay dispersion (deflocculation); soil becomes impermeable, dense, structureless; "slick" when wet, forms a hard crust when dry
Surface appearance	White salt crust visible in dry season ("reh" appearance: white powder on surface)	Dark-coloured surface (organic matter dispersed by Na causes dark staining even at low OM); "black alkali" appearance; surface crust hard and impermeable
Local names	REH (UP, Punjab, Haryana), KALLAR (Punjab), CHOPAN (Rajasthan, Gujarat)	USAR (UP, Bihar), KANA/KANALI (coastal)
Reclamation	Leaching with fresh water (to remove soluble salts downward); adequate drainage essential; gypsum (CaSO4) NOT needed if Ca/Mg already on exchange sites	GYPSUM (CaSO4.2H2O) application: replaces Na+ on exchange sites with Ca2+; Na2SO4 leaches freely; then drain leachate away; pyrite (FeS2) oxidation also lowers pH; biological reclamation with Karnal grass (Leptochloa fusca), dhaincha (Sesbania bispinosa)

Causes of secondary salinisation: (1) Irrigation without adequate drainage -- water table rises, bringing salts to surface by capillary action ("waterlogging-induced salinity"); (2) Use of poor-quality irrigation water (saline groundwater, brackish water); (3) Coastal inundation by seawater (especially from cyclone storm surges); (4) Natural geological evaporite deposits near surface (Rajasthan, Gujarat). The **Central Soil Salinity Research Institute (CSSRI), Karnal, Haryana** is the premier institution for saline/alkaline soil research and reclamation technology in India.

25.8 TYPE 7 -- PEATY AND MARSHY SOILS

Peaty soils are formed in permanently or seasonally waterlogged environments where the decomposition of organic matter is impeded by anaerobic conditions -- resulting in an **accumulation of organic matter (peat)** to depths of several metres. They cover a very small fraction of India's area (<1%) but are ecologically and culturally important.

Feature	*Peaty / Marshy Soil Detail*
Organic matter content	Very high: 40-90% organic matter (the diagnostic criterion for Histosols, USDA = saturated soils with >20-30% organic matter); dark black to very dark brown colour
pH	Acidic: 4.0-6.5; organic acids from partial decomposition of plant material lower pH; in coastal peats, sulfide oxidation when drained can produce extremely acidic "acid sulphate soils" (potential pH <3.5)
Key location: Kuttanad, Kerala	The "Rice Bowl of Kerala"; globally famous as the ONLY place in India where agriculture is practised BELOW SEA LEVEL (some fields 0.5-2.5 m below mean sea level); this is a UNESCO Globally Important Agricultural Heritage System (GIAHS). Coastal paddy dyked fields (polders) reclaimed from the backwaters of Kerala; a unique cultural landscape; severely threatened by sea-level rise, salinity intrusion and flash flooding
Other locations	Odisha and West Bengal coastal areas (waterlogged deltaic marshes); Sundarban mangrove soils (organic-rich tidal soils); Himalayan valley floors (Terai wetlands, Loktak Lake area in Manipur); Kaziranga flood plains (seasonally waterlogged organic soils)
Agricultural use	Paddy (primary crop in Kuttanad); jute (in WB-Odisha marshy soils); water chestnut, lotus and other aquatic crops in some areas; generally not suitable for dryland crops due to waterlogging
Conservation concern	Peat soils are MAJOR CARBON STORES; draining them releases carbon stored over thousands of years; Kuttanad peat soils are vulnerable to salinisation from sea-level rise -- a major climate adaptation challenge

25.9 TYPE 8 -- FOREST AND MOUNTAIN SOILS

Forest and Mountain soils cover approximately **3 lakh sq km (~8-9% of India)** -- mainly in the Himalayan ranges, Western Ghats, Eastern Ghats, and Northeast hill regions. They vary enormously with altitude, aspect, rainfall, and vegetation type, making them the most heterogeneous of all India's soil types.

Zone/Type	*Location*	*Soil Character*	*Associated Vegetation*
Himalayan foothills / Terai soils	UP-Bihar-WB-Assam Terai, Bhabar belt	Alluvial-influenced; young; fertile; high organic matter from forest litter; acidic under dense forest; BHABAR belt is stony/gravelly (loses rivers underground); TERAI is waterlogged, rich organic	Tropical moist deciduous (sal, shisham, khair); terai grasslands (Saccharum, Phragmites); tiger habitat (Corbett, Dudhwa)
Subtropical mountain soils	HP, Uttarakhand, Darjeeling,	Brown forest soils; moderate organic matter; pH slightly acidic (5.5-6.5);	Subtropical Pine (Chir Pine); Subtropical broad-leaved hill

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(1,000-2,000 m)	Meghalaya hills, NE states mid-elevations	chestnut brown colour; better developed than higher zones but shallow on slopes; erosion risk on cleared slopes	forests (oaks, chestnuts, Schima); shola grasslands at WG
Temperate mountain soils (2,000-3,000 m)	J&K, HP, Uttarakhand, Sikkim, Arunachal Pradesh mid-elevations	HUMUS-RICH brown podzolic or cambic soils; well-developed A horizon; pH 4.5-6.0; high organic matter under closed forest; shallow to moderate depth; good for apple, potato, temperate fruits	Himalayan Moist Temperate (Abies, Picea, oak, Rhododendron) on wet aspects; Dry Temperate (Deodar, Pinus wallichiana) on dry/rain-shadow aspects
Sub-Alpine soils (3,000-4,000 m)	All Himalayan states at sub-alpine altitudes	Shallow; humus-rich but poorly decomposed (cold slows decomposition); acidic; peaty patches near streams; frost-heaving; cryic temperature regime (soil temp <8 deg C)	Sub-Alpine forests (Abies spectabilis, Betula utilis, Rhododendron campanulatum); bugyals at upper limit
Alpine soils / Cryosols (>4,000 m)	Trans-Himalayan plateau; above tree line in all Himalayan states	Extremely shallow; permanently or seasonally frozen (permafrost at higher elevations); poor drainage; patterned ground (frost polygons); very low organic matter accumulation; barely formed mineral soil over rock	Alpine meadows (bugyals); cushion plants; sedge communities (Kobresia); sparse shrubs (Artemisia, Caragana)
Western Ghats forest soils	WG at all elevations; highest on western face	Red-yellow to brown; laterite on exposed ridges; deep humus in evergreen forest patches; shola soil = extremely humus-rich, waterlogged in patches; high earthworm activity	Tropical Wet Evergreen and Semi-Evergreen (WG windward); Shola forests at high WG elevations; transition to red soil on leeward

25.10 SOIL EROSION AND DEGRADATION IN INDIA

India's soils face a severe degradation crisis. The **National Bureau of Soil Survey and Land Use Planning (NBSS&LUP),** Nagpur -- under ICAR -- estimates that approximately **~120 million hectares (12 crore ha) of India's ~329 million ha total geographic area is under some form of soil degradation**, representing approximately 36-37% of India's land. Annual topsoil loss is estimated at **~5,334 million tonnes per year** (ICAR), of which approximately 29% is permanently lost to the sea, 10% is deposited in reservoirs (reducing their storage capacity), and 61% is deposited elsewhere in the landscape.

TYPES OF SOIL EROSION IN INDIA

Erosion Type	*Mechanism*	*Primary Areas*	*Scale (approx.)*
Sheet Erosion	Uniform removal of a thin surface layer by rainfall impact and thin surface flow; often invisible until fertility declines dramatically; the most insidious form	Agricultural fields on gentle slopes across India, especially in the dry deciduous zone and semi-arid Deccan; most widespread form	~74% of water-eroded area; ~89 million ha affected by water erosion in total (various water erosion forms combined)
Rill Erosion	Development of small channels (rills, 2-20 cm deep)	Sloped agricultural fields in Rajasthan, UP, MP,	Part of the ~89 million ha water erosion category

	as surface water concentrates; precursor to gully erosion	Chhattisgarh, Odisha, AP after heavy rain events	
Gully Erosion and Ravine Formation	Deep channels (gulley = >50 cm deep) that cut into the landscape; eventually form "ravine lands" -- badlands utterly unusable for agriculture without massive engineering	CHAMBAL RAVINES (Rajasthan-UP-MP border): ~4 lakh ha of spectacular ravine landscape; YAMUNA RAVINES; MAHANADI and GODAVARI gullied catchments; also Chhota Nagpur plateau; Bundelkhand	~2-4 million ha of severe gully/ravine land in India; Chambal valley = most iconic (historically also a dacoit refuge)
Wind Erosion	Sand movement by wind: creep (slow rolling on surface), saltation (bouncing), suspension (fine particles carried in air); creates sand dunes; depletes topsoil in arid areas	Western Rajasthan (Thar Desert), Gujarat (Kachchh-Rann), Punjab-Haryana semi-arid fringes	~14 million ha under wind erosion (NBSS&LUP); approximately 12% of total degraded area
Streambank Erosion	Lateral cutting of river banks; loss of agricultural land to the river channel; meander migration; most dramatic during monsoon floods	All major rivers; most severe along the Brahmaputra (Assam loses 8,000+ ha/year to Brahmaputra erosion according to some estimates), Ganga in Bihar, Kosi meanders	Difficult to quantify precisely; significant in Assam, Bihar, WB river plains
Chemical Degradation	Salinisation, alkalinisation, acidification, nutrient depletion from continuous monoculture without nutrient replacement; pollution from industrial effluents	Salinisation: IGP under canal irrigation (Punjab, Haryana, UP, Rajasthan); Acidification: NE India, WG under plantation monoculture; Pollution: industrial corridors	~7 million ha saline/alkaline; widespread N-P-K imbalances and micronutrient depletion across India

SOIL CONSERVATION MEASURES

Conservation Measure	*Mechanism*	*Application in India*
Contour Bunding / Contour Farming	Ploughing and planting along contour lines (lines of equal elevation) reduces slope length and velocity of runoff; reduces sheet and rill erosion by up to 50-70%	Widely practiced in Deccan dryland areas (Maharashtra, Karnataka, AP); promoted under watershed development programs (PMKSY-Watershed Component); standard MGNREGS activity
Terracing (Bench Terracing)	Converting steep slopes into a series of level steps (benches); eliminates slope entirely for the platform; water retained on the step; sediment trapped	Himalayan terraced agriculture (Uttarakhand, HP, J&K, NE states); paddy terraces; new terraces constructed under MGNREGS and watershed programs
Gully Plugging and Check Dams	Small earthen or stone structures across gullies that slow runoff, trap sediment, raise water table, and allow revegetation	Chambal Ravine reclamation; Rajasthan desert watershed programs; MGNREGS primary activity type; also serves groundwater recharge function
Shelter Belts and Wind Breaks	Rows of trees planted perpendicular to prevailing wind direction reduce	Rajasthan desert area: Prosopis cineraria, Acacia tortilis, Salvadora persica used as windbreaks;

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	wind speed behind the tree rows; reduce wind erosion and soil moisture loss	Central Arid Zone Research Institute (CAZRI), Jodhpur works on desert afforestation
Strip Cropping	Alternating strips of row crops and close-ground-cover crops (legumes, grasses) across the slope; close-cover strips trap sediment from upslope row crop strips	Punjab and Haryana dryland farming; advocated by ICAR for semi-arid areas to combine soil conservation with farm income
Agroforestry	Integration of trees with crops and/or livestock; tree roots hold soil, canopy intercepts rainfall impact, litter builds organic matter, root residues improve soil structure	ICRAF and ICAR research shows 30-50% reduction in soil erosion under agroforestry vs open field; critical in NE India where jhum (shifting cultivation) causes severe erosion
Zero Tillage / Conservation Tillage	Eliminating or minimising ploughing; leaving crop residue on surface; reduces erosion, preserves soil structure and organic carbon, saves energy	Punjab-Haryana wheat: Happy Seeder technology (sows wheat directly into paddy stubble without burning); adopted by 30 lakh ha+ in Punjab alone; PUSA decomposer (liquid microbial decomposer) for rapid residue breakdown instead of burning

25.11 SOIL HEALTH -- GOVERNMENT SCHEMES AND POLICY

Scheme / Policy	*Year*	*Key Provision*	*Status/Impact*
Soil Health Card (SHC) Scheme	Launched February 19, 2015 by PM Modi at Suratgarh, Rajasthan	Tests 12 soil parameters per farm holding: (a) Chemical: pH, EC, Organic Carbon (OC), Nitrogen (N), Phosphorus (P), Potassium (K); (b) Micronutrients: Sulphur (S), Zinc (Zn), Boron (B), Iron (Fe), Manganese (Mn), Copper (Cu); issues personalised recommendations for fertiliser and amendment use; targets all ~14 crore farm holdings in India, issued every 3 years	Over 23 crore SHCs distributed across India by 2022-23; revealed widespread Zn deficiency (40-50% of IGP soils), organic matter decline, and N deficiency across most Indian soils; primary tool for rationalising fertiliser use
PM-PRANAM (PM Programme for Restoration, Awareness, Nourishment and Amelioration of Mother Earth)	Announced Union Budget 2023-24	Incentivises states to reduce subsidy burden on chemical fertilisers by promoting organic and bio-fertiliser alternatives; states that save on fertiliser subsidy receive a portion of the savings for alternate use; encourages integrated soil management	Framework announced; implementation in progress as of 2024; linked with PM BIO-INSPIRE innovation platform for agri-bio inputs
National Mission on Natural Farming (NMNF)	2024 (announced Budget 2024-25; building on earlier ZBNF/natural farming initiatives)	Rs.2,481 crore; target 1 crore farmers on 7.5 million ha under natural farming by 2025-26; 10,000 bio-input resource centres; linked with NITI Aayog's natural farming push; based on Subhash Palekar's Zero Budget Natural Farming (ZBNF) principles	Building on Andhra Pradesh's APCNF (Andhra Pradesh Community Natural Farming) success (~800,000 farmers by 2024 -- world's largest natural farming programme); extended nationally
PKVY (Paramparagat	2015 (organic farming cluster	Cluster-based organic farming; 50 farmers per cluster; financial support	Expanded coverage; NE states targeted through

Krishi Vikas Yojana)	scheme)	for certification (PGS-India system -- Participatory Guarantee System), inputs, market linkage; promotes traditional seeds and organic practices; targets 5 lakh ha	MOVCD-NE (Mission Organic Value Chain Development for North East) -- separate NE-specific organic farming program
Integrated Watershed Management Programme (IWMP / PMKSY-WDC)	2009 (IWMP); renamed under PMKSY 2015	Treatment of degraded watersheds (soil conservation, water harvesting, afforestation, livelihood development) in identified micro-watersheds; based on Ridge-to-Valley approach; 8,214 watersheds treated in 12th plan; one of the largest land management programs globally	Under PMKSY (Pradhan Mantri Krishi Sinchayee Yojana) Watershed Development Component; targeting soil conservation in 162 priority watersheds; integrates MGNREGS activities
National Mission for Sustainable Agriculture (NMSA)	2014-15 (one of 8 NAPCC missions)	Integrated soil and water management for rainfed agriculture; soil health improvement; efficient water use; climate adaptation for agriculture; targets 15 states with highest vulnerability to climate change in agriculture	Climate change adaptation framework for agriculture; soil health as a central pillar; links to SHC scheme

CURRENT AFFAIRS

Stubble Burning and Soil Health -- Delhi AQI Crisis: Rice paddy stubble burning in Punjab and Haryana (October-November) after kharif harvest is among the most visible soil-crop management issues in India. An estimated 20-22 million tonnes of paddy straw is burned annually in Punjab+Haryana, contributing 25-35% of Delhi's extreme winter air pollution. Beyond the AQI crisis: stubble burning destroys soil microbiology, reduces organic matter, and kills beneficial soil organisms. The Supreme Court has repeatedly issued orders against burning; PUSA bio-decomposer (liquid formulation from IARI Delhi) and Happy Seeder technology (direct sowing without burning) are the primary alternatives. As of 2024: the Punjab government began a large-scale distribution of bio-decomposer to farmers, and the area of stubble burning reportedly declined but remained substantial.

PM-PRANAM and Natural Farming (Budget 2023-24, 2024-25): The shift in government policy from chemical-intensive to natural/organic farming reflects multiple soil health concerns: (a) Excessive urea use has acidified soils in some areas; (b) Continued use of high N without OC addition depletes soil organic matter; (c) Punjab-Haryana'-wheat-paddy belt shows micronutrient deficiencies (Zn especially) from continuous monoculture; (d) Pesticide residues in soil affecting microbial diversity. The National Mission on Natural Farming (NMNF, 2024, Rs.2,481 crore) targets 1 crore farmers and 7.5 million ha under natural farming -- the largest national natural farming programme globally if targets are met.

25.12 PYQ ANALYSIS -- CHAPTER 25 (2010-2025)

Source	Year	Marks	Question
UPSC Civil	2024	15M	"Discuss the major types of soils in India. Examine the factors that have led to soil degradation and the measures needed for soil conservation."
UPSC Civil	2023	12M	"What is laterite soil? Discuss the process of laterisation, the distribution of laterite soils in India and their agricultural characteristics."
UPSC Civil	2022	10M	"Compare and contrast black cotton soil (Regur) and alluvial soil in India with respect to their origin, distribution, chemical properties and agricultural

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			importance."
UPSC Civil	2021	15M	"Discuss the problem of soil degradation in India. What are the major causes, the extent of the problem, and the policy measures to address it?"
UPSC Civil	2020	10M	"What is the significance of the Soil Health Card scheme? How does it help in sustainable agriculture and soil conservation?"
UPSC Civil	2019	10M	"Explain the formation of black cotton soil in India. Why is it suited to cotton cultivation? What are its limitations for farming?"
UPSC Civil	2018	12M	"Discuss the distribution and characteristics of alluvial soils in India. Differentiate between Khadar and Bhangar."
UPSC Civil	2016	10M	"Explain the main types of soil found in India, showing how relief, parent material and climate influence soil formation."
IFoS GS	2024	15M	"Discuss the classification of Indian soils under both the traditional NCERT framework and the USDA Soil Taxonomy. How do different soil types determine forest type distribution in India?"
IFoS GS	2023	10M	"Explain Jenny's clorpt equation for soil formation. Discuss how climate and parent material interact to produce the diversity of Indian soil types."
IFoS GS	2022	10M	"Discuss the relationship between soil type and natural vegetation in India, with specific reference to alluvial soils, black soils and laterite soils."
IFoS GS	2021	10M	"Describe the formation and characteristics of laterite soils with reference to their distribution in India and their significance for forestry and plantation agriculture."

KEY NOTE	**Frequency:** Soil types + degradation + conservation (Civil 2024); Laterite (Civil 2023); Black vs Alluvial comparison (Civil 2022); soil degradation policy (Civil 2021); Soil Health Card (Civil 2020); black cotton soil (Civil 2019); alluvial + Khadar-Bhangar (Civil 2018); all soil types introduction (Civil 2016). IFoS: USDA taxonomy + vegetation (2024); Jenny clorpt (2023); soil-vegetation relationship (2022); laterite in forestry (2021). For 2025-26: PM-PRANAM (2023) + NMNF (2024) natural farming; stubble burning-soil health link; Soil Health Card coverage (23 crore+); gypsum for alkaline soils in UP/Punjab -- all high-probability current-affairs hooks.

25.13 MODEL BOOK

Discuss the major types of soils in India, their characteristics and agricultural significance. How do climate and parent material interact to determine soil type distribution?

UPSC Civil (Mains) | 15 Marks | 210 Words

India's soil diversity is extraordinary -- a product of varied parent geology, climate, topography and biological activity. Jenny's clorpt equation (S = f(cl, o, r, p, t)) captures the interplay: at the macro-scale, climate (cl) is dominant; at the local scale, parent material (p) often predominates.

1. **Alluvial Soils (~43% of India -- Largest):** Transported soils of Indo-Gangetic-Brahmaputra plains and river deltas; formed by Himalayan river deposition. Sub-types: KHADAR (newer alluvium, lower ground, finer, more fertile, annually renewed by floods, no kankar) and BHANGAR (older alluvium, higher terraces, coarser, lime nodules "kankar," less fertile than khadar). Chemistry: N and humus deficient; adequate K and Ca. Crops: wheat, paddy, sugarcane, pulses. USDA = Entisols/Inceptisols.
2. **Black/Regur Soils -- Vertisols (~16%):** Parent material = Deccan Trap basalt; montmorillonite clay; swells when wet (self-ploughing as cracks form when dry). pH 7.5-8.5. Rich in Ca, Mg, Fe; deficient in N, P, organic matter. Maharashtra, MP, Gujarat, AP. Primary crop: cotton. USDA = Vertisols.
3. **Red and Yellow Soils (~11%):** Formed by weathering of ancient Archaean crystalline rocks; red from

hematite (oxidised, well-drained sites); yellow from limonite (waterlogged sites). Sandy, porous, poor fertility. Tamil Nadu, Goa, Jharkhand, Odisha, Chhattisgarh. Crops: millets, groundnut, tobacco. USDA = Alfisols/Ultisols.

4. **Laterite Soils (~8%):** Intense leaching (>200 cm rainfall) removes SiO2; sesquioxides (Fe2O3, Al2O3) accumulate. Acidic (pH 4.5-6.0). Very poor in nutrients. WG, Eastern Ghats, Odisha, Jharkhand, NE India. Plantation crops: tea, coffee, rubber, cashew. Used as building material ("laterite brick"). USDA = Ultisols/Oxisols. Term coined by Buchanan (1807) from Kerala.
5. **Arid/Desert Soils (~5%):** Sandy, alkaline (pH 8-9.5), very low organic matter; kankar near surface. Western Rajasthan, Kachchh. Bajra, moth bean, guar; canal irrigation essential. USDA = Aridisols.
6. **Saline-Alkaline Soils (~2%):** Saline (Reh/Kallar: EC >4 dS/m; neutral salts; reclaimed by leaching) vs Alkaline (Usar: Na2CO3 dominated; pH >8.5; destroys soil structure; reclaimed by gypsum application). ~7 million ha across IGP, Gujarat, coastal areas.
7. **Peaty Soils (<1%):** Waterlogged, high organic matter (40-90%); Kuttanad Kerala (below sea level farming, UNESCO GIAHS); Odisha-WB coasts; acidic. USDA = Histosols.
8. **Forest/Mountain Soils (~9%):** Himalayan, WG, NE India; highly variable by altitude; shallow on slopes; humus-rich under closed forest; subject to erosion when cleared.

Climate-Parent Material Interaction: In the Deccan, basalt parent material + semi-arid climate = Vertisols (montmorillonite clay preserved); in the WG, similar latitude but high rainfall + varied rock = laterite (SiO2 leached). In the IGP, Himalayan river sediment + alluvial deposition = young fertile alluvial soils regardless of climate. Climate determines the INTENSITY of weathering; parent material determines the DIRECTION (which minerals form). This is why black soil and laterite can coexist within 300-400 km on the same Deccan Plateau.

India's soil types are a living archive of its geology, climate and agricultural history. The Soil Health Card scheme (2015; 23 crore+ cards issued) is now the primary tool for diagnosing and addressing soil nutrient deficiencies at the farm level. Soil degradation (~120 million ha affected) requires an integrated response of conservation farming (zero tillage), watershed development, and policy incentives (PM-PRANAM 2023, NMNF 2024) for the transition from chemical-intensive to sustainable agriculture.

What is laterite soil? Discuss the process of laterisation, distribution of laterite soils in India, and their agricultural and forestry characteristics.

IFOS Civil (Mains) | 15 Marks | 200 Words

Laterite soils are the product of one of the most intense weathering processes on Earth -- laterisation -- occurring in high-rainfall, high-temperature tropical environments. The term "laterite" was coined by Dr. Francis Buchanan in 1807 near Angadipuram, Kerala, from the Latin "later" (brick), describing the soil's use as a traditional building material.

Process of Laterisation: In areas receiving >200 cm of annual rainfall at high temperatures, intense chemical weathering attacks soil minerals. SILICA (SiO2) -- the most abundant constituent of most rocks -- is dissolved and LEACHED AWAY by acidic soil water. The SESQUIOXIDES -- iron oxide (Fe2O3, giving the characteristic red colour) and aluminium oxide (Al2O3) -- are relatively INSOLUBLE and ACCUMULATE in the remaining soil. The result is a soil dominated by iron-aluminium oxides, with a brick-red, dense hardpan layer (the "laterite crust") near the surface that hardens IRREVERSIBLY when exposed to air (dehydration of iron hydroxides to iron oxides). This process is irreversible -- once silica is leached and sesquioxides have hardened, the soil cannot be easily reverted to productive use.

Distribution in India: Laterite soils cover ~2.5 lakh sq km (~8% of India), found primarily in: (1) Western Ghats

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(western Karnataka, Goa, coastal Maharashtra -- Konkan laterite); (2) Kerala highlands; (3) Eastern Ghats (Odisha, Jharkhand, Chhattisgarh plateau); (4) NE India (Meghalaya plateau, Assam uplands); (5) Nilgiris and WG upper elevations (TN); (6) Some patches in AP. The common thread: all areas receive >150-200 cm rainfall.

CHEMICAL AND PHYSICAL PROPERTIES:

pH: Strongly acidic (4.5-6.0); basic cations (Ca, Mg) leached away; aluminium toxicity below pH 5.0.
Nutrient status: VERY POOR in N, P (P strongly fixed by Fe and Al at low pH), K, Ca, Mg, and organic matter; among the least fertile of all Indian soil types for annual crops.
Hardpan: Ironstone hardpan layer near the surface can impede root penetration and water movement; traditional use as building bricks in Kerala, Goa, and Karnataka.

AGRICULTURAL AND FORESTRY SIGNIFICANCE:

Plantation crops: Laterite soils support TEA (Darjeeling, Assam, Nilgiris, WG), COFFEE (Coorg, Chikmagalur, Wayanad, Araku Valley), RUBBER (Kerala), CASHEW (Goa, Kerala, AP, MH), COCONUT (Kerala, Karnataka). These species are ACID-TOLERANT and adapted to deep, freely draining laterite profiles. This is not accidental: these species co-evolved with laterite soils in tropical-subtropical humid environments.

Forest type: Undisturbed laterite soils of the WG support TROPICAL WET EVERGREEN forests (Champion and Seth Group 1) and SEMI-EVERGREEN forests (Group 2) -- the richest plant communities in India. The same laterite soils that are agriculturally challenging sustain among the world's most biodiverse forest ecosystems because: (a) the acid pH suits evergreen species; (b) rapid nutrient cycling from litter decomposition bypasses the poor soil nutrient status; (c) deep laterite weathering creates a large available water reservoir for tree roots even in the dry season.

Conservation concern: Deforestation of WG laterite slopes removes the litter-based nutrient cycle that sustains the ecosystem; bare laterite exposed to sun hardens rapidly (cuirasse formation); cannot be re-cultivated; landslide risk increases dramatically on deforested laterite slopes (Wayanad 2024 = classic deforested laterite + extreme rainfall + steep slope = catastrophic landslide).

Laterite soils illustrate a fundamental paradox: they support some of India's most ecologically rich forests when undisturbed, but are among the least productive agricultural soils when cleared. Their conservation -- particularly in the biodiversity-rich WG and NE India -- is both an ecological and economic imperative.

CHAPTER 26

ENERGY RESOURCES

Coal, Petroleum, Natural Gas and Nuclear Energy

CHAPTER AT A GLANCE

- India is the WORLD'S 3rd LARGEST ENERGY CONSUMER (after USA and China) and 3rd largest CO2 emitter from energy. Total installed power capacity crossed 900 GW in 2024 (including renewables). Coal accounts for ~50% of total electricity generation. India imports ~80-85% of its crude oil needs. Energy security and the coal-to-renewables transition are among the most important policy debates in India today.
- COAL: India has the 4th largest coal reserves globally (~319.02 billion tonnes proved + indicated + inferred; GSI 2021-22). 3rd largest coal producer. Reserves concentrated in Jharkhand, Odisha, Chhattisgarh, WB, MP, Telangana, Maharashtra. Gondwana coalfields (Permian age; ~98% of reserves; non-coking + coking coal) vs Tertiary coalfields (NE India; Assam, Meghalaya, Nagaland; lignite/sub-bituminous). Damodar Valley = most important coal belt.
- PETROLEUM: India has limited domestic crude oil reserves (~600 million tonnes proved); produces only ~15-20% of its needs; imports ~80-85% of crude. Major oil fields: Bombay High (Mumbai Offshore -- Arabian Sea, operated by ONGC); Rajasthan Barmer Basin (Cairn/Vedanta; India's largest onshore); Assam (Digboi -- Asia's first oil well, 1889; Naharkatia, Moran); Gujarat (Cambay Basin: Ankleshwar, Kalol). India's refining capacity ~254 million tonnes/year (world's 2nd largest; Jamnagar = world's largest single refinery complex -- 1.24 MMTPA).
- NATURAL GAS: Proved reserves ~1.3 trillion cubic metres (MoPNG data). Major fields: KG Basin (Krishna-Godavari: D6 block operated by Reliance + ONGC -- India's richest gas discovery; the iconic KG-D6 production; now recovering after decline); Bombay High (associated gas); Rajasthan; Assam; Gujarat. LNG imports growing: Petronet LNG terminals at Dahej (17.5 MMTPA) and Kochi (5 MMTPA). PM Urja Ganga pipeline to North-East and other gas grid expansions.
- NUCLEAR ENERGY: India has 7,480 MW nuclear capacity (24 reactors operating as of 2024). Main technology: Pressurised Heavy Water Reactor (PHWR) using natural uranium with heavy water as moderator. Key plants: Tarapur (MH; India's oldest; 1969; 480 MW); Rawatbhata (RJ; RAPS); Kudankulam (TN; Russian VVER-1000 technology; 2,000 MW + units 3-6 under construction); Kaiga (KA); Narora (UP); Kakrapar (GJ); Kalpakkam (TN; PFBR -- Prototype Fast Breeder Reactor -- India's first FBR under commissioning in 2024). India's 3-stage nuclear programme (Homi Bhabha, 1954): Stage 1 = PHWRs (natural U fuel); Stage 2 = FBRs (Pu-239 from Stage 1 + thorium); Stage 3 = Thorium-based reactors (India has 30% of world thorium reserves).
- COAL CHALLENGES: Environmental impact (deforestation, land acquisition, tribal displacement, air/water pollution); India committed to net zero by 2070 (COP26 2021); 500 GW non-fossil capacity by 2030; reducing coal dependence while meeting energy access for 1.4 billion. Coal India Limited (CIL) -- world's largest coal producer; produces ~80% of India's coal; government-owned. COAL FIRE: Jharia (Jharkhand) underground coal fire burning for 100+ years (since 1916); threatens Jharia township; BCCL (Bharat Coking Coal Ltd) manages this crisis.
- OIL AND GAS INSTITUTIONS: ONGC (Oil and Natural Gas Corporation -- PSU; upstream; largest E&P company); IOC (Indian Oil Corporation -- downstream; largest company by revenue; Mathura, Panipat, Digboi refineries); HPCL (Hindustan Petroleum); BPCL (Bharat Petroleum; privatisation stalled); OIL (Oil India Limited; Assam-Rajasthan E&P); GAIL (Gas Authority of India Ltd; gas transmission + distribution); PNGRB (Petroleum and Natural Gas Regulatory Board -- sector regulator).
- ENERGY SECURITY POLICY: IEA (India became full member in 2021); Strategic Petroleum Reserve (SPR) at Visakhapatnam, Mangaluru, Padur (5.33 MT capacity; ~9.5 days of crude import cover); OALP (Open Acreage Licensing Policy, 2018) for attracting E&P investment; Hydrocarbon Exploration and Licensing Policy (HELP, 2016) replaced NELP; National Gas Grid (PNGRB; target 35,000 km pipeline by 2030); One Nation One Gas Grid.

26.1 INTRODUCTION -- INDIA'S ENERGY LANDSCAPE

Energy is the lifeblood of modern economies. India -- the world's most populous nation and one of its fastest-growing economies -- faces one of the most complex energy challenges of the 21st century: providing affordable, reliable energy access to 1.4 billion people while simultaneously reducing its carbon footprint to meet Paris Agreement commitments and domestic climate goals.

India is the **world's 3rd largest energy consumer** (after the USA and China), the **3rd largest CO2 emitter from energy**, and the **3rd largest crude oil importer** globally. Its **total installed electricity generation capacity crossed 900 GW** in 2024 (including all generation sources), making it the 3rd largest electricity generation capacity globally. Yet **per capita energy consumption is still only about 30% of the world average**, reflecting the development gap and the enormous unmet energy demand as India industrialises.

INDIA'S ENERGY MIX -- OVERVIEW

Energy Source	*Installed Capacity / Production*	*% of Total Generation*	*Key Note*
COAL (Thermal Power)	~215 GW installed thermal capacity (coal-based); actual: Coal generates ~50-55% of India's electricity	~50-52% of total electricity (FY 2023-24)	Coal remains the backbone of India's electricity system despite rapid renewable growth; CIL produces ~80% of India's coal
RENEWABLES (Solar + Wind + Others)	~200+ GW installed (solar ~90 GW, wind ~47 GW as of early 2024; growing rapidly)	~20-22% of total generation (but much higher % of installed capacity due to lower capacity factors)	Fastest-growing energy source; India targets 500 GW non-fossil capacity by 2030; solar costs fallen dramatically
HYDRO	~47 GW installed large hydro; additional ~5 GW small hydro	~10-12% of total generation; important for peaking power	Key states: Himachal Pradesh, Uttarakhand, Arunachal Pradesh, Sikkim, Karnataka; seasonal variation in output
NUCLEAR	~7,480 MW (24 reactors operating as of 2024)	~3% of total generation	Baseload, low-carbon; India's 3-stage nuclear programme targets massive expansion; Kudankulam biggest plant
GAS (Natural Gas Power Plants)	~25 GW installed; many stranded (insufficient domestic gas)	~3-4%	Many gas-based power plants running at low Plant Load Factor (PLF) due to gas shortage; LNG imports help but expensive
OIL (Diesel, Naptha Plants)	Small; mostly backup/emergency	<1%	Oil-fired generation very expensive; mostly being phased out

26.2 COAL -- INDIA'S PRIMARY COMMERCIAL ENERGY SOURCE

Coal is India's most abundant fossil fuel and the dominant source of commercial energy, underpinning both electricity generation and steel production. India has the **4th largest coal reserves** in the world (after USA, Russia, and Australia) and is the **2nd or 3rd largest coal producer** globally (varies year to year; China is by far the largest). Understanding coal's geography -- types, distribution, production centres -- is among the most frequently tested topics in UPSC Geography and IFoS.

COAL TYPES IN INDIA

Coal Type	Carbon Content	Calorific Value	Formation Age / Process	Indian Occurrence
Anthracite	> 90% carbon	Highest (35+ MJ/kg)	Oldest, highest-grade; formed under extreme heat and pressure; rare in India	Very small quantities in J&K (Kalakot coalfields, Riasi district); negligible for commercial purposes
Bituminous (Coking and Non-coking)	50-90% carbon; coking coal has specific caking property	High (25-35 MJ/kg)	Permian age (~280 million years); from Gondwana sediments; good quality	MOST IMPORTANT type in India; Gondwana coalfields (Jharkhand, Odisha, CG, WB, MP, Telangana, Maharashtra); Coking coal: Jharia, Bokaro, Raniganj (limited); Non-coking: majority of Indian coal
Sub-bituminous	~45-55% carbon	Moderate (18-25 MJ/kg)	Intermediate grade	Some Gondwana coalfields; some Tertiary coalfields
Lignite (Brown Coal)	25-35% carbon	Low (10-20 MJ/kg)	Younger formation (Eocene/Oligocene); partially coalified plant material; high moisture	Neyveli Lignite Corporation (NLC) in Tamil Nadu (Neyveli deposits: ~3,900 MT reserves -- India's largest lignite deposit; powers NLC power plants); also Rajasthan (Barsingsar, Bikaner); Gujarat; J&K (Kalakot has some lignite)

KEY NOTE

Coking Coal vs Non-Coking Coal -- Critical Distinction (IFoS): COKING COAL (also called metallurgical coal) has the special property of becoming plastic/sticky when heated (caking property) and solidifying into coke -- which is essential for the blast furnace steelmaking process (coke reduces iron ore). India's coking coal deposits are limited and concentrated in: Jharia Coalfield (Jharkhand -- India's MOST IMPORTANT coking coal deposit; but plagued by underground fires burning since 1916), Bokaro (Jharkhand), West Bokaro (Jharkhand), and limited amounts in Raniganj (WB). India IMPORTS most of its premium coking coal from Australia (BHP, Glencore), USA and Canada because domestic coking coal is insufficient in quality and quantity for steel plants. NON-COKING coal (steam coal/thermal coal) is the majority of Indian coal production and is used for power generation. This distinction is frequently tested.

GONDWANA VS TERTIARY COALFIELDS

Feature	Gondwana Coalfields	Tertiary Coalfields
Age	Permian Period (~280-250 Ma); Gondwana Supercontinent sediments	Eocene to Miocene (55-5 Ma); much younger
% of India's coal reserves	~98% of India's total coal reserves	~2% of total reserves
Location	Peninsular India river valleys: Damodar Valley (Jharkhand-WB), Mahanadi Valley (Odisha-CG), Godavari Valley (Telangana-AP), Son-Narmada Valley (MP)	Northeast India: Assam (Jaintia Hills, Makum, Margherita), Meghalaya (East Khasi Hills, Jaintia Hills), Nagaland, Arunachal Pradesh; also J&K (minor)
Coal quality	Generally BETTER quality; bituminous grade; both coking and non-coking	LOWER quality; sub-bituminous to lignite grade; high sulphur content in

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		some NE deposits; NE coal has high ash and sulphur
Structural context	Found in rift valleys (grabens) or river basin sedimentary sequences within the Gondwana stratigraphic system; coal seams interbedded with Gondwana sedimentary rocks	Sedimentary basins formed during Cenozoic era; associated with younger mountain-building in NE India

MAJOR COALFIELDS -- STATE-WISE DISTRIBUTION

Coalfield	*State*	*Key Features*	*Reserves / Production Note*
Jharia	Jharkhand (Dhanbad district)	MOST IMPORTANT: largest bituminous coalfield; primary source of coking coal in India; coal seams 50-100 m thick; but plagued by UNDERGROUND FIRES burning since 1916 (when fire started at Jalakeria colliery); fire has consumed significant reserves; Jharia Development Authority (JADA) managing crisis including relocation of Jharia town	Largest reserve of high-grade bituminous coal; indispensable for Indian steel industry; over 30 billion tonnes proved reserves
Raniganj	West Bengal (Paschim Bardhaman / Burdwan district)	India's OLDEST coalfield (commercial mining since 1774 by East India Company); spans WB-Jharkhand border (WB portion called Raniganj, Jharkhand portion is eastern Jharia-adjacent); both coking and non-coking coal	~17 billion tonnes reserves; declining older mines; new mechanised mines being developed
Bokaro	Jharkhand	High-grade coking coal; supplies Bokaro Steel Plant (BSP) of SAIL; part of the Damodar Valley coal belt	Major coking coal source for steel sector
Korba	Chhattisgarh (Korba district)	Part of Mahanadi-Son coalfield system; large non-coking coal reserves; feeds NTPC Korba Super Thermal Power Plant (2,600 MW -- one of India's largest)	South Eastern Coalfields Ltd (SECL) operates here
Singrauli	Madhya Pradesh (Singrauli district)	Northern Coalfields Ltd (NCL) area; also spans UP border; major power generation coal source; NTPC Vindhyachal Super Thermal Power Plant (4,760 MW) -- India's largest thermal power plant -- nearby	Critical to India's power grid
Talcher-Angul	Odisha (Angul, Dhenkanal districts)	Part of Mahanadi coalfield; Mahanadi Coalfields Ltd (MCL); growing rapidly as India's eastern coal hub; also fuel for NALCO aluminium smelter; Talcher Fertilizer Plant (IFFCO-GAIL JV using coal gasification technology -- innovative)	Fastest growing coalfield in India by production
Wardha Valley / Chandrapur	Maharashtra (Chandrapur, Yavatmal)	Western Coalfields Ltd (WCL); non-coking coal for Maharashtra power plants; associated with Chandrapur Super Thermal Power Station	Important for Maharashtra's power supply
Singareni	Telangana (Khammam, Karimnagar, Adilabad, Mancherial)	SCCL (Singareni Collieries Company Ltd) -- a joint venture between Telangana state government and GoI; the only significant coalfield in southern peninsular India; important for southern states coal supply	Andhra Pradesh-Telangana power supply backbone

Neyveli (Lignite)	Tamil Nadu (Cuddalore district)	NLC India Ltd (formerly Neyveli Lignite Corporation) -- largest lignite mine and power complex; open-cast mining of lignite; NLC powers Tamil Nadu significantly; recent expansion of solar by NLC alongside lignite	~3,900 MT lignite reserves; unique industrial township; NLC also developing solar nationally

COAL INDIA LIMITED (CIL) -- WORLD'S LARGEST COAL MINER

Coal India Limited (CIL) -- a Central Public Sector Enterprise (CPSE) under the Ministry of Coal -- is the **world's largest coal-producing company** and **India's most valuable PSU** (among the top by market capitalisation). It produces approximately **80% of India's total coal output.** CIL was formed in 1975 by nationalising private coal companies following the Coal Mines Nationalisation Act, 1973. Its subsidiaries operate across the major coalfields:

CIL Subsidiary	*State(s)*	*Major Coalfields Operated*
ECL (Eastern Coalfields Ltd)	West Bengal, Jharkhand (eastern)	Raniganj, Sripur, Mugma
BCCL (Bharat Coking Coal Ltd)	Jharkhand (Dhanbad)	Jharia (coking coal); manages Jharia fire crisis
CCL (Central Coalfields Ltd)	Jharkhand (Hazaribagh, Ramgarh)	Bokaro, North Karanpura, South Karanpura
NCL (Northern Coalfields Ltd)	Madhya Pradesh, Uttar Pradesh	Singrauli coalfield
WCL (Western Coalfields Ltd)	Maharashtra, Madhya Pradesh	Wardha Valley, Umrer, Wani
SECL (South Eastern Coalfields Ltd)	Chhattisgarh, Madhya Pradesh	Korba, Bilaspur, Surguja, Chirmiri
MCL (Mahanadi Coalfields Ltd)	Odisha	Talcher-Angul, IB Valley
NEC (North Eastern Coalfields)	Assam, Meghalaya (small)	Margherita, Ledo (Assam Tertiary coalfields)
CMPDIL (Central Mine Planning and Design Institute)	Ranchi, Jharkhand	R&D and planning; not a mining company

CURRENT AFFAIRS

Coal India's FY 2023-24 Production Milestone: Coal India Limited achieved a record production of 773 million tonnes (MT) in FY 2023-24 -- the highest ever annual production by any single coal company globally. The Government of India's target for CIL was 1 billion tonnes by 2026-27. India's total coal production (including CIL + captive mines + SCCL) crossed 1 billion tonnes (1 BT) for the first time in 2023-24, making India the 2nd country after China to ever cross 1 billion tonnes of annual coal production.

ENVIRONMENTAL ISSUES IN COAL MINING

Issue	*Detail*
Deforestation and land acquisition	Open-cast mining (which accounts for >90% of CIL production) requires removal of overburden, which destroys topsoil, forest cover and agricultural land; Hasdeo Arand forest (Chhattisgarh, part of "lungs of Chhattisgarh") is threatened by coal block expansion; tribals displaced without adequate compensation under LARR Act 2013
Jharia underground fire	Burning continuously since 1916; consumes reserves; toxic fumes and subsidence; Jharia town relocation is a decades-old unresolved crisis; approximately 27,000 families need to be relocated; Supreme Court and JADA oversight
Water pollution	Coal mine drainage (acid mine drainage -- AMD -- in some sulphide-containing coal zones) contaminates rivers; fly ash from thermal power plants (India generates ~230 MT fly

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	ash/year) contaminates rivers if impoundments fail; groundwater contamination from colliery water
Air pollution	Coal combustion is India's largest source of SO2, NOx, PM2.5 and mercury emissions; NTPC and other thermal plants face MOEF&CC emission norms (tightened in 2017; many plants still non-compliant as of 2024); coal truck traffic and loading areas create severe local air pollution
Fly ash management	~230 MT fly ash produced annually; mandatory use in bricks (fly ash bricks), cement (PPC), road construction under the Fly Ash Notification 2021; NTPC targets 100% fly ash utilisation; but utilisation gap remains
Tribal displacement	Extensive coal-bearing areas overlap with Scheduled Tribe population areas in Jharkhand, Chhattisgarh, Odisha; displacement without consent or adequate rehabilitation; Forest Rights Act (FRA) 2006 provisions often bypassed; Vedanta Niyamgiri case (SC 2013) established right of gram sabha to decide on mining in forest/tribal lands -- a landmark judgment

ENV ALERT

Coal and Climate Commitments -- The Core Tension:
India's coal dependence creates a fundamental tension with its climate commitments: at COP26 (Glasgow, 2021), India pledged **Net Zero by 2070**, **500 GW of non-fossil electricity capacity by 2030**, **50% of electricity from non-fossil sources by 2030**, and **reduction of emissions intensity of GDP by 45% by 2030** vs 2005. Yet India also said at COP26 that it would **"phase down" (not "phase out") coal** -- a distinction it successfully inserted into the Glasgow Climate Pact. Coal production reached a record 1 billion tonnes in 2023-24, and several new coal-fired power plants are in the pipeline. India's argument: with 300 million people still energy-poor and per-capita consumption at 30% of global average, coal remains necessary for development; the West industrialised on coal and has no moral authority to ask India to forgo it. This coal dilemma is among the most important UPSC Mains environmental-ethics-policy questions.

26.3 PETROLEUM (CRUDE OIL) -- INDIA'S CRITICAL IMPORT DEPENDENCE

Petroleum (crude oil and its refined products -- petrol, diesel, LPG, kerosene, aviation turbine fuel, naphtha) is the most economically strategic of India's energy resources. India is the **world's 3rd largest oil consumer** yet has very limited domestic reserves, making it **critically dependent on imports for 80-85% of its crude oil needs** -- a major energy security vulnerability and a persistent source of trade deficit (crude oil typically accounts for 25-30% of India's total import bill).

CRUDE OIL RESERVES AND PRODUCTION

India's total proved crude oil reserves are approximately **600-700 million tonnes** (varying by source and year). India's domestic crude oil production has been **stagnant or declining** in recent years -- approximately **29-30 million tonnes per year** (2022-24) -- significantly below its own needs (~250 MT/year of crude processed). The primary challenge is that most of India's major existing fields are mature (especially Bombay High), with declining production without major new discoveries.

MAJOR OILFIELDS IN INDIA

Oilfield	*State/Region*	*Operator*	*Key Feature*
Bombay High (Mumbai High)	Arabian Sea -- Offshore Maharashtra (about 160 km west of Mumbai)	ONGC (Oil and Natural Gas Corporation)	India's LARGEST single oilfield by cumulative production; discovered 1974; peak production ~1983; now declining rapidly despite enhanced oil recovery (EOR) efforts; produced over 600 MT of crude oil since discovery; also India's most

			important gas-producing field; major ONGC asset; loss of Bombay High = significant blow to India's energy security
Barmer Basin (Rajasthan)	Rajasthan (Barmer and Jaisalmer districts)	Cairn Oil and Gas (now Vedanta); ONGC (as JV partner)	INDIA'S LARGEST ONSHORE OIL DISCOVERY in decades; Mangala field (within Rajasthan basin) -- Cairn discovered in 2004; production started 2009; peak ~175,000 barrels/day; total estimated 1+ billion barrels; Rajasthan has become a significant oil producer; pipeline to Bhogat coast (Jamnagar area); technically challenging tight oil
Assam-Arakan Basin	Assam (Dibrugarh, Sibsagar, Tinsukia districts), Nagaland	OIL India Limited (OIL) and ONGC	India's OLDEST oil province; Digboi oilfield (Tinsukia, Assam) -- ASIA'S FIRST OIL WELL drilled commercially in 1889 (disputed with Burma/Myanmar); Digboi refinery (1901 -- one of world's oldest operating refineries); Naharkatia, Moran, Hugrijan, Jorhat fields operated by OIL and ONGC; Assam production declining but historically significant
Cambay Basin (Khambhat Basin)	Gujarat (Bharuch, Vadodara, Kheda, Surat districts); onshore and shallow offshore	ONGC; Oil India; some private companies	Ankleshwar (discovered 1958 -- India's first major commercial oil discovery); Kalol, Nawagam, Kosamba, Mehsana; declining older fields; also significant gas; Gujarat's long history as an oil-producing state
KG Basin (Krishna-Godavari Basin)	Offshore Andhra Pradesh-Odisha coast; Bay of Bengal (Block D1, D3, D6)	Reliance Industries Ltd (RIL) -- Block D6; ONGC; GAIL	INDIA'S MOST IMPORTANT RECENT GAS DISCOVERY (D6 block); Dhirubhai-1 and Dhirubhai-3 gas fields; peak gas production 2010 (60 mmscmd); then catastrophic decline to ~5 mmscmd by 2015 due to geological complexity; ongoing legal dispute between RIL and MoPNG over production sharing; new satellite fields being developed; potential for oil too
Cauvery Basin	Tamil Nadu (Nagapattinam area), offshore Bay of Bengal	ONGC	Narimanam, Kovilappal fields; small production; important for TN's local supply
Andaman-Nicobar Offshore	Andaman Sea; deep water	ONGC	Promising frontier basin; deep-water exploration ongoing; no commercial production yet; strategic importance

KEY NOTE

Digboi -- Asia's First Oil Well: The Digboi oilfield in Tinsukia district, Assam, drilled its first commercial well in **1889** by the Assam Oil Company (later nationalised into ONGC). The Digboi Refinery was established in **1901** and is one of the world's oldest continuously operating refineries. The name "Digboi" is popularly (though unreliably) attributed to workers' instructions to "dig, boy!" while laying the Assam-Bengal Railway. The field is now in deep decline but retains historical importance as a pioneer of South Asian petroleum industry.

INDIA'S REFINERY CAPACITY

Although India has limited crude production, it has **developed one of the world's largest refinery capacities** --

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approximately **254 million metric tonnes per annum (MMTPA)** as of 2023-24 (about 5 million barrels per day), making India the **2nd largest refinery capacity holder in Asia** (after China) and among the top 5 globally. India has transformed into a major exporter of petroleum products (refined fuels), even while importing crude oil -- a strategic choice to add domestic value.

Refinery	*State*	*Capacity (MMTPA)*	*Operator / Note*
Jamnagar (Domestic)	Gujarat (Jamnagar)	35	Reliance Industries Ltd (RIL); part of the Jamnagar Refinery Complex
Jamnagar (Export Oriented -- SEZ)	Gujarat (Jamnagar)	35 (SEZ) + 5 (ROGC)	RIL; together with the domestic refinery, Jamnagar is the WORLD'S LARGEST SINGLE-LOCATION REFINERY COMPLEX (~75 MMTPA total; processes diverse crudes)
Koyali (Vadodara)	Gujarat	18	IOC (Indian Oil Corporation); one of IOC's oldest refineries
Mathura	Uttar Pradesh	11	IOC; serves Delhi NCR and North India market
Panipat	Haryana	25	IOC; one of IOC's largest; Panipat Petrochemical Complex
Haldia	West Bengal	7.5	IOC; East India petroleum hub
Barauni	Bihar	6	IOC; historically important; supplied UP-Bihar
Numaligarh	Assam	9 (under expansion)	Numaligarh Refinery Ltd (NRL) -- subsidiary of OIL and BPCL; recently acquired fully by OIL; NE India-focused
Digboi	Assam	0.65	ONGC; oldest operating refinery in India (1901); small but historically significant
Paradip	Odisha	15	IOC; newest IOC refinery; East coast location; processing of high-sulphur crude
Mangaluru	Karnataka	15	MRPL (Mangalore Refinery and Petrochemicals Ltd) -- ONGC subsidiary
Kochi	Kerala	15.5	BPCL; Kerala LNG terminal also at Kochi
Chennai / Manali	Tamil Nadu	10.5 (IOC) + 9 (CPCL) = total ~20	IOC + CPCL (Chennai Petroleum Corporation Ltd); Tamil Nadu refining hub
Vizag / Vishakhapatnam	Andhra Pradesh	11.5 (ongoing expansion to 15+)	HPCL; East coast refinery; Strategic Petroleum Reserve at Vizag

OIL IMPORT DEPENDENCE -- ENERGY SECURITY DIMENSIONS

Aspect	*Detail*
Import volume	India imports approximately 210-230 million tonnes of crude oil per year (2022-24 data); worth approximately USD 130-160 billion/year depending on global oil prices; among the largest items in India's import bill
Source countries	Iraq (historically largest supplier), Saudi Arabia, Russia (jumped to 30%+ of India's crude imports after Western sanctions post-Ukraine war Feb 2022, as Indian refiners bought Russian Urals crude at steep discount), UAE, Kuwait, Nigeria, USA (shale oil); diversification is a strategic priority

India's Russia crude imports post-2022	Post-Ukraine war (February 2022), India dramatically scaled up purchases of discounted Russian crude; by 2023, Russia became India's single LARGEST crude supplier (~35-40% of imports at peak); Western criticism of India for "funding Russia's war machine"; India's position: sovereign right to buy cheap energy for its developing economy; energy security is non-negotiable
Strategic Petroleum Reserve (SPR)	India maintains strategic crude oil reserves at 3 underground rock cavern locations: Visakhapatnam (AP), Mangaluru (Karnataka), and Padur (Karnataka); total capacity ~5.33 million tonnes (~9.5 days of crude import cover); much lower than IEA's recommended 90-day cover; India joined IEA in 2021 as full member; Phase 2 SPR expansion planned at Chandikhol (Odisha) and Padur extension
Petrol and diesel prices	India deregulated petrol prices in 2010 and diesel in 2014; prices now linked to international crude prices + taxes (centre + state taxes constitute 50-55% of the retail price of petrol/diesel in India); LPG (cooking gas) still partially subsidised via PM Ujjwala Yojana; ethanol blending programme (E20 by 2025) to reduce petrol import dependence
Hydrocarbon Exploration and Licensing Policy (HELP)	2016 -- replaced the old NELP (New Exploration and Licensing Policy, 1997-2011); HELP introduced: (a) Open Acreage Licensing Policy (OALP) -- companies can bid for any unlicensed block online at any time; (b) Revenue sharing contract replacing PSC (Production Sharing Contract); (c) Uniform licensing for all types of hydrocarbons (oil, gas, CBM, shale); aim: attract investment in upstream E&P

26.4 NATURAL GAS -- INDIA'S TRANSITIONAL FUEL

Natural gas -- primarily methane (CH_4) -- is the cleanest of the three fossil fuels (lowest CO_2 per unit of energy; no SO_2 emissions; low particulate matter) and is internationally positioned as the **"transition fuel"** bridging the gap between coal and renewables in the global energy transition. India's proved natural gas reserves are approximately **1.3 trillion cubic metres (tcm)** -- placing it in the 2nd tier of global gas reserves (far below Russia's 38 tcm or Iran's 32 tcm but significant for South Asia). India's domestic gas production (~90-100 billion cubic metres/year BCM at peak, now declining to ~60-70 BCM) falls short of demand, making India increasingly dependent on **Liquefied Natural Gas (LNG)** imports.

MAJOR NATURAL GAS FIELDS

Gas Field / Basin	*Location*	*Operator*	*Status and Significance*
KG-D6 (Dhirubhai-1 and D-3)	KG Basin (Krishna-Godavari), offshore Andhra-Odisha, Bay of Bengal (Block D6)	Reliance Industries Ltd (RIL); BP (British Petroleum, 33% partner); NIKO Resources	INDIA'S MOST IMPORTANT GAS DISCOVERY (2002); announced with fanfare as potential to make India gas-surplus; peak production ~60 mmscmd (million standard cubic metres per day, 2010); then crashed to ~5 mmscmd (2015) due to unexpected geological complexity; major legal controversy over RIL's production obligations; now recovering with new satellite fields; MJ field development ongoing; key for India's "gas economy" vision
Bombay High Gas	Offshore Maharashtra, Arabian Sea	ONGC	Associated gas (produced alongside crude oil) from the Bombay High oilfield; India's oldest large gas source; supplied Mumbai and Gujarat for decades; declining with crude production

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KG Basin (ONGC blocks)	KG Basin, offshore AP	ONGC	UD-1, G4, GS-29 fields; less celebrated than RIL's D6 but important steady production; ONGC's KG gas to fuel power and fertiliser plants in AP and TN
Cambay Basin Gas	Gujarat (Bharuch, Vadodara)	ONGC, private companies	Associated and free gas from mature Cambay Basin fields; feeds Hazira LNG terminal and GAIL pipelines; some gas used for fertiliser plants and power generation in Gujarat
Assam Gas Fields	Assam (Dibrugarh, Sibasagar, Jorhat)	OIL India and ONGC	Associated gas from Assam oil fields; limited pipeline connectivity; some used locally for power; NE India has gas but insufficient infrastructure to utilise it fully
Cauvery Basin	Offshore TN	ONGC	Small offshore gas fields; potential for more with deep water exploration

LNG INFRASTRUCTURE IN INDIA

India imports LNG through dedicated regasification terminals:

LNG Terminal	*State*	*Capacity (MMTPA)*	*Operator*	*Key Note*
Dahej LNG Terminal	Gujarat	17.5	Petronet LNG Ltd (PLL)	India's LARGEST and first LNG terminal (commissioned 2004); expanded multiple times; handles Qatar LNG (long-term contract with Qatargas); receives spot LNG from global markets
Hazira LNG Terminal	Gujarat	5	Shell India Markets and Total Energies	Shell-Total JV; competitive with Dahej; flexible capacity; spot LNG market participant
Kochi LNG Terminal	Kerala	5	Petronet LNG Ltd	Expanded from 2.5 to 5 MMTPA; underutilised for years due to lack of pipeline connectivity (Kochi-Koottanad-Bangalore-Mangaluru/KKBMPL pipeline now operational but demand ramp-up slow)
Dabhol LNG Terminal (Ratnagiri Gas and Power)	Maharashtra (Ratnagiri)	5	RGPPL (JV of NTPC, GAIL, MSEB)	Formerly the infamous Enron Dabhol Power Plant (global controversy in 1990s-2000s); now operating as LNG terminal feeding power plant
Ennore LNG Terminal	Tamil Nadu (Chennai/ Ennore)	5 (Phase 1)	Indian Oil -- LNG terminal (IOC)	Serves South India; critical for Chennai and Tamil Nadu gas market; Chennai City Gas Distribution

NATURAL GAS PIPELINE NETWORK AND GAS GRID

India's natural gas pipeline network -- operated primarily by **GAIL (Gas Authority of India Ltd)** and now also by other licensed players under **PNGRB (Petroleum and Natural Gas Regulatory Board)** -- has been expanding rapidly with the ambition of creating a **"National Gas Grid"** or **"One Nation One Gas Grid."**

Pipeline/Project	*Route*	*Status / Significance*
HVJ Pipeline (Hazira-	Gujarat to UP-MP	India's first and historically most important gas

Vijaipur-Jagdishpur)		pipeline; the backbone of India's gas distribution; HVJ + GREP (Gas Rehabilitation Expansion Project) carries gas from Hazira to UP and North India
GREP (Gas Rehabilitation Expansion Project)	Extension of HVJ system	Expanded the HVJ network into Bihar, Jharkhand, Odisha, WB; part of the gas grid buildout
DVPL (Dahej-Vijaipur Pipeline)	Gujarat to Madhya Pradesh	Connects Dahej LNG terminal to the HVJ system; handles the Qatar LNG and spot LNG imports
DUPL+DPPL	Dahej-Uran-Panvel-Dabhol	Mumbai area gas distribution from Dahej; feeds Maharashtra industrial consumers
PM Urja Ganga (Jagdishpur-Haldia-Bokaro-Dhamra pipeline -- JHBDPL)	Eastern India: UP to WB-Odisha; connects to existing north India grid	Launched 2016; designed to bring piped natural gas (PNG) to eastern states (UP, Bihar, Jharkhand, WB, Odisha) which were historically un-gasfied; key for PM's "gas-based economy" vision; Varanasi, Patna, Ranchi, Kolkata to be included
KGPL (KG-Pelhampur or Central India Gas pipeline)	Andhra Pradesh to Andhra Pradesh coast	Carries KG Basin gas to consumers in AP and TN; critical for power and fertiliser plants
CNG and PNG Expansion	City Gas Distribution (CGD) in 295+ cities/districts licensed by PNGRB as of 2024	PNGRB has licensed CGD networks across India covering 87%+ of India's geography (9th CGD bid round 2022); PNG (Piped Natural Gas) for homes; CNG for vehicles; MGL (Mahanagar Gas -- Mumbai), IGL (Indraprastha Gas -- Delhi), Adani Gas, Gujarat Gas are major CGD companies

26.5 NATURAL NUCLEAR ENERGY -- INDIA'S THREE-STAGE PROGRAMME

India's nuclear energy programme is among the most strategically distinctive in the world -- designed not merely to generate electricity but to **exploit India's unique resource endowment** through a carefully sequenced three-stage strategy conceived by **Dr. Homi Jehangir Bhabha** (the "Father of the Indian Nuclear Programme") in **1954.** India has **24 operational nuclear reactors** with a total capacity of **~7,480 MW** as of 2024, and an ambitious plan to expand to **22,480 MW by 2031** and ultimately over **63,000 MW by 2032** (target revised multiple times; ambitious but delayed).

INDIA'S THREE-STAGE NUCLEAR PROGRAMME

Stage	*Reactor Type*	*Fuel*	*By-product*	*Significance*	*Status*
STAGE 1	Pressurised Heavy Water Reactor (PHWR)	Natural Uranium (U-235 -- only 0.7% fissile; NO enrichment needed -- key advantage; India has domestic uranium but limited	Plutonium-239 (Pu-239) -- accumulated in spent fuel; CRITICAL FEEDSTOCK FOR STAGE 2	Provides the fissile material (Pu-239) that will fuel Stage 2; currently generates electricity as a by-product; India has ~10-11 operating PHWR units (Tarapur PHWR 540 MW units, Rawatbhata RAPS 220 MW and 700 MW units, Kakrapar, Kaiga, Narora)	OPERATIONAL -- Stage 1 PHWRs are the bulk of India's current nuclear capacity

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		supply)			
STAGE 2	Fast Breeder Reactor (FBR)	Mixed oxide fuel -- Pu-239 (from Stage 1) + Uranium-238 (depleted uranium; abundant and cheap)	Thorium-233 (converted from Thorium-232 blanket around the reactor core) AND more Pu-239; the FBR "breeds" more fuel than it consumes	The CRITICAL BRIDGE STAGE: uses Stage 1 Pu-239, breeds MORE fissile material from U-238 (which is 99.3% of natural uranium -- making vast uranium reserves usable), AND converts thorium to U-233 for Stage 3. The FBR multiplies India's nuclear fuel base by 100x.	PROTOTYPE STAGE: Prototype Fast Breeder Reactor (PFBR, 500 MW) at IGCAR Kalpakkam, TN -- achieved first criticality in 2024 (decades delayed from original 2012 target); commercial FBRs to follow
STAGE 3	Advanced Heavy Water Reactor (AHWR) / Thorium-based reactors	Uranium-233 (U-233, bred from thorium in Stage 2) + Thorium-232	Minimal long-lived waste; U-233 cycle has proliferation-resistance advantages	The ENDGAME: exploits India's massive THORIUM RESERVES (India has ~25-30% of world's known thorium reserves -- estimated 846,477 tonnes, world's 2nd after Brazil by some estimates); U-233 from thorium is the fuel; theoretically unlimited energy supply from domestic thorium; addresses India's critical uranium scarcity at the macro-scale	RESEARCH AND DEVELOPMENT STAGE: AHWR design at BARC (Bhabha Atomic Research Centre), Trombay, Mumbai; no commercial unit yet; probably 2040s+ for commercial deployment

KEY NOTE

Why India chose this 3-Stage path: India lacks sufficient high-grade uranium (U) to power a large fleet of conventional enriched-uranium reactors (used by the USA, France, most nuclear powers). Its natural uranium resources are limited (primarily in Jharkhand -- Jadugoda mine; Andhra Pradesh -- Tummalapalle mine; Meghalaya -- Domiasiat/Nongbah). However, India has **25-30% of the world's thorium reserves** (coastal monazite sands in Kerala, TN, AP, Odisha; also in Rajasthan and Bihar). Thorium (Th-232) cannot be directly fissioned but can be converted to Uranium-233 (U-233, which CAN be fissioned) by neutron bombardment in a reactor. The 3-stage programme is India's strategy to reach Stage 3 (thorium utilisation) by first building sufficient Pu-239 stockpile through Stage 1 and 2. This is a multi-decade national project -- perhaps the most ambitious energy technology programme in Indian history.

NUCLEAR POWER PLANTS IN INDIA

Plant	*State*	*Capacity (MW)*	*Reactor Type*	*Note*
Tarapur	Maharashtra (Palghar)	480 MW (2x160 + 2x540)	Units 1-2: Boiling Water Reactor (BWR) -- US origin (GE, pre-NPT); Units 3-4: PHWR 540 MW (NPCIL designed)	India's OLDEST nuclear plant (Units 1-2 commissioned 1969); fuel supply controversy after Pokhran-I 1974 test (USA suspended fuel supply); NPCIL developed indigenous 540 MW PHWR design

Rawatbhata (RAPS)	Rajasthan (Chittorgarh)	1,180 MW (2x100 + 2x200 + 2x220 + various upgrades)	PHWR (Canada-designed originally; Unit 1-2 = CANDU design; Units 3-6 = NPCIL PHWR)	Rajasthan Atomic Power Station; Units 7-8 being constructed (700 MW each); one of India's largest nuclear complexes
Kalpakkam (MAPS + PFBR)	Tamil Nadu (Kalpakkam, near Chennai)	440 MW MAPS (2x220 MW) + 500 MW PFBR	MAPS: PHWR; PFBR: Fast Breeder Reactor (sodium-cooled)	MAPS = Madras Atomic Power Station; PFBR = Prototype Fast Breeder Reactor operated by BHAVINI (Bharatiya Nabhikiya Vidyut Nigam Ltd), a subsidiary of DAE; PFBR achieved first criticality in 2024 -- India's FIRST FBR (Stage 2 milestone)
Narora	Uttar Pradesh (Bulandshahr)	440 MW (2x220 MW)	PHWR	NPCIL; supplies Delhi NCR; site of a 1993 fire incident (managed safely without radiation release -- important for safety record)
Kakrapar	Gujarat (Surat)	440 MW (2x220 MW) + 1,400 MW under construction (2x700 MW)	PHWR	NPCIL; 700 MW units 3-4 at Kakrapar are India's largest indigenous PHWR units; Unit 3 achieved criticality 2020
Kaiga	Karnataka (Uttara Kannada)	880 MW (4x220 MW)	PHWR	NPCIL; Kaiga-1 set world record for CANDU/PHWR reactor continuous operation without shutdown: 962 days (2019); supplied power to Karnataka grid
Kudankulam	Tamil Nadu (Tirunelveli district)	2,000 MW (2x1,000 MW) + units 3-6 under construction (4x1,000 MW)	Pressurised Water Reactor (VVER-1000) -- Russian technology (Atomstroyexport /ROSATOM)	India's LARGEST nuclear power station; Indo-Russian civilian nuclear cooperation; technology transfer; faced protests from Tamil Nadu fishing community (2011-2012) before Units 1-2 commissioned; Units 3-6 under construction; Russia agreed to 6 more units (7-12) at same site; Indo-Russian nuclear cooperation continues despite Ukraine war
Gorakhpur Haryana Anu Vidyut Pariyojana (GHAVP)	Haryana (Fatehabad)	2,800 MW (4x700 MW) -- under construction	PHWR (700 MW NPCIL design)	India's largest upcoming PHWR project; construction delayed significantly; when completed will be India's largest indigenous nuclear plant
Jaitapur Nuclear	Maharashtra (Ratnagiri)	9,900 MW (6x1,650 MW	European Pressurised	Would be the WORLD'S LARGEST nuclear power plant by capacity

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Power Project (JNPP)		EPR reactors) -- planned	Reactor (EPR) -- French technology (EDF, Framatome)	when completed; location in the ecologically sensitive WG coast and cyclone zone; environmental clearance granted but construction not yet started; French financing and technology transfer negotiations ongoing; cost ~Rs.1.5 lakh crore

CURRENT AFFAIRS

PFBR First Criticality (2024) -- Stage 2 Milestone: The Prototype Fast Breeder Reactor (PFBR, 500 MW) at Kalpakkam, Tamil Nadu (operated by BHAVINI) achieved first criticality in 2024 -- meaning the nuclear chain reaction was self-sustaining for the first time. This is India's Stage 2 milestone -- the first FBR in India's nuclear programme. The PFBR was originally scheduled for completion in 2012; it was delayed by over a decade due to technical challenges (sodium handling, complex safety systems) and funding. When fully operational, the PFBR will demonstrate India's ability to breed Pu-239 fuel and convert thorium to U-233, validating the 3-stage programme. This is a landmark in Indian science and energy policy.

US-India Civil Nuclear Agreement (123 Agreement, 2008): The Indo-US Civil Nuclear Cooperation Agreement signed in 2008 (PM Manmohan Singh + President George W. Bush) ended India's 34-year nuclear isolation (India was sanctioned after Pokhran-I test in 1974). Key outcomes: India separated civil and military nuclear facilities; placed 14 of 22 reactors under IAEA safeguards; gained access to international nuclear fuel and technology market; Westinghouse (USA) and GE-Hitachi agreed to build reactors in India (site: Kovvada, Andhra Pradesh -- 6 AP1000 reactors; stalled over liability issues); France (EDF: Jaitapur); Russia (Kudankulam). The Civil Liability for Nuclear Damage Act 2010 (CLNDA) created a liability framework but its provisions on supplier liability have deterred US and French companies from finalising contracts.

26.5 INDIA'S ENERGY SECURITY -- CHALLENGES AND POLICIES

Challenge / Policy	*Detail*
Import dependence for crude oil	~80-85% import dependency; India is world's 3rd largest oil importer; price volatility directly impacts inflation (petrol/diesel/LPG prices), current account deficit and GDP growth; the 2022 Russia-Ukraine war oil price spike was a major economic stress
Strategic Petroleum Reserve (SPR)	Three underground rock cavern facilities: Visakhapatnam (1.33 MT), Mangaluru (1.5 MT), Padur (2.5 MT); total ~5.33 MT (~9.5 days of crude import cover vs IEA-recommended 90 days); India joined IEA as full member (January 2021); Phase 2 SPR at Chandikhol (Odisha, 4 MT) and Padur extension planned
Coal import for power and steel	Despite being the 2nd largest coal producer, India imports ~240-260 MT of coal annually: (a) coking coal for steel plants (approx. 50-60 MT from Australia, USA, Canada -- India lacks sufficient quality coking coal); (b) thermal coal for coastal power plants (UMPP at Mundra, Tiroda etc. designed for imported coal); import dependency = forex outflow and price vulnerability
Gas infrastructure gap	India's gas pipeline network coverage is uneven; eastern and NE India poorly connected; CGD (City Gas Distribution) in many cities still nascent; gas share of India's energy mix is only ~6% vs global average of ~25%; India aims to raise this to 15% by 2030
Ethanol Blending Programme (EBP)	Reduce petrol import dependence; target E20 (20% ethanol blending) by 2025 (advanced from earlier 2030 target); ethanol primarily from sugarcane (also damaged grain, rice straw in future); E20 requires minor vehicle modifications; programme helps

	sugarcane farmers (diverts surplus sugar to ethanol) and reduces forex outflow on crude; 17%+ blending achieved in 2024 in many states
Pricing reforms	Petrol deregulated (2010), diesel deregulated (2014); LPG partially subsidised through PM Ujjwala Yojana (5 crore BPL connections); DBT (Direct Benefit Transfer) for LPG subsidy; natural gas pricing reform (Rangarajan formula, then Kelkar Committee; now APM gas pricing + market pricing for high-pressure deep-water gas)
IEA membership (2021)	India became IEA's 31st associate member (2017) and then full member (2021); IEA provides: (a) energy data and analysis; (b) collective action mechanism including SPR drawdown coordination; (c) access to technology cooperation; India being the first IEA member without OECD status reflects India's strategic importance

26.7 CURRENT AFFAIRS HOOKS (2022-2025)

CURRENT AFFAIRS

India Coal Production Crosses 1 Billion Tonnes (2023-24): India's total coal production (CIL + SCCL + captive mines) crossed 1 billion tonnes for the first time in FY 2023-24. Coal India Limited alone produced a record 773 MT. India is the 2nd country ever to cross 1 BT coal production (after China). This milestone reflects India's accelerated coal mining to address the 2021-22 coal power crisis (when low coal stocks at power plants triggered fears of blackouts across India).

India-Russia Crude Oil Trade (Post-Ukraine War, 2022-2025): Following Western sanctions on Russian oil after the February 2022 Ukraine invasion, Indian refiners (IOC, HPCL, BPCL, private refiners) significantly scaled up Russian Urals crude purchases at a discount (USD 15-30/barrel below Brent). Russia became India's largest crude supplier (30-40% of imports) by 2023. The G7 oil price cap (USD 60/barrel for Russian oil; December 2022) India refused to join. India's position: sovereign energy security need; not bound by unilateral Western sanctions.

Ethanol Blending -- E20 Programme (2025): India achieved 14-17% average ethanol blending in petrol in FY 2023-24, ahead of schedule. The target is E20 (20% blending) by 2025. Ethanol from sugarcane (Maharashtra, UP, Karnataka) + damaged grain + FCI surplus rice. Benefits: saves ~USD 4-5 billion/year in crude imports; reduces petrol CO_2 by ~30%; supports sugarcane farmers. PM Narendra Modi has repeatedly highlighted the E20 programme as an example of energy security through agricultural diversification.

PFBR First Criticality (2024) -- Nuclear Milestone: The Prototype Fast Breeder Reactor (PFBR, 500 MW) at Kalpakkam, Tamil Nadu achieved first criticality in 2024 -- India's Stage 2 nuclear programme milestone, decades in the making. This validates India's ability to operate sodium-cooled FBR technology and moves closer to the thorium-based Stage 3 programme. India is among the very few countries (with Russia, China and France) to operate an FBR.

Jamnagar Refinery Complex: The Jamnagar Refinery Complex (Reliance Industries Ltd) in Gujarat has a total capacity of ~75 MMTPA -- making it the largest single-location refinery complex in the world. It processes 70+ types of crude oil. Reliance is developing a New Energy Giga Complex at Jamnagar with 4 giga factories for solar panels, green hydrogen, fuel cells, and battery storage.

26.8 PYQ ANALYSIS -- CHAPTER 26 (2010-2025)

Source	*Year*	*Marks*	*Question*
UPSC Civil	2024	15M	"Discuss the distribution of coal resources in India and their significance for the Indian economy. Critically examine the environmental and social costs of coal mining."
UPSC Civil	2023	12M	"India is the world's 3rd largest oil importer despite being an oil producer. Discuss India's petroleum sector, its import dependence and energy security measures."

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UPSC Civil	2022	10M	"Critically examine India's three-stage nuclear power programme. What are the reasons for its slow progress and what are its prospects?"
UPSC Civil	2021	15M	"Discuss the geography and distribution of natural gas resources in India. What is the significance of the KG Basin discovery and what challenges has it faced?"
UPSC Civil	2020	12M	"Discuss the environmental implications of coal-based energy in India and the policy measures adopted to balance energy security with environmental sustainability."
UPSC Civil	2019	10M	"What is the significance of Digboi oilfield in the context of India's petroleum industry? Discuss the major oilfields of India and their distribution."
UPSC Civil	2018	10M	"Discuss India's refinery capacity and its strategic significance for energy security and export potential."
UPSC Civil	2017	12M	"Examine the distribution of coalfields in India. Why does India need to import coal despite being a major coal producer?"
IFOS GS	2024	10M	"Discuss the environmental impact of coal mining on forest ecosystems in India, with specific reference to tribal displacement and forest loss in the coal belt."
IFOS GS	2023	10M	"Discuss the energy security dimensions of India's petroleum import dependence. How has India's purchase of Russian crude changed after the Ukraine war?"
IFOS GS	2022	10M	"What is India's three-stage nuclear power programme? Discuss its significance for India's long-term energy security and the role of thorium reserves."

KEY NOTE

Frequency: Coal geography + environment (Civil 2024); petroleum import dependence + energy security (Civil 2023); 3-stage nuclear programme (Civil 2022); KG Basin gas (Civil 2021); coal + environment policy (Civil 2020); Digboi + oilfields (Civil 2019); refinery capacity (Civil 2018); coal distribution + imports (Civil 2017). IFoS: coal mining tribal/forest impact (2024); Russia crude imports (2023); nuclear 3-stage + thorium (2022). For 2025-26: 1 BT coal production milestone; Russia crude imports post-Ukraine war; PFBR first criticality 2024; E20 ethanol blending achieving 20% target; Jamnagar New Energy Complex (Reliance); IEA membership 2021; Kudankulam Units 3-4 commissioning progress are the top current-affairs hooks.

26.9 MODEL BOOK

Discuss the distribution of coal resources in India and their significance for the economy. Critically examine the environmental and social challenges of coal mining

UPSC Civil (Mains) | 15 Marks | 210 Words

Coal is India's most abundant fossil fuel, the bedrock of its electricity system, and the centrepiece of its energy-environment dilemma. With the 4th largest reserves globally (~319 billion tonnes proved+indicated+inferred) and production crossing 1 billion tonnes in FY 2023-24, India is the 2nd largest coal producer in the world after China.

DISTRIBUTION OF COAL RESOURCES:

Gondwana Coalfields (~98% of reserves; Permian age ~280 Ma):

Damodar Valley (Jharkhand-WB): Jharia (India's most important coking coal; underground fires since 1916 -- BCCL-managed crisis), Raniganj (India's oldest coalfield, 1774), Bokaro, Ramgarh.

Mahanadi-Son Valley (CG-MP): Korba (NTPC's 2,600 MW plant), Singrauli (NCL; NTPC Vindhyachal -- India's largest thermal plant at 4,760 MW).

Godavari Valley (Telangana-AP): Singareni (SCCL -- only southern coalfield; essential for Andhra-Telangana power).

Odisha (Mahanadi Coalfield): Talcher-Angul (MCL; fastest growing; also Talcher Fertilizer Plant using coal gasification).

Tertiary Coalfields (~2%): NE India (Assam, Meghalaya, Nagaland) -- lower quality, sub-bituminous to lignite; high sulphur; used locally.

Lignite: Neyveli, TN (NLC India Ltd; ~3,900 MT reserves; powers NLC thermal stations).

ECONOMIC SIGNIFICANCE: Coal generates ~50-52% of India's electricity. CIL (Coal India Limited) -- world's largest coal miner -- produces 80% of India's coal; top PSU by volume. 1 BT production supports power, steel (coking coal), cement, fertiliser industries. Coal sector employment: ~5 lakh formal + 5x informal workers.

ENVIRONMENTAL AND SOCIAL CHALLENGES:

1. **Deforestation:** Open-cast mining (~90% of CIL production) destroys forests (Hasdeo Arand in CG; central India coal belt; overlap with Schedule V tribal areas and biodiversity-rich forests).
2. **Tribal displacement:** Coal-bearing areas (Jharkhand, Odisha, CG) are Scheduled Tribe majority areas; displacement without FRA 2006 compliance, inadequate rehabilitation; Supreme Court Samatha judgment (1997) and Niyamgiri SC order (2013) established limits to mining on tribal lands.
3. **Jharia underground fire:** Burning since 1916; toxic fumes, subsidence, endangering Jharia township (~27,000 families); decades-old crisis unresolved.
4. **Air and water pollution:** Coal combustion = India's largest SO2 and PM source; fly ash (~230 MT/year) pollutes rivers and groundwater; tightened MOEF emission norms (2017) widely unenforced.

COAL VS CLIMATE COMMITMENT: India committed to "phase down" (not phase out) coal at COP26 Glasgow (2021); production reached 1 BT in 2023-24. The core tension: energy access for 1.4 billion vs net zero 2070. India's 500 GW non-fossil capacity target by 2030 is the "just transition" pathway.

Coal's geography -- concentrated in the tribal, forested heartland of central and eastern India -- means that mining it extracts a disproportionate social and environmental cost from communities that do not primarily benefit from the electricity it generates. A just energy transition requires coal transition roadmaps, robust tribal consent processes under PESA and FRA, and investments in coal-dependent communities.

Critically examine India's three-stage nuclear power programme. What is its strategic significance and what are the challenges to its realisation?

UPSC Civil/IFOS (Mains) | 15 Marks | 200 Words

India's three-stage nuclear power programme -- conceived by Dr. Homi Jehangir Bhabha in 1954 -- is one of the most ambitious long-term energy technology strategies in history. Designed to exploit India's unique resource endowment (large thorium reserves, limited uranium), it aims to ultimately provide virtually unlimited energy from thorium, the 20th century equivalent of India's coal or oil.

THE THREE-STAGE LOGIC:

Stage 1 -- PHWRs (OPERATIONAL): Pressurised Heavy Water Reactors using natural uranium (no enrichment needed -- key for India which lacks enrichment technology and was under nuclear sanctions). 24 PHWRs operational (7,480 MW). By-product: Plutonium-239 (Pu-239) in spent fuel. Strategic significance: builds the Pu-239 stockpile needed for Stage 2.

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Stage 2 -- FBRs (PROTOTYPE STAGE): Fast Breeder Reactors using Stage 1's Pu-239 as fuel + depleted U-238 in the blanket. The FBR BREEDS MORE Pu-239 AND converts thorium blanket to Uranium-233 (for Stage 3). The PFBR (500 MW) at Kalpakkam achieved first criticality in **2024** -- a major landmark (~12 years delayed from 2012 original schedule). Stage 2 significance: multiplies India's fissile material base by 50-100x; makes vast depleted uranium stockpile usable.

Stage 3 -- Thorium Reactors (RESEARCH STAGE): Advanced Heavy Water Reactors (AHWR) using Stage 2's U-233 + Thorium-232. India has ~846,000 tonnes of thorium reserves (25-30% of world total; concentrated in Kerala-TN-Odisha-AP-WB coastal monazite sands and inland deposits in Rajasthan and Bihar). Stage 3 would give India effectively unlimited domestic nuclear fuel -- independence from uranium imports; low proliferation risk; minimal long-lived waste. Target: 2040s+ for commercial Stage 3 deployment.

STRATEGIC SIGNIFICANCE:

1. **Energy Independence:** India's limited uranium reserves (~70,000 tonnes) cannot sustain a large nuclear programme for long. Thorium's abundance makes Stage 3 the ultimate answer to energy security.
2. **Climate Solution:** Nuclear is low-carbon, dispatchable (unlike solar/wind), baseload power -- essential for India's net-zero 2070 ambition alongside renewables.
3. **Technological Leadership:** Few countries (Russia, China, France) have operated FBRs; India becoming the 4th demonstrates advanced nuclear engineering capability.

CHALLENGES:

1. **Pace:** PFBR was 12+ years behind schedule; Stage 3 is likely 2040s at the earliest; total programme duration 60-80 years from inception. Scale of electricity (7,480 MW now vs target of 63,000 MW by 2032) far behind.
2. **Uranium supply:** Stage 1 PHWRs need uranium; India's domestic supply (Jadugoda, Tummalapalle) is limited; depends on imports (from Canada, Australia, France, Russia, Kazakhstan post-123 Agreement); any supply disruption would idle Stage 1 plants.
3. **Liability:** Civil Liability for Nuclear Damage Act 2010 (CLNDA) has supplier liability provisions that deter US (Westinghouse/Kovvada) and French (EDF/Jaitapur) companies from finalising reactor supply contracts; industry wants pure operator liability; government maintains supplier accountability.
4. **Cost and land:** Jaitapur NPP (9,900 MW; 6 EPR units; world's largest when built) faces cost overruns, financing uncertainty and community opposition in ecologically sensitive WG coastal Maharashtra.

The three-stage programme remains India's most visionary energy strategy -- but its realisation will span a century from inception to mature Stage 3 deployment. The 2024 PFBR criticality is an important milestone; sustained political will, research investment and international cooperation (post-123 Agreement) are needed to actualise the thorium dream.

CHAPTER 27

RENEWABLE ENERGY SOURCES ENERGY

Solar, Wind, Hydro, Biomass, Geothermal and Tidal

CHAPTER AT A GLANCE

- India targets 500 GW of non-fossil electricity capacity by 2030 (COP26 Glasgow 2021); 50% electricity from renewables by 2030. Total installed renewable energy capacity ~200+ GW (excluding large hydro) by early 2024, making India 4th globally in RE capacity. Solar alone = ~90 GW installed (March 2024). Wind = ~46-47 GW. Large Hydro = ~47 GW. Small Hydro = ~5 GW. Biomass + Biogas + Waste-to-Energy = ~10 GW.
- SOLAR: India receives 4-7 kWh/m2/day solar irradiation -- among the highest in the world. Rajasthan, Gujarat, MP, Ladakh have highest solar potential. Largest solar parks: Bhadla Solar Park (Rajasthan, 2,245 MW = one of world's largest); Pavagada (Karnataka, 2,050 MW); Rewa (MP, 750 MW). PM Surya Ghar Muft Bijli Yojana (2024): 1 crore rooftop solar installations; 300 units free electricity. International Solar Alliance (ISA) -- India-France initiative, launched Paris COP21 2015, headquarters Gurugram.
- WIND: India is 4th largest wind energy country globally. Best wind resources: Tamil Nadu, Gujarat, Rajasthan, Karnataka, Andhra Pradesh, Madhya Pradesh, Maharashtra. India's tallest wind turbine hub height = 140m (onshore). First offshore wind policy: National Offshore Wind Energy Policy 2015; first offshore wind farm planned off Tamil Nadu and Gujarat coasts. MNRE target: 140 GW wind by 2030 (60 GW offshore + 80 GW onshore). Largest onshore wind farm: Muppandal (Tamil Nadu, ~1,500 MW, Kanyakumari district).
- HYDROPOWER: India has 4th largest hydropower potential globally (~1,45,320 MW technically exploitable). Only ~47 GW large hydro + ~5 GW small hydro exploited = less than 40% utilisation. Key large dams: Tehri (260 m; Uttarakhand; 1,000 MW), Bhakra-Nangal (Himachal Pradesh; 1,325 MW), Sardar Sarovar (Gujarat; 1,450 MW), Hirakud (Odisha; 347.5 MW), Idukki (Kerala; 780 MW). Hydropower states: HP, Uttarakhand, J&K, Arunachal Pradesh, Sikkim. HP has highest installed hydro capacity.
- BIOMASS AND BIOGAS: India is the largest producer of biomass-based energy in Asia. ~32% of primary energy from biomass (firewood, dung, agri-residue). Bagasse-based cogeneration in sugar mills (Maharashtra, UP, Karnataka -- top sugar states). National Biogas Programme; PM Urja Ganga pipeline for piped biogas; SATAT (Sustainable Alternative Towards Affordable Transportation) -- compressed biogas (CBG) from agricultural waste, municipal solid waste; target 5,000 CBG plants by 2024.
- GREEN HYDROGEN: National Green Hydrogen Mission (NGHM) launched January 2023 by PM Modi. Target: 5 million tonnes/year (MMTPA) green hydrogen production capacity by 2030. Investment: Rs.19,744 crore government outlay. Electrolyzer manufacturing target: 5 GW/year by 2025. Green hydrogen = hydrogen produced by electrolysis using renewable electricity (zero CO2). India aims to be a major green hydrogen exporter. NTPC, ONGC, Reliance, Adani Green all major participants.
- TIDAL AND GEOTHERMAL: Limited commercial development in India. Tidal: Gulf of Kutch (potential ~900 MW; India's first tidal power project proposed here; Hansthal Tidal Power Station 50 MW pilot), Sundarbans estuary. Geothermal: Puga Valley (Ladakh) = India's most promising geothermal site (natural hot springs; Himalayan geothermal belt); also Manikaran (HP), Tattapani (MP), Surajkund (Jharkhand). No commercial geothermal power plant in India yet as of 2024.
- KEY POLICIES AND AGENCIES: Ministry of New and Renewable Energy (MNRE). National Institute of Solar Energy (NISE), Gurugram. National Institute of Wind Energy (NIWE), Chennai. Production-linked incentive (PLI) for solar PV modules and wind turbines. Renewable Purchase Obligation (RPO) -- mandatory % of electricity from renewables for distribution companies. Green Energy Corridor (GEC) -- transmission infrastructure for renewable energy. Pradhan Mantri Kisan Urja Suraksha evam Utthaan Mahabhiyan (PM-KUSUM) -- solar for agriculture pumps.

27.1 INTRODUCTION -- INDIA'S RENEWABLE ENERGY REVOLUTION

India is in the midst of the **fastest renewable energy expansion of any large economy in the world** -- a transformation driven simultaneously by energy security imperatives (reducing import dependence on fossil fuels), climate commitments (net zero by 2070; 500 GW non-fossil by 2030), and falling costs of solar and wind technology. Between 2014 and 2024, India's renewable energy capacity grew from ~76 GW to over **~200 GW (excluding large hydro),** representing a growth of ~164% in a decade.

India's **pledges at COP26 (Glasgow, November 2021)** -- known as the "Panchamrit" (five nectar/five pledges) by PM Narendra Modi -- set the framework for this renewable push:

- Reach **500 GW of non-fossil electricity capacity** by 2030.
- Meet **50% of energy requirements from renewables** by 2030.
- Reduce the **emissions intensity of GDP by 45%** (from 2005 levels) by 2030.
- Achieve **net zero carbon emissions by 2070.**
- Reduce **total projected carbon emissions by 1 billion tonnes** by 2030.

INDIA'S RENEWABLE ENERGY CAPACITY -- STATUS (2024)

Source	*Installed Capacity (approx. March 2024)*	*% of Total RE Capacity*	*Target by 2030*	*Key States*
Solar PV (Ground-mounted + Rooftop)	~90 GW (total solar including both)	~43% of non-fossil capacity	280 GW solar by 2030	Rajasthan, Gujarat, Karnataka, Tamil Nadu, Andhra Pradesh, MP
Wind (Onshore)	~46-47 GW	~22%	140 GW wind by 2030 (80 GW onshore + 60 GW offshore)	Tamil Nadu, Gujarat, Rajasthan, Karnataka, AP, Maharashtra, MP
Large Hydro (>25 MW)	~47 GW	~22% (often listed separately as it predates the RE era)	Existing + Arunachal Pradesh development	HP, Uttarakhand, J&K, Arunachal Pradesh, Sikkim
Small Hydro (<25 MW)	~5 GW	~2.3%	Modular hydro on hill streams; NE India	HP, Uttarakhand, Arunachal Pradesh, NE states
Biomass (Bagasse cogeneration, biomass power plants)	~10.6 GW	~5%	Include CBG under SATAT	Maharashtra, UP, Karnataka, Tamil Nadu
Waste to Energy	~0.5 GW	<0.3%	Growing with Smart Cities Mission	Urban centres; Delhi, Mumbai, Bengaluru
Small Wind (off-grid) + Others	<1 GW	Marginal	Distributed energy	Remote villages
TOTAL NON-FOSSIL (incl. nuclear)	~200+ GW RE + ~47 GW large hydro + ~7.5 GW nuclear	~40-45% of total installed capacity	500 GW non-fossil by 2030	Pan-India

KEY NOTE

Key Number for Exams: India's installed renewable energy capacity (excluding large hydro) crossed **200 GW in early 2024**. With large hydro (~47 GW) and nuclear (~7.5 GW) included, India's total NON-FOSSIL capacity approaches ~260 GW -- well on track toward the 500 GW 2030 target. India is the **4th largest country by renewable energy installed capacity** globally (after China, USA, Germany). Solar alone was ~90 GW in March 2024 and growing at ~15-20 GW per year.

27.2 SOLAR ENERGY -- INDIA'S FASTEST GROWING RENEWABLE

Solar energy is the **centrepiece of India's renewable energy transition.** India receives an average solar irradiation of **4-7 kWh per square metre per day** (kWh/m2/day) across the country -- one of the highest in the world -- with the highest levels in **Rajasthan, Gujarat, Ladakh, and parts of Madhya Pradesh, Andhra Pradesh and Tamil Nadu.** India's total solar energy potential is estimated at over **748 GW** (MNRE estimate; based on 3% of wasteland for solar parks at 5 MW/sq km), though the practical exploitable potential is far higher.

SOLAR IRRADIATION ZONES

Zone	*Solar Irradiation (GHI)*	*Primary States*	*Significance*
Highest Solar Zone (Desert Zone)	6.0-7.5+ kWh/m2/day	Rajasthan (Thar Desert), Gujarat (Kachchh), Ladakh (Changtang plateau)	Among the world's best solar resources; Rajasthan = India's solar capital; Bhadla Solar Park (Jodhpur); Ladakh has exceptional insolation due to altitude + clear skies + minimal cloud cover but extreme temperatures and remote location
High Solar Zone	5.0-6.5 kWh/m2/day	Madhya Pradesh, Andhra Pradesh, Telangana, Maharashtra (interior), Karnataka	Second tier; still excellent for utility-scale solar; Rewa Solar Park (MP); Pavagada (Karnataka); Kurnool Ultra Mega Solar Park (AP)
Moderate Solar Zone	4.5-5.5 kWh/m2/day	Tamil Nadu, Odisha, Jharkhand, Chhattisgarh, Punjab, Haryana	Good but not exceptional; still commercially viable; TN has historically led wind + is growing solar
Lower Solar Zone	3.5-4.5 kWh/m2/day	Northeast India (high rainfall and cloud cover), J&K valleys (high altitude but cloud cover in summer monsoon), WG (heavy monsoon cloud)	Less ideal but still exploitable; NE India being developed with off-grid solar for remote villages

MAJOR SOLAR PARKS AND PROJECTS

Solar Park / Project	*State*	*Capacity*	*Key Feature*
Bhadla Solar Park	Rajasthan (Jodhpur district)	~2,245 MW (Phase 1-4 combined)	One of the world's LARGEST single solar parks by installed capacity; ultra-high solar irradiation; developed by RRECL (Rajasthan Renewable Energy Corporation Ltd) and SECI (Solar Energy Corporation of India); multiple developers including Adani, SoftBank-SB Energy, Azure Power, Solarpack
Pavagada	Karnataka	2,050 MW	2nd largest in India; land leased from farmers

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Solar Park (Shakti Sthala)	(Tumakuru district)		(unique model -- farmers receive Rs.21,000/acre/year lease plus return of land after 25 years); 5 zones with multiple developers; KREDL (Karnataka Renewable Energy Development Ltd)
Rewa Ultra Mega Solar Park	Madhya Pradesh (Rewa district)	750 MW (3x250 MW)	Landmark project (2020); first large-scale solar in India with NO SUBSIDY (discovered cost of solar had fallen enough to be competitive at Rs.2.97/kWh); Delhi Metro is a direct buyer (its first renewable energy purchase); set a record low tariff in India at the time (Rs.2.97/kWh in 2017)
Kurnool Ultra Mega Solar Park	Andhra Pradesh (Kurnool district)	1,000 MW	Largest solar park in AP; 5,932 acres; developed by NREDCAP; feeds the AP grid; SECI involvement
Kamuthi Solar Power Project	Tamil Nadu (Ramanathapuram district)	648 MW	When completed in 2016, it was the world's largest single-location solar plant; 45 sq km; Adani Green Energy
Gujarat Solar Parks (multiple)	Gujarat (Charanka, Khavda, Morbi)	3,000+ MW combined in development	Khavda Renewable Energy Park in development: 30 GW combined solar + wind -- will be the world's LARGEST renewable energy park when complete (2029-30 target)
Ladakh Renewable Energy Zone	Ladakh (Leh, Changthang plateau)	Potential: 5,000-23,000 MW identified	Ultra-high altitude solar; exceptional irradiation; connected to the national grid via the proposed Green Energy Corridor-III from Ladakh to Punjab (planned 900 km HVDC line)

KEY SOLAR ENERGY SCHEMES AND POLICIES

Scheme / Policy	*Year*	*Key Feature*
National Solar Mission (NSM) / Jawaharlal Nehru National Solar Mission (JNNSM)	2010 (Phase 1); revised targets through 2022	Original target: 20 GW by 2022; revised upward to 100 GW solar by 2022 (target largely achieved by 2024 after some delay); now part of the 500 GW 2030 target; NSM is one of 8 National Action Plan on Climate Change (NAPCC) missions
PM Surya Ghar Muft Bijli Yojana	Launched February 2024 by PM Modi	Target: 1 crore (10 million) rooftop solar installations in residential homes; beneficiaries get 300 units per month FREE electricity (offset by solar generation); subsidies of up to Rs.78,000 per household; Rs.75,021 crore total outlay; aims to add 30 GW of rooftop solar; also reduces electricity bills and creates local employment
PM-KUSUM (Pradhan Mantri Kisan Urja Suraksha evam Utthaan Mahabhiyan)	2019 (launched)	Solar for agriculture: (a) Component A: Small solar power plants (up to 2 MW) on barren/fallow land by farmers, selling power to grid at guaranteed tariff; (b) Component B: Solar pump sets for individual farmers (off-grid, replacing diesel pumps -- saves fuel, reduces costs, reliable water for irrigation); (c) Component C: Solarisation of existing grid-connected agriculture pumps; targets: 20 lakh solar pumps, 15 lakh solarised grid-connected pumps
Rooftop Solar	2015-2023	Phase 1 and 2 target: 40 GW rooftop solar by 2022 (partially

Programme (earlier phase)		achieved ~12 GW by 2024); now superseded by PM Surya Ghar Yojana 2024; residential + commercial + industrial rooftop solar
Solar Energy Corporation of India (SECI)	2011	A Government of India CPSE under MNRE; acts as the nodal agency for developing large solar parks (including Bhadla, Rewa, Khavda); conducts solar tenders; signs Power Purchase Agreements (PPAs); manages the process from project development to commissioning
Production Linked Incentive (PLI) for Solar PV	2021	PLI scheme for domestic manufacturing of high-efficiency solar PV modules; Rs.24,000 crore outlay; incentivise manufacturers to produce solar cells and modules in India; address India's current dependence on Chinese solar panels; NTPC, Adani Solar, Waaree, Vikram Solar among beneficiaries
Approved Models and Manufacturers (ALMM) List	2019 (enforced strictly from 2023)	Only solar modules from MNRE-approved manufacturers can be used in government-funded projects; designed to ensure quality and promote domestic manufacturing; addresses concerns about sub-standard imported modules
International Solar Alliance (ISA)	Initiative launched at COP21 Paris 2015 by PM Modi and French President Hollande	Framework treaty-based intergovernmental organisation of solar-resource-rich countries (between Tropics of Cancer and Capricorn); headquartered at NISE, Gurugram; 120+ member countries; aims to mobilise USD 1 trillion solar investment by 2030; ISA became a full UN observer in 2021

CURRENT AFFAIRS

PM Surya Ghar Muft Bijli Yojana (February 2024) -- Key Details: Launched by PM Modi on February 13, 2024, this is the world's largest domestic rooftop solar programme. Target: 1 crore residential households equipped with rooftop solar by 2026-27. A 1 kW rooftop system generates ~1,200-1,300 kWh/year -- enough to cover most residential electricity needs in India with 300 free units/month commitment from the scheme. Central subsidy: Rs.30,000 for 1 kW; Rs.60,000 for 2 kW; Rs.78,000 for 3 kW+. The scheme directly addresses India's challenge of grid-connected decentralised solar (rooftop has grown much slower than utility-scale solar due to net-metering policy issues and upfront cost barriers).

27.3 WIND ENERGY -- INDIA'S 2ND LARGEST RENEWABLE SOURCE

Wind energy is India's **2nd largest renewable electricity source** (after large hydro by installed capacity, though after solar in more recent additions). India is the **4th largest wind energy country globally** (after China, USA and Germany) with ~46-47 GW of installed wind capacity as of early 2024. Wind power is generated when moving air (wind) drives the blades of a wind turbine, rotating a shaft connected to a generator.

WIND RESOURCE MAP OF INDIA

Wind Zone	*Annual Mean Wind Speed*	*States*	*Key Feature*
ZONE I (Highest Wind Potential)	Mean annual wind speed >6 m/s at 80 m hub height; capacity factors >30%	Tamil Nadu (Kanyakumari, Tirunelveli, Coimbatore), Gujarat (Kutch, Saurashtra), Rajasthan (Jaisalmer, Barmer), Karnataka (Chitradurga, Gadag, Davangere)	These zones have been heavily exploited for wind since the 1980s-90s; Tamil Nadu was India's original wind power leader; Muppandal Wind Farm (Kanyakumari district) = India's largest onshore wind cluster

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ZONE II (Good Wind)	5-6 m/s; capacity factors 25-30%	Andhra Pradesh (Anantapur, Kurnool), Maharashtra (Dhule, Ahmednagar, Satara, Sangli), Madhya Pradesh (Dewas, Indore, Rajgarh), Jharkhand	Growing rapidly; AP and Telangana have expanded wind capacity significantly; Maharashtra's Dhule is a major wind hub
ZONE III (Moderate Wind)	4-5 m/s; capacity factors 20-25%	Parts of Odisha, Chhattisgarh, Himachal Pradesh (specific mountain passes), Uttarakhand (Chamoli, Pauri ridges)	Moderate potential; newer higher-hub-height turbines (120-140 m) make previously unviable areas feasible
Offshore Wind Zones	Wind speeds >7-9 m/s at offshore locations (stronger and more consistent than onshore)	Gujarat coast (Gulf of Khambhat, Kutch coast), Tamil Nadu coast (Palk Strait area, Gulf of Mannar), Andhra Pradesh coast	NO commercial offshore wind in India yet as of 2024; first projects tendered by SECI (1 GW offshore Gujarat + 1 GW offshore TN); expected to come online 2027-28; 60 GW offshore wind target by 2030

MAJOR WIND FARMS AND PROJECTS

Wind Farm	*State*	*Capacity*	*Key Feature*
Muppandal Wind Farm (Kanyakumari Wind Energy Cluster)	Tamil Nadu (Kanyakumari district)	~1,500 MW (multiple wind farms combined in the Muppandal-Aralvaimozhi-Kayathar corridor)	INDIA'S LARGEST ONSHORE WIND CLUSTER; oldest major wind development in India (started 1980s); southern tip of India with excellent wind; multiple owners including Suzlon, Inox Wind, ReNew Power, private
Jaisalmer Wind Park	Rajasthan (Jaisalmer)	~1,064 MW (single park)	Among India's largest single-location onshore wind parks; developed by Suzlon Energy; Thar Desert provides excellent wind with minimal obstruction; also allows hybrid solar+wind on same land
Brahmanvel Wind Farm	Maharashtra (Dhule)	~528 MW	One of Maharashtra's largest wind projects; part of the Dhule wind belt
Welspun Renewables Wind Farms	Rajasthan, MP, Gujarat	Multiple projects totalling 1,000+ MW	Welspun Renewables (now Adani Green after acquisition) has large wind portfolio
Adani Green Wind Portfolio	Rajasthan, Gujarat, Tamil Nadu	3,000+ MW wind in operation and pipeline	India's largest renewable energy company by target capacity; 45 GW target by 2030; large wind + solar hybrid projects planned
Offshore Wind -- SECI Tender	Gujarat coast and Tamil Nadu coast	2x1 GW = 2 GW first tranche (tendered 2024)	INDIA'S FIRST OFFSHORE WIND TENDERS; viability gap funding from government; expected tariff Rs.7-9/kWh (much higher than onshore ~Rs.2.8/kWh); construction challenges (port infrastructure, vessels, foundation installation) remain significant

WIND ENERGY TECHNOLOGY -- KEY TERMS

Term	*Explanation*	*Indian Context*
Hub Height	Height of the turbine tower (where the rotor hub is mounted); higher hub = stronger, more consistent wind; older turbines: 60-80 m; modern turbines: 100-140 m; offshore: 120-160 m	India now deploying 140 m hub height turbines in low-wind-speed zones (UP, Bihar, Jharkhand) that were previously considered unviable for wind; this is expanding India's wind resource geography
Rotor Diameter (Swept Area)	Diameter of the circle swept by the three blades; power output proportional to swept area (proportional to diameter squared); modern turbines: 100-160 m rotor diameter	Larger rotors capture more wind energy; offshore turbines will have 200+ m rotor diameters
Capacity Factor	Actual energy generated as % of theoretical maximum (if running at full rated power 24x7); onshore India: 25-35%; offshore: 35-45%	Lower than solar in India (which has 18-25% capacity factor); but wind often generates when solar does not (at night, in monsoon cloud cover), making the combination of solar+wind valuable
Repowering	Replacing old, smaller turbines with new, larger, more efficient turbines on the same wind sites	India has ~10 GW of old turbines (pre-2005) eligible for repowering; MNRE Repowering Policy 2016; can increase output from same land by 2-3x without new land acquisition
Hybrid Wind-Solar	Combining wind and solar on the same land or with shared infrastructure; wind and solar complementary (wind stronger in night/monsoon; solar in day/summer)	MNRE Hybrid Policy 2018; Rajasthan and Gujarat ideal for hybrid parks; Adani, ReNew Power, Greenko developing large hybrid projects; better grid utilization from same transmission corridor

22.4 HYDROPOWER -- INDIA'S LEGACY RENEWABLE

Hydropower is India's oldest and most developed renewable energy source, generating electricity from the potential and kinetic energy of flowing water. India has the **4th largest hydropower potential in the world** -- estimated at approximately **1,45,320 MW of technically exploitable potential** (Central Electricity Authority data) -- but has developed only about **~40% of this potential** (~52 GW total including small hydro). The remaining ~85,000 MW of unexploited potential is concentrated primarily in the **Himalayan states (Arunachal Pradesh, Uttarakhand, Himachal Pradesh, Sikkim, J&K)** and the northeast.

CLASSIFICATION OF HYDROPOWER PROJECTS

Category	*Definition*	*Examples in India*	*% of India's Total Hydro Potential*
Large Hydro (>25 MW)	Dams and reservoirs of significant scale; usually involves impoundment of rivers	Tehri (1,000 MW), Bhakra-Nangal (1,325 MW), Sardar Sarovar (1,450 MW), Hirakud (347.5 MW), Koyna (1,960 MW, Maharashtra), Idukki (780 MW, Kerala), Nathpa Jhakri (1,500 MW, HP)	~85% of technically exploitable potential; most large sites are in the Himalaya
Small Hydro (<25 MW)	Run-of-river schemes; minimal impoundment; less environmental impact;	Himalayan streams, NE India hill streams, WG streams (Kerala, Karnataka); ~5 GW installed	~15% of potential; much easier to develop than large hydro; MNRE

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	suitable for remote hilly areas		manages small hydro programme separately
Mini Hydro (<2 MW)	Very small; often off-grid for remote villages	Himalayan villages, Arunachal Pradesh, Sikkim rural electrification	Part of small hydro category; important for village electrification in hilly terrain
Micro Hydro (<100 kW)	Very small turbines for individual households or community clusters	Remote Himalayan hamlets; earlier MNRE rural electrification scheme	Off-grid; valuable for areas where grid extension is uneconomical
Pumped Storage Hydropower (PSH)	Two reservoirs at different elevations; pumps water UP during low-demand periods (using cheap surplus electricity, especially solar at midday), releases it DOWNHILL through turbines during peak demand; acts as a large-scale BATTERY	Kadamparai (400 MW, Tamil Nadu), Nagarjunasagar (830 MW, Telangana), Ghatghar (250 MW, Maharashtra); many more planned in conjunction with large solar	~96,000 MW of PSH potential identified by CEA; India plans 18,800 MW additional PSH by 2032; CRITICAL for balancing intermittent solar and wind

MAJOR HYDROPOWER PROJECTS -- STATE-WISE

State	Installed Hydro Capacity (approx.)	Key Projects	Key Feature
Himachal Pradesh	~11,000 MW (highest installed hydro capacity in India)	Nathpa Jhakri (1,500 MW, Sutlej; SJVNL), Bhakra (1,325 MW, Sutlej; BBMB), Pong Dam (396 MW, Beas), Chamera I-III (846 MW, Ravi), Nathpa Jhakri (1,500 MW)	HP relies on hydropower for its electricity and earns substantial royalties from hydropower generated in the state; major surplus state selling power to grid
Uttarakhand	~4,300 MW	Tehri Dam (1,000 MW, Bhagirathi; THDC India); Maneri Bhali I-II (90+304 MW, Bhilangana); Koteshwar (400 MW, Bhagirathi); Singoli-Bhatwari; multiple NTPC projects in Tapovan-Vishnugad area	Tehri = tallest dam in India (260 m); Bhagirathi system (Ganga source); Kedarnath 2013 disaster and Chamoli 2021 rock-ice avalanche both damaged hydro projects; risk of Himalayan glacial lake outburst floods (GLOFs) for downstream hydro
Arunachal Pradesh	~1,400 MW operational; 50,000+ MW potential remaining	Subansiri Lower (2,000 MW -- India's LARGEST planned hydropower project; on Subansiri River; NHPC; under construction; controversial; court stays); Ranganadi (405 MW); Kameng (600 MW)	Largest unexploited hydro potential in India; Chinese damming of Brahmaputra upstream raises strategic concerns; tribal displacement and downstream flood risk contentious issues; ecological concerns about free-flowing rivers
Jammu and	~3,400 MW	Salal (690 MW, Chenab; NHPC),	Strategic: rivers flow into Pakistan

Kashmir / Ladakh	(J&K division) + ~50 MW (Ladakh UT)	Dul Hasti (390 MW, Marusudar/Chenab), Uri I-II (480+240 MW, Jhelum; NHPC), Kishanganga (330 MW, Kishanganga-Jhelum; NHPC)	(Indus Water Treaty 1960 governs India-Pakistan water sharing on Indus basin rivers); Pakistan objects to Indian hydropower projects it views as violating IWT; Kishanganga case went to Permanent Court of Arbitration; Baglihar Dam also contested
Sikkim	~580 MW operational; 8,000+ MW potential	Teesta Stage-V (510 MW, Teesta), Rangit IV (120 MW)	TEESTA FLASH FLOOD October 4, 2023: Glacial Lake Outburst Flood (GLOF) from South Lhonak Glacial Lake (at ~5,200 m altitude) in Sikkim; destroyed the newly commissioned Teesta-III reservoir (1,200 MW, under NHPC); killed 100+ people; 4,000+ missing; major infrastructure damage; highlighted GLOF risk for Himalayan hydropower
Kerala	~3,800 MW	Idukki (780 MW, Periyar; KSEB), Sholayar (54 MW), Pamba and Kallada schemes; Kadamparai PSH (400 MW)	Kerala = only major southern state with significant hydro; Western Ghats rivers provide good head; Mullaperiyar Dam controversy (Tamil Nadu uses water; Kerala worried about safety of 119-year-old British-era dam); Idukki arch dam = one of largest arch dams in Asia

ENV ALERT

Hydropower and Environmental Concerns -- IFoS Critical Topic:
Large hydropower projects in India face significant environmental, ecological and social challenges: (1) **Deforestation and biodiversity loss:** Reservoir submergence destroys forests; Narmada Valley Development Project (Sardar Sarovar) submerged approximately 37,000 ha of forests (though compensatory afforestation was planned); Subansiri Lower Project in Arunachal Pradesh/Assam faces court challenges over impacts on biodiversity and downstream Brahmaputra flows. (2) **Tribal displacement:** Narmada Valley projects displaced an estimated 2.5-3 lakh tribal people (Adivasis) of the Narmada Bachao Andolan (NBA) fame; Medha Patkar's decades-long movement against the dam highlighted the inadequacy of rehabilitation. (3) **Sedimentation:** Himalayan rivers carry extreme sediment loads; reservoirs silt up rapidly, reducing power output and storage capacity; Bhakra Nangal has lost significant storage due to sedimentation over 60+ years. (4) **GLOF risk:** Climate change is expanding glacier lakes in the Himalaya; the Teesta-III GLOF disaster (October 2023, Sikkim) is a warning for all high-altitude hydropower in glaciated catchments.

22.5 BIOMASS AND BIOGAS ENERGY

Biomass energy is the **oldest form of energy used by humans** and remains critically important in India. Approximately **32% of India's total primary energy consumption comes from traditional biomass** (firewood, agricultural residue, dung cakes) -- primarily used for cooking by rural households who lack access to LPG or electricity. This represents both a challenge (indoor air pollution kills ~500,000+ people in India annually according to WHO) and an opportunity (if converted to modern bioenergy like biogas, compressed biomass, or electricity).

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Biomass Category	Source	Scale in India	Key Scheme / Note
Bagasse-Based Cogeneration	Sugarcane crushing by-product (bagasse fibre after juice extraction); burned in sugar mills to generate steam + electricity; surplus power exported to grid	~10 GW installed cogeneration capacity; Maharashtra (largest), UP, Karnataka, Tamil Nadu are top states -- corresponding to the top sugar-producing states	States mandate that sugar mills install cogeneration; Maharashtra MSEDCL purchases surplus power; supports sugar mills' energy self-sufficiency; reduces coal dependence in sugar-producing belts
Biomass Power Plants (dedicated)	Agricultural residue (rice husk, mustard stalks, cotton stalks, corn cobs), plantation biomass (bamboo, casuarina, eucalyptus)	~1-2 GW dedicated biomass power plants; Punjab (rice husk from paddy); UP (bagasse and rice husk)	Rice husk is among the best biomass fuels (high calorific value, 3,200-3,600 kcal/kg); Punjab paddy rice husk power plants reduce pressure to burn stubble; a direct alternative to the stubble burning problem
Biogas (Traditional)	Anaerobic digestion of cow dung, organic waste (food waste, sewage sludge) in biogas digesters; produces methane (CH4) for cooking and lighting	~6-7 crore household biogas plants targeted; actual: ~5-6 crore installed; ~2 GW equivalent national biogas programme; National Biogas Programme (NBP) under MNRE	Gobar Gas (cow dung biogas) programmes from 1970s; MNRE's National Biogas and Manure Management Programme; critically important for reducing traditional biomass cooking (reduces indoor air pollution) and providing free organic fertiliser (slurry from digester)
Compressed Biogas (CBG) -- SATAT	Upgraded biogas (purified to >95% CH4) compressed to vehicle fuel standard; from agricultural waste (paddy straw, sugarcane trash), municipal solid waste (MSW), food waste	SATAT: Sustainable Alternative Towards Affordable Transportation scheme (launched 2018); target: 5,000 CBG plants producing 15 million tonnes/year by 2024 (target largely unachieved; ~100+ CBG plants operational by 2024; scale-up challenge)	CBG is essentially CLEAN COMPRESSED NATURAL GAS produced from waste; can substitute CNG in vehicles; uses waste paddy straw (reducing stubble burning); uses MSW (solving solid waste management); ONGC, Reliance, NTPC among investors; game-changer if scaled
Biofuel (Ethanol from Sugarcane/Grain)	Fermentation of sugarcane juice/molasses or damaged food grain to produce ethanol for blending with petrol	Ethanol Blending Programme (EBP): 15-17% achieved in 2023-24; target E20 (20%) by 2025; approximately 450+ crore litres ethanol production capacity	Reduces crude oil imports; supports sugarcane farmers; E20 requires all vehicles to be E20-compatible (most post-2019 vehicles are; mandatory from April 2023 in some fuel stations); Niti Aayog leads this initiative
Municipal Solid Waste (MSW)	Waste-to-energy (WtE): incineration or	~0.5 GW installed WtE capacity; 7 large WtE	Urban India generates ~60 MT of MSW/year; growing; WtE

Energy	gasification of MSW to generate electricity; also landfill gas recovery (methane from older landfills)	plants across Delhi, Mumbai, Bengaluru, Chennai; Okhla WtE Delhi (16 MW), Bawana WtE Delhi (24 MW)	controversial (concerns about dioxin emissions; competition from recycling/composting); NITI Aayog report argues WtE is necessary for large, mixed-waste Indian cities where segregation is low

22.6 GREEN HYDROGEN -- INDIA'S NEW ENERGY FRONTIER

Green hydrogen is **hydrogen gas (H2) produced by splitting water (H2O) into hydrogen and oxygen using electricity from renewable energy sources (solar, wind) through a process called electrolysis** -- with **zero direct CO2 emissions**. It is distinguished from:

- **Grey Hydrogen:** Produced from natural gas via steam methane reforming (SMR); ~95% of current global hydrogen production; high CO2 emissions.
- **Blue Hydrogen:** Same SMR process but with carbon capture and storage (CCS) to reduce CO2 emissions; not truly zero-emission; CCS costs remain high.
- **Green Hydrogen:** Electrolysis using renewable electricity; truly zero-emission at the point of production; currently ~4-8x more expensive than grey hydrogen but cost declining rapidly.

NATIONAL GREEN HYDROGEN MISSION (NGHM)

NGHM Feature	*Detail*
Launch	Approved by Union Cabinet on January 4, 2023; launched by PM Modi on January 18, 2023
Target	5 million tonnes per year (MMTPA) green hydrogen production capacity by 2030
Outlay	Rs.19,744 crore government financial support (2023-30); leveraging Rs.8 lakh crore total investment (public + private)
Electrolyzer manufacturing	Target: 5 GW per year electrolyzer manufacturing capacity in India by 2025; PLI scheme for electrolyzer manufacturing
Export ambition	India aims to become a MAJOR EXPORTER of green hydrogen (and green ammonia -- for fertilisers, made from green H2 + atmospheric N2) to Europe, Japan, Korea, Australia; "Green Hydrogen Hubs" to be developed at major ports (Kandla, Paradip, Vizag, Tuticorin)
Key sectors targeted	(a) Steel production (replace coking coal with green hydrogen-based direct reduced iron (DRI)); (b) Fertiliser (green ammonia replacing natural gas-based ammonia for urea; India imports ~9 MT ammonia/year); (c) Shipping fuel (green hydrogen / green ammonia as maritime fuel for decarbonisation); (d) Long-distance trucking and heavy transport (fuel cells or hydrogen ICE)
SIGHT (Strategic Interventions for Green Hydrogen Transition)	An umbrella programme under NGHM; PLI for green hydrogen production, electrolyzer manufacturing; standards development; R&D
Key private sector players	Reliance Industries (35 GW solar + 2 MMTPA green H2 target; Jamnagar New Energy Complex); Adani Green Energy; NTPC (has already commissioned small green H2 pilot at Vindhyachal and Simhadri plants); ONGC (Green Hydrogen Corporation in partnership)

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Green Hydrogen Strategic Case (1/2): India imports ~9 MT natural gas-based ammonia annually for fertilisers. Green hydrogen can produce GREEN AMMONIA to replace these imports.

Green Hydrogen Strategic Case (2/2): Green hydrogen DRI can replace coking coal imports for steel. Cost challenge: green H2 currently USD 4-6/kg vs grey H2 USD 1-2/kg; target USD 1/kg by 2030 as renewable and electrolyzer costs fall.

22.7 TIDAL, GEOTHERMAL AND OCEAN ENERGY

Energy Type	*Potential in India*	*Specific Locations*	*Status and Challenge*
TIDAL ENERGY	Approximately 9,000 MW total national potential identified (CEA estimate); practically exploitable ~7,000 MW; most cost-effective sites: Gulf of Kutch and Gulf of Cambay (Khambhat)	Gulf of Kutch (Kachchh): ~900 MW at Hansthal Creek; tidal range 5-8 m (excellent); Gulf of Khambhat (Cambay): tidal range up to 12 m (best in India; potential 7,000 MW); Sundarbans: smaller tidal range but available	No commercial tidal plant in India as of 2024; NEERI (National Environmental Engineering Research Institute) and MEL (Marine Engineering Ltd) have done feasibility studies; environmental concerns (Kachchh is a UNESCO tentative WHS for the Rann; marine biodiversity); very high capital cost of tidal barrages; international experience limited (only La Rance, France 240 MW and Sihwa, South Korea 254 MW are operational commercial tidal barrages globally)
WAVE ENERGY	India has ~40,000 km of EEZ coastline; ~40 GW theoretical wave energy potential along the western coast (Arabian Sea, particularly off Kerala-Karnataka); eastern coast has lower wave energy	Western coast from Kerala to Maharashtra; Lakshadweep; Andaman and Nicobar Islands (high wave energy in Bay of Bengal)	No commercial wave energy plant in India; CSIR-NIO (National Institute of Oceanography), Goa and IIT Madras conducting research; wave energy converters (WECs) still immature technology globally; high costs and harsh marine operating environment; not near commercial viability in India
OCEAN THERMAL ENERGY CONVERSION (OTEC)	India has excellent OTEC potential in the tropical Indian Ocean and near the Lakshadweep and Andaman Islands; temperature difference between surface (28-30 deg C) and deep water (5 deg C at 500-1,000 m depth) of 20-25 deg C is needed for OTEC	Lakshadweep Islands (particularly Kavaratti; OTEC pilot project by NIOT -- National Institute of Ocean Technology, Chennai); Andaman Islands	NIOT commissioned a 1 kW (experimental) OTEC plant at Kavaratti, Lakshadweep; no commercial OTEC yet anywhere in the world; OTEC technology remains in R&D stage globally; India one of the few countries actively testing OTEC
GEOTHERMAL	India has several	Puga Valley (Ladakh):	No commercial geothermal

ENERGY	geothermal provinces; most significant: the Himalayan Geothermal Province (active volcanic-tectonic zone); geothermal surface manifestations at ~350 locations across India; GSI estimates ~10,000 MW potential	hottest springs in India (surface temperature up to 84-98 deg C; sub-surface potentially much higher); Manikaran (HP; 90+ deg C springs); Tattapani (MP; 60 deg C); Surajkund (Jharkhand; 88 deg C); Rajgir (Bihar); Sohana (Haryana); Assam (NE volcanic belt)	power plant in India as of 2024; ONGC (geothermal energy) and GSI (Geological Survey of India) doing exploration at Puga; Puga Valley potentially the best site in India (may have 50-100 MW potential); cost of deep geothermal drilling in remote high-altitude Ladakh is the primary challenge; global status: only Iceland (~27% electricity from geothermal), Kenya, El Salvador and a few others have significant geothermal electricity

27.8 RENEWABLE ENERGY TRANSMISSION -- THE GRID CHALLENGE

Renewable energy -- particularly solar and wind -- is intermittent (not available 24x7) and geographically concentrated in areas far from demand centres (Rajasthan solar, Gujarat and Tamil Nadu wind, Himalayan hydro). This creates major challenges for integrating renewables into India's electricity grid.

Challenge / Solution	Detail
Grid integration challenge	Solar generates only in daytime; wind is variable; hydro is seasonal; the grid must balance generation and demand in real-time; without storage or backup, excess renewable generation causes grid instability; under-generation causes power cuts
Green Energy Corridor (GEC) -- Phases 1 and 2	MoP + MNRE + Power Grid Corporation of India (PGCIL) scheme; GEC Phase 1 (2015-2022): ~9,000 circuit km of intra-state transmission lines for renewable energy evacuation from 8 high-RE states (Rajasthan, Gujarat, HP, MP, AP, Karnataka, TN, Maharashtra); GEC Phase 2: 10,750 circuit km; Rs.12,031 crore; connects 7 states (HP, Gujarat, Rajasthan, Karnataka, AP, Maharashtra, TN); includes interstate transmission for Rajasthan solar and Gujarat wind
Ladakh Green Energy Corridor (GEC-III)	A new HVDC (High Voltage Direct Current) transmission line proposed from Leh, Ladakh to the national grid (potentially to Punjab or Haryana via J&K); estimated cost Rs.14,000-20,000 crore; 900+ km; will enable massive Ladakh solar development; required for the 5-10 GW solar potential identified in the Changthang plateau
Pumped Storage Hydropower (PSH) for Grid Balancing	PSH acts as a large-scale electricity "battery": pump water up using cheap solar electricity at midday; release it through turbines during evening peak demand; CEA identifies 96,000 MW of PSH potential in India; MNRE planning 18,800 MW additional PSH by 2032
Battery Energy Storage Systems (BESS)	Lithium-ion batteries (and emerging sodium-ion, iron-air batteries) can store solar/wind energy for hours; SECI has tendered multiple BESS projects (1,500 MWh BESS alongside new solar projects); high cost still a challenge (Rs.3-5 crore/MWh currently); declining rapidly
Renewable Purchase Obligation (RPO)	PNGRB-mandated minimum % of electricity that distribution companies (DISCOMs), open access consumers, and captive users must procure from renewables; solar-specific RPO + wind-specific RPO + general RE RPO; DISCOMs that don't meet RPO pay into a Renewable Energy Development Fund (REDF)

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27.9 CURRENT AFFAIRS HOOKS (2022-2025)

CURRENT AFFAIRS

PM Surya Ghar Muft Bijli Yojana (February 2024): Launched February 13, 2024 -- world's largest domestic rooftop solar programme. Target: 1 crore households with rooftop solar by 2026-27; 300 units/month free electricity; subsidy up to Rs.78,000 per household. Rs.75,021 crore total outlay. Aims to add 30 GW rooftop solar. By March 2025, over 12 lakh registrations received, with 6+ lakh installations sanctioned. A flagship scheme for PM second term energy agenda.

National Green Hydrogen Mission (January 2023): Approved January 4, 2023; launched January 18, 2023 by PM Modi. Target: 5 MMTPA green hydrogen production by 2030. Rs.19,744 crore government outlay; leveraging Rs.8 lakh crore total investment. Electrolyzer manufacturing PLI launched. India aims to become a green hydrogen exporter to Europe, Japan, Korea. NTPC commissioned small pilot green hydrogen production at Vindhyachal and Simhadri thermal plants using on-site solar.

India's Solar Capacity Crosses 90 GW (2024): India's total solar installed capacity crossed 90 GW by March 2024, making it the 3rd country to have 100 GW solar capacity (China ~650 GW, USA ~170 GW, India ~90 GW). Solar costs in India have fallen to Rs.2.5-3.0/kWh (utility scale) -- cheaper than new coal power (Rs.4-5/kWh). PLI scheme for solar PV module manufacturing accelerating domestic production; Adani Solar, Waaree, Vikram Solar, Premier Energies expanding manufacturing capacity significantly.

Teesta GLOF Disaster and Hydro Risk (October 2023): On October 4, 2023, the South Lhonak Glacial Lake (at ~5,200 m altitude, Sikkim) burst its moraine dam, releasing a catastrophic flood down the Teesta River. The flood destroyed the nearly completed Teesta Stage-III Dam (1,200 MW; Rs.14,000 crore; 25 years under construction by NHPC). 100+ killed; 4,000+ missing; major infrastructure damage across Sikkim and North Bengal. A stark warning for the ~30 high-altitude dams in Himalayan glacier catchments facing similar GLOF risk.

Khavda Renewable Energy Park (Gujarat) -- World's Largest RE Park: Adani Green Energy is developing the Khavda Renewable Energy Park in Gujarat's Rann of Kutch area -- targeting 30 GW of combined solar and wind capacity. When complete (targeted by 2029-30), it will be the world's LARGEST RENEWABLE ENERGY PARK. The site covers ~538 sq km; located in a non-arable, non-forest, extremely sunny and windy desert landscape near the Pakistan border. Adani Group has committed 70% of its Rs.1 lakh crore renewable energy investment to this single park.

IFOS FOCUS

IFoS -- Renewable Energy and Forest/Ecology Nexus:

(1) **Solar parks and land use:** Large solar parks (Bhadla, Pavagada, Khavda) are developed on wasteland, fallow land, and semi-arid areas. While this is better than agricultural land conversion, even "wasteland" often has significant dryland biodiversity (thorny scrub, grassland birds like Great Indian Bustard). The SC has raised concerns about solar/wind parks in GIB critical habitat zones (Rajasthan). (2) **Wind turbines and birds/bats:** Wind turbines cause bird and bat mortality; the Kanyakumari zone (Muppandal, Aralvaimozhi) is a major raptor and migratory bird flyway; wind turbines there kill thousands of birds annually (including Steppe Eagles, Honey Buzzards); MNRE has developed bird and bat conservation guidelines for wind projects. (3) **Hydropower and rivers:** Free-flowing rivers in Arunachal Pradesh (Subansiri, Siang, Dibang, Lohit) are among the world's most biodiverse river systems; 168 large hydropower projects planned in the NE India river basins would fragment these rivers completely; the WII 2012 cumulative impact study found this would be ecologically devastating. (4) **Biomass plantations and monoculture:** Energy plantation (eucalyptus, casuarina) to supply biomass power plants can reduce native vegetation diversity; MNRE's energy plantation programme should use native, multi-purpose trees rather than exotic monocultures. (5) **Green Hydrogen and coastal ecosystems:** Green hydrogen export hubs are planned at major ports; offshore wind farm development near ecologically sensitive coastal areas (mangroves, coral reefs, turtle nesting sites) needs careful marine spatial planning.

27.10 PYQ ANALYSIS -- CHAPTER 27 (2010-2025)

Source	Year	Marks	Question
UPSC Civil	2024	15M	"Discuss the potential and progress of renewable energy in India. How significant is solar energy for meeting India's energy security and climate goals?"
UPSC Civil	2023	12M	"What is green hydrogen? Discuss the National Green Hydrogen Mission and its significance for India's decarbonisation pathway."
UPSC Civil	2022	10M	"Discuss the prospects and challenges of offshore wind energy development in India."
UPSC Civil	2021	15M	"Critically evaluate India's hydropower development with reference to potential, progress and the environmental and social challenges of large dam construction."
UPSC Civil	2020	12M	"Discuss the International Solar Alliance (ISA). How is it positioned to drive global solar energy adoption? What is India's role?"
UPSC Civil	2019	10M	"Discuss the significance of biomass and bioenergy in India's rural energy landscape. How can SATAT scheme transform India's organic waste into energy?"
UPSC Civil	2018	10M	"What are the major renewable energy sources available in India? Discuss the steps taken by the government to harness them."
UPSC Civil	2017	10M	"Discuss the challenges in grid integration of renewable energy in India. What role can pumped storage hydropower play?"
IFoS GS	2024	10M	"Discuss the ecological impacts of large-scale solar parks and wind farms on biodiversity in India, with particular reference to the Great Indian Bustard."
IFoS GS	2023	10M	"Examine the relationship between hydropower development and river ecology in the northeastern Himalayan river systems."
IFoS GS	2022	10M	"Discuss the potential of biomass energy in India. How does SATAT address both energy and solid waste management challenges?"

KEY NOTE

Frequency: Solar energy + energy security (Civil 2024); green hydrogen NGHM (Civil 2023); offshore wind (Civil 2022); hydropower challenges (Civil 2021); ISA (Civil 2020); biomass/SATAT (Civil 2019); RE overview (Civil 2018); grid integration + PSH (Civil 2017). IFoS: GIB + solar/wind ecology (2024), NE hydro + river ecology (2023), SATAT biomass (2022). For 2025-26: PM Surya Ghar (Feb 2024; 1 crore rooftops); NGHM 2023 (green hydrogen 5 MMTPA); solar crossing 90+ GW; Teesta GLOF Oct 2023 (hydropower risk); Khavda RE Park 30 GW (world's largest planned); PLI solar PV module manufacturing (domestic solar industry) -- all high-priority current affairs.

27.11 MODEL BOOK

Discuss the potential and progress of solar energy in India. How significant is solar energy for meeting India's energy security and climate goals?

UPSC Civi (Main) | 15 Marks | 210 Words .

Introduction: Solar energy has emerged as India's most transformative renewable energy source -- and potentially the solution to its twin challenges of energy security (reducing import dependence) and climate action (net zero by 2070). India receives 4-7 kWh/m2/day of solar irradiation, among the highest globally.

Potential: MNRE estimates India's solar energy potential at 748+ GW (3% of wasteland at 5 MW/sq km). This is vastly more than India's current total power demand (~500 GW peak). Key high-potential zones: Rajasthan (Thar Desert; 6.0-7.5+ kWh/m2/day), Gujarat (Rann of Kutch), Ladakh (high altitude + clear skies), Madhya Pradesh, Andhra Pradesh, Telangana.

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PROGRESS (AS OF 2024):

Installed capacity: ~90 GW solar (March 2024); 3rd country globally after China and USA; grew from barely 3 GW in 2014.

Major solar parks: Bhadla (Rajasthan, 2,245 MW -- one of world's largest); Pavagada (Karnataka, 2,050 MW); Rewa (MP, 750 MW, landmark no-subsidy project at Rs.2.97/kWh); Kurnool (AP, 1,000 MW). Khavda (Gujarat, 30 GW under development -- will be world's largest RE park).

Cost decline: Solar tariffs have fallen from Rs.18/kWh (2010) to Rs.2.5-3.0/kWh (2024) -- now cheaper than new coal power (Rs.4-5/kWh). This dramatic cost reduction is the single biggest driver of India's solar expansion.

Schemes: National Solar Mission (2010; 100 GW target); PM Surya Ghar Muft Bijli Yojana (February 2024; 1 crore rooftop solar; 300 units/month free); PM-KUSUM (solar pumps for farmers); PLI for domestic solar PV manufacturing; International Solar Alliance (ISA -- India-France; COP21 Paris 2015; 120+ members; HQ Gurugram).

SIGNIFICANCE FOR ENERGY SECURITY:

1. **Import substitution:** Every GW of solar installed reduces oil/LNG import bill; 1 GW solar saves approximately 1.5-2 million barrels of oil equivalent annually; at USD 80/barrel, 100 GW solar = USD 12-16 billion/year import saving.
2. **Green hydrogen synergy:** Cheap Indian solar + National Green Hydrogen Mission (5 MMTPA by 2030) = India producing the world's cheapest green hydrogen (<USD 1/kg target), replacing natural gas (LNG imports) for fertiliser and steel.
3. **COP26 Panchamrit:** Solar is the primary vehicle for achieving 500 GW non-fossil by 2030 and 50% RE share by 2030.

CHALLENGES:

1. **Manufacturing dependence:** India imports ~80% of solar PV cells and modules from China; PLI scheme is addressing but domestic manufacturing still insufficient.
2. **Grid integration:** Intermittent solar requires storage (PSH, BESS) and grid reinforcement (GEC); evening peak demand cannot be met by solar without storage.
3. **Land and ecology:** Large solar parks require land; careful siting needed to avoid conflict with GIB habitat and biodiversity hotspots.

Conclusion: Solar energy is no longer a niche technology in India -- it is the foundation of the energy transition. The dramatic cost reduction, massive park development, and new scheme (PM Surya Ghar 2024) targeting distributed rooftop solar position India to potentially be the world's solar energy leader of the 21st century.

What is green hydrogen? Discuss India's National Green Hydrogen Mission and its significance for decarbonising hard-to-abate sectors

UPSC Civil/IFOS (Mains) | 15 Marks | 200 Words

Green hydrogen -- hydrogen produced by electrolysis of water using renewable electricity -- is the "fuel of the future" for sectors that cannot be easily electrified: steel production, fertiliser manufacturing, shipping, aviation, and heavy-duty transport. Unlike grey hydrogen (from natural gas, with CO2 emissions) or blue hydrogen (from gas with carbon capture), green hydrogen has ZERO operational carbon emissions.

TYPES OF HYDROGEN -- KEY DISTINCTION:

Grey Hydrogen: Natural gas + steam methane reforming (SMR); ~95% of current global H2 production; high CO2 (10-12 kg CO2/kg H2).

Blue Hydrogen: SMR + carbon capture and storage (CCS); lower CO2 but not zero; expensive; questionable whether CCS is reliable long-term.

Green Hydrogen: Renewable electricity (solar/wind) + electrolysis (PEM or Alkaline electrolyzer); water split into H2 + O2; ZERO CO2; currently USD 4-6/kg but falling (target USD 1/kg by 2030).

NATIONAL GREEN HYDROGEN MISSION (NGHM):

Launch: Approved January 4, 2023; launched by PM Modi January 18, 2023.

Target: 5 MMTPA green hydrogen production capacity by 2030.

Outlay: Rs.19,744 crore government outlay; leverages Rs.8 lakh crore total investment.

Electrolyzer PLI: Production-linked incentive for domestic electrolyzer manufacturing; target 5 GW/year manufacturing capacity by 2025.

SIGHT scheme: Strategic Interventions for Green Hydrogen Transition -- umbrella programme for incentivising green H2 production, infrastructure and R&D.

SIGNIFICANCE FOR HARD-TO-ABATE SECTORS:

1. **Steel (Direct Reduced Iron with green H2):** India is the world's 2nd largest steel producer; steel production uses coking coal (which India imports ~50-60 MT/year); green hydrogen DRI can replace coking coal entirely, making steel production carbon-free; JSW Steel and Tata Steel have announced green hydrogen pilot projects.
2. **Fertilisers (Green Ammonia):** India imports ~9 MT of ammonia (made from natural gas -- grey hydrogen) annually for urea production; green ammonia (green H2 + atmospheric N2 via Haber-Bosch process) can replace this entirely; IFFCO (India's largest fertiliser cooperative) has commissioned the world's first green ammonia plant at Kalol, Gujarat (2023).
3. **Shipping and Aviation:** India has 12 major ports and the 2nd largest merchant shipping fleet in Asia; green hydrogen/ammonia as maritime fuel and sustainable aviation fuel (SAF) from green H2 are pathways to decarbonising these sectors.
4. **Import substitution:** Replacing grey hydrogen imports + LNG imports for fertilisers saves India USD 5-10 billion/year in forex outflows as the green hydrogen cost falls.

CHALLENGES:

1. **Cost:** Green H2 at USD 4-6/kg is 4-8x more expensive than grey H2 at USD 1-2/kg; USD 1/kg target requires extreme renewable cost reduction + electrolyzer efficiency improvement.
2. **Infrastructure:** Hydrogen pipelines and storage are very different from natural gas (H2 embrittlement of steel pipes; cryogenic storage for liquid H2); entirely new infrastructure ecosystem needed.
3. **Water:** Electrolysis consumes fresh water (~9 litres/kg H2); green hydrogen production in water-scarce Rajasthan or Gujarat requires desalinated water -- adding cost.

Green hydrogen is not a short-term solution but a 2030-2050 technology. The NGHM is India's bet on being a first-mover -- using its vast renewable energy resources (cheap solar in Rajasthan, wind in Tamil Nadu) to produce the world's cheapest green hydrogen and transition hard-to-abate sectors while building an export industry. If successful, it could reduce India's fossil fuel import dependence by USD 25-50 billion/year by 2040.

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CHAPTER 28

TYPES OF FARMING & CROPPING PATTERNS IN INDIA

CHAPTER AT A GLANCE

- Agriculture supports ~46% of workforce and contributes ~17-18% of GDP (2023-24). Net Sown Area (NSA) = ~140 million ha; ~55% of NSA is rain-fed (unirrigated). India is the world's largest producer of milk, pulses, spices, jute, and 2nd largest in wheat, rice, sugarcane, cotton, vegetables. Gross Cropped Area (GCA) ~190 million ha; Cropping Intensity (CI) = GCA/NSA x 100 = ~136%.
- FARMING TYPES by method: (1) Subsistence -- Primitive/Shifting/Jhum (NE India; rotational; Bewar/Dahiya/Podu/Kumari) vs Intensive Subsistence (irrigated; high population density; double-triple cropping); (2) Commercial -- Plantation (tea/coffee/rubber; scale); Mixed (crops+livestock); Dry/Dryland; Specialized (single commodity). By input: Organic/Natural vs Conventional/Chemical. By technology: Traditional/Low-input vs Modern/High-input (Green Revolution model).
- CROPPING SEASONS -- Three: (1) KHARIF (Jun-Sep/Oct): Sown at monsoon onset; harvested at monsoon end. Major crops: paddy, maize, cotton, groundnut, soybean, jute, bajra, jowar, arhar. (2) RABI (Oct-Nov to Feb-Mar): Sown in winter; harvested in spring. Major crops: wheat, gram (chickpea), mustard, barley, linseed, peas. Dependent on WD rain + residual monsoon moisture + irrigation. (3) ZAID (Mar-May): Short summer season between Rabi and Kharif; minor but important. Crops: watermelon, muskmelon, cucumber, fodder, moong, urad.
- MAJOR CROPS -- state-wise production leaders: Paddy = WB > UP > Punjab; Wheat = UP > MP > Punjab; Sugarcane = UP > MH > Karnataka; Cotton = Gujarat > MH > Telangana; Groundnut = Gujarat > Rajasthan > AP; Soybean = MP > MH > Rajasthan; Jute = WB > Bihar > Assam; Tea = Assam > WB > TN; Coffee = Karnataka > Kerala > TN; Rubber = Kerala (>90% of production).
- GREEN REVOLUTION (1960s-70s): HYV (High Yielding Variety) seeds + chemical fertilisers + irrigation + pesticides. Led by Dr. M.S. Swaminathan (India) and Norman Borlaug (CIMMYT wheat). Wheat revolution began in Punjab-Haryana from 1965-66. India went from food-deficit (importing PL-480 wheat from USA) to food-surplus. But: confined to wheat and rice; concentrated in Punjab-Haryana-WUP; soil degradation; groundwater depletion; declining soil organic matter; falling crop diversification; farmer debt.
- SHIFTING CULTIVATION (JHUM): Practice in NE India -- forest cleared, burned (ash = nutrient-rich), cultivated for 2-3 years, then abandoned to regenerate (fallow for 7-15 years, now shortened to 3-5 years due to population pressure). Names by region: Jhum (Assam, Arunachal, Nagaland, Manipur, Mizoram, Tripura), Kumari (Kerala), Podu (Odisha, AP), Bewar/Dahiya (Chhattisgarh, MP), Erka (Karnataka), Kurwa (Jharkhand). Banned/discouraged; sedentarisation programmes (NERCORMP, WGDP) trying to provide alternatives.
- PRECISION AGRICULTURE and TECHNOLOGY: GPS/GIS-based soil and crop mapping; remote sensing (NDVI for crop health monitoring); IoT sensors (soil moisture, temperature); drone spraying; AI-based crop advisory (Kisan AI, Agribot); digital agri marketplace (eNAM -- National Agriculture Market). PM-KISAN (direct income support Rs.6,000/year to farmers). Farmer Producer Organisations (FPOs) -- 10,000 FPO target by 2023-24.
- FOOD SECURITY ARCHITECTURE: National Food Security Act (NFSA) 2013 -- 75% rural, 50% urban population entitled to subsidised grains (5 kg/person/month) under TPDS. NFSA covers ~81 crore people. Antyodaya Anna Yojana (AAY) -- poorest of poor -- 35 kg/month at Rs.2/kg wheat, Rs.3/kg rice. PM Garib Kalyan Anna Yojana (PMGKAY) launched in 2020 (COVID) -- extended multiple times; from Jan 2024 merged with NFSA providing 5 kg free per person per month (no cost) to 81 crore beneficiaries.

28.1 INTRODUCTION -- AGRICULTURE IN INDIA

Agriculture is the **bedrock of Indian civilization and economy** -- it feeds 1.4 billion people, employs ~46% of the workforce (Economic Survey 2023-24), and contributes ~17-18% to GDP. India's agricultural geography is extraordinarily diverse: from paddy cultivation in the flooded deltas of the Ganga and Brahmaputra to dryland millets in the Thar Desert, from apple orchards in the Himalayas to rubber plantations in Kerala, from the wheat heartland of Punjab-Haryana to the tea gardens of Assam -- all within a single national territory spanning tropical, subtropical and temperate climatic zones.

India's **Net Sown Area (NSA)** is approximately **140 million hectares** -- the largest in the world after the USA. The **Gross Cropped Area (GCA)** -- total area actually planted including multiple crops on the same land in a year -- is approximately **190-195 million hectares.** The ratio GCA/NSA x 100 gives the **Cropping Intensity,** which stands at approximately **136%** nationally -- meaning the average piece of agricultural land is cropped 1.36 times per year. States like Punjab (190%+) and Haryana (175%+) have the highest cropping intensities, reflecting intensive double-cropping under irrigation.

KEY AGRICULTURAL STATISTICS

Parameter	*India Data*	*Global Rank / Note*
Net Sown Area (NSA)	~140 million ha	2nd largest in world after USA; ~42% of India's geographic area
% workforce in agriculture	~46% (ESS 2022-23; declining from 70% in 1950s)	One of the highest globally for a G20 economy; reflects low farm productivity and lack of non-farm jobs in rural India
Agriculture % of GDP	~17-18% (2023-24)	Disproportionately large share (vs workforce of 46%); low farm income per worker
Irrigated area	~69-72 million ha (net irrigated; ~50% of NSA)	Largest irrigated area in the world; but 50% of NSA still rain-fed
Food grain production	~320-330 million tonnes (2023-24)	Record highs; India a major exporter of rice, wheat, sugar
Largest producer globally	Milk (220+ MT); Pulses (~28 MT); Spices; Jute (80%+ of world); Banana; Mango; Guava	India is world #1 in several categories
2nd largest producer	Wheat, Rice, Sugarcane, Cotton, Groundnut, Vegetables, Fruits	Key for global food security
Cropping Intensity	~136% (national average)	Punjab >190%; Bihar-WB ~130%; dry states (Rajasthan) ~110%

28.1 TYPES OF FARMING IN INDIA

SUBSISTENCE FARMING

Subsistence farming is **farming primarily for own consumption** -- the farmer produces enough to feed the family and possibly a small surplus for local barter/sale. It is characterised by small land holdings, traditional tools, low inputs, and dependence on rainfall. Subsistence farming takes two major forms in India:

A. <u>Primitive / Shifting Subsistence Farming</u>

This is the **oldest form of agriculture** -- practised primarily by tribal communities in forested hill areas of northeast India, central India, and parts of the Western and Eastern Ghats. The most widespread form in India is **Jhum cultivation (also called Jhuming or Shifting Cultivation).**

Feature	*Shifting Cultivation (Jhum / Jhuming) Detail*
Mechanism	Forest plot cleared (trees felled or lopped); dry vegetation burned (fire releases nutrients from biomass into ash -- a natural fertiliser flush); mixed multi-crop cultivation for 2-3

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	seasons; plot abandoned and allowed to regenerate (forest fallow); community moves to next plot
Fallow period	Traditionally 7-15 years (sufficient for secondary forest regrowth and nutrient restoration); now often shortened to 3-5 years due to population growth and land scarcity -- this is ECOLOGICALLY UNSUSTAINABLE because the forest cannot recover sufficient nutrients in this time
Regional names	Jhum (Assam, Arunachal Pradesh, Nagaland, Manipur, Mizoram, Meghalaya, Tripura); Podu (Odisha, Andhra Pradesh, Telangana); Kumari (Kerala, Karnataka); Bewar or Dahiya (Madhya Pradesh, Chhattisgarh); Erka (Karnataka); Kurwa (Jharkhand); Bagad/Waltre (Odisha); Bringa/Bun (Orissa hill tribes)
Crops grown	Mixed multi-crop system -- finger millet (ragi), upland rice, maize, pulses, vegetables, tubers, chillies, ginger, cardamom; intercropping maximises diversity and reduces risk; NO monoculture
States affected	Primarily northeast India: Nagaland (over 1 lakh ha under jhum annually), Mizoram, Manipur, Arunachal Pradesh; also Jharkhand, Chhattisgarh, Odisha (eastern hill areas); some in Kerala and Karnataka hills
Environmental impact	DEFORESTATION: jhum is estimated to affect 1.5-2 lakh ha per year in NE India alone; reduced fallow periods = primary forest conversion; soil erosion on cleared slopes; biodiversity loss; contribution to NE India's forest cover decline (Arunachal lost 257 sq km per SFR 2023, partly attributable to jhum and infrastructure)
Policy response	Government of India discourages jhum; NERCORMP (North East Region Community Resource Management Project -- IFAD-funded); integrated watershed development; settled horticulture (pineapple, banana, citrus) as alternatives; Nagaland Jhum Control Act; but livelihood alternatives insufficient for full transition

KEY NOTE

Prelims Mnemonic -- Shifting Cultivation Names: "Jhum = NE India (Assam-Arunachal-Nagaland-Manipur-Mizoram-Meghalaya-Tripura); Podu = Odisha-AP; Kumari = Kerala; Bewar/Dahiya = MP-CG; Erka = Karnataka; Kurwa = Jharkhand." A useful memory aid: **J-P-K-B-E-K** or "Just Podu, Kumari -- Bewar/Erka/Kurwa." Frequently tested in Prelims as match-the-region questions.

B. Intensive Subsistence Farming

Intensive subsistence farming is practiced where **high population density demands maximum yield from small land holdings**. Unlike shifting cultivation, the same plot is cultivated year after year using intensive inputs of labour, irrigation, and increasingly chemical inputs. It is dominant in:

- **Indo-Gangetic Plain** (UP, Bihar, WB, Punjab, Haryana) -- paddy-wheat double cropping.
- **Brahmaputra and Bengal deltas** -- paddy cultivation with multiple crops per year.
- **Peninsular India river valleys** (Cauvery, Krishna, Godavari deltas) -- irrigated rice with high cropping intensity.

Characteristics: small fragmented holdings (average Indian farm size ~1.08 ha; declining from 2.3 ha in 1970-71); heavy labour investment; irrigation; multiple cropping seasons. The Green Revolution transformed intensive subsistence farming in Punjab-Haryana into **intensive commercial farming** with HYV seeds, chemical fertilisers, and tube-well irrigation.

COMMERCIAL FARMING

Commercial farming is **farming primarily for the market** -- the farmer produces a surplus and sells it. It is characterised by larger land holdings (relatively), improved inputs, market orientation, and often specialisation. Commercial farming takes several forms in India:

Type of Commercial Farming	Character	Key Examples in India
PLANTATION FARMING	Large-scale, single-crop (monoculture); capital-intensive; hired labour; processing infrastructure on or near estate; export-oriented; originated as colonial enterprise	Tea (Assam, WB, TN, Kerala -- 60-70% of Indian tea); Coffee (Karnataka -- Coorg/Kodagu, Chikmagalur; Kerala; TN -- Araku Valley AP); Rubber (Kerala -- ~90%); Cardamom (Kerala, Karnataka); Coconut (Kerala, TN, Karnataka); Sugarcane (in some areas managed plantation-style for mill supply)
MIXED FARMING	Combination of crop cultivation and livestock rearing on the same farm; animals provide draft power, manure, milk (income supplementation); waste from crops = animal feed; animal waste = crop fertiliser	Mixed farming dominant in Punjab, Haryana (wheat + cattle/buffalo for dairy); UP (sugarcane + cattle); Rajasthan (millet + sheep/goat herding); Gujarat (cotton-groundnut + cattle)
DRY / DRYLAND FARMING	Farming without irrigation in areas receiving <50-75 cm annual rainfall; depends entirely on rainwater; coarse cereals, millets, oilseeds adapted to dry conditions; soil moisture conservation techniques critical	Rajasthan (bajra, moth bean, guar, sesame); Marathwada-Vidarbha-Karnataka interior (sorghum, cotton, chickpea -- all dryland crops); Andhra Pradesh (groundnut, millet, castor); Bundelkhand (sorghum, arhar)
SPECIALISED / MONO-CROP FARMING	Single crop dominates the farm economy; oriented to one market segment; may be called "ranching" for livestock	Jharkhand Lac (shellac); West Bengal Jute; Punjab Wheat-Rice monoculture; Kolar (Karnataka) -- once famous for sericulture; Kashmir Saffron; Maharashtra Grapes (Nashik); Himachal Pradesh Apples (Shimla, Kinnaur)
HORTICULTURE FARMING	Fruits, vegetables, flowers, ornamental plants; high value per unit area; requires cold chain infrastructure; market proximity important	Nashik grapes (Maharashtra); Kolar/Chikkamagaluru (grapes, flowers); Nilgiris (tea + vegetables); Spiti Valley Himachal Pradesh (apples at high altitude); Belgaum Karnataka (grapes); Delhi-NCR (vegetables for urban market)
CO-OPERATIVE FARMING	Farmers pool resources (land, capital, labour, market) while retaining individual ownership; collective bargaining; examples mostly in dairy	AMUL (Anand, Gujarat) -- the world's largest dairy cooperative; model replicated nationally under NDDB (National Dairy Development Board); Iffco (fertiliser cooperative); tribal cooperatives for tendu leaf, bamboo, sal seed in central India

SPECIAL FARMING PRACTICES

Practice	Definition and Indian Context
Organic Farming	Farming without synthetic chemicals (no chemical fertilisers, pesticides, herbicides); uses compost, vermicompost, green manure, biopesticides; soil health-focused. India has ~4.3 million ha under certified organic farming (2023; 3rd largest globally by area). Largest organic

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	states: Sikkim (100% organic -- world's first organic state, certified 2016), Rajasthan, MP. PKVY (Paramparagat Krishi Vikas Yojana) cluster-based scheme; MOVCD-NE for NE states.
Natural Farming / Zero Budget Natural Farming (ZBNF)	Subhash Palekar's system: zero external inputs; uses cow dung-based preparations (Jeevamrit = fermented cow dung+urine+jaggery+gram flour; Bijamrit = seed treatment); no irrigation beyond natural; minimal tillage. Adopted by Andhra Pradesh (APCNF -- 800,000+ farmers by 2024 -- world's largest single state natural farming programme). National Mission on Natural Farming (NMNF, 2024): Rs.2,481 crore; 1 crore farmers; 7.5 million ha target.
Contract Farming	Farmer grows crop as per pre-agreed contract with a buyer (agro-processor, food company, export house) -- guaranteed price, technical support, sometimes inputs; reduces market risk. Examples: PepsiCo potato for chips (Punjab); Nestle tomato (HP, MH); sugarcane for mills (Maharashtra, UP).
Precision Agriculture	Technology-enabled input optimisation: remote sensing (satellite + drone), IoT soil sensors, variable-rate input application (fertigation, drip irrigation); GPS mapping; AI-based advisory. Still nascent in India but growing; ICAR, ICRISAT, SAC (Space Applications Centre) developing tools.
Integrated Farming System (IFS)	Combining crop, horticulture, livestock, fishery, poultry, apiculture on the same farm to maximise resource use efficiency and diversify income; ICAR promotes IFS models for small farmers; reduces risk from single-crop failure.
Agroforestry	Trees integrated with crops and/or livestock on the same land; trees provide shade, reduce erosion, fix nitrogen (if leguminous), provide fuel/timber/fruit income. India has ~25 million ha under agroforestry. National Agroforestry Policy (2014); NITI Aayog has promoted agroforestry for carbon sequestration under PM Krishi Sinchayee Yojana.

28.3 CROPPING SEASONS OF INDIA

India has THREE principal cropping seasons, reflecting the country's monsoon-dominated agriculture. Understanding these seasons -- their timing, climatic basis, and associated crops -- is one of the most frequently tested topics in UPSC Geography.

Season	*Period*	*Sown*	*Harvested*	*Climatic Basis*	*Key Crops*
KHARIF (Autumn Crops)	June-July sowing; September-October harvesting	At the ONSET of SW Monsoon (as first rains arrive)	At the END of SW Monsoon (before winter)	Warm, humid, long-day length conditions; SW monsoon provides the primary moisture; high temperature (>20-25 deg C) needed for germination	Paddy (rice), Maize, Cotton, Groundnut, Soybean, Jute, Bajra (Pearl Millet), Jowar (Sorghum), Arhar (Pigeon Pea/Tur), Urad (Black Gram), Moong (Green Gram), Guar (Cluster Bean), Sesamum, Sugarcane (planted in Kharif; harvested in Rabi), Turmeric, Ginger
RABI (Spring Crops)	October-November sowing; February-March harvesting	At the START of WINTER (after SW monsoon withdrawal)	In SPRING (before summer heat)	Cool, dry conditions with short-day length; depends on: (a) residual soil moisture from SW	Wheat (most important Rabi crop), Gram (Chickpea -- Chana), Mustard (Sarson/Rapeseed), Barley

				monsoon; (b) winter rain from Western Disturbances (essential for wheat in Punjab-Haryana); (c) irrigation; temperature 10-20 deg C optimal for wheat germination and grain filling	(Jau), Linseed (Alsi), Berseem (fodder clover), Peas, Potato (in some rotations)
ZAID (Summer Crops)	March-April to June	Between RABI harvest and KHARIF sowing	Before monsoon onset (by June)	Short hot-dry summer period; almost entirely dependent on IRRIGATION; daylight hours long; high temperature tolerant varieties only	Watermelon, Muskmelon, Cucumber (all cucurbits), Vegetables (bottle gourd, bitter gourd, pumpkin), Fodder crops (maize for fodder, cowpea), Urad/Moong (in some areas for Zaid crop), Sunflower (in some areas)

KEY NOTE

Kharif vs Rabi -- Critical Exam Distinction: The most tested fact is: KHARIF = sown at monsoon onset, harvested at monsoon end; RABI = sown at winter onset, harvested in spring. **Confusion crops:** (1) COTTON -- Kharif, NOT Rabi; (2) MUSTARD -- Rabi, NOT Kharif; (3) SUGARCANE -- planted in Kharif but takes ~10-12 months to mature (harvested in Rabi season of the FOLLOWING YEAR, Nov-March); (4) POTATO -- primarily Rabi in the plains (UP, Bihar, WB) but can be grown in Kharif in hill areas; (5) GRAM (CHICKPEA) -- Rabi; often confused with green gram (MOONG) which is Kharif. Also: JUTE -- Kharif in WB-Assam-Bihar; GROUNDNUT -- primarily Kharif but second crop also possible in Rabi (Tamil Nadu, AP).

28.4 MAJOR CROPS OF INDIA -- DISTRIBUTION AND CHARACTERISTICS

FOOD CROPS

Crop	*Season*	*Soil*	*Climate*	*Major Producing States (Rank Order)*	*Key Features*
PADDY (Rice)	Kharif (primary); Rabi in some areas (TN, AP)	Alluvial, clayey (water-retention); delta/coastal soils excellent	High rainfall (>150 cm) OR irrigation essential; high temperature (22-35 deg C); high humidity; standing water during growth	WB > UP > Punjab > Andhra Pradesh > Bihar > Odisha > Chhattisgarh	India = 2nd largest rice producer (after China); also 2nd largest exporter. Delta regions (Ganga, Cauvery, Godavari, Mahanadi, Krishna) = rice bowls. NE India (Assam, Manipur) = traditional rice heartland. Varieties: basmati (Punjab, Haryana, WP), Sona Masoori (AP, TN,

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					Karnataka). CAUVERY DELTA (TN) = "Rice Bowl of TN"; THANJAVUR district = "Granary of TN."
WHEAT	Rabi (Nov-Mar)	Well-drained fertile loam (IGP alluvial); slightly alkaline OK	Cool dry weather during growing season; frost during tillering; temperature 10-15 deg C; sunshine during grain filling; 30-100 cm rain (or irrigation equivalent)	UP > MP > Punjab > Haryana > Rajasthan > Bihar	India = 2nd largest wheat producer (after China); major exporter (record exports 2021-22; then export ban due to domestic price concerns 2022). Punjab "Granary of India." The Green Revolution (1965-66 onward) based on HYV wheat (Sonalika, Kalyan Sona varieties -- developed with Norman Borlaug's CIMMYT wheat and MS Swaminathan's leadership at IARI).
JOWAR (Sorghum)	Kharif (primary); also Rabi in Maharashtra-Karnataka	Light loamy to medium black soil; drought-tolerant	Dryland crop; 45-100 cm rainfall; warm climate (25-30 deg C)	MH > Karnataka > MP > Rajasthan > Andhra Pradesh	Coarse cereal; staple food in Deccan plateau; Marathwada and Vidarbha (MH); also "dual purpose" -- grain for food + straw for fodder. Maharashtra = "Jowar Bowl."
BAJRA (Pearl Millet)	Kharif	Sandy loam; arid soils	Most drought-tolerant cereal; <50 cm rainfall; extreme heat tolerant (>40 deg C); poor soil tolerant	Rajasthan > UP > Haryana > Gujarat > MP	India = world's largest bajra producer (~40% of global); Rajasthan alone produces ~50% of India's bajra. Semi-arid and arid zone staple. "Nutri-cereals" initiative (PM Modi renamed coarse cereals "Shree Anna" -- millets); 2023 = International Year of Millets (IYoM) -- India pushed for this at UNGA.
MAIZE (Corn)	Kharif (primary); also Rabi in some areas	Well-drained loam; alluvial; black cotton soil	25-75 cm rain or irrigation; 21-28 deg C; tolerates a wide range	Karnataka > MP > Bihar > Andhra Pradesh > Rajasthan > Telangana	India = 7th largest maize producer; rapidly growing due to ethanol blending programme demand (maize = alternative to sugarcane

					for ethanol); poultry feed industry; Karnataka leads. MP and Bihar fast-growing producers.
GRAM (Chickpea)	Rabi (Oct-Nov to Feb-Mar)	Light sandy loam; black soil; well-drained	Cool, dry; 40-75 cm rain or residual moisture; temperature 20-25 deg C	MP > Rajasthan > Maharashtra > UP > Andhra Pradesh	India = world's largest chickpea producer AND consumer (~70% of global production; ~85% of consumption). Desi chana (small, dark) vs Kabuli chana (large, cream). Critical protein source for vegetarian population. Pulses deficit in India despite being largest producer -- demand exceeds domestic supply; imports from Australia, USA, Canada.
ARHAR (Pigeon Pea / Tur)	Kharif	Various; well-drained	Warm; 50-75 cm rain; drought-tolerant when established	MH > MP > Andhra Pradesh > Telangana > Karnataka > Rajasthan	India = world's largest producer AND consumer (~85% of global). "Dal" (lentil) supply chain essential; price spikes when drought reduces output (as in 2023 -- tur dal prices crossed Rs.200/kg). Maharashtra-MP "tur belt."

CASH CROPS

Crop	*Season*	*Key States*	*World Rank*	*Key Features*
SUGARCANE	Kharif (planted); 10-12 months crop; harvested Oct-March of next year	UP > MH > Karnataka > TN > Bihar > Gujarat	India = 2nd largest producer (Brazil #1); largest CONSUMER globally	UP = "Sugarcane State" (35-40% of India output); MH has highest per-unit productivity. Sugar mills are the backbone of rural UP-MH economy. Sugarcane farmers often victim of "sugarcane arrears" (mills delay payment). Ethanol from sugarcane is India's primary E20 feedstock. FRP (Fair and Remunerative Price) mechanism.
COTTON (White Gold)	Kharif (Apr-May in Gujarat; Jun-Jul in MH-AP)	Gujarat > MH > Telangana > AP > Karnataka > MP	India = 2nd largest producer (China #1); largest exporter of cotton	Black cotton soil (Vertisol) is the ideal. Bt-Cotton (transgenic with Bacillus thuringiensis gene for bollworm resistance) introduced 2002; now covers >95% of cotton area. Vidharbha farmer suicides linked to Bt-cotton failures (debt cycle). Gujarat = most productive cotton state (highest yield); MH =

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				largest area.
JUTE (Golden Fibre)	Kharif (Mar-May); harvested Jul-Sep	WB > Bihar > Assam	India = world's largest producer (>80% of global supply); Bangladesh is 2nd	WB alone produces ~70% of India's jute; Hooghly River district = "Jute belt." Alluvial soil + humid climate + high rainfall (150-200 cm) ideal. Jute is used for sacking, burlap, carpets; eco-friendly alternative to plastic bags. National Jute Board. Retting (soaking in water to separate fibres) is water-intensive and a pollution concern.
GROUNDNUT	Kharif (primary in most areas); Rabi in TN-AP	Gujarat > Rajasthan > AP > TN > Karnataka	India = 2nd largest producer (China #1)	India's most important oilseed. Saurashtra (Gujarat) = "Groundnut Country." Used for oil, peanut butter, poultry feed. Kharif in most states; TN can grow a Rabi groundnut too. Aflatoxin contamination a major export barrier.
SOYBEAN	Kharif	MP > MH > Rajasthan	India = 5th largest producer	MP = "Soya Pradesh" (grows >55% of India's soybean on Malwa Plateau black soils). Used for oil (soyoil) and meal (animal feed). Introduced widely from 1970s-80s. A major kharif rotation with wheat (soya-wheat is now the dominant rotation in Malwa, like paddy-wheat in Punjab).
MUSTARD / RAPESEED	Rabi (Oct-Nov to Feb-Mar)	Rajasthan > UP > Haryana > MP > WB	India = 3rd largest producer	India's most important Rabi oilseed. Rajasthan alone grows ~45-50% of India's mustard. Yellow flowers across Rajasthan-Haryana-UP fields in winter = iconic agricultural landscape. Used for mustard oil (primary cooking oil in eastern and northern India). Recently: GM mustard variety (HT Mustard/Dhara Mustard Hybrid -- DMH-11) approved by GEAC (2022); facing legal challenge (SC).

PLANTATION CROPS

Crop	*States*	*World Rank*	*Key Feature*
TEA	Assam (55% of India production), WB (Darjeeling + Dooars 25%), TN (Nilgiris), Kerala, HP (Kangra), Uttarakhand (Kumaon)	India = 2nd largest producer (China #1); 4th largest exporter	Darjeeling Tea = GI-tagged (first Indian product to get GI tag, 2004). Assam tea = strong CTC (cut-tear-curl) variety; mainly for blending. Nilgiri tea = delicate, aromatic. Tea Board of India regulates. Labour-intensive: tea garden workers (largely Adivasi) face issues of wages, housing, healthcare under Plantation Labour Act 1951. Major importers: UK, Russia, UAE, USA, Iran.
COFFEE	Karnataka (70%: Coorg/Kodagu, Chikmagalur, Hassan), Kerala (20%), TN (10%; Araku Valley AP = a	India = 7th largest producer; 5th largest exporter	Two varieties: Arabica (shade-grown, mild, higher price; Karnataka-Kerala highlands) and Robusta (bold, lower altitude, also Karnataka-Kerala). Coffee Board of India. Indian coffee known for shade-grown, washed varieties. Araku Valley arabica = GI-tagged; tribal cooperative producing model. Blossom

	specialty GI-tagged hill coffee)		Showers (April pre-monsoon rain) critical for coffee flowering.
RUBBER	Kerala (>90% of area and production); small amounts in TN, Karnataka, NE India (Tripura, Assam)	India = 5th largest producer	Hevea brasiliensis (Para rubber tree). Kerala plantation crop since British era. Rubber Board of India. Rubber price volatility = recurring issue for Kerala farmers. Used for tyres, latex gloves, footwear. India is also a large importer of natural rubber (automotive sector demand exceeds domestic supply).
CARDAMOM (Elaichi)	Kerala (Idukki, Wayanad), Karnataka (Coorg)	India = 2nd largest producer and exporter (Guatemala is #1)	GI-tagged (Kerala cardamom). Grown under shade trees in WG foothills. "Queen of Spices." Small cardamom = Elettaria cardamomum (Kerala, Karnataka). Large cardamom = Amomum subulatum (Sikkim, Darjeeling -- different species). Used in sweets, tea, biryani; also in pharmaceuticals.
COCONUT	Kerala (32%), Karnataka (22%), TN (30%), AP	India = 2nd or 3rd largest producer (Indonesia #1, Philippines #2)	Thrives on coastal sandy soils with high humidity. State tree of Kerala. Products: copra (dried kernel for oil), coir (husk fibre), toddy (fermented sap), tender coconut water. Coconut Development Board of India. Kerala's "coconut-palm" landscape defines its cultural identity.

28.5 THE GREEN REVOLUTION -- ACHIEVEMENT AND CRITIQUE

The **Green Revolution** was a technological transformation of Indian agriculture from approximately **1965-66 to the 1970s,** characterised by the adoption of **High Yielding Variety (HYV) seeds,** expanded irrigation, chemical fertilisers, and pesticides. It converted India from a food-deficit country (dependent on PL-480 wheat imports from the USA) to a food-surplus nation capable of building buffer stocks.

Feature	*Green Revolution Detail*
Key scientists	Dr. M.S. Swaminathan (India; IARI -- Indian Agricultural Research Institute, New Delhi; "Father of Green Revolution in India"); Norman Borlaug (Mexico/CIMMYT; Nobel Peace Prize 1970; developed semi-dwarf wheat varieties)
HYV seeds	Semi-dwarf wheat varieties (Sonalika, Kalyan Sona) and rice varieties (IR-8 "Miracle Rice" -- developed at IRRI, Philippines); short-stemmed so high-fertiliser doses do NOT cause lodging (falling over); high harvest index (more grain per total biomass)
Starting point	Punjab, Haryana and western UP in 1965-66 (wheat). Then spread to rice in parts of eastern India, WB, AP, TN from 1970s.
Impact on food production	India's food grain production rose from ~72 million tonnes (1965-66) to ~260 million tonnes (2000-01) and ~330 million tonnes (2023-24); wheat production in Punjab alone rose from ~1.7 MT (1965) to ~20 MT (2023)
Geographic concentration	Initially concentrated in Punjab, Haryana, WUP (the "Green Revolution belt"); eastern India (Bihar, eastern UP, WB, Odisha) remained marginal; NE India and dryland areas almost untouched; created regional inequality in agricultural productivity
Social impact -- positive	Significant increase in farm incomes in Green Revolution states; Punjab-Haryana became prosperous; India's rural GDP rose; food prices declined in absolute terms; urban consumers benefited from cheaper food

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Social impact -- negative	Displaced agricultural labourers (mechanisation reduced labour demand); large farmers benefited most (access to inputs, credit, irrigation); small farmers less able to afford the "package" of HYV+fertiliser+irrigation; regional inequality deepened (BIMARU states vs Green Revolution states)
Environmental costs	Groundwater depletion (Punjab water table falling 50 cm/year in some areas; estimated unsustainable for 10-20 more years of paddy cultivation); soil degradation (organic carbon decline; nutrient imbalances from NPK-only focus); loss of traditional crop diversity (thousands of traditional rice and wheat varieties replaced by a few HYVs); pesticide poisoning (Malwa region Punjab = "cancer train" to PGI Chandigarh due to high pesticide exposure)

UPSC CIVIL

Civil GS-3 -- Green Revolution Critique Framework: The "Green Revolution paradox" is a high-value exam topic. Structure the answer as: (a) Achievements -- food self-sufficiency, production records, hunger reduction; (b) Geographic inequity -- Punjab-Haryana vs Bihar-Odisha; (c) Ecological costs -- groundwater, soil health, biodiversity loss; (d) Economic costs -- input dependency, farm debt (Punjab farmer debt crisis), terms of trade for agriculture; (e) New imperatives -- Evergreen Revolution (MS Swaminathan's own concept: productivity without ecological harm), PM-PRANAM, NMNF 2024, natural farming, millets (International Year of Millets 2023). MS Swaminathan passed away in September 2023 -- expect a question on his legacy.

28.1 MILLETS (SHREE ANNA) -- INDIA'S NUTRITIONAL CEREALS

The International Year of Millets 2023 (IYoM 2023) -- championed by India at the United Nations General Assembly -- brought global attention to millets as **"nutri-cereals"** or **"Shree Anna"** (the auspicious grain, as PM Modi designated them). Millets are small-seeded grasses that are drought-tolerant, grow on marginal soils with minimal inputs, are nutritionally superior to polished rice and wheat, and have been cultivated in India for thousands of years.

Millet Type	*Scientific Name*	*Primary States*	*Key Nutritional / Agricultural Feature*
Bajra (Pearl Millet)	Pennisetum glaucum	Rajasthan, Gujarat, UP, Haryana, Maharashtra	Most widely grown millet in India; most drought-tolerant cereal; rich in iron and zinc; high protein (11-12%); Rajasthan = 50% of India production; "nutri-cereal" for arid zone population
Jowar (Sorghum)	Sorghum bicolor	Maharashtra, Karnataka, MP, Rajasthan, AP	2nd most grown millet; major food and fodder crop in Deccan; anti-nutritional factors lower than in wheat; gluten-free; both Kharif and Rabi varieties
Ragi (Finger Millet)	Eleusine coracana	Karnataka (50%+ of India production), TN, Andhra Pradesh, Odisha, Uttarakhand	Richest cereal in calcium (344 mg/100g -- higher than milk per calorie); excellent for infants and elderly; grows in poor laterite soils; important tribal food. Karnataka's "Ragi Mudde" is a traditional staple.
Foxtail Millet	Setaria italica	Andhra Pradesh, Karnataka, TN, Rajasthan	Good source of dietary fibre and protein; ancient cultivation (5000+ years); suitable for diabetics (low glycaemic index); AP calls it "Korralu"; TN calls it "Thinai"
Kodo	Paspalum	Chhattisgarh (primary),	Important tribal cereal; high dietary fibre; low fat;

Millet	scrobiculatum	MP, Jharkhand, Odisha	gluten-free; "Kodon" in CG; Chhattisgarh State Minor Forest Produce Federation (MFP Federation) has been promoting its value chain
Little Millet	Panicum sumatrense	Various tribal areas across India	Nutritious; small-scale cultivation; important for food security in tribal belts
Proso Millet	Panicum miliaceum	MP, Rajasthan, UP	Quick maturing (60-65 days); used in poultry feed; can be grown in short kharif windows
Barnyard Millet	Echinochloa frumentacea	Uttarakhand, Himachal Pradesh, NE India	Extremely drought-tolerant; high iron and fibre; "Jhangora" in Uttarakhand; traditional hill tribal cereal

CURRENT AFFAIRS	**International Year of Millets 2023 (IYoM 2023) -- Key Facts:** India proposed the declaration of 2023 as IYoM at the UN FAO; the UNGA adopted the resolution (72nd session, 2016; implementation 2023). Prime Minister Modi personally championed millets globally -- served millet dishes at G20 Summit dinner (September 2023, New Delhi). Government initiatives: (a) NITI Aayog and ICAR developing millet value chains; (b) Mandatory inclusion of millets in PDS ration shops in some states; (c) "Shree Anna" portal for millet recipes and awareness; (d) Export promotion: India's millet exports grew 28% in 2023. Key argument: millets require 70% less water than paddy; grow without chemical inputs; more nutritious than polished rice/wheat; important for climate-resilient food systems.

28.7 LAND REFORMS AND LANDHOLDING PATTERNS

Land reforms in independent India aimed to **dismantle the exploitative agrarian structure inherited from colonial rule** -- characterised by large zamindari estates, absentee landlordism, and landless peasant labour. Three major waves of land reform legislation followed Independence:

Land Reform Wave	*Period*	*Content*	*Outcome*
1. Abolition of Intermediaries (Zamindari Abolition)	1950s	Zamindari Abolition Acts in various states; zamindars (landlords under the British Permanent Settlement) and jagirdars had their intermediary rights abolished; land theoretically vested in the state and redistributed to actual tillers; compensated zamindars with bonds	Largely successful in abolishing the zamindari system; >20 million hectares of land transferred. BUT: wealthy zamindars retained their "home farms" (khud-kasht) and evicted tenants before legislation took effect; legal challenges delayed implementation; large landlords often converted to "self-cultivating" status to retain land.
2. Tenancy Reforms	1950s-1970s	Security of tenure for tenants (protection from eviction); fixation of fair rents (usually 1/4 to 1/5 of produce); right of tenants to purchase the land they tilled (conferment of ownership)	Uneven implementation; many states (Kerala, West Bengal, Maharashtra) implemented effectively; others (Bihar, UP) largely ineffective due to landlord influence on state machinery. Operation Barga (West Bengal, 1978): registration of sharecroppers under Left Front government = most successful tenancy reform in India.
3. Land Ceiling	1960s-1972	Maximum limit on	Only ~5-6 million ha declared as surplus

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Acts	(first round); 1972 (new ceilings); 1972-1974 (amendment to close loopholes)	individual/family landholding (ceiling) to prevent large concentration; surplus land (above ceiling) to be acquired by state and distributed to landless/marginal farmers. Ceiling limits varied: 3-4 ha (wet irrigated land) to 30-54 ha (dry unirrigated) depending on state.	(far less than expected); loopholes exploited (benami transfers to relatives, false partitioning of family, exclusion of orchards/plantations, judicial challenges); landless labourer rarely the beneficiary (dalits and tribals got little of the redistributed land). One of the most widely agreed failures of Indian land reform policy.

Despite the limited success of land redistribution, some positive land reforms were achieved:

- **Operation Barga (WB, 1978):** 1.5 million sharecroppers registered; contributed to the "agricultural miracle" of West Bengal in the 1980s-90s.
- **Kerala Land Reforms Act (1963, effective 1970):** One of India's most progressive land reforms; reduced tenancy significantly; benefited many small cultivators.
- **Forest Rights Act (2006):** Recognised forest dwellers' rights to cultivate forest land they have been tilling for generations.

CURRENT LANDHOLDING PATTERNS

Category	*Farm Size*	*% of Holdings*	*% of Total Area Owned*	*Key Issue*
Marginal	<1 ha	68.5%	~21%	Most Indian farmers; average farm 0.38 ha; cannot be economically productive without non-farm income; food insecure despite owning land
Small	1-2 ha	~18%	~19%	Small but viable if irrigated and input-efficient; PM-KISAN Rs.6,000/year is targeted here
Semi-medium	2-4 ha	~8%	~18%	Middle group; access to credit and market is the critical difference
Medium	4-10 ha	~4.5%	~20%	Able to invest in mechanisation and technology
Large	>10 ha	~1%	~22%	Controls disproportionate land share; capitalist farming in Punjab-Haryana

KEY NOTE

Average Farm Size Trend: India's average farm size has fallen from 2.3 ha (1970-71) to **1.08 ha (2015-16 Agricultural Census)** -- a 53% reduction in 45 years. This is driven by population growth and inheritance-based fragmentation. Small and marginal farmers (below 2 ha) now constitute over 86% of all holdings. This structural challenge -- **too many farmers on too little land** -- is at the heart of India's agrarian crisis. The solution requires BOTH agricultural productivity enhancement AND job creation outside agriculture to absorb surplus farm workers.

28.8 FOOD SECURITY -- POLICY ARCHITECTURE

Scheme / Policy	*Year*	*Key Feature*
National Food Security Act (NFSA)	2013	Legal entitlement for subsidised grains: 75% of rural population and 50% of urban population (covering ~81 crore people) entitled to 5 kg of grain/person/month at highly subsidised prices (Rs.3/kg rice; Rs.2/kg wheat; Re.1/kg coarse cereals); Antyodaya Anna Yojana (AAY -- 35 kg/household/month for poorest of poor) integrated;

		implemented through TPDS (Targeted Public Distribution System)
PM Garib Kalyan Anna Yojana (PMGKAY)	2020 (COVID); extended multiple times; merged with NFSA from Jan 2024	Originally a COVID-19 relief programme providing 5 kg additional FREE grain per person; extended 11 times till Dec 2023; from January 1, 2024 merged with NFSA -- now 81 crore beneficiaries receive 5 kg grain PER MONTH FREE OF COST (zero price); world's largest food security programme; annual government expenditure ~Rs.2 lakh crore on food subsidy
Mid-Day Meal Scheme (now PM POSHAN)	1995 (universalised); renamed PM POSHAN in 2021-22	Cooked meal to ~11.8 crore children in government/government-aided schools (Classes I-VIII); reduces dropout rates; improves nutrition; reduces teacher absenteeism (child-attendance incentive); supported by NFSA; cost-sharing between centre and states
Integrated Child Development Services (ICDS) / Poshan Abhiyaan	1975 (ICDS); PM POSHAN Abhiyaan 2018	Supplementary nutrition to children <6 years and pregnant/lactating mothers through Anganwadi Centres; POSHAN Abhiyaan (National Nutrition Mission) -- convergence programme to reduce stunting, wasting, undernutrition, anaemia; targets from NHFS/NFHS data
One Nation One Ration Card (ONORC)	2019 (piloted); pan-India by 2021	Portability of ration card -- NFSA beneficiary can access their entitled grain from ANY PDS shop in India (Aadhar-enabled, biometric authentication); critical for migrant workers; all states/UTs integrated as of 2021
eNAM (National Agriculture Market)	2016	Online agricultural marketplace linking 1,000+ APMC mandis across India; transparent price discovery; reduces intermediaries; electronic payments; uses the Rashtriya e-Market Services (ReMS) platform; target: all 7,000 regulated mandis eventually
PM KISAN (Pradhan Mantri Kisan Samman Nidhi)	December 2018 (extended nationally Feb 2019)	Direct income support of Rs.6,000 per year (Rs.2,000 per installment, 3 installments) to all small and marginal farmer families owning up to 2 ha of cultivable land; transferred directly to bank accounts (DBT); covers ~11 crore farmers; annual outlay ~Rs.66,000 crore; no production conditionality

28.9 CURRENT AFFAIRS HOOKS (2022-2025)

CURRENT AFFAIRS

International Year of Millets 2023 (IYoM 2023) and Shree Anna: 2023 = IYoM declared by UNGA on India's proposal. PM Modi served millet dishes at G20 New Delhi Summit dinner (September 2023). "Shree Anna" brand for Indian millets. India's millet exports grew 28% in 2023. Mandatory millet inclusion in PDS explored. NITI Aayog + ICAR + state govts promoted millet value chains. India supplies 20%+ of world millet production. IYoM 2023 revived global interest in traditional drought-tolerant climate-resilient crops.

PMGKAY Free Grain Merged with NFSA (January 1, 2024): From January 1, 2024, the PM Garib Kalyan Anna Yojana was merged with the National Food Security Act (NFSA). All 81 crore NFSA beneficiaries now receive 5 kg grain per month FREE OF CHARGE (no cost at all; earlier nominal price of Re.1-3/kg). This is the world's largest food security programme by coverage. Annual government food subsidy bill = approximately Rs.2 lakh crore (2024-25 Budget estimate).

MS Swaminathan Passed Away (September 28, 2023): "Father of the Green Revolution in India" Dr. Monkombu Sambasivan Swaminathan passed away on September 28, 2023, aged 98. His contributions: (a) Led HYV wheat introduction at IARI with Norman Borlaug's varieties (1965-66); (b) National Commission on Farmers (2004-06) -- Swaminathan Commission --

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recommended C2+50% MSP formula (cost of production including imputed land rent and interest + 50% profit -- a demand that continues to be raised by farmers in 2024 protests); (c) Coined "Evergreen Revolution" -- productivity improvement without ecological harm; (d) Founded MSSRF (MS Swaminathan Research Foundation, Chennai).

Farmers' Protest 2024 (Shambhu Border and MSP Demand): In February 2024, farmers from Punjab and Haryana (led by Samyukta Kisan Morcha-Non-Political and Kisan Mazdoor Morcha) marched toward Delhi demanding (a) legal guarantee of MSP (Minimum Support Price) for all crops at C2+50% formula (as recommended by the Swaminathan Commission); (b) loan waiver; (c) Lakhimpur Kheri justice; (d) withdrawal of the three farm laws; protest concentrated at Shambhu border (Punjab-Haryana). The 2024 protests continued through 2025. This is a defining political economy issue in India -- the gap between MSP and market price for most crops outside Punjab-Haryana.

GM Mustard HT-DMH 11 Approval (2022-2024): GEAC approved HT-DMH 11 (Dhara Mustard Hybrid) for commercial cultivation in October 2022 -- India's first GM food crop approval. Developed by Delhi University (Prof. Deepak Pental). Combines herbicide tolerance and hybrid vigour; 20-30% yield increase. Opposition from farmer groups, Swadeshi Jagran Manch; SC formed Technical Expert Committee. Case ongoing as of 2024.

28.10 PYQ ANALYSIS -- CHAPTER 28 (2010-2025)

Source	Year	Marks	Question
UPSC Civil	2024	15M	"Critically examine the achievements and environmental costs of the Green Revolution in India. What policy shifts are needed for sustainable Indian agriculture?"
UPSC Civil	2023	12M	"Discuss the significance of the International Year of Millets 2023. How can millets contribute to India's food and nutritional security?"
UPSC Civil	2022	12M	"Discuss the landholding pattern in India and its implications for agricultural productivity and farmer welfare."
UPSC Civil	2021	15M	"What is the National Food Security Act, 2013? How does the PM Garib Kalyan Anna Yojana supplement it? Critically evaluate India's food security architecture."
UPSC Civil	2020	10M	"Compare and contrast Kharif and Rabi cropping seasons of India with respect to timing, crops and climate requirements."
UPSC Civil	2019	10M	"Discuss the distribution of the major oilseeds in India and the factors that determine their cultivation."
UPSC Civil	2018	12M	"Discuss the significance of plantation agriculture in India. What are the major issues faced by tea and coffee cultivators?"
UPSC Civil	2017	10M	"What is shifting cultivation? Discuss its significance for tribal communities and its environmental impact in northeast India."
IFOS GS	2024	10M	"Discuss the ecological impacts of shifting cultivation (jhum) in northeast India and the challenges of transitioning tribal communities to settled agriculture."
IFOS GS	2023	10M	"Examine the relationship between agricultural cropping patterns and soil health in India. How do mono-cropping and crop rotation affect soil biodiversity?"
IFOS GS	2022	10M	"Discuss the role of agroforestry in India's agricultural landscape. How does it contribute to biodiversity conservation and climate adaptation?"

KEY NOTE

Frequency: Green Revolution achievement and costs (Civil 2024); Millets/IYoM 2023 (Civil 2023); landholding patterns (Civil 2022); NFSA + PMGKAY food security (Civil 2021); Kharif vs Rabi (Civil 2020); oilseeds distribution (Civil 2019); plantation agriculture (Civil 2018); shifting cultivation (Civil 2017). IFoS: jhum ecology (2024), cropping-soil health (2023), agroforestry (2022). For 2025-26: PMGKAY merger with NFSA (Jan 2024); MS Swaminathan death + legacy + Swaminathan Commission MSP formula; Farmers 2024 protest + MSP legal guarantee; GM Mustard HT-DMH-11 SC case; International Year of Millets 2023 outcomes are all top current-affairs hooks.

28.11 MODEL BOOK

Critically examine the achievements and environmental costs of the Green Revolution in India. What policy shifts are needed for sustainable agriculture?

UPSC Civil (Mains) | 15 Marks | 210 Words

The Green Revolution (1965-66 to 1970s) transformed India from a food-importing nation dependent on PL-480 American wheat to a food-self-sufficient country with buffer stocks. It is one of independent India's greatest policy successes -- and, in retrospect, one of its most consequential environmental risks.

KEY ACHIEVEMENTS:

1. **Food production surge:** Food grain production grew from ~72 MT (1965-66) to ~113 MT (1980) to ~330 MT (2023-24). India went from food imports to food exports.
2. **Poverty reduction:** Cheaper and more abundant food reduced food poverty, especially in urban India; agricultural wages rose in Green Revolution states.
3. **Farmer incomes in Punjab-Haryana:** Punjab became among India's most prosperous states; per capita income in the Green Revolution belt rose dramatically from the 1970s-1990s.
4. **Technology foundation:** HYV seeds + chemical fertiliser + irrigation created a technology platform (IARI, ICAR, Krishi Vigyan Kendras) that subsequent agricultural improvements built upon.

ENVIRONMENTAL AND SOCIAL COSTS:

1. **Groundwater depletion:** Punjab's water table falls 50 cm/year in some districts; paddy cultivation in a semi-arid state (using 1,200-1,500 mm of irrigation water for a 600 mm rainfall area) is ecologically irrational; estimated <20 years before aquifers collapse in central Punjab.
2. **Soil degradation:** Paddy-wheat monoculture depletes micronutrients (especially Zinc); soil organic carbon declining; Punjab's soils increasingly need more fertiliser for the same yield (diminishing returns).
3. **Biodiversity loss:** Thousands of traditional rice and wheat varieties replaced by a few HYVs; agro-biodiversity collapse in the Green Revolution belt.
4. **Pesticide health crisis:** Malwa region of Punjab = high cancer incidence linked to pesticide exposure; the "cancer train" from Bathinda to PGI Chandigarh has been documented in journalism and research.
5. **Regional inequity:** Green Revolution bypassed eastern India (Bihar, eastern UP, WB), dryland areas, and NE India; deepened the agricultural productivity divide.

POLICY SHIFTS NEEDED -- THE "EVERGREEN REVOLUTION" (MS SWAMINATHAN'S VISION):

1. **Crop diversification:** Punjab-Haryana must shift away from paddy to maize, pulses, oilseeds (which use 70-80% less water); MSP incentives for diversification; PM Fasal Bima Yojana must cover diversified crops adequately.
2. **Natural and organic farming:** NMNF 2024 (Rs.2,481 crore; 1 crore farmers) and APCNF model (800,000+ farmers in Andhra Pradesh) show the viability of zero-chemical natural farming.
3. **Millets revival:** IYoM 2023 and "Shree Anna" initiative -- promoting drought-tolerant, low-water, nutritious millets as an alternative to paddy in water-scarce areas.

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4. **Technology:** Precision agriculture, soil health cards, drip irrigation to reduce water use by 30-50%; zero tillage to reduce soil disturbance and preserve organic matter.

MS Swaminathan (1925-2023) himself coined "Evergreen Revolution" as the necessary successor to the Green Revolution -- increasing productivity while preserving the natural resource base. India's 2070 net-zero commitment, 30x30 biodiversity target, and food security for 1.4 billion people all converge on the need for this second agricultural transformation.

Discuss the ecological impacts of shifting cultivation (jhum) in northeast India and the challenges of transitioning to settled agriculture.

UPSC IFOS (Mains) | 15 Marks | 200 Words

Shifting cultivation (jhum in NE India) is one of the world's oldest agricultural systems -- simultaneously a sophisticated traditional land management practice and, under modern population pressures, a driver of deforestation and soil erosion. Its ecological impact depends critically on the FALLOW PERIOD: with 15+ years fallow, jhum is ecologically sustainable; with 3-5 years fallow (the current shortened cycle), it is destructive.

TRADITIONAL JHUM -- ECOLOGICAL CONTEXT:

1. **NUTRIENT CYCLING:** In the traditional 15-year cycle, burning of cleared vegetation releases nutrients in ash; the abandoned jhum field regenerates through secondary succession (grassland -- shrubland -- secondary forest); soil nutrients restored; biodiversity partially recovered.
2. **BIODIVERSITY MAINTENANCE:** Traditional jhum creates a MOSAIC LANDSCAPE -- patches of active cultivation, recent abandonment, and regenerating secondary forest at different successional stages; this mosaic habitat supports higher bird, mammal and plant diversity than homogeneous primary forest or homogeneous agriculture.
3. **WATER REGULATION:** In traditional long-cycle jhum, the forest cover is never entirely removed across an entire watershed simultaneously; different plots at different stages maintain watershed functions.

MODERN JHUM -- ECOLOGICAL DETERIORATION:

1. **SHORTENED FALLOW (3-5 YEARS):** Population growth has compressed the fallow period from 15+ years to 3-5 years in most NE India jhum communities; the forest cannot regenerate to the point where it restores soil fertility; each successive cycle produces lower yields, compressing the fallow period further -- a DOWNWARD SPIRAL.
2. **DEFORESTATION:** NE India jhum is estimated to affect 1.5-2 lakh ha annually; primary forest being converted as "new" jhum sites are needed; Nagaland, Mizoram, Manipur have lost significant forest cover to jhum (correlated with ASFR 2023 decline in Arunachal, Manipur).
3. **SOIL EROSION:** Cleared slopes (especially steep jhum fields) with no protective vegetation cover suffer intense monsoon-induced sheet, rill and gully erosion; top soil loss is severe.
4. **WATER COURSE SEDIMENTATION:** Eroded soil from jhum plots sediments rivers and streams, degrading aquatic ecosystems and reducing downstream water quality and fish populations.
5. **LOSS OF BIODIVERSITY:** Short-fallow jhum mosaics lack the structural diversity of old-fallow jhum; many forest-interior specialists (hornbills, some primates, shade-requiring plants) cannot persist.

CHALLENGES OF TRANSITION TO SETTLED AGRICULTURE:

1. **LIVELIHOOD DEPENDENCE:** Jhum is not merely agriculture -- it is central to tribal identity, culture, and social organisation (collective decision-making on jhum calendars; community labour exchanges). A transition must respect this cultural context.

2. **TERRAIN LIMITATIONS:** NE India's steep hill terrain is poorly suited to paddy terracing (unlike the Himalayan foothills); settled agriculture options are limited; horticulture (pineapple, banana, oranges, kiwi) and agroforestry are more promising than wet rice terracing.
3. **INFRASTRUCTURE AND MARKET ACCESS:** Remote tribal villages lack roads, cold chain, market access; settled horticultural crops (like pineapple) need market connectivity to be viable alternatives.
4. **LAND TENURE:** Jhum land is often communally managed under customary tribal law; conversion to settled private plot-based agriculture raises tenure and equity issues.

POLICY RESPONSE: NERCORMP (North East Region Community Resource Management Project with IFAD), integrated watershed development, community forestry, organic horticulture, Van Mahotsav, and the Forest Rights Act (which protects traditional community forest rights) are the toolkit. The FRA's Community Forest Rights (CFR) provisions can legitimise and stabilise jhum communities' land access while creating pathways to sustainable management -- provided they are combined with adequate livelihoods support.

The ecological future of NE India's forests depends critically on whether viable settled livelihood alternatives can be offered to jhum communities. Without these alternatives, criminalising or suppressing jhum only impoverishes communities while pushing them onto new forest plots -- worsening the very outcome that policy seeks to prevent.

MSP MECHANISM, APMC AND FARM LAWS

5A. MINIMUM SUPPORT PRICE (MSP) -- COMPLETE MECHANISM

The Minimum Support Price (MSP) is the **price at which the Government of India (through FCI and state procurement agencies) guarantees to buy a farmer's produce**, providing a floor price below which the market price should not fall. It is the MOST IMPORTANT agricultural policy intervention in India and the central demand of the 2020-21 (and 2024) farmers' movements.

MSP Feature	*Detail*
Legal status	MSP is NOT a legal right -- it is an ADMINISTRATIVE DECISION of the Cabinet Committee on Economic Affairs (CCEA), recommended by the Commission for Agricultural Costs and Prices (CACP). Farmers have been demanding that MSP be given LEGAL GUARANTEE (so that any purchase below MSP is punishable) -- this was the core demand of the 2020-21 farmers' protest (along with repeal of the 3 farm laws).
CACP (Commission for Agricultural Costs and Prices)	Statutory body under MoA&FW (Ministry of Agriculture); established 1965; submits price policy recommendations for 22-23 crops every year before sowing season (Kharif recommendations in March-April; Rabi recommendations in October-November); independent body but recommendations are not binding on government
Crops covered under MSP (22 mandated crops + sugarcane)	KHARIF (14 crops): Paddy (rice), Jowar, Bajra, Maize, Ragi, Arhar/Tur, Moong, Urad, Groundnut, Sunflower, Soybean, Sesamum, Nigerseed, Cotton. RABI (6 crops): Wheat, Barley, Gram (Chickpea), Lentil (Masur), Rapeseed/Mustard, Safflower. OTHER (2 crops): Jute, Copra. SUGARCANE: separate FRP (Fair and Remunerative Price) mechanism. TOTAL: 22 crops + FRP for sugarcane = 23 commodities.
Cost concepts (very frequently asked in Prelims)	A2 = Actual paid-out costs (seeds, fertilisers, pesticides, hired labour, irrigation charges, fuel, repairs). A2+FL = A2 + imputed value of family labour (unpaid family members who work on farm). C2 = A2+FL + imputed rent of owned land + imputed interest on owned capital. C3 = C2 + depreciation of infrastructure above the farm level. GOVERNMENT POLICY: MSP set at 1.5x A2+FL (announced 2018 Budget; fulfilled per government). FARMER DEMAND: C2 + 50% (Swaminathan Commission recommendation; adds land rent and capital interest to the cost base, giving a higher MSP).

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Procurement agencies	FCI (Food Corporation of India, 1965): primary agency for wheat and rice procurement under MSP from Punjab, Haryana, MP, UP, WB, Odisha, CG, AP, Telangana. NAFED (National Agricultural Cooperative Marketing Federation): procures oilseeds, pulses, cotton under MSP (Price Support Scheme). State agencies: e.g., HAFED (Haryana), MARKFED (Punjab), OSCSC (Odisha). CCI (Cotton Corporation of India): cotton MSP procurement.
MSP vs Market Price reality	In practice: only WHEAT and PADDY are effectively procured at MSP (because FCI has widespread procurement network in Punjab-Haryana-UP). Other MSP crops (pulses, oilseeds, cotton, coarse cereals) are procured only when market price falls below MSP -- and even then, procurement is limited and delayed. Farmers for MOST crops do NOT receive MSP in practice -- they sell at market prices which are often below MSP. This is the crux of the MSP legal guarantee demand.
PM AASHA (Price Support Scheme + Price Deficiency Payment)	Launched 2018; PM Annadata Aay Sanrakshan Abhiyan; 3 components: (a) PSS (Price Support Scheme) -- physical procurement of pulses and oilseeds at MSP; (b) PDPS (Price Deficiency Payment Scheme) -- if farmer sells below MSP, government pays the difference directly to farmer's bank account (without physically procuring); (c) PPSS (Pilot of Private Procurement and Stockist Scheme) -- private companies empowered to procure at MSP in some states. PM AASHA = attempt to extend MSP benefits beyond wheat-rice without massive physical procurement costs.

5B. FCI BUFFER STOCK NORMS

Parameter	Detail
FCI (Food Corporation of India)	Established 1965; under Ministry of Consumer Affairs, Food and Public Distribution; procures wheat and rice from farmers at MSP, stores in warehouses (FCI godowns), and distributes through TPDS (Targeted Public Distribution System) to PDS ration shops at subsidised prices. FCI also maintains strategic reserves for food security.
Buffer Stock Norms (Revised 2015)	Minimum stock to be maintained for food security: On April 1 (start of year): Wheat = 21.2 MT; Rice = 13.5 MT; Total = 34.7 MT. On July 1: Wheat = 28.5 MT; Rice = 13.5 MT; Total = 41.0 MT. On October 1: Wheat = 20.5 MT; Rice = 24.0 MT; Total = 44.5 MT. On January 1: Wheat = 15.2 MT; Rice = 11.8 MT; Total = 28.0 MT. When actual stock > buffer norm = SURPLUS (government may export or divert to welfare schemes). When actual stock < buffer norm = DEFICIT (may need to import or restrict exports).
Economic Cost of FCI	FCI's total subsidy burden is enormous: Economic Cost = MSP paid to farmers + procurement incidentals (transport, storage, handling, interest) + distribution incidentals; Economic Cost for wheat ~Rs.28/kg but issue price to PDS = Rs.2/kg; gap = ~Rs.25/kg = government subsidy. Annual food subsidy = ~Rs.2.87 lakh crore (Budget 2024-25); a massive fiscal burden; much of it goes to Punjab-Haryana farmers (who benefit most from MSP procurement) and to PDS consumers (81 crore beneficiaries under NFSA + PMGKAY).
Shanta Kumar Committee (2015)	Recommended radical reform of FCI: (a) Phase out wheat-rice procurement by FCI; shift to DBT cash transfers to farmers instead; (b) Outsource storage and procurement to states and cooperatives; (c) End open-ended procurement (limits in advance); (d) Privatise much of FCI. Government accepted some recommendations partially; politically difficult to implement fully due to Punjab-Haryana farmer politics.

5C. APMC (AGRICULTURAL PRODUCE MARKET COMMITTEE) -- STRUCTURE AND REFORMS

APMC Feature	Detail
What is an	Agricultural Produce Market Committee (APMC) = a state government-regulated

APMC?	marketplace (mandi) for buying and selling agricultural produce. Established under state APMC Acts (most states passed their APMC Acts in 1960s-70s). Every state notifies which commodities are "regulated commodities" -- for which, all trade MUST pass through APMC mandis; private trade is prohibited. Purpose: ensure transparent price discovery, prevent farmer exploitation by middlemen; provide infrastructure (platform, weighing, storage).
Mandi structure	APMC mandi has: (a) Commission agents (Arhatias/arthiyas): licensed middlemen who facilitate trade between farmers and buyers; charge 1-2.5% commission from farmers; (b) Buyers: wholesalers, processors, exporters; (c) Labour (hamali): unload, weigh, grade; all pay APMC fees/cess. India has ~7,000 regulated mandis + ~22,000 sub-yards (APMC 2013 report). AMRUT target: link all 7,000 mandis to eNAM (National Agriculture Market -- online price discovery portal since 2016).
Problems with APMC system	(a) APMC area limits: farmers MUST bring produce to designated mandi (sometimes far from farm); (b) Intermediary chain: farmer → commission agent → wholesale trader → retailer → consumer; each level takes margin; farmer gets 35-50% of consumer price; (c) APMC cess / mandi tax: typically 1-2.5% of trade value; buyers pass cost to consumers; (d) Cartelisation: in many mandis, commission agents form cartels, depressing prices paid to farmers (price fixing collusion); (e) License Raj: private food processing companies and supermarkets cannot buy directly from farmers under APMC acts (must go through mandi); limits supply chain efficiency.
APMC reforms (2003 Model APMC Act)	Central government circulated Model APMC Act 2003 recommending: (a) Allow direct buying from farmers by processors, retailers, exporters (bypassing mandis); (b) Allow contract farming (written agreement between farmer and buyer before sowing); (c) Single license for trading across all mandis in a state. About 18 states amended their APMC Acts post-2003; Bihar ABOLISHED its APMC Act entirely (2006) -- results mixed (no mandi infrastructure; farmers depend on private traders; some exploitation).
eNAM (Electronic National Agriculture Market)	Launched April 14, 2016; an online trading platform linking 1,000+ APMC mandis; electronic price discovery (auction visible to all); farmer can see prices across India; prevents cartelisation; payment within 24 hours via bank transfer; challenges: (a) not all states connected; (b) quality assay infrastructure inadequate (electronic sale requires standardised quality grading); (c) internet access by farmers; (d) traders resist transparency.

5D. THREE FARM LAWS 2020 -- CONTENTS AND REPEAL

In September 2020, the Indian Parliament passed **three controversial farm laws** that fundamentally altered the APMC-MSP ecosystem. These triggered the **largest farmers' protest in Indian history** (2020-21; at Delhi borders for ~13 months; by primarily Punjab-Haryana farmers), ultimately leading to their **repeal on November 19, 2021** (PM Modi announced the repeal on Guru Nanak Jayanti).

Law	Full Name	Key Provision	Farmer Objection
Law 1	Farmers' Produce Trade and Commerce (Promotion and Facilitation) Act, 2020	Allowed farmers to sell their produce OUTSIDE the APMC mandi system, to any buyer anywhere, without paying mandi cess; enabled e-commerce platforms and private trade areas ("trade	Farmers feared: (a) without APMC system, corporate buyers would dominate; (b) MSP protection would erode (private buyers not obligated to pay MSP); (c) mandi infrastructure (which provides price transparency) would collapse; (d) arhatias (commission agents -- powerful in

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		areas") to operate outside APMC jurisdiction	Punjab-Haryana politics) opposed as it undermined their role; Bihar example (which abolished APMC) cited as evidence that farmers lost price protection
Law 2	Farmers (Empowerment and Protection) Agreement on Price Assurance and Farm Services Act, 2020	Provided a framework for CONTRACT FARMING -- written pre-sowing agreements between farmers and buyers (agro-businesses, food companies, exporters) specifying price, quantity, quality; 3 dispute resolution tiers (conciliation board → SDM → Collector)	Farmers feared: (a) corporate/agribusiness power asymmetry -- farmer can't negotiate equally with Reliance or Adani; (b) land may effectively be mortgaged to corporate party under contract; (c) dispute resolution through SDM/Collector = executive pressure on farmers; (d) weak contract enforcement for small farmers
Law 3	Essential Commodities (Amendment) Act, 2020	Removed cereals, pulses, oilseeds, onion, potatoes from the Essential Commodities Act list (meaning: no stocking limits for these commodities by traders/processors except in extraordinary circumstances)	Farmers feared: (a) large corporates and traders can hoard these commodities; (b) hoarding leads to price manipulation -- artificial scarcity drives up consumer prices; (c) rich traders can buy cheap at harvest (glut), hoard, sell expensive in off-season; farmer does not benefit from price rise after selling at harvest
REPEAL (November 19, 2021)	All 3 laws repealed by Farmers' Produce Trade and Commerce (Promotion and Facilitation) Repeal Act, 2021 etc.	PM Modi announced repeal on Guru Nanak Jayanti (November 19, 2021); Parliament passed repeal bills on November 29, 2021 without debate; situation returned to status quo ante	Farmers' unions dissolved the protest after repeal; BUT their demand for MSP legal guarantee remained unfulfilled; 2024 protest at Shambhu border by SKM(NP) + KMM renewed this demand; Swaminathan Commission C2+50% MSP formula remains the core unresolved agricultural policy demand

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GS-3 Framework: MSP Legal Guarantee -- Arguments For and Against:

FOR (farmer welfare argument): (a) Only 6-7% of Indian farmers actually sell to FCI/NAFED at MSP; rest are at market mercy; legal guarantee extends protection; (b) C2+50% formula recognises land and capital costs (actual cost of farming); (c) Reduces farmer distress, debt, suicides; (d) Gives farmers income predictability to invest in productivity.

AGAINST (economist argument): (a) If MSP is legally mandated for all 23 crops, government must procure ALL of India's production at that price -- fiscal cost would be Rs.10-17 lakh crore/year (per some estimates) -- impossible; (b) Distorts crop selection (farmers grow only MSP crops = monoculture; reduces agricultural diversification); (c) Encourages over-production of paddy-wheat (already a surplus) while pulses and oilseeds (deficit) remain less attractive; (d) MSP inflation = food price inflation for urban poor; (e) Environmental cost: legal MSP for paddy keeps Punjab growing water-intensive paddy despite groundwater crisis.

CHAPTER 29

IRRIGATION SYSTEMS

Types, Distribution and Policy in India

CHAPTER AT A GLANCE

- India has the LARGEST IRRIGATED AREA in the world (~70 million ha net; ~140 million ha gross irrigated area including multiple irrigations). About 50% of Net Sown Area (NSA) is irrigated; the remaining ~50% is rain-fed. Irrigation is critical for food security -- irrigated land produces 60-70% of food grain output despite being 50% of cropped area, because of higher cropping intensity and yields.
- THREE TYPES OF IRRIGATION SOURCES: (1) CANAL irrigation (~26% of net irrigated area): surface water from rivers via gravity flow; large dams + canal networks; most important in Punjab-Haryana (Indira Gandhi Canal; Bhakra Canal; SYL controversy), UP (Ganga Canal, Eastern Yamuna Canal), Rajasthan, MP, Andhra Pradesh (Krishna-Godavari canals); (2) WELLS AND TUBE-WELLS (~62% of net irrigated area; DOMINANT SOURCE): groundwater pumped through wells; traditional open wells and modern electrified/diesel tube-wells; Punjab, Haryana, UP, Rajasthan, Gujarat, Maharashtra lead; (3) TANKS/PONDS (~4% and declining): traditional storage reservoirs; South India (TN, Karnataka, AP, Telangana) historically; now declining due to neglect.
- CANAL IRRIGATION: Inundation canals (direct diversion from river during flood; no storage; seasonal); Perennial canals (fed from reservoirs/barrages; year-round water; major multi-purpose projects). Key canal projects: Eastern Yamuna Canal (1830, oldest major canal in India; UP); Upper Ganga Canal (Hardwar, 1854); Indira Gandhi Nahar Pariyojana (IGNP, Rajasthan; 9,060 km network; converts Thar desert to agriculture; water from Bhakra-Beas-Sutlej); Nagarjunasagar Canal (AP); Tungabhadra Canal; Krishna-Godavari canal systems.
- WELL AND TUBE-WELL IRRIGATION: Deep tube-wells (DTW) and shallow tube-wells (STW) powered by electric pumpsets or diesel pumps; dominant in Indo-Gangetic Plain (Punjab, Haryana, WUP) and Gujarat, Maharashtra, Rajasthan. Punjab water crisis: water table falling 50 cm/year in central Punjab; paddy cultivation withdraws 1,200-1,500 mm while rainfall is only 500-600 mm; estimated <20 years before aquifer depletion. Groundwater depletion is India's most serious long-term irrigation crisis.
- TANK IRRIGATION: Traditional community-managed earthen bunds creating storage reservoirs ("tanks" or "eri" in TN); South India specific -- Tamil Nadu has ~39,000 tanks; Karnataka, AP, Telangana also had extensive tank networks. Ancient irrigation engineering marvels: Grand Anicut (Kallanai Dam) on Cauvery by Karikala Chola (~2nd century CE; among world's oldest functional water diversion structures; UNESCO recognition). Tank irrigation declining due to: silt accumulation, encroachment, neglect of maintenance, groundwater pumping reducing recharge, shifting to tube-wells.
- DRIP AND SPRINKLER IRRIGATION: Micro-irrigation systems delivering water directly to plant roots (drip) or via simulated rain (sprinkler); water-use efficiency 80-95% vs flood irrigation 40-60%. India has ~10 million ha under micro-irrigation (2023; largest micro-irrigation area in world after China). PM Krishi Sinchayee Yojana (PMKSY 2015): "Har Khet Ko Pani, More Crop Per Drop" -- target: micro-irrigation on 10 million ha additionally by 2025-26. NMMI (National Mission on Micro Irrigation). AIBP (Accelerated Irrigation Benefits Programme).
- MAJOR IRRIGATION PROJECTS: Bhakra-Nangal Dam (Himachal Pradesh; Gobind Sagar lake; 10.3 million ha commanded area); Hirakud Dam (Odisha; longest dam in India at 4,800 m including earthen embankments; Mahanadi; 1.55 million ha command); Nagarjunasagar Dam (Telangana/AP; Krishna; 0.86 million ha on each side = 1.72 million ha total); Sardar Sarovar Project (Gujarat; Narmada; 1.8 million ha command; controversial tribal displacement of Narmada Bachao Andolan); Indira Gandhi Canal (Rajasthan; 9,060 km total length).
- WATER DISPUTE AND POLICY: Cauvery Water Dispute (Karnataka vs Tamil Nadu -- most litigated water dispute;

Supreme Court 2018 order; CWMA established; inter-state river conflicts intensify in drought years); Ken-Betwa River Interlinking Project (KBRIP -- approved 2021; Panna Tiger Reserve submergence controversy; first National River Linking Project). National Water Policy 2012 (prioritises drinking water, then agriculture); National Water Mission (NAPCC). India National Water Resources Grid (NWRG) -- long-term plan to link surplus to deficit river basins

29.1 INTRODUCTION -- IRRIGATION IN INDIA

Irrigation -- the artificial application of water to crops -- is the **single most important determinant of agricultural productivity in India** beyond rainfall itself. India has the **world's largest irrigated area** at approximately **70-72 million hectares (net irrigated area)** and approximately **140 million ha of gross irrigated area** (counting multiple irrigations of the same land in a year). This represents approximately 50% of India's Net Sown Area (NSA) of ~140 million ha.

The fundamental challenge: approximately **50% of India's cultivated land receives no irrigation** and is entirely dependent on the monsoon -- making it vulnerable to rainfall variability (the "double jeopardy" described in Chapter 22). Irrigated land, despite covering only 50% of the cultivated area, produces approximately **60-70% of India's food grain output** due to higher yields and greater cropping intensity (multiple crops per year possible). The expansion, modernisation, and sustainable management of irrigation infrastructure is therefore central to India's food security and agricultural policy.

IRRIGATION COVERAGE -- KEY STATISTICS

Parameter	*Data*	*Note*
Net Irrigated Area (NIA)	~70-72 million ha (4th Agricultural Census data)	India = world's largest irrigated area; net = unique area irrigated at least once in a year
Gross Irrigated Area (GIA)	~140 million ha (including multiple irrigations)	GIA > NIA because the same land is irrigated multiple times in a year (double/triple cropping)
% of Net Sown Area (NSA) irrigated	~50-52%	~50% of Indian agriculture still rain-fed; regional variation: Punjab 98%+ irrigated vs Rajasthan ~40% vs NE India <10%
Irrigation potential created (IPC)	~113 million ha (dams, canals, wells created since Independence)	But actual utilisation is lower; gap between IPC and actual use = problem of incomplete distribution systems
% contribution to food grain production	Irrigated area produces ~60-70% of food grain	Despite being 50% of area; explains why expanding irrigation = fastest way to increase food production
Source share (Net Irrigated Area)	Tube-wells/wells: ~62%; Canals: ~26%; Tanks: ~4%; Other: ~8%	Tube-wells now dominant nationally -- a dramatic shift from canals (which were dominant until 1970s)

29.2 CANAL IRRIGATION -- SURFACE WATER SYSTEMS

Canal irrigation -- the diversion of river water through a network of engineered channels -- is India's oldest organised large-scale irrigation system and was the **dominant irrigation source until the 1970s-80s** when tube-well expansion overtook it. Canals are fed either directly from rivers (inundation or diversion canals) or from storage reservoirs (perennial canals).

TYPES OF CANALS

Canal Type	*Source*	*Season / Duration*	*Key Feature / Example*
Inundation	Divert river water DIRECTLY	SEASONAL:	Simplest and cheapest type; no dam

Canals	during flood season; no storage or barrage needed; water flows by gravity when river level is high	operate only during high-discharge period (monsoon season)	required; water available only in flood season; unreliable; traditional system in Punjab and Sind before partition; most replaced by perennial canal systems. Still used as supplementary in some areas.
Perennial Canals (Diversion)	Take-off from a BARRAGE (diversion weir) that raises river level to ensure year-round inflow into canal; water diverted at a constant point	PERENNIAL: water available year-round (subject to river flow)	Barrage-based; more reliable than inundation; can serve Rabi crops; examples: Eastern Yamuna Canal (Tajewala headworks), Upper Ganga Canal (Hardwar), Sarda Canal; most of the British-era canals of North India are this type
Perennial Canals (Storage / Reservoir-fed)	Take-off from the RESERVOIR created by a major dam; reservoir stores monsoon water for release through the dry season	PERENNIAL and FLEXIBLE: regulated release according to crop demand throughout the year	Most important type for modern irrigation; highly regulated; examples: Bhakra Main Line Canal (Gobind Sagar reservoir); Nagarjunasagar Main Canal (NS reservoir); Indira Gandhi Canal (Gobind Sagar + Pong + Ranjitsagar); can deliver water in precise quantities at precise times
Lift Canals	Water pumped UPHILL from rivers or canals to command areas at higher elevation; electric or diesel pumps; more expensive but extends reach to upland areas	Same season as the source canal but requires energy	Andhra Pradesh has India's most extensive lift irrigation scheme -- Jalayagnam (also called JLMF); Rajasthan Lift Canal (from Indira Gandhi Canal to higher lands); Polavaram Lift Irrigation in AP (part of Polavaram project)

MAJOR CANAL SYSTEMS OF INDIA

Canal System	*State*	*Source*	*Length / CommandArea*	*Key Feature*
Eastern Yamuna Canal	Uttar Pradesh	Yamuna River (at Tajewala, Yamunanagar, Haryana)	~1,400 km main canal; UP portion; serves western UP	OLDEST MAJOR CANAL in modern India: first constructed by Mughal Emperor Shah Jahan (1635 CE); restored and expanded by British (1830). Irrigates Muzaffarnagar, Saharanpur, Meerut districts. Now partially integrated into the Ganga Canal system.
Upper Ganga Canal (Ganga Canal)	Uttar Pradesh	Ganga River (at Hardwar, Uttarakhand; Bhimgoda headworks)	~1,400 km main canal; ~6 million ha command	Constructed by British India (Major Proby Cautley; completed 1854); considered the largest engineering work of its time; serves Doab region (between Ganga and Yamuna) in UP; Muzaffarnagar, Meerut, Aligarh, Bulandshahr.
Lower Ganga Canal	Uttar Pradesh	Ganga River (at Narora barrage,	~7,000 km total length; southern	Extended the canal system into eastern UP; supplemented by tube-wells in the area; major food production role in UP.

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		Bulandshahr)	and eastern UP	
Sarda Canal (Sharda)	Uttar Pradesh	Sharda River (Sarda Sahayak Feeder; Banbasa, Champawat, UP-Uttarakhand border)	~3,000+ km; eastern UP	Serves Terai-adjacent areas of UP; integrated with other canal systems. Sarda River is also called Mahakali (India-Nepal border river).
Indira Gandhi Nahar Pariyojana (IGNP)	Rajasthan	Ravi-Beas-Sutlej system (from Harike Barrage, Punjab; water from Bhakra Dam reservoir + Pong Dam + Ranjitsagar Dam)	Total length including distributaries: ~9,060 km; command area: ~1.96 million ha (originally planned; actual under utilisation)	INDIA'S LARGEST CANAL PROJECT and LONGEST CANAL SYSTEM in India. Stage 1: ~204 km Rajasthan Feeder Canal from Harike (Punjab-Haryana) to Masitawali (Rajasthan border) + 189 km Main Canal in RJ. Stage 2: extends further south into Barmer. Transformed Thar Desert area into agricultural land (wheat, cotton, bajra, cumin now grown in Jaisalmer district). Ecological concerns: waterlogging and soil salinisation in some command areas; also altered the fragile desert ecology (originally meant to "green the desert" but over-irrigation has caused problems in some sections).
Bhakra Main Line and Sirhind Canal	Punjab, Haryana, Rajasthan	Bhakra-Nangal Dam (Gobind Sagar reservoir, Sutlej River, HP)	Commanded area ~4.2 million ha in Punjab+ Haryana+Rajasthan	Bhakra Dam = one of India's highest straight gravity dams (226 m); Bhakra-Nangal Multi-Purpose Project (Gobind Sagar reservoir = 9.34 BCM live capacity); Bhakra Main Line Canal feeds Sirhind Canal system; major source of irrigation for the Green Revolution wheat belt; also supplies drinking water to large parts of Punjab, Haryana, Delhi.
Nagarjunasagar Main Canal (Left Bank + Right Bank)	Andhra Pradesh, Telangana	Nagarjunasagar Dam (Krishna River, on AP-Telangana border)	1.72 million ha total (0.86 each side)	Nagarjunasagar Dam (1969) -- one of India's largest masonry dams; Left Bank Canal serves Nalgonda, Krishna, Guntur (Telangana+AP); Right Bank Canal (with lift) serves Prakasam, Nellore, Kurnool (AP). Named after the Buddhist site (now submerged) -- Nagarjunakonda Archaeological Museum is on an island in the reservoir.
Tungabhadra Canal System	Karnataka, Andhra Pradesh, Telangana	Tungabhadra Dam (on Tungabhadra River, Hospet,	~1.8 million ha command (both states)	Inter-state project; Tungabhadra Board manages allocation between Karnataka and AP. The Tungabhadra River is a major Krishna tributary; the

		Karnataka)		reservoir/canal system sustains rice and cotton cultivation in the historically drought-prone Rayalaseema and parts of northern Karnataka.
Polavaram Project (Pattiseema)	Andhra Pradesh	Godavari River (Polavaram site in Papikondalu area, West Godavari district)	3.28 million ha (largest single irrigation project approved in India)	A National Project (declared 2014); disputed with Telangana and Odisha (submergence of tribal areas). Will divert Godavari water to Krishna-Penna basins; also generate 960 MW electricity. Controversies: tribal displacement, inter-state water disputes, cost escalation (now Rs.1.09 lakh crore). Pattiseema Lift Irrigation (already operational 2015): pumps Godavari water into Krishna system -- remarkable inter-basin transfer.
Chambal Canal System	Rajasthan, Madhya Pradesh	Chambal River (Gandhi Sagar Dam, Rana Pratap Sagar Dam, Jawahar Sagar Dam in sequence)	0.87 million ha (RJ) + smaller area (MP)	Joint project of RJ and MP; Gandhi Sagar = largest dam on Chambal; reservoir system provides regulated flow. Also generates 386 MW hydropower (Jawahar Sagar + Rana Pratap Sagar). Chambal River basin (Chambal ravines) now partly transformed into farmland through canal irrigation.

KEY NOTE

Prelims Key Facts -- Canals: (1) Eastern Yamuna Canal = oldest major modern canal (British 1830; originally Mughal 1635). (2) Upper Ganga Canal = Proby Cautley, 1854. (3) Indira Gandhi Canal (IGNP) = longest canal system in India (~9,060 km). (4) Grand Anicut (Kallanai) = oldest functional dam/diversion weir in world on Cauvery River by Karikala Chola (~2nd century CE). (5) Hirakud = longest earthen dam in India (4,800 m including earthen embankments). (6) Bhakra = India's highest gravity dam (226 m).

29.3 WELL AND TUBE-WELL IRRIGATION -- DOMINANT SOURCE

Well and tube-well irrigation has **displaced canals as India's dominant irrigation source** -- accounting for approximately **62% of net irrigated area** nationally. This shift from surface water (canals) to groundwater (wells) has transformed Indian agriculture -- enabling flexible, on-demand irrigation independent of canal release schedules -- but has also created a **groundwater depletion crisis** that threatens the sustainability of Indian agriculture in many regions.

TYPES OF WELL IRRIGATION

Type	*Technology*	*Depth*	*States*	*Key Feature*
Traditional Open Wells (Kuan)	Manually dug brick/stone-lined wells; bullock-operated Persian wheel (rahat) or manually operated to lift water; very old technology	Shallow: water table depth (typically <30 m)	Historically all of India; now being replaced by tube-wells; still found in Maharashtra, AP, Karnataka, Gujarat	Low cost; community-owned; low pumping rate (cannot irrigate large areas); dependent on shallow water table depth; affected first when groundwater declines

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Shallow Tube-Wells (STW)	Machine-drilled (or manually jetted) tube of 100-150 mm diameter; electric or diesel pumpsets; portable; low capital cost	15-60 m depth; access shallow unconfined aquifers	Eastern India (Bihar, eastern UP, WB, Odisha) where shallow water table exists; also Assam	Low installation cost; important for small farmers who share or individually own STWs; Bihar has millions of STWs for paddy irrigation; eastern India STW expansion was a major agricultural success story of the 1980s-2000s
Deep Tube-Wells (DTW)	Large-diameter bore-wells (200-300 mm); electrified pump-sets; high initial capital; state-sector or cooperative-owned; large flow rate	60-300 m depth; tap deeper confined aquifers	Punjab, Haryana, western UP, Gujarat, Maharashtra, Rajasthan	Higher capital cost but larger and more reliable flow; state-owned DTWs were the dominant mode in the Green Revolution belt; private DTW ownership widespread in Punjab-Haryana (almost every farmer owns one)
Dug-cum-Bore Wells (DCBW)	Combines a dug well with a tube-well bore at the bottom; increases the effective aquifer access of the dug well	20-50 m typical depth	Deccan plateau states (MH, Karnataka, AP) where hard rock reduces open-well yield	Useful in hard rock Deccan areas where shallow wells run dry but there are fractures at depth; deepening of the bore increases yield from fractured rock aquifers

THE GROUNDWATER CRISIS

India's groundwater overdraft is one of its most serious long-term environmental and agricultural challenges. The **Central Ground Water Board (CGWB)** classifies blocks (administrative units) as:

- **SAFE:** Extraction < 70% of annual recharge.
- **SEMI-CRITICAL:** Extraction 70-90% of annual recharge.
- **CRITICAL:** Extraction 90-100% of annual recharge.
- **OVEREXPLOITED:** Extraction >100% of annual recharge -- groundwater is being permanently mined.

Groundwater Crisis Feature	*Detail*
Scale	As of 2022 (CGWB assessment), approximately 1,592 out of ~6,965 assessed blocks (about 23%) in India are OVEREXPLOITED; additionally, ~687 blocks are Critical; these are mostly in Punjab, Haryana, western UP, Rajasthan, Delhi, Tamil Nadu, Karnataka
Punjab water table decline	Punjab's central wheat-rice belt (Ludhiana, Fatehpur Sahib, Sangrur, Patiala districts) is witnessing water table declines of 30-50 cm per year on average; in the worst blocks (Jalandhar, Ludhiana), the decline is 1+ metre/year; estimated that parts of Punjab have <20 years of economically accessible groundwater remaining at current extraction rates
Root cause -- paddy in Punjab-Haryana	Paddy (transplanted rice) is a HIGH-WATER crop requiring standing water for most of its growth; it consumes 1,200-1,500 mm of water in an area receiving only 500-600 mm of rainfall; the ENTIRE DEFICIT is met by groundwater; Punjab-Haryana paddy cultivation is ecologically irrational -- rice is a tropical-monsoon crop being grown in a semi-arid region using mined groundwater; it was incentivised by (a) MSP for wheat+rice, (b) free/heavily subsidised electricity for tube-well pumps (major state policy), (c) Green Revolution

	package that locked in wheat-rice rotation
Electricity subsidy link	Punjab, Haryana, UP, Tamil Nadu, Maharashtra all provide FREE or heavily subsidised electricity for agricultural tube-well pumping; this zero-price signal encourages pumping beyond what would be rational at market prices; removing the subsidy is politically extremely difficult (farmers are powerful voters); but it is the single most impactful policy lever for reducing groundwater overextraction
Rajasthan dark zones	Western Rajasthan (Barmer, Jaisalmer, Churu, Bikaner) -- areas that receive <250 mm rainfall -- have historically had fresh groundwater in deep aquifers (Thar Desert aquifers); these are FOSSIL AQUIFERS (not rechargeable at human timescales); once depleted, gone permanently; Rajasthan has declared many such blocks as "Dark Zones" -- no new bore-wells permitted; but enforcement is weak
GRACE satellite data	NASA's GRACE (Gravity Recovery and Climate Experiment) satellites detected significant groundwater depletion in the IGP from 2002-2010 (Rodell et al., 2009, Nature) -- some of the world's fastest groundwater depletion rates; India refused to accept these findings initially but CGWB data has confirmed the trends

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Groundwater Crisis -- Policy Response Imperative:
The groundwater crisis is simultaneously India's most acute environmental problem and its most intractable agricultural policy challenge -- because it is deeply intertwined with food security, farmer incomes, and political economy. Policy responses attempted: (1) **Punjab Preservation of Subsoil Water Act 2009:** delays paddy transplanting to June 10 (from May-early June) -- reduces groundwater use by ~15-17% by matching transplanting with onset of monsoon (so rainfall does water the crop rather than tube-wells); effective but farmers initially opposed it; (2) **Paddy diversification incentives:** Rs.17,500/ha compensation for farmers shifting from paddy to maize, pulses, oilseeds in Punjab (Punjab government scheme); only partial uptake; (3) **PM-KUSUM:** solar pump sets reducing diesel pumping costs; but if electricity is free anyway, doesn't reduce groundwater extraction; (4) **Atal Bhujal Yojana (Atal Jal):** Rs.6,000 crore World Bank-funded scheme (2020-25) for community-led groundwater management in 7 over-exploited states (Gujarat, Haryana, Karnataka, MP, Maharashtra, Rajasthan, UP); involves community Water Security Plans and performance-based incentives for states that reduce groundwater overextraction.

29. 4 TANK IRRIGATION -- TRADITIONAL COMMUNITY WATER HARVESTING

Tank irrigation is India's **oldest form of organized irrigation** -- earthen embankments (bunds) built across small streams and depressions to create storage ponds ("tanks" in English; "eri" in Tamil; "cheruvu" or "kunta" in Telugu; "kere" in Kannada) that store monsoon runoff and release it progressively for crop irrigation. Tank irrigation was the **traditional backbone of South Indian agriculture** for over 2,000 years, with elaborate networks of interconnected "tank cascades" covering hundreds of square kilometres in Tamil Nadu, Karnataka, Andhra Pradesh and Telangana.

Tank Irrigation Feature	*Detail*
Distribution	Tamil Nadu (~39,000 tanks; highest in India); Karnataka (~36,000 tanks); AP and Telangana (~65,000 tanks combined); Odisha, MP, Maharashtra, Jharkhand (Eastern Ghats tribal areas) -- also significant numbers; North India has far fewer tanks (different climate and topography)
% of irrigated area	Currently ~4% of net irrigated area nationally (declining from ~20% in 1950-51); in TN still ~20-25% of irrigated area but declining

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Types of tanks	(a) Small village tanks (<10 ha command): thousands of farmer-managed tanks; (b) Medium tanks (10-40 ha): often PWD-maintained; (c) Large tanks (>40 ha): state-managed; some very large tanks (like Chembarambakkam, Chennai's primary water supply reservoir = originally an irrigation tank)
Ancient irrigation marvels	(a) Grand Anicut / Kallanai Dam: built by Karikala Chola on the Cauvery River (~2nd century CE; 300+ m long; now a UNESCO tentative WHS); one of the oldest functional water diversion structures in the world. (b) Veeranam Tank (TN): ancient tank (attributed to Parantaka Chola, 10th century CE); feeds Chennai's water supply via pipeline. (c) Hussain Sagar Lake (Hyderabad): built by Hussain Shah Wali (1562 CE); famous for Budha statue on rock.
Decline of tank irrigation	(a) Silt accumulation (desilting required every 10-20 years but neglected); (b) Encroachment of tank bed and foreshore areas by agriculture and construction; (c) Groundwater competition -- tube-wells more reliable and flexible than seasonal tank supply; (d) Breakdown of traditional community management systems (nirakattis -- traditional tank managers); (e) Deficient monsoons leaving tanks unfilled; (f) Road and railway construction breaking tank cascade systems
Revival efforts	MGNREGS (desilting of tanks is one of the largest categories of work; thousands of tanks desiltd since 2006); Jal Shakti Abhiyan (JSA) -- Catch the Rain campaign for rejuvenating tanks and water bodies; Mission Water Conservation (several state programs); Tamil Nadu Water Resources Conservation Act 2010

29. 5 MICRO-IRRIGATION -- DRIP AND SPRINKLER SYSTEMS

Micro-irrigation (drip and sprinkler) represents the **most water-efficient form of modern irrigation** -- applying water directly at or near the plant root zone, minimising evaporation, runoff, and deep percolation losses that characterize flood (surface) irrigation. India has **~10 million ha under micro-irrigation** (2023) -- the largest micro-irrigated area in the world after China.

Feature	*Drip Irrigation*	*Sprinkler Irrigation*
Mechanism	Perforated pipes or emitters deliver water drop-by-drop directly to plant root zone; water travels only 2-5 cm into soil; no surface wetting	Perforated pipes with nozzles spray water over the crop canopy in a simulated rainfall pattern; covers larger area per installation
Water efficiency	85-95% efficiency (very high); compared to flood irrigation at 40-60%	75-85% efficiency; better than flood but less than drip
Best crops	Row crops: tomato, chilli, brinjal, cotton, sugarcane, grapes, banana, pomegranate, mango (orchard); vegetable gardens	Cereals and pulses (wheat, sorghum, maize, soybean, groundnut, gram); sugarcane; potato; onion
Water use reduction vs flood irrigation	Saves 30-50% water for most crops; up to 70% for water-intensive crops (sugarcane)	Saves 25-40% water vs flood irrigation
Capital cost	Higher (Rs.60,000-1,50,000/ha for drip); justified by high-value crops	Moderate (Rs.15,000-60,000/ha); suitable for field crops
Leading states	Maharashtra (grapes, pomegranate, sugarcane drip -- Maharashtra leads nationally; 40%+ of India drip area); Gujarat (cotton, groundnut); Karnataka (tomato, chilli, grapes); AP and TN (paddy and pulses)	Rajasthan, Haryana, UP, Punjab, MP (wheat, maize, gram, soybean, mustard)

KEY GOVERNMENT SCHEMES FOR MICRO-IRRIGATION

Scheme	Year / Authority	Key Feature
PM Krishi Sinchayee Yojana (PMKSY)	2015; Department of Water Resources, River Development and Ganga Rejuvenation (DoWR, RD and GR)	Umbrella scheme for all irrigation; "Har Khet Ko Pani" (water to every field) + "More Crop Per Drop" (efficiency). Integrates multiple earlier schemes: AIBP (Accelerated Irrigation Benefits Programme), IWMP (Watershed Component), On-Farm Water Management. PMKSY target: complete all 99 identified "incomplete" irrigation projects under AIBP; achieve micro-irrigation on 10 million ha additionally by 2025-26
National Mission on Micro Irrigation (NMMI) / Per Drop More Crop (PDMC)	Subsumed under PMKSY from 2015; Per Drop More Crop component of PMKSY	Subsidises drip and sprinkler installation; typically 50-55% central subsidy + 15-20% state subsidy (for small/marginal farmers total can reach 70-75%); implements through state Horticulture Departments and Departments of Agriculture
Pradhan Mantri Fasal Bima Yojana (PMFBY)	2016; Ministry of Agriculture	Crop insurance including yield losses from drought (relevant for rain-fed farmers); coverage target: 50% of gross cropped area; subsidised premiums (farmers pay 2% Kharif, 1.5% Rabi, 5% commercial crops)
Atal Bhujal Yojana (Atal Jal)	2020-25; Jal Shakti Ministry; World Bank funded Rs.6,000 crore	Community-led groundwater management in 7 over-exploited states (Gujarat, Haryana, Karnataka, MP, Maharashtra, Rajasthan, UP); 8,350 Gram Panchayats; performance-based incentives for states that reduce groundwater extraction; Water Security Plans at village level
Jal Shakti Abhiyan (JSA) -- Catch the Rain	2019 onwards; Jal Shakti Ministry	Water conservation campaign: rainwater harvesting structures, recharge wells, check dams, desilting of tanks and ponds; "Catch the Rain, Where it Falls, When it Falls" motto; mobilises public awareness and village-level action; MGNREGS convergence
National Aquifer Mapping and Management Programme (NAQUIM)	2012-2017 (Phase 1); continuing	CGWB mapping of aquifer systems across India; provides scientific basis for sustainable groundwater use planning; critical for identifying safe extraction limits by block

29. 6 TRADITIONAL WATER HARVESTING STRUCTURES

India has a rich heritage of **community-based traditional water harvesting systems** -- locally adapted technologies that stored rainwater or channelled groundwater for irrigation and drinking, often without state involvement. These systems, developed over centuries and millennia, represent sophisticated engineering embedded in local culture and governance. Many are now being revived under MGNREGS and Jal Shakti Abhiyan.

Structure	Region	Description
Kund / Kundis	Rajasthan (primarily Jaisalmer, Barmer)	Circular underground cisterns with a saucer-shaped catchment area; plastered with lime; collect and store rainwater (even small amounts); traditional solution for drinking water in desert; each household traditionally had its own kund; revival under Rajasthan Groundwater Conservation (Talab) efforts
Johad / Talab	Rajasthan (primarily Alwar,	Traditional earthen bund (embankment) across seasonal streams creating small ponds (johads); Rajendra Singh ("Water Man of India"; Magsaysay Award 1995; Ramon Magsaysay Award; now chairs National Water Mission) revived

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	Bharatpur, Sawai Madhopur)	over 1,000 johads in Alwar district through Tarun Bharat Sangh (TBS); triggered revival of the Arvari River (once dead) through johad construction
Bawdi / Baoli / Stepwell	Rajasthan, Gujarat, Delhi, Karnataka	Elaborate stepped wells (bawdis or baolis or vav in Gujarati) providing groundwater access; architectural and utilitarian; many heritage structures: Chand Baori (Abhaneri, Rajasthan -- 13 floors deep; 9th century CE), Rani ki Vav (UNESCO WHS 2014, Patan, Gujarat -- 11th century CE), Agrasen ki Baoli (Delhi)
Karez (Qanat)	Ladakh, Balochistan origin	Underground channel tapping an unconfined aquifer at a higher elevation and directing it downslope via a gentle-gradient underground tunnel; gravity-fed; traditional irrigation in arid Ladakh; similar to Iranian qanat; requires no pumping energy; some being restored in Ladakh
Zabo / Ruza	Nagaland	Pond constructed below runoff from hillside; rainwater collected into a pond (zabo = "impounding water" in Naga); used by Chakhesang Naga; unique agroforestry + water conservation combination where the upper watershed is forested (to generate runoff), middle is grazed, lower is cultivated with the zabo-stored water
Ahar-Pyne	Bihar	Ahar = rectangular catchment embankment; Pyne = gravity channel from river to Ahar; traditional system of the ancient Bihar plains; stores monsoon runoff in ahars, feeds via pynes from rivers; very ancient (Mauryan era references); now largely abandoned or broken by modern irrigation but revival efforts ongoing
Surangam	Kerala (Kasaragod)	Horizontal shaft dug into laterite hillsides to tap subsurface groundwater; gravity-fed; flows without pumping; Kerala's equivalent of the Ladakh karez; used by tribal communities and small farmers in Kasaragod's hilly laterite terrain; now listed under traditional water conservation heritage
Phad (Pata) system	Maharashtra (Nashik, Satana)	Community canal system where a weir on a river diverts water to an elaborate network of channels (phads) serving several villages; managed by a community committee (Panchakomati) which decides water distribution, maintenance, and rules; completely self-governing; a remarkable institution of community irrigation governance
Eri (Tank Cascade)	Tamil Nadu	Network of interconnected tanks where overflow from one tank flows into the next (cascade); the entire watershed is managed as an integrated system; the nirakatti (traditional tank manager) managed the system; part of Tamil Nadu's ancient agricultural civilization. Over 39,000 tanks in Tamil Nadu; now partially revived through MGNREGS desilting

IFoS FOCUS	**IFOS -- IRRIGATION AND FOREST/ECOLOGY NEXUS:** (1) **Large dam reservoirs** submerge forests; Sardar Sarovar submerged ~37,000 ha of forest; Subansiri Lower project in AP/Assam faces concerns about submergence of biodiversity-rich forests. (2) **Canal irrigation and invasive species:** The lining of canal sides with concrete reduces moist-ground habitat for native plants; canal banks are often colonised by invasive species (Lantana, Parthenium, Prosopis juliflora); canal water spread enables invasion of agriculture and forest margins. (3) **Groundwater decline and trees:** Trees with deep tap roots (Prosopis cineraria -- khejri in Rajasthan; Diospyros -- Indian ebony) depend on groundwater; rapid water table decline causes tree mortality, especially in over-exploited western Rajasthan blocks. (4) **Traditional water harvesting and biodiversity:** Johads and tanks create wetland microhabitats supporting aquatic

vegetation, frogs, birds, and small mammals; their revival can restore local biodiversity. (5) **Drip irrigation and soil biota:** Continuous targeted moisture application in drip irrigation can alter the soil microbial and invertebrate communities; effects depend on crop type and irrigation frequency.

29. 7 NATIONAL RIVER LINKING PROJECT (NRLP) -- CONNECTING SURPLUS TO DEFICIT BASINS

The National River Linking Project (NRLP) -- also called the National Water Grid or National Perspective Plan -- is India's **most ambitious and controversial water resource project**: a plan to link 37 rivers through 30 links (14 Himalayan river links + 16 peninsular river links), transferring water from perceived "surplus" basins (Ganga, Brahmaputra, Mahanadi, Godavari) to "deficit" basins (Krishna, Cauvery, Pennar, Sabarmati, Mahi, Chambal), creating a **unified national water grid.**

NRLP Feature	*Detail*
Origin of concept	First proposed by K.L. Rao (1972; as "Ganga-Cauvery Link"); then revised by Capt. M.N. Dastur (1977; "Garland Canal"); reconceptualised by National Water Development Agency (NWDA, established 1982) into current form; Supreme Court ordered implementation in 2002 (WRIT PETITION)
Scale	30 link canals (14 Himalayan + 16 Peninsular); estimated 34.5 million ha additional irrigation; 34 GW additional hydropower; transfer of 178 BCM water annually; estimated cost (pre-2020 revision) = Rs.5.60 lakh crore
Ken-Betwa Link Project (KBLP/KBRIP)	FIRST link project to get SC approval and Cabinet clearance (2021); links Ken River (Panna, MP, Vindhya ranges) to Betwa River (Hamirpur, UP-MP border); provides irrigation to drought-prone Bundelkhand (6.56 lakh ha); 103 MW hydropower; Cost: Rs.44,605 crore (revised 2021). CONTROVERSY: the Daudhan Dam (on Ken, in Panna Tiger Reserve) will submerge ~9,000 ha of forest including part of Panna TR core zone (2019 WII Cumulative Impact Study flagged this). SC gave environmental clearance despite objections from wildlife/forest officials.
Opposition and concerns	(1) Inter-state disputes: "surplus" state refuses to acknowledge surplus (Odisha-Chhattisgarh Mahanadi link; UP-Bihar objected to Kosi-Mechi link). (2) Ecological concerns: dam construction and inter-basin water transfer alter river hydrology, disrupt fish migration, change sedimentation patterns, reduce estuarine salinity (impacts mangroves and marine fisheries). (3) Displacement: massive displacement of tribal and rural communities from reservoir submergence areas. (4) "Surplus" is seasonal, not annual -- massive Himalayan floods in August do not translate to surplus water available for transfer to peninsular India (rivers carry sediment-laden monsoon water; the "surplus" calculation is contested by hydrologists). (5) Cost and feasibility: at Rs.5.60+ lakh crore, funding the entire project is beyond current government budgets.
Peninsular River Development Component	16 links planned; Mahanadi-Godavari (to transfer Mahanadi water to Godavari and further south); Godavari-Krishna; Krishna-Pennar; Pennar-Cauvery; these transfers face opposition from Odisha (Mahanadi), Chhattisgarh, and states that would be upstream "donors"
International dimension	Brahmaputra River (from Tibet) carries enormous water volumes; China has built dams on the upper Brahmaputra (Yarlung Tsangpo); potential for diversion upstream threatens India's share; any NRLP Himalayan links involving Brahmaputra water have trans-boundary implications vis-a-vis China and Bangladesh (lower riparian)

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29. 8 INTER-STATE WATER DISPUTES -- MAJOR CASES

Dispute	States	River	Key Detail
Cauvery Water Dispute	Karnataka vs Tamil Nadu (+ Kerala + Puducherry)	Cauvery (Kaveri) River	Most litigated water dispute in India. Karnataka's reservoirs (Krishnarajasagar, Kabini, Hemavathi) hold SW monsoon water; TN needs it for Samba paddy (NE monsoon season) and the Cauvery delta. CWDT (Cauvery Water Disputes Tribunal) set up 1990; final award 2007; Supreme Court order 2018 (TN gets 177.25 TMC; Karnataka 284.75 TMC; Kerala 30 TMC; Puducherry 7 TMC). Cauvery Water Management Authority (CWMA) established 2018 to implement the order. Dispute flares every drought year -- protests, bandhs, violent clashes.
Krishna Water Dispute	Maharashtra, Karnataka, Andhra Pradesh, Telangana	Krishna River	KWDT-I (1973 award): allocated 560, 700, 800 TMC to MH, KA, AP respectively. After Telangana bifurcation (2014), AP's share was to be divided between new AP and Telangana. KWDT-II reconstituted; proceedings ongoing. Nagarjunasagar, Srisailam, Tungabhadra reservoirs; disputes over sharing in drought years.
Mahanadi Dispute	Chhattisgarh vs Odisha	Mahanadi River	CG built multiple barrages (Kalma Barrage 2011, Murel Barrage etc.) in upstream Mahanadi catchment; Odisha claims CG's upstream structures reduce Hirakud reservoir inflows and damage Odisha's irrigation and ecology. Mahanadi River Water Disputes Tribunal constituted 2018; proceedings ongoing.
Ravi-Beas (SYL Canal)	Punjab vs Haryana vs Rajasthan	Ravi and Beas rivers (Indus system)	SYL = Satluj-Yamuna Link Canal; Ravi-Beas waters arbitrated in 1981 (Punjab gets 3.5 MAF; Haryana 3.5 MAF; Rajasthan 8.6 MAF from IGNP). Construction of SYL Canal to deliver Haryana's share was blocked by Punjab (Punjab Assembly passed a law "de-notifying" the canal land 2016; SC struck down the law; but canal still not built). One of India's most protracted and politically charged water disputes.
Narmada Dispute	MP, Gujarat, Maharashtra, Rajasthan	Narmada River	Narmada Water Disputes Tribunal (NWDT) award 1979: MP gets 18.25 MAF, Gujarat 9.0 MAF, Maharashtra 0.25 MAF, Rajasthan 0.5 MAF. Sardar Sarovar Project height controversy (Narmada Bachao Andolan vs SSP authority); final height of 138.68 m approved by Supreme Court 2000. Tribal displacement from submergence areas (Madhya Pradesh adivasis) = one of India's most significant human rights cases.
Mullaperiyar Dam (Periyar)	Kerala vs Tamil Nadu	Periyar River	119-year-old British-era dam (1895) in Kerala managed by Tamil Nadu under an 1886 treaty lease. Kerala wants dam height not raised above 142 feet (safety concerns about old masonry dam); TN wants to raise it to 152 feet (more storage for TN irrigation). SC constituted a committee (2010); allowed TN to raise water level to 142 feet. Dispute ongoing; Kerala wants new dam.

UPSC CIVIL	**Civil GS-2 / GS-3 -- Inter-State Water Disputes Framework:** The constitutional basis: **Article 262** empowers Parliament to provide by law for adjudication of interstate water disputes; **Inter-State River Water Disputes Act 1956** establishes the Tribunal mechanism. Parliament EXCLUDED water disputes from Supreme Court jurisdiction (Art 131) -- they must go through Tribunals. Key case: **Cauvery** -- where the SC ultimately intervened despite Art 262 exclusion (held that SC has inherent

power to enforce a Tribunal award). The Inter-State River Water Disputes (Amendment) Bill 2019 was passed by Lok Sabha to set up a permanent tribunal -- but Rajya Sabha passage pending. Always include: Art 262; ISRWDA 1956; permanent vs ad hoc tribunal; CWMA as compliance mechanism.

29. 9 NATIONAL WATER POLICY AND INSTITUTIONS

Policy / Institution	*Year*	*Key Provision / Role*
National Water Policy	1987 (first); revised 2002; revised 2012 (current operative)	Priority order for water use: (1) Drinking water; (2) Irrigation; (3) Hydropower; (4) Ecology and Navigation; (5) Industrial and other uses. NWP 2012 also emphasises: equitable access to water as a right; treating water as an economic good; PPP in water infrastructure; demand management; inter-sectoral allocation.
National Water Mission (NWM)	2009 (one of 8 NAPCC missions)	Targets: 20% increase in water use efficiency; basin-level integrated water resources management; data collection and scientific planning for water. Sub-missions include: surface water monitoring, groundwater assessment, demand-side management, water conservation.
National Water Resources Grid (NWRG)	Long-term vision document	A conceptual framework for the NRLP -- linking all major river basins of India into a single water transfer network; infrastructure for surplus-to-deficit transfer; very long-term (50+ year horizon); the NRLP is its operational expression.
Jal Shakti Ministry	2019 (merger of Ministry of Water Resources + Ministry of Drinking Water and Sanitation)	Created a unified ministry for all water-related issues; aims for convergence between drinking water (Jal Jeevan Mission) and irrigation/conservation; Jal Shakti Abhiyan; National Aquifer Mapping Programme (NAQUIM).
Jal Jeevan Mission (JJM)	August 2019; target August 2024	Rs.3.60 lakh crore outlay; target: Functional Household Tap Connection (FHTC) to every rural household in India (19.35 crore households) by August 2024; by early 2024, ~75% of rural households covered (~14.5 crore FHTCs); some states (Goa, Telangana, Haryana, Gujarat) declared 100% coverage. Focuses on safe drinking water supply but indirectly affects irrigation by prioritizing potable water infrastructure.
Central Water Commission (CWC)	1945 (established)	Premier technical organisation under DoWR; responsible for policy, planning and development of water resources; monitors 155 major reservoirs; flood forecasting (FloodWatch app); project appraisal and DPR review; river basin management.
National Water Development Agency (NWDA)	1982	The technical arm for planning the National River Linking Project; prepares DPRs for all 30 links; studies hydrology of surplus and deficit basins; manages NRLP studies and feasibility reports.
Central Ground Water Board (CGWB)	1954 (established)	Under Jal Shakti Ministry; maps and monitors groundwater resources; classifies blocks as safe/semi-critical/critical/overexploited; NAQUIM programme; issues groundwater development guidelines; advises on tube-well spacing, depth, and sustainable yield.

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29. 10 CURRENT AFFAIRS HOOKS (2022-2025)

CURRENT AFFAIRS

Ken-Betwa River Linking Project -- Supreme Court Clearance (2023): The Supreme Court gave its clearance for the Ken-Betwa River Interlinking Project (KBRIP) in 2023, India's first river linking project to receive final approval. The Daudhan Dam will submerge ~9,000 ha including part of Panna Tiger Reserve core zone. Conservationists pointed out the irony: Panna TR is a conservation success story (tigers went locally extinct 2009, reintroduced, now 80+ tigers), and the dam will destroy the very habitat that enabled this recovery. The National Tiger Conservation Authority (NTCA) and Wildlife Institute of India (WII 2019 Cumulative Impact Study) had flagged serious ecological concerns. The project proceeds under India's development priority framework, with compensatory afforestation mandated.

Jal Jeevan Mission -- Coverage Update (2024): Jal Jeevan Mission (JJM, launched August 15, 2019) reached its target of providing Functional Household Tap Connection (FHTC) to 75%+ of rural households by early 2024 (original target: every household by August 2024). States with 100% coverage: Goa, Telangana, Haryana, Gujarat, Punjab, Sikkim, Himachal Pradesh, and union territories. States lagging: Rajasthan, UP, Bihar, Manipur, Meghalaya. JJM has transformed rural water supply access but "functional" connections depend on sustained water source adequacy and maintenance -- challenges remain in water-scarce states.

Cauvery Crisis (August 2023 -- Karnataka vs Tamil Nadu): The Supreme Court in September 2023 directed Karnataka to release 5,000 cusecs of Cauvery water to Tamil Nadu for the month of September -- despite Karnataka's plea that its own reservoirs were critically low due to deficient monsoon (2023 = below-normal year, 94% LPA with severe August deficit). Large-scale protests in Karnataka (bandh, vehicle rallies against water release). The Cauvery Water Management Authority (CWMA) struggled to enforce the release. Illustrated how below-normal monsoons (linked to El Nino 2023) immediately translate into interstate water conflicts.

Atal Bhujal Yojana Progress (2020-2025): The World Bank-funded Atal Bhujal Yojana (Atal Jal) -- Rs.6,000 crore programme for groundwater management in 7 overexploited states -- has been progressing since 2020. By 2024, approximately 8,350 Gram Panchayats in Gujarat, Haryana, Karnataka, MP, Maharashtra, Rajasthan and UP have Water Security Plans. The scheme incentivises states (performance grant) for achieving groundwater reduction targets. Early results: some blocks in Rajasthan and Haryana showing reduced extraction. But the challenge is enormous -- over 1,500 blocks nationally are overexploited, and the scheme targets only the most critical.

29. 11 PYQ ANALYSIS -- CHAPTER 29 (2010-2025)

Source	Year	Marks	Question
UPSC Civil	2024	15M	"Critically evaluate India's irrigation system. Discuss the causes and consequences of groundwater depletion and suggest sustainable solutions."
UPSC Civil	2023	12M	"What is the National River Linking Project (NRLP)? Discuss the Ken-Betwa River Link as the first project under NRLP and the environmental and social concerns it raises."
UPSC Civil	2022	10M	"Discuss the significance and challenges of traditional water harvesting systems in India. How can they contribute to addressing India's water crisis?"
UPSC Civil	2021	15M	"Examine the causes of interstate water disputes in India. Discuss the Cauvery water dispute as a case study of inter-state river water sharing conflicts."
UPSC Civil	2020	12M	"Compare and contrast the different types of irrigation in India. What is the significance of micro-irrigation for sustainable water management?"

UPSC Civil	2019	10M	"Discuss the role of canal irrigation in India's agriculture. What are the advantages and limitations of canal irrigation?"
UPSC Civil	2018	10M	"What is the significance of tank irrigation in South India? Discuss the reasons for its decline and prospects for revival."
UPSC Civil	2017	10M	"Critically examine the National Water Policy 2012 and its implications for water resource management in India."
IFOS GS	2024	10M	"Discuss the environmental impacts of large dam construction on forest ecosystems and biodiversity in India, with reference to the Ken-Betwa Project."
IFOS GS	2023	10M	"Examine the relationship between groundwater depletion and the health of forests and tree populations in India's overexploited groundwater zones."
IFOS GS	2022	10M	"Discuss the traditional water harvesting structures of India (johad, kund, eri, zabo, ahar-pyne) and their ecological and social significance."

KEY NOTE

Frequency: Irrigation + groundwater (Civil 2024); NRLP + Ken-Betwa (Civil 2023); traditional water harvesting (Civil 2022); interstate water disputes + Cauvery (Civil 2021); types of irrigation + micro-irrigation (Civil 2020); canal irrigation (Civil 2019); tank irrigation (Civil 2018); National Water Policy (Civil 2017). IFoS: Ken-Betwa dam forest ecology (2024), groundwater-forest link (2023), traditional water systems ecology (2022). For 2025-26: Ken-Betwa SC clearance 2023 + Panna TR impact; Cauvery 2023 crisis (El Nino + below-normal monsoon); JJM coverage update 2024; Atal Bhujal Yojana progress; Mahanadi Tribunal proceedings -- all high-priority.

29. 12 MODEL BOOK

Critically evaluate India's irrigation systems. Discuss the causes and consequences of groundwater depletion and suggest sustainable solutions.

UPSC Civil (Mains) | 15 Marks | 210 Words

India has the world's largest irrigated area (~70 million ha net) but faces a paradox: while irrigation drives food production, its dominant mode -- groundwater extraction via tube-wells -- is ecologically unsustainable in much of the country. Three types of irrigation sources serve India: Canals (~26%), Tube-wells/Wells (~62%), and Tanks (~4%).

TYPES OF IRRIGATION -- BRIEF EVALUATION:

Canal irrigation: Covers ~26% of irrigated area; major canal systems (IGNP, Bhakra, Nagarjunasagar, Upper Ganga Canal) enabled the Green Revolution. Advantages: surface water renewable; large command areas. Limitations: tail-end inequity; waterlogging and salinisation in poorly-drained commands; costly maintenance; seepage losses (40-60% water lost in unlined canals).

Tank irrigation: ~4% of irrigated area (declining from ~20% in 1950); traditional community-managed systems in South India (TN 39,000 tanks; KA, AP, Telangana). Ecological advantages; biodiversity habitats; waterlogging absent. Declining due to siltation, encroachment, neglect.

Tube-well irrigation: ~62% of irrigated area; flexible, on-demand; the backbone of the Green Revolution intensification. BUT: leading to a groundwater crisis.

GROUNDWATER DEPLETION -- CAUSES:

1. **Paddy cultivation in semi-arid Punjab-Haryana:** Rice requires 1,200-1,500 mm irrigation water in a 500-600 mm rainfall zone; the entire deficit mined from groundwater; water table declining 30-50 cm/year in Punjab; estimated <20 years before aquifer collapse in central Punjab.

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2. **Free/subsidised electricity:** Punjab, Haryana, UP, TN all provide free or heavily subsidised electricity for agricultural tube-well pumping; zero marginal cost encourages over-extraction; politically very difficult to reform.
3. **No extraction regulation:** Groundwater is legally treated as a "property right" attached to land ownership; no permit required to drill a bore-well; no extraction limit per farmer; the "tragedy of the commons" operates.

CONSEQUENCES:

1. **Food security threat:** Punjab-Haryana produce ~35-40% of India's wheat and ~20% of rice for the PDS; their aquifer collapse would be a national food security emergency.
2. **Saltwater intrusion:** Coastal aquifer overextraction in TN, AP, Gujarat, Kerala draws in seawater; permanent salinisation.
3. **Ecosystem harm:** Declining water tables kill deep-rooted trees (Prosopis cineraria, Diospyros); wetlands and ponds dry up; biodiversity loss.
4. **Farmer debt:** As water tables fall, farmers must deepen bore-wells repeatedly; escalating pump energy and deepening costs increase debt.

SUSTAINABLE SOLUTIONS:

1. **Crop diversification in Punjab:** Shift from paddy to maize, pulses, oilseeds; MSP for diversified crops; Punjab Preservation of Subsoil Water Act 2009 (delays transplanting) has helped ~15-17%.
2. **Electricity pricing reform:** DBT of electricity subsidy directly to farmers (not as free power) -- most impactful but most politically difficult.
3. **Micro-irrigation:** PMKSY-PDMC subsidises drip/sprinkler; saves 30-50% water; currently 10 million ha covered nationally; target 20 million ha additional.
4. **Atal Bhujal Yojana:** Rs.6,000 crore World Bank-funded community groundwater management (7 overexploited states; 8,350 Gram Panchayats); Water Security Plans; performance grants.
5. **Traditional water harvesting:** Johads (Rajasthan), tanks (South India), ahar-pyne (Bihar) desiltation under MGNREGS recharges groundwater; Jal Shakti Abhiyan mobilises this.

India's irrigation challenge is not lack of water but misallocation and mismanagement -- growing the wrong crops in the wrong places with the wrong price signals. The solution requires political courage (electricity reform), institutional innovation (Atal Jal community governance), and technology adoption (micro-irrigation + solar pumps) delivered simultaneously.

Discuss the traditional water harvesting systems of India. How can they contribute to addressing the water crisis?

UPSC Civil/IFOS (Mains) | 10 Marks | 150 Words

India's traditional water harvesting systems represent centuries of locally-adapted engineering wisdom -- storing rainwater, recharging groundwater, and managing seasonal flows without state infrastructure. Their revival is emerging as a critical element of India's water security strategy.

MAJOR TRADITIONAL SYSTEMS:

1. **Johad (Rajasthan):** Earthen embankments creating small ponds; revived by Rajendra Singh (Tarun Bharat Sangh); over 1,000 johads in Alwar district triggered the revival of the Arvari River -- a dramatic demonstration of rainwater harvesting restoring a dead river.
2. **Kund/Kundis (Rajasthan desert):** Underground cisterns with saucer-shaped catchments; collect every drop of rain even in Jaisalmer's <150 mm rainfall zone; drinking water solution for desert households.
3. **Eri/Tank Cascade (Tamil Nadu):** 39,000+ interconnected tanks managed by village committees (nirakatti

system); the entire watershed managed as one hydrological unit; once the foundation of Tamil Nadu agriculture.

4. **Ahar-Pyne (Bihar):** Ancient rectangular catchment embankments (ahars) with gravity channels (pynes) from rivers; Mauryan-era system; now largely abandoned but revival attempts underway.
5. **Zabo (Nagaland):** Integrated agroforestry + water pond system of Chakhesang Naga; forested upper slopes generate runoff; stored in lower pond; unique ecological wisdom combining conservation and irrigation.
6. **Surangam (Kerala):** Horizontal shafts tapping laterite hillside groundwater; gravity-fed; zero-energy; used by tribal communities in Kasaragod.
7. **Phad System (Maharashtra):** Community-governed canal from river weir; managed by Panchakomati (5-community committee); a governance institution as well as a water system.

CONTRIBUTION TO WATER CRISIS SOLUTIONS:

1. **Groundwater recharge:** Johads and tanks increase groundwater recharge -- Rajendra Singh's johads in Alwar raised the water table by several feet in surrounding areas, recharging tube-wells and reviving springs.
2. **Flood mitigation:** Distributed rainwater storage across a watershed reduces peak flood flows; thousands of tanks and johads collectively moderate downstream flood intensity.
3. **Community water security:** Traditional systems are community-governed -- requiring no state budget for operation once built; sustainable because the community has a direct stake in maintenance.
4. **Climate resilience:** Small distributed storage systems spread risk across many micro-catchments; more resilient to drought than centralised canal systems; "Catch the Rain, Where it Falls" (Jal Shakti Abhiyan motto) captures this philosophy.

POLICY INTEGRATION: MGNREGS has desiltd thousands of tanks and ponds; Jal Shakti Abhiyan mobilises traditional systems revival; PM has highlighted johad and tank revival at national platforms. The challenge: GOVERNANCE -- most traditional systems had institutional arrangements (nirakatti, Panchakomati) that have eroded; revival of the physical structure without reviving the governance institution is only partially effective.

Traditional water systems are not merely historical curiosities -- they are models of sustainable, community-based water management that modern India needs to integrate with state-level infrastructure. Their revival, supported by MGNREGS and Jal Shakti Abhiyan, can complement large infrastructure and address the groundwater crisis from the demand side.

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CHAPTER 30

AGRICULTURAL EVOLUTIONS

Green, White, Blue, Yellow, Pink and Beyond

CHAPTER AT A GLANCE

- GREEN REVOLUTION (1960s-70s): HYV seeds + chemical fertiliser + irrigation; Dr. M.S. Swaminathan (IARI) + Norman Borlaug (CIMMYT); wheat variety Sonalika/Kalyan Sona; rice variety IR-8 (IRRI Philippines); wheat from 11 MT (1960-61) to 35 MT (1977-78) to ~110 MT (2022-23); confined to Punjab-Haryana-WUP wheat and limited rice belt. MS Swaminathan (1925-2023) posthumously awarded Bharat Ratna (2024). Swaminathan Commission (NCF 2004-06): C2+50% MSP recommendation.
- WHITE REVOLUTION (Operation Flood, 1970-1996): Dr. Verghese Kurien ("Father of White Revolution," "Milkman of India"); NDDB (National Dairy Development Board, 1965, Anand, Gujarat); AMUL cooperative model (village society -> district union -> state federation); milk from 20 MT (1969-70) to 220+ MT (2022-23); India = world's LARGEST milk producer (since 1998; 22% of world production); National Programme for Dairy Development (NPDD).
- BLUE REVOLUTION (Fisheries): PM Matsya Sampada Yojana (PMMSY, 2020, Rs.20,050 crore); India = world's 3rd largest fish producer (14.73 MT in 2022-23); 2nd largest aquaculture producer; fish exports Rs.57,587 crore (FY2022-23); Andhra Pradesh = largest fish-producing state; inland fisheries now > marine (60:40); National Fisheries Development Board (NFDB, 2006, Hyderabad).
- YELLOW REVOLUTION (Oilseeds): Technology Mission on Oilseeds (TMO, 1986, Rajiv Gandhi government); oilseed production doubled in 5-7 years; India produces ~38-40 MT oilseeds (2022-23); BUT imports 60%+ edible oil (palm oil from Indonesia/Malaysia); NMEO-OP (National Mission on Edible Oil -- Oilpalm, 2021, Rs.11,040 crore): 1 million ha oilpalm plantations in NE India + Andaman to reduce edible oil imports.
- PINK REVOLUTION: TWO definitions -- (1) Meat and poultry revolution (India = 3rd largest egg producer; 4th largest broiler); (2) Onion production (Maharashtra Nashik = "Onion Capital of India"; India = 2nd largest onion producer). APEDA handles agri-food exports. Buffalo meat (carabeef) exports significant. Andhra Pradesh, Telangana, TN, MH = top poultry states.
- GOLDEN REVOLUTION (Horticulture): India = 2nd largest fruit+vegetable producer (after China); total horticulture production 342 MT (2021-22) exceeds food grain production (315 MT); MIDH (Mission for Integrated Development of Horticulture, 2014-15); Mango = UP, AP, Bihar (India = world's largest producer); Banana = India largest producer; Grapes = MH (Nashik); Apple = HP (Kinnaur, Kullu-Manali), J&K (Shopian, Pulwama).
- ROUND REVOLUTION (Potato) + SILVER REVOLUTION (Eggs): India = 2nd largest potato producer (after China; ~60 MT 2022-23; UP > WB > Bihar > GJ > MP); India = 3rd largest egg producer (129 billion eggs 2021-22; AP, Telangana, MH, TN = top states). EVERGREEN REVOLUTION: MS Swaminathan concept -- "productivity without ecological harm"; beyond Green Revolution; includes soil health, biodiversity, traditional varieties, water conservation.
- RAINBOW REVOLUTION: Holistic post-2014 vision combining all sub-sector revolutions; includes crop+livestock+fisheries+horticulture+NTFP+organic; schemes: PM-KISAN, PMFBY, PMKSY, eNAM, FPOs (10,000 FPOs), PM Garib Kalyan Anna Yojana, PMGKAY. Key recent events: MS Swaminathan Bharat Ratna 2024 (posthumous); 109 biofortified variety releases (August 2024); NMEO-OP oilpalm expansion; farmers' protest MSP guarantee demand 2024.

30.1 MASTER QUICK-REFERENCE -- ALL AGRICULTURAL REVOLUTIONS

Revolution	Sector	Key Figure / Institution	Period / Launch	Production Milestone	Current Status / Scheme

GREEN	Food Grains (Wheat, Rice)	Dr. M.S. Swaminathan (IARI) + Norman Borlaug (CIMMYT); ICAR	1960s-1970s; wheat from 1965-66	Wheat 11 MT (1960) -> 35 MT (1977) -> 110 MT (2023); Food grain 72 MT (1965) -> 330 MT (2023-24)	Evergreen Revolution (Swaminathan concept); BGREI (Eastern India); Second Green Revolution; 109 biofortified varieties (Aug 2024)
WHITE	Milk and Dairy	Dr. Verghese Kurien; NDDB (1965, Anand); AMUL cooperative	Operation Flood Phase 1 (1970), 2 (1981), 3 (1985)	20 MT (1969-70) -> 220+ MT (2022-23); world's largest milk producer since 1998	National Programme for Dairy Development (NPDD); National Livestock Mission; PM Matsya Sampada -- separate from dairy
BLUE	Fisheries (Marine + Inland + Aquaculture)	NFDB (2006, Hyderabad); Ministry of Fisheries, Animal Husbandry and Dairying	Post-1990s; PMMSY 2020	4 MT (1950-51) -> 14.73 MT (2022-23); 3rd largest fish producer; 2nd largest aquaculture	PM Matsya Sampada Yojana (PMMSY, 2020, Rs.20,050 crore); Fisheries Master Plan; Blue Economy initiative
YELLOW	Oilseeds (Groundnut, Mustard, Soybean, Sunflower)	Technology Mission on Oilseeds (TMO, 1986); Rajiv Gandhi government	TMO launched 1986	Oilseed production doubled 1986-93; ~38-40 MT now; BUT 60%+ edible oil still imported	NMEO-OP (2021, Rs.11,040 crore, oilpalm NE India); GM Mustard HT-DMH-11 (GEAC approved 2022; SC scrutiny)
PINK	Meat/Poultry OR Onion	APEDA (for exports); State Poultry Federations	1990s onwards	India = 3rd largest egg producer (129 billion eggs 2021-22); Onion = 2nd globally; Buffalo meat (carabeef) major export	Rashtriya Gokul Mission; National Livestock Mission; APEDA agri-food exports
GOLDEN	Horticulture (Fruits, Vegetables, Flowers)	MIDH (Mission for Integrated Development of Horticulture,	Post-2000 acceleration	342 MT horticulture (2021-22) > food grain (315	MIDH; Kisan Rail; Kisan Udaan (air cargo); PM KUSUM for cold chain; One

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		2014-15); NHB		MT) for first time; India = 2nd globally in F&V	District One Product (ODOP)
ROUND	Potato	ICAR-CPRI (Central Potato Research Institute, Shimla)	Post-Green Revolution	~60 MT (2022-23); India = 2nd globally after China; UP > WB > Bihar > GJ > MP	PepsiCo contract farming; potato processing sector growing (5-10% processed vs 80%+ in USA)
SILVER	Eggs / Poultry	National Programme for Poultry Development; State cooperatives	1970s-80s onwards	3rd largest egg producer; 129 billion eggs (2021-22); AP+TS+TN+MH = 70%+ of output	Integrated poultry farming; NFDB; NPBD (National Programme on Bovine Breeding and Dairy Development)
EVERGREEN	Comprehensive sustainability	Dr. M.S. Swaminathan (MSSRF, Chennai); NCF 2004-06	Concept since 2000s	Productivity WITHOUT ecological harm; bridges Green Revolution gap	PM-PRANAM; NMNF 2024; natural farming; soil health cards; seed sovereignty; biodiversity conservation
RAINBOW	All-inclusive agricultural transformation	NITI Aayog + Ministry of Agriculture + multiple line ministries	Post-2014 (NDA)	Combines all above sub-sector revolutions into one policy vision	PM-KISAN; PMFBY; PMKSY; eNAM; 10,000 FPOs; MIDH; PMMSY; PMGKAY -- all under one umbrella

30.2 GREEN REVOLUTION -- THE FOUNDATIONAL AGRICULTURAL TRANSFORMATION

The **Green Revolution** was the most transformative event in Indian agricultural history -- a package of technology (HYV seeds + chemical fertilisers + irrigation) that converted India from a **food-deficit, PL-480-import-dependent country** to a **food-surplus nation with overflowing buffer stocks** within a decade. It is also, in retrospect, the source of some of India's most serious long-term agricultural and environmental challenges.

BACKGROUND -- INDIA'S FOOD CRISIS OF THE 1960S

Pre-Green Revolution Challenge	*Detail*
Food production crisis	India's population was growing at 2.1-2.2% per year while food production grew at only ~1-1.5%; food shortages were chronic; famines (Bengal 1943) and near-famines were a recurring risk
PL-480 dependence	Public Law 480 (US Agricultural Trade Development and Assistance Act 1954) allowed India to import American wheat in exchange for payment in Indian rupees (not hard currency); India was described as "ship-to-mouth" (living on the next

	shipment of food aid); humiliating dependence on USA; politically constraining (US cut food aid during 1965 Indo-Pak war to pressure India)
Yield stagnation	Traditional Indian wheat and rice varieties had LOW HARVEST INDEX (tall plants, most biomass in stem, not grain) and responded poorly to chemical fertilisers (with more nitrogen, plants lodged/fell over rather than producing more grain)
Irrigation insufficient	Only ~30 million ha irrigated in 1960 (now 70 million ha); without reliable water supply, fertilisers alone would not work

THE TECHNOLOGY PACKAGE -- HYV SEEDS

HYV Comonent	*Detail*
Key innovation -- SEMI-DWARF varieties	Traditional tall wheat/rice plants allocated most energy to stem (straw) and lodged when fertilised; semi-dwarf plants with shorter, stronger stems allocated more energy to GRAIN (high harvest index = weight of grain / total above-ground biomass); semi-dwarf gene in wheat came from Norin-10 (Japanese variety); in rice from a Taiwanese semi-dwarf
WHEAT varieties	Sonalika (from CIMMYT via Borlaug; released by IARI 1967); Kalyan Sona (released 1967; one of the most widely grown wheat varieties in history); Sharbati Sonora; C-306 -- these HYVs transformed Punjab-Haryana production; gave 2-3x higher yields than traditional varieties with adequate fertiliser and water
RICE varieties	IR-8 ("Miracle Rice"; developed at IRRI, Los Banos, Philippines; released 1966); IR-36 (1976); in India: Jaya (released 1968 by IARI); Ratna; these were early varieties; modern varieties have become much more diverse. India now has 4,000+ registered rice varieties (both traditional and HYV)
Chemical Fertilisers	NPK: Nitrogen (urea; DAP -- di-ammonium phosphate; ammonium sulphate), Phosphorus (SSP, DAP), Potassium (MOP -- muriate of potash); Fertiliser Corporation of India (FCI) and National Fertilisers Ltd (NFL) set up; critical partnership with irrigation -- fertiliser only works with water
Irrigation	Tube-well revolution (especially in Punjab and Haryana) enabled year-round groundwater access independent of canal schedules; green revolution and tube-well expansion were simultaneous and mutually reinforcing

KEY INSTITUTIONS AND SCIENTISTS

Institution / Person	*Role*	*Established*
Dr. M.S. Swaminathan (1925-2023)	Director, IARI (Indian Agricultural Research Institute, New Delhi); introduced Borlaug's HYV wheat to India; oversaw adaptation and testing of semi-dwarf varieties in Indian conditions; coordinated the rollout in Punjab-Haryana; called "Father of Green Revolution in India"; Nobel Peace Prize was Norman Borlaug's (1970) -- Swaminathan received Ramon Magsaysay Award (1971), Padma Vibhushan (1989), World Food Prize (1987, first ever recipient); posthumously awarded BHARAT RATNA (February 2024) -- India's highest civilian honour	IARI: 1905 (Pusa, Bihar; moved to New Delhi after 1934 earthquake)
Norman Borlaug (1914-2009)	American plant scientist; developed semi-dwarf high-yielding wheat varieties at CIMMYT (Mexico); introduced them to India and Pakistan in collaboration with Swaminathan; Nobel Peace Prize 1970; called "Father of the	CIMMYT (International Maize and Wheat Improvement

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	Green Revolution"; worked with ICAR teams in India during 1960s	Centre, Mexico City): 1966
IARI (Indian Agricultural Research Institute)	Premier crop science research institution; developed and adapted HYV varieties; headquarters New Delhi (Pusa campus); State-of-the-Art labs; develops new crop varieties through conventional breeding; IARI also released 109 biofortified crop varieties in August 2024 (PM Modi event)	1905 (Pusa, Bihar); moved Delhi 1936
ICAR (Indian Council of Agricultural Research)	Umbrella body overseeing all agricultural research institutions in India (103 institutes, 73 Krishi Vigyan Kendras); coordinates national agricultural research system; New Delhi headquarters	1929
CIMMYT (International Maize and Wheat Improvement Centre)	Developed the original semi-dwarf wheat varieties that started the Green Revolution in South Asia; Borlaug's base; now focuses on climate-resilient crop varieties	1966; Mexico City
IRRI (International Rice Research Institute)	Developed IR-8 "Miracle Rice" and subsequent high-yielding rice varieties; partnered with ICAR for rice varieties in India; Los Banos, Philippines	1960
National Seeds Corporation (NSC)	Government of India PSU; multiplies and distributes HYV seeds and other certified seeds to farmers; major role in Green Revolution seed supply chain	1963

GREEN REVOLUTION -- PRODUCTION IMPACT

Crop / Year	*Production (Million Tonnes)*	*Note*
Wheat -- 1960-61	11 MT	Pre-Green Revolution baseline; India importing wheat under PL-480
Wheat -- 1968-69	16.54 MT	Early Green Revolution impact; Punjab wheat transformed
Wheat -- 1977-78	31.75 MT	Full Green Revolution impact; India food-surplus
Wheat -- 2000-01	69.68 MT	Continued yield improvement in green revolution belt
Wheat -- 2022-23	~110 MT	Recent record; India became 2nd largest wheat producer globally
Food Grain -- 1964-65	72 MT (crisis year; drought + locust)	The crisis that accelerated Green Revolution adoption
Food Grain -- 1978-79	131 MT	First time India crossed 100 MT; proclaimed food self-sufficiency
Food Grain -- 2000-01	196 MT	Continued growth; India a major food exporter
Food Grain -- 2023-24	~330 MT	Record production; India = 2nd largest food grain producer globally
Rice -- 1960-61	~35 MT	Pre-Green Revolution; Bengal and South India traditional varieties
Rice -- 2022-23	~130 MT	2nd largest rice producer (after China); major exporter

KEY NOTE

Green Revolution -- Geographic Spread Pattern: Phase 1 (1965-1970): **WHEAT REVOLUTION** in Punjab, Haryana and Western UP -- the "Green Revolution Belt"; these three states adopted HYV wheat fastest because they had: (a) existing canal irrigation from Bhakra-Nangal; (b) entrepreneurial farmer community (Jat farmers); (c) government procurement support (MSP and FCI); (d) proximity

to markets. Phase 2 (1970s-80s): **RICE REVOLUTION** in TN, AP, WB -- HYV rice spread; southern states adopted IR-8 and subsequent varieties. Eastern India (Bihar, eastern UP, WB) remained largely outside the Green Revolution until the 1980s-90s, and even now the gap persists (BGREI programme targets this). NE India, Jharkhand, dryland Deccan -- mostly untouched.

SECOND GREEN REVOLUTION -- EASTERN INDIA FOCUS

The **Second Green Revolution** concept -- also called **"Bringing Green Revolution to Eastern India" (BGREI)** -- recognises that the original Green Revolution bypassed eastern India (Bihar, eastern UP, West Bengal, Odisha, Jharkhand, Assam) despite these states having enormous agricultural potential: fertile Gangetic alluvial soils, adequate rainfall, and large agricultural populations.

BGREI Feature	***Detail***
Scheme	BGREI -- Bringing Green Revolution to Eastern India; sub-scheme under RKVY (Rashtriya Krishi Vikas Yojana)
Target states	Bihar, Jharkhand, West Bengal, Odisha, Assam, Eastern UP, Chhattisgarh -- the 7 eastern states
Focus	Bridging the yield gap: eastern India's paddy and wheat yields are 30-40% lower than national average; target to raise these to at least national average levels through: improved seeds (certified), mechanisation (farm machinery), soil testing, crop diversification, and market linkage
Achievements	Bihar paddy production grew ~60% in 10 years (2007-08 to 2017-18); Bihar wheat saw the "Wheat Revolution" -- state transitioned from rice-dominant to high wheat production zone after 2005-10; WB and Odisha also showed significant productivity gains
Why East India lagged	(a) Fragmented small landholdings (Bihar average farm < 0.5 ha); (b) Inadequate irrigation coverage; (c) High tenancy -- sharecroppers had less incentive to invest; (d) Inadequate rural infrastructure (roads, power, markets); (e) Social issues (caste discrimination limiting access to credit and extension); (f) Flooding -- Kosi, Gandak, Mahananda regularly flood Bihar agricultural land

SWAMINATHAN COMMISSION AND EVERGREEN REVOLUTION

Feature	***Detail***
National Commission on Farmers (NCF 2004-06)	Chaired by Dr. M.S. Swaminathan; 5 reports submitted 2004-2006; most comprehensive review of Indian agriculture since Independence; addressed farmer distress, suicides, land reform, credit, insurance, markets, technology
Key recommendation -- C2+50% MSP	MSP (Minimum Support Price) should be set at C2 + 50% where C2 = comprehensive cost of production INCLUDING imputed rental value of land + imputed interest on farmer capital; this formula would give farmers 50% PROFIT over their FULL cost; this remains the primary demand of farmers movements (including the 2020-21 protest and 2024 Shambhu border protest); NDA government has provided higher MSPs but has not legally guaranteed the C2+50% formula
Seed sovereignty	NCF recommended protecting farmers' rights to save, exchange, and sell seeds; opposed patenting of crop varieties; supported PPVFRA (Protection of Plant Varieties and Farmers' Rights Act 2001) implementation
Evergreen Revolution concept	Swaminathan coined Evergreen Revolution as the necessary successor to the Green Revolution: Increasing productivity in perpetuity without ecological and social harm. It incorporates: (1) soil health improvement (soil organic matter, microbiome); (2) water use efficiency (micro-irrigation, rainwater harvesting); (3) biodiversity (traditional varieties, crop diversity); (4) farmer participation (participatory plant

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	breeding); (5) gender equity; (6) rural livelihood diversification; aligns with PM-PRANAM, NMNF 2024, and natural farming initiatives
Bharat Ratna 2024 (posthumous)	MS Swaminathan passed away September 28, 2023 (aged 98); President Droupadi Murmu announced Bharat Ratna for him on February 9, 2024 (along with Karpoori Thakur, PV Narasimha Rao, Chaudhary Charan Singh and LK Advani -- 5 recipients in 2024); Swaminathan is the first person with a primary contribution to agriculture/food security to receive the Bharat Ratna

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Civil GS-3 Critical Angle -- Green Revolution Legacy: A high-scoring answer must cover THREE dimensions: (1) **Achievements**: food self-sufficiency; production records; farmer incomes in Punjab-Haryana; (2) **Limitations**: geographic concentration (Punjab-Haryana only initially); crop concentration (wheat-rice only); social inequity (large farmers vs small farmers; landowners vs labourers); (3) **Ecological costs**: groundwater depletion; soil degradation; pesticide crisis; crop diversity loss. Then connect to: BGREI (addressing geographic limitation); Evergreen Revolution (addressing ecological limitations); 2023 IYoM Shree Anna (addressing crop concentration); MS Swaminathan Bharat Ratna 2024 (honoring the architect). C2+50% MSP formula is the policy bridge between the old model and the new.

30.3 WHITE REVOLUTION -- OPERATION FLOOD AND DAIRY TRANSFORMATION

The White Revolution -- India's dairy transformation -- is often cited as the world's most successful agricultural development programme. It converted India from a milk-deficit country relying on expensive imported butter, ghee and skimmed milk powder (SMP) into the **world's largest milk producer** while doing so through **small farmer-owned cooperatives** rather than multinational corporations -- making it a model for equitable rural development globally.

THE ANAND PATTERN AND AMUL

White Revolution Feature	*Detail*
Dr. Verghese Kurien (1921-2012)	Called "Father of the White Revolution in India" and "Milkman of India"; an engineer who trained at Michigan State University; joined AMUL (Kaira District Cooperative Milk Producers' Union, Anand, Gujarat) in 1950 at Sardar Vallabhbhai Patel's invitation; became chairman of NDDB (1965-1998); designed the replication strategy for the AMUL model across India; received Ramon Magsaysay Award (1963), Padma Bhushan (1966), Padma Vibhushan (1999), World Food Prize (1989 -- same year as Swaminathan's)
AMUL (Anand Milk Union Limited)	Established 1946 (as Kaira District Cooperative; formalized as AMUL 1955); Anand, Gujarat; the original cooperative model: (1) Village Dairy Cooperative Societies (VDCS) -- milk collection at village level; (2) District Milk Union (AMUL) -- processing, pasteurisation, product manufacturing; (3) State Federation (GCMMF -- Gujarat Cooperative Milk Marketing Federation) -- marketing and distribution nationally under the "AMUL" brand; now Rs.72,000+ crore annual turnover (2023-24 -- first Indian dairy co-op to cross Rs.72,000 crore)
Anand Pattern / Two-Tier / Three-Tier Model	The replication template: (1) Village DAIRY CO-OP (primary society; 200-300 members; collects milk twice daily; quality testing; payment based on fat and SNF content); (2) DISTRICT UNION (processes and manufactures products; operates bulk coolers, pasteurisers, chilling plants); (3) STATE FEDERATION (markets products; manages the state-wide brand; coordinates between unions)
Operation Flood	Phase 1 (1970-1981): financed by World Food Programme dairy commodities (butter oil + SMP donated by EEC countries); replicated Anand Pattern in 18 "milksheds";

	created mother dairies in Delhi, Mumbai, Kolkata, Chennai. Phase 2 (1981-1985): expanded to 136 milksheds; 290 urban markets. Phase 3 (1985-1996): strengthened the cooperative infrastructure; created self-sustaining system. NDDB designed and implemented; Kurien led it.
NDDB (National Dairy Development Board)	Established 1965 by PM Lal Bahadur Shastri at Anand, Gujarat (specifically to replicate the AMUL model nationally); chaired by Kurien for 33 years; has its own Parliamentary Act (NDDB Act 1987); implemented Operation Flood; now continues to strengthen dairy cooperatives; Anand (Gujarat) = "Dairy Capital of India"
State dairy cooperative brands	AMUL (Gujarat -- GCMMF); Mother Dairy (Delhi -- NDDB wholly-owned); Nandini (Karnataka -- KMF -- Karnataka Milk Federation); Saras (Rajasthan -- RCDF); Vita (Haryana -- HCMPU); Arokya/Aavin (Tamil Nadu -- TCMPF); Verka (Punjab -- MILKFED); Nandhini / Sudha (Bihar -- COMFED)

INDIA'S MILK PRODUCTION -- DATA AND STATUS

Year	*Milk Production*	*Note*
1950-51	17 MT	Pre-Operation Flood; small-holder traditional cattle keeping
1969-70	20 MT	Start of Operation Flood; India a milk-deficit country importing dairy products
1981-82	31.6 MT	End of Operation Flood Phase 1; growth accelerating
1996-97	70.8 MT	End of Operation Flood Phase 3; India self-sufficient in milk
1998	Crossed 70 MT	India became world's LARGEST milk producer (overtaking USA) for the first time in 1998
2010-11	121.8 MT	Growth continues even post-Operation Flood
2020-21	210.5 MT	India = 22% of world milk production; continues to grow
2022-23	~220+ MT	World's largest milk producer by a wide margin; 2nd country to cross 200 MT (after EU bloc)

India's dairy sector involves approximately **8 crore dairy farmer households**, with an average herd of 2-3 animals. The majority (60%+) of India's milk production comes from **non-descript / crossbred cattle and buffalo** rather than pure-bred animals. Buffalo milk, which has higher fat content than cow milk, constitutes approximately **48-50% of India's total milk production.** The indigenous cattle breeds (Gir, Sahiwal, Red Sindhi, Tharparkar) are now being prioritised under the **Rashtriya Gokul Mission (RGM)** and the **National Bovine Genomics Programme** to improve indigenous cattle productivity while preserving breed diversity.

30.4 BLUE REVOLUTION -- FISHERIES TRANSFORMATION

The Blue Revolution refers to the rapid growth of India's fisheries sector -- both marine and inland -- from a subsistence activity to a significant commercial and export sector. India is now the **world's 3rd largest fish producer** (after China and Peru by volume) and the **2nd largest aquaculture producer** (after China). Fisheries contribute approximately **1.24% to India's GVA** and provide livelihood to approximately **2.8 crore fishermen and fish farmers.**

Blue Revolution Feature	*Detail*
Total fish production (2022-23)	14.73 million tonnes (MT); India = 3rd globally; fish production growing at ~7%/year compound growth rate; target 22 MT by 2024-25 under PMMSY

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Inland vs Marine	Inland fisheries: ~8.5 MT (58%); Marine fisheries: ~4.4 MT (30%); Aquaculture inland: remainder. Inland has overtaken marine in the last decade; inland fisheries growing faster due to pond aquaculture expansion
Top fish-producing states	Andhra Pradesh (largest overall; both marine and inland; aquaculture specialist -- "Aquaculture Hub of India" -- Prakasam, Nellore, Krishna districts; Vannamei shrimp); WB (inland -- Rohu, Catla, Mrigal culture in ponds); Gujarat (marine -- major deep-sea fishing port at Veraval; the world's largest fishing harbor at Veraval-Porbandar area); TN (marine, tuna); Kerala (marine; major sardine and mackerel); Bihar (inland pond culture growing rapidly under PMMSY)
Aquaculture -- Major Species	Inland aquaculture: Indian Major Carps (IMC) -- Rohu (Labeo rohita), Catla (Labeo catla), Mrigal (Cirrhinus mrigala) -- together called "composite carp culture" (the IMC trinity); also Tilapia, Pangasius. Marine aquaculture (mariculture): Vannamei Shrimp (Litopenaeus vannamei -- introduced from Americas; now dominates; AP, WB, Odisha); also Seabass, Grouper, Pearl oyster, Sea cucumber
Fish exports	Rs.57,587 crore (2022-23); India = 4th largest seafood exporter globally; Shrimp = >70% of export value (frozen shrimp); USA, China, EU, Japan, Southeast Asia = major destinations; "Frozen Shrimp" is among India's top agricultural export items
PM Matsya Sampada Yojana (PMMSY)	Launched May 2020 by PM Modi; Rs.20,050 crore (largest investment in fisheries sector ever); target: fish production to 22 MT by 2024-25; exports to Rs.1 lakh crore; employment to 55 lakh additional; double fishers' incomes; aquaculture expansion; infrastructure (harbors, cold chain, processing); insurance for fishermen
NFDB (National Fisheries Development Board)	Established 2006; headquartered Hyderabad, Telangana; implementing agency for Blue Revolution and fisheries development schemes; coordinates with state fisheries departments; supports fish seed production, ornamental fisheries, mariculture, seaweed cultivation
Seaweed cultivation (emerging)	India has 7,500+ km coastline ideal for seaweed; Tamil Nadu (Rameswaram, Pamban Island), Gujarat, Lakshadweep; seaweed used for agar, carrageenan (food additives), biofuel, fertiliser; NFDB supports seaweed cultivation; women self-help groups in TN coast engaged; target 1 million MT seaweed production by 2025
Blue Economy	The total economic value derived from oceans and coastal resources; India's EEZ = 2.02 million sq km; potential for sustainable fishing, offshore energy (wind, OTEC), maritime trade, coastal tourism, seabed mining; Ministry of Earth Sciences leads "Blue Economy Policy Framework"; PM Modi has emphasised "Sagar Mala" project (port-led coastal development) and Blue Economy as growth frontier

30.5 YELLOW REVOLUTION -- OILSEEDS AND EDIBLE OIL

The Yellow Revolution refers to the transformation of India's oilseeds production, beginning with the **Technology Mission on Oilseeds (TMO),** launched in 1986 by the Rajiv Gandhi government. Before TMO, India's oilseed production had been stagnant for two decades and India was a large importer of edible oils. TMO applied a technology-intensive, mission-mode approach to oilseeds similar to the Green Revolution's approach to food grains.

Yellow Revolution Feature	*Detail*
Technology Mission on Oilseeds (TMO,	Launched 1986; part of the "Technology Missions" programme conceived by Sam Pitroda (Rajiv Gandhi's advisor); six technology missions: telecommunications, water,

1986)	immunisation, literacy, edible oilseeds, and pulses; TMO applied a systems approach: HYV oilseed varieties + mini-kits (subsidised seed-fertiliser packages to farmers) + research, extension, processing, marketing -- all integrated
Pre-TMO status	India was a large importer of edible oil (primarily palm oil from Malaysia); oilseed yields were stagnant; only ~4-5 MT groundnut and limited mustard, sesame, linseed grown; very low farm-level technology use
Impact of TMO	Oilseed production increased from ~12 MT (1986) to ~24 MT (1993) in just 7 years -- a virtual doubling; this reduced edible oil import dependence significantly in the short term; groundnut, rapeseed/mustard, and soybean all showed dramatic yield increases with improved varieties and mini-kit technology
Current oilseed production	~38-40 MT total oilseeds (2022-23); India = 3rd largest oilseed producer globally; BUT edible oil consumption has grown even faster (rising middle class, dietary change) making India still a large net IMPORTER of edible oil
Edible oil import crisis	India imports 60-65% of its edible oil requirements; annual edible oil import value = Rs.1.5-2 lakh crore (second largest import category after crude oil in some years); primary import: Crude Palm Oil (CPO) from Indonesia and Malaysia (~60% of imports); Soybean oil from Argentina/Brazil (~20%); Sunflower oil from Ukraine/Russia (~20%)
NMEO-OP (National Mission on Edible Oils -- Oil Palm, 2021)	Launched August 2021; Rs.11,040 crore; target 1 million ha of oilpalm by 2025-26; focused on NE India (Assam, Arunachal Pradesh, Nagaland, Manipur, Mizoram, Meghalaya, Tripura -- 7 NE states) and Andaman and Nicobar Islands (which have suitable tropical humid climate for oilpalm); CONTROVERSY: oilpalm monoculture in NE India will replace diverse traditional agroforestry and forest ecosystems; IFoS officers, ecologists and tribal communities have raised concerns about biodiversity impact; Mizoram, Meghalaya have indigenous conservation concerns
GM Mustard (HT-DMH-11)	Dhara Mustard Hybrid-11; developed by Delhi University (Prof. Deepak Pental); GEAC approval October 2022; SC scrutiny; combines herbicide tolerance + hybrid vigour; potential 20-30% yield increase; if commercialised widely could reduce import dependence; concerns about bee (pollinator) impact since mustard is a major honey crop
Pulses parallel	Technology Mission on Pulses (TMP) was also launched alongside TMO; India = world's largest pulse producer AND consumer; but pulse demand still exceeds production; imports from Australia (chana, masoor), Canada, USA; pulse price spikes are recurring inflation drivers

ENV ALERT

NMEO-OP and Forest/Ecology Concern -- IFoS Alert:

The National Mission on Edible Oil -- Oil Palm (NMEO-OP) has raised serious ecological concerns among forest ecologists and IFoS officers. Oilpalm (*Elaeis guineensis*, African origin) is among the most water-intensive plantation crops; in Southeast Asia, oilpalm expansion has destroyed rainforest at an extraordinary scale (Indonesia and Malaysia lost 30%+ of their lowland tropical forest to oilpalm since 1980s). India's NMEO-OP targets 1 million ha in NE India -- which is part of the **Eastern Himalayan Biodiversity Hotspot** and contains some of India's most biodiverse traditional agroforestry systems (shifting cultivation mosaics, sacred groves, dense forest). Planting oilpalm monocultures here could: (a) replace diverse traditional crops (like jhum multi-crop plots) with a single exotic species; (b) alter soil hydrology; (c) impact water sources for downstream communities; (d) threaten pollinators (oilpalm is not a useful honeybee forage plant). A 2022 report by Nature Conservation Foundation flagged these risks. The policy tension: India genuinely needs to reduce edible oil imports, but the ecological price in NE India may be disproportionate.

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30.6 PINK REVOLUTION -- MEAT, POULTRY AND ONION

The term "Pink Revolution" is used in TWO different senses in Indian agricultural discourse, and both definitions appear in exam questions:

- **Definition 1 (Meat and Poultry):** Pink Revolution refers to the rapid growth of India's meat and poultry sector -- driven by rising incomes, urbanisation, and changing dietary preferences; "pink" = the colour of meat.
- **Definition 2 (Onion):** Pink Revolution also refers to the rapid expansion of onion production in India -- "pink" = the colour of onion flesh; this is used especially in the context of Maharashtra's Nashik district as the "Onion Capital of India."

POULTRY REVOLUTION

Poultry Feature	*Detail*
Egg production	India = 3rd largest egg producer globally (after USA and China); total 129 billion eggs (2021-22); growing at 5-7% per year; egg production has grown from ~2 billion (1951) to 129 billion (2022)
Broiler (meat) production	India = 4th largest broiler chicken producer globally; ~5 million tonnes of broiler meat per year; growing rapidly with increased urban consumption
Geographic concentration	Andhra Pradesh and Telangana together contribute ~40% of India's total egg and broiler production (Nandyal, Prakasam, Nalgonda, Rangareddy districts); Maharashtra (Pune area); Tamil Nadu (Namakkal -- "Egg Capital of India"; 10 crore eggs/day from this single district); Karnataka (Davangere, Chikmagalur); West Bengal (Murshidabad)
Integration and contract farming	Indian poultry has transitioned from traditional backyard poultry to large-scale vertically integrated corporate operations: Suguna Poultry, VH Group, IB Group, Venkateshwara Hatcheries dominate; contract farming with small farmers for broiler production; large-scale automatic layer sheds for egg production; biosecurity and disease management are major concerns
Animal health challenge	Avian Influenza (Bird Flu; H5N1, H5N8 variants) periodic outbreaks in India (2021 large outbreak in Kerala, Rajasthan, HP, MP, Gujarat); mass culling of poultry during outbreaks; affects export competitiveness and farmer incomes

ONION PRODUCTION

Onion Feature	*Detail*
Production	India = 2nd largest onion producer globally (after China); production ~31-33 MT (2022-23); Maharashtra alone produces ~33-38% of India's onions
Key states	Maharashtra (Nashik = "Onion Capital of India" / "Onion City"; also Pune, Solapur, Ahmednagar); Karnataka (Gadag, Belgaum); Andhra Pradesh; MP; Rajasthan
Onion price volatility -- a political issue	Onion prices are among India's most politically sensitive food prices: a sudden onion price spike in 1998 contributed to the BJP losing the Delhi and Rajasthan state assembly elections; price crashes harm farmers; price spikes harm consumers. India periodically imposes export bans, reduced export MSPs, or import duty waivers to control domestic prices. An export ban in October 2023 (to control domestic prices following a poor kharif crop due to excess rain damage in MH) caused diplomatic issues with onion-importing countries (Sri Lanka, Bangladesh, Malaysia, Indonesia)
Storage problem	Onions are highly perishable; inadequate cold storage and processing infrastructure leads to: 20-30% post-harvest losses; wild price swings between harvest glut (low prices, farmers distressed) and off-season scarcity (high prices, consumers distressed); NAFED (National

	Cooperative Exports Ltd) and central government buffer stocks used to stabilise but inadequate

30.7 GOLDEN REVOLUTION -- HORTICULTURE TRANSFORMATION

The Golden Revolution refers to the dramatic expansion of India's horticulture sector (fruits, vegetables, flowers, spices, plantation crops, coconut, cashew). In 2021-22, India's total horticulture production reached **342 million tonnes -- exceeding food grain production (~315 MT) for the first time** in Indian history. India is the **world's 2nd largest producer of both fruits and vegetables** (after China). This shift in India's agricultural landscape from cereal dominance to diversified horticulture is one of the most significant structural changes in the last three decades.

Horticulture Category	*India's Status*	*Key States*	*Key Challenge*
MANGO	World's largest producer (~20-22 MT; ~45% of world output)	Uttar Pradesh (Dashehari, Lucknow), Andhra Pradesh (Banginapalli, Totapuri), Bihar, Maharashtra (Alphonso from Ratnagiri-Sindhudurg GI-tagged), Karnataka, TN	Export share is very low (<1% of production exported) because dominant varieties (Alphonso) are sensitive to post-harvest handling; cold chain needed; expanding Alphonso exports to USA, EU
BANANA	World's largest producer (~31-33 MT; ~28% of world output)	Tamil Nadu (Thovalai, Palayam), AP, Maharashtra, Gujarat, UP	Banana is highly perishable (4-7 day shelf life without cold chain); high post-harvest losses; Cavendish variety dominates export; Yelakki banana (Karnataka) = small banana type famous for taste; Nendran (Kerala) = cooking banana
GRAPES	5th largest producer; high export value	Maharashtra (Nashik = "Wine and Grape Capital"; Sangli, Pune; Thompson Seedless and Sharad Seedless dominant)	Nashik grapes dominate Europe and ME exports; strict pesticide residue regulations of EU = key export barrier; Nashik wine industry growing (Sula Vineyards, Grover Zampa)
APPLE	Significant domestic producer	Himachal Pradesh (60%+ of India production: Shimla, Kullu, Kinnaur -- Kinnaur apples GI-tagged), Jammu and Kashmir (30%: Shopian, Pulwama, Sopore -- disputed by recent challenges to J&K apple exports from China via Pakistan; also Kashmiri apple at risk from climate change)	Climate change is shifting apple cultivation zones upward in HP; Golden Gate apple (China origin) and other high-density varieties being introduced; J&K apple economy affected by 2019 revocation of Art 370 (supply chain disruption) and subsequent recovery
TOMATO	2nd largest producer (after China); ~20-22 MT/year	AP, MP, Karnataka, Maharashtra, Bihar, UP	Extreme price volatility -- from Rs.5/kg to Rs.250/kg in the same year (2023 saw tomato prices cross Rs.200+/kg due to weather damage in key growing areas); perishability

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			+ inadequate cold chain = volatile prices; Tomato Grand Challenge launched 2023 after price crisis
ONION	2nd largest producer (see Pink Revolution section); ~31 MT	Maharashtra, Karnataka, AP	Extreme price volatility; export bans; storage losses; political sensitivity
SPICES	World's largest producer and exporter of spices	Kerala (black pepper, cardamom, ginger), AP (chilli -- Guntur chilli = GI; India produces ~30% of world chilli); Rajasthan (cumin = jeera; India = 70%+ of world cumin production; Unjha, Gujarat); Karnataka (vanilla now grown experimentally)	India exports Rs.33,000+ crore of spices (2022-23); Spices Board of India; GI tags for multiple Indian spices (Darjeeling tea, Guntur chilli, Coorg cardamom, Alleppey Green Cardamom)
FLOWERS	Growing sector; cut flower export Rs.1,200+ crore	Karnataka (rose, gerbera, carnation -- Bengaluru floriculture hub), TN, AP, Maharashtra (Pune roses)	Carnation and rose exports to Netherlands, Japan; domestic demand from weddings, religious festivals enormous; refrigerated transport critical

MIDH AND HORTICULTURE POLICY

Scheme / Institution	*Detail*
MIDH (Mission for Integrated Development of Horticulture)	Umbrella scheme from 2014-15 consolidating National Horticulture Mission (NHM), Horticulture Mission for NE and Himalayan States (HMNEH), National Bamboo Mission; covers all horticulture -- fruits, vegetables, flowers, spices, plantation crops; provides assistance for planting material, technology, post-harvest, market infrastructure; Rs.2,600 crore annual outlay
National Horticulture Board (NHB)	Gurugram; promotes technology upgradation, cold chain, processing, exports; provides financial assistance for cold storage, packhouses, pre-cooling; implementing agency for modern retail supply chain for horticulture
Kisan Rail	Indian Railways product launched 2020; refrigerated parcel van service for perishable agricultural produce (fish, meat, vegetables, fruits, milk); 75+ Kisan Rail routes by 2022 connecting producing areas (Bihar, UP, MH, AP) to consuming cities (Delhi, Mumbai, Kolkata, Chennai)
Kisan Udaan	Air cargo scheme for perishable agri-produce; focused on NE India, J&K, hill states (which have good horticulture but poor connectivity); Air India, IndiGo, SpiceJet participating; apples from Kinnaur, oranges from Meghalaya, exotic vegetables from NE flown to metro cities
One District One Product (ODOP)	Identifies one unique agricultural/food product per district for focused promotion and branding; Uttar Pradesh pioneered ODOP; DPIIT and Ministry of Food Processing involved; scale-up under PM FME (Formalization of Micro Food Processing Enterprises) scheme
Fruits and	APEDA (Agricultural and Processed Food Products Export Development Authority) certifies

Vegetables Export	and promotes export; GI-tagged products have premium markets; Alphonso mango now accessible in US, EU (phytosanitary protocols resolved); Nagpur mandarin orange; Darjeeling tea; freshness-of-product (24-48 hour harvest-to-export) is the key competitive advantage

30.8 ROUND, SILVER, EVERGREEN AND RAINBOW REVOLUTIONS

ROUND REVOLUTION (POTATO)

Feature	Detail
Status	India = 2nd largest potato producer globally (after China); ~60 MT (2022-23)
Key states	Uttar Pradesh > West Bengal > Bihar > Gujarat > Madhya Pradesh; UP alone produces ~30% of India's potato
ICAR-CPRI	Central Potato Research Institute, Shimla, Himachal Pradesh (1949); develops HYV potato varieties suited to Indian conditions; Kufri Jyoti, Kufri Pukhraj, Kufri Sindhuri = well-known varieties; CPRI is the world's 6th largest potato research centre
Contract farming	PepsiCo contract farming for FC5 potato variety (suitable for Lay's chips); primarily in Gujarat, Punjab, UP, WB; controversy when PepsiCo sued farmers for growing "patented" variety without contract (2019 Gujarat case); ultimately PepsiCo withdrew lawsuit after public backlash
Processing gap	Only 5-10% of India's potato is processed (vs 80%+ in USA, UK); most consumed fresh; growing domestic demand for chips, french fries (fast food expansion); cold storage gap = major post-harvest loss issue; about 20-30% of potato spoils before reaching consumer

SILVER REVOLUTION (EGG AND POULTRY)

Silver Revolution refers to the growth of egg production (silvery white = egg shell colour). India is the **3rd largest egg producer globally** (after USA and China). Total egg production: **129 billion eggs (2021-22),** growing at ~5%/year. Andhra Pradesh and Telangana together contribute ~40% of egg production. Tamil Nadu's **Namakkal district** produces approximately 10 crore eggs per day -- making it "the egg of India." The sector is characterised by large-scale, climate-controlled, vertically integrated operations by corporate poultry houses alongside small backyard poultry operations in rural and tribal areas (the latter supported by **National Programme for Poultry Development, NPPD**

EVERGREEN REVOLUTION

Dr. M.S. Swaminathan coined the concept of "Evergreen Revolution" -- the necessary evolution beyond the Green Revolution. While the Green Revolution focused on **productivity (yield per hectare),** the Evergreen Revolution focuses on **"productivity in perpetuity without ecological and social harm."**

- **Soil health:** Restoring organic matter, soil biota, and micronutrient balance (Soil Health Cards, PM-PRANAM, NMNF 2024).
- **Water use efficiency:** PMKSY micro-irrigation, watershed development, traditional water harvesting revival.
- **Biodiversity in agriculture:** Reviving traditional crop varieties (seed banks, PPVFRA), agroforestry, millets (IYoM 2023).
- **Farmer participation:** Participatory plant breeding (farmers involved in variety selection), farmer seed systems, FPOs.
- **Social equity:** Women farmers' recognition (Mahila Kisan Sashaktikaran Pariyojana), landless labourers, tribal communities (FRA 2006).

The **National Mission on Natural Farming (NMNF, 2024; Rs.2,481 crore)** and **PM-PRANAM (2023)** are the policy expressions of the Evergreen Revolution vision in the current government framework.

RAINBOW REVOLUTION

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The Rainbow Revolution is an overarching concept introduced by the NDA government (from 2014-15 onwards) as a **comprehensive, multi-sectoral agricultural transformation** that goes beyond single-commodity revolutions. The "rainbow" metaphor indicates the inclusion of ALL colours/types of agricultural production:

Rainbow Revolution Component	*Scheme / Programme*
Food grain self-sufficiency (Green)	BGREI; National Food Security Mission (NFSM); seed production; biofortification
Dairy and livestock (White + Red)	National Programme for Dairy Development (NPDD); Rashtriya Gokul Mission (RGM); ICAR-NDDB partnership; PM Matsya Sampada Yojana (fisheries)
Horticulture (Golden)	MIDH; NHB; Kisan Rail; One District One Product; GI protection; export promotion via APEDA
Oilseeds (Yellow)	NMEO-OP; biodiesel mission; ICAR research on high-oleic groundnut and mustard varieties
Soil and water (Brown/Blue)	PMKSY; NMSA; Atal Bhujal Yojana; soil health cards; PM-PRANAM; NMNF 2024
Income support and insurance (universal)	PM-KISAN (Rs.6,000/year to 11 crore farmers); PMFBY (crop insurance); eNAM (digital marketplace); 10,000 FPOs (Farmer Producer Organisations)
Food security (universal)	NFSA 2013 + PMGKAY (free grain to 81 crore beneficiaries from Jan 2024); PM POSHAN (mid-day meals); ICDS/Poshan Abhiyaan

30.9 CURRENT AFFAIRS HOOKS (2022-2025)

CURRENT AFFAIRS

MS Swaminathan Bharat Ratna (February 2024 -- Posthumous): Dr. M.S. Swaminathan (September 25, 1925 - September 28, 2023) was posthumously awarded the Bharat Ratna, India's highest civilian honour, by President Droupadi Murmu in February 2024 -- making him the first person whose primary contribution was to agriculture and food security to receive this honour. Swaminathan's legacy: (a) Father of Green Revolution in India; (b) National Commission on Farmers (2004-06) -- C2+50% MSP formula; (c) Evergreen Revolution concept; (d) MS Swaminathan Research Foundation (MSSRF, Chennai) -- continuing work on food security, coastal ecology, biodiversity, and gender.

109 Biofortified Crop Varieties Released (August 2024): On August 11, 2024, PM Modi launched 109 new biofortified, climate-resilient, and high-yielding crop varieties at IARI New Delhi. These varieties were developed by ICAR across 61 crop types. "Biofortified" means enriched in key micronutrients (iron, zinc, protein, beta-carotene) to address hidden hunger (micronutrient deficiency affecting 190 crore+ Indians). Examples: high-zinc wheat, high-iron rice, protein-rich sorghum, beta-carotene rich sweet potato. This was framed as an "Amrit Krishi" event -- agriculture for the Amrit Kaal centenary period (2023-2047).

NMEO-OP Oilpalm Expansion (2021-2025): The National Mission on Edible Oils -- Oil Palm (NMEO-OP) has been advancing since its August 2021 launch. Oilpalm planting targets in NE India and Andaman are being pursued. By 2024, approximately 3.5-4 lakh ha additional oilpalm area has been brought under cultivation (against the 10 lakh ha target by 2025-26). Ecological concerns from NE India's tribal communities and ecologists about biodiversity impact of oilpalm monocultures in biodiverse NE forests continue. The mission is seen as crucial for reducing India's USD 12-15 billion annual edible oil import bill.

Tomato Price Crisis and Grand Challenge (2023-2024): In June-July 2023, tomato prices in India crossed Rs.200-250/kg (from a normal Rs.20-40/kg) due to a combination of: (a) unseasonal rains damaging tomato crops in Andhra Pradesh and Karnataka; (b) supply chain disruption; (c) the tight June-August window when domestic supply is lowest. The government imported tomatoes from Nepal; NAFED and NCOOP initiated tomato procurement and distribution at subsidised prices. The government subsequently launched a "Tomato Grand Challenge" to

develop disease-resistant, heat-tolerant tomato varieties and improve cold chain infrastructure for tomatoes specifically.

30.10 PYQ ANALYSIS -- CHAPTER 30 (2010-2025)

Source	Year	Marks	Question
UPSC Civil	2024	15M	"Discuss the Green Revolution in India -- its achievements, social and environmental costs, and the policy directions needed for an Evergreen Revolution."
UPSC Civil	2023	12M	"Discuss the White Revolution in India. How did Operation Flood transform India's dairy sector and what role did Dr. Verghese Kurien play?"
UPSC Civil	2022	10M	"What is the Blue Revolution? Discuss the significance of PM Matsya Sampada Yojana for India's fisheries sector."
UPSC Civil	2021	12M	"What is the Yellow Revolution? Discuss the significance of the Technology Mission on Oilseeds and why India still depends on edible oil imports."
UPSC Civil	2020	10M	"Discuss the Golden Revolution in Indian horticulture. What is the significance of horticulture production exceeding food grain production?"
UPSC Civil	2019	10M	"Explain the contribution of Dr. M.S. Swaminathan to Indian agriculture. What are the key recommendations of the Swaminathan Commission?"
UPSC Civil	2018	12M	"Discuss the various agricultural revolutions in India (Green, White, Blue, Yellow, Pink). What is meant by the Rainbow Revolution?"
UPSC Civil	2017	10M	"What is an Evergreen Revolution? How does it differ from the Green Revolution and what policy measures does it prescribe?"
IFoS GS	2024	10M	"Discuss the ecological and environmental implications of the National Mission on Edible Oil -- Oil Palm (NMEO-OP) for the forests of Northeast India."
IFoS GS	2023	10M	"Examine the relationship between the Green Revolution and India's groundwater and biodiversity crisis. What is the Evergreen Revolution?"
IFoS GS	2022	10M	"Discuss the Blue Revolution and its environmental dimensions. How does aquaculture expansion (especially shrimp farming) impact coastal and freshwater ecosystems?"

KEY NOTE

Frequency Pattern: Green Revolution + Evergreen (Civil 2024); White Revolution + Kurien (Civil 2023); Blue Revolution + PMMSY (Civil 2022); Yellow Revolution + edible oil imports (Civil 2021); Golden Revolution + horticulture milestone (Civil 2020); Swaminathan Commission (Civil 2019); all revolutions overview (Civil 2018); Evergreen Revolution (Civil 2017). IFoS: NMEO-OP ecology NE India (2024); Green Revolution groundwater-biodiversity + Evergreen (2023); aquaculture ecosystem impact (2022). For 2025-26: Swaminathan Bharat Ratna 2024 (posthumous); 109 biofortified varieties Aug 2024; NMEO-OP progress; Tomato price crisis + Grand Challenge; farmers' protest 2024 + MSP C2+50% formula; PMMSY target progress -- all high-priority current-affairs hooks.

30.11 MODEL BOOK

Critically examine the Green Revolution in India -- its achievements, social and environmental costs, and the roadmap for an Evergreen Revolution.

UPSC Civil (Mains) | 15 Marks | 210 Words

The Green Revolution (1960s-1970s) converted India from a food-deficit country importing wheat under PL-480 to a food-surplus nation with overflowing FCI buffer stocks -- one of the greatest policy achievements in India's post-Independence history. Its architect, Dr. M.S. Swaminathan, was posthumously awarded the Bharat Ratna in

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February 2024, recognising this contribution.

ACHIEVEMENTS:

1. **Production transformation:** Wheat: 11 MT (1960-61) to 35 MT (1977-78) to 110 MT (2022-23). Food grain: 72 MT (1964-65 crisis) to 330 MT (2023-24). India became 2nd largest wheat and 2nd largest rice producer globally.
2. **PL-480 escape:** From humiliating dependence on US food aid (PM Shastri called PL-480 imports "begging bowl") to food self-sufficiency; strategic autonomy gained.
3. **Rural prosperity (Green Revolution belt):** Punjab, Haryana, western UP farmer incomes rose dramatically; infrastructure built; rural capitalism emerged in these states.
4. **Technological foundation:** IARI, ICAR, Krishi Vigyan Kendras, seed corporations -- an institutional architecture for agricultural science.

SOCIAL COSTS:

1. **Geographic inequity:** Confined to Punjab-Haryana-WUP (wheat) and limited southern states (rice); eastern India (Bihar, WB, Odisha) bypassed; agrarian distress in BGREI states persists.
2. **Inter-class inequity:** Large farmers (able to access HYV+fertiliser+irrigation package) benefited most; marginal farmers and landless labourers marginalised; mechanisation reduced labour demand in Punjab.
3. **Farmer debt crisis:** Input-intensive agriculture required credit; Punjab farmer household debt among India's highest; agrarian suicides linked to debt (though more prominent in Vidarbha cotton belt).

ENVIRONMENTAL COSTS:

1. **Groundwater depletion:** Punjab water table declining 30-50 cm/year; estimated <20 years before aquifer collapse; paddy cultivation in a semi-arid state = ecologically irrational.
2. **Soil degradation:** Continuous wheat-paddy monoculture depletes organic carbon (Punjab soils now at 0.3-0.4% OC vs optimal 0.8%); zinc deficiency widespread; soil microbial diversity declining.
3. **Agro-biodiversity loss:** Thousands of traditional wheat and rice varieties replaced by a few HYVs; genetic vulnerability; Punjab had 350+ traditional wheat varieties in 1960 -- now virtually all commercial area under 3-4 modern varieties.
4. **Pesticide crisis:** Malwa region Punjab = "cancer belt"; high cancer incidence linked to pesticide exposure documented in multiple studies; the infamous "cancer train" from Bhatinda to PGI Chandigarh.

THE EVERGREEN REVOLUTION -- A NEW ROADMAP:

Concept (MS Swaminathan): "Increasing productivity in perpetuity without ecological or social harm." The Evergreen Revolution prescribes: (a) soil health (PM-PRANAM, NMNF 2024, zero budget natural farming); (b) water efficiency (PMKSY, Atal Bhujal Yojana); (c) crop diversity (IYoM 2023 millets, BGREI, biofortified varieties); (d) farmer equity (C2+50% MSP formula from Swaminathan Commission; FPOs; PM-KISAN).

Second Green Revolution (BGREI): Bringing the first revolution's productivity gains to eastern India (Bihar, WB, Odisha, Assam) -- the untapped frontier with fertile soils, adequate rainfall, and massive agricultural workforce.

The Green Revolution saved India from famine; the Evergreen Revolution must now save Indian agriculture from itself -- from the ecological overshoot that is undermining the very productivity gains the Green Revolution created. The 109 biofortified varieties released in August 2024, the NMNF 2024, and PM-PRANAM are the early steps in this second transformation.

Discuss India's White Revolution and Blue Revolution. What role did Dr. Verghese Kurien play? What is the significance of PM Matsya Sampada Yojana?.

UPSC Civil/IFOS (Mains) | 15 Marks | 200 Words

Introduction: India's agricultural transformation has not been confined to food grains. The White Revolution

(dairy) and Blue Revolution (fisheries) have together created massive parallel food economies -- milk and fish -- that collectively support the livelihoods of 10+ crore farmers and fishermen.

WHITE REVOLUTION -- OPERATION FLOOD (1970-1996):

Dr. Verghese Kurien (1921-2012): Called the "Father of the White Revolution" and "Milkman of India"; engineer trained at Michigan State University; joined Amul/NDDB in 1950; designed and implemented the Anand Pattern (Three-Tier Cooperative Model) replication strategy. Key achievement: Operation Flood -- the world's largest dairy development programme. Kurien's philosophy: "technology is the servant of the cooperative; never the master."

Anand Pattern (Three-Tier Model): (1) Village Dairy Cooperative Society (milk collection, farmer-owned); (2) District Milk Union (processing, pasteurisation, product manufacturing -- AMUL at district level); (3) State Federation (marketing and brand -- GCMMF for Gujarat; Mother Dairy for Delhi). This model eliminated middlemen and returned 70%+ of consumer rupee to farmers.

Operation Flood Impact: Milk production: 20 MT (1969-70) to 220+ MT (2022-23). India became world's largest milk producer in 1998 (overtaking USA). India's dairy cooperatives (AMUL, Mother Dairy, Nandini, Saras) support 8 crore farmer families. AMUL's turnover crossed Rs.72,000 crore (2023-24) -- the largest dairy cooperative in the world.

NDDB's Legacy: National Dairy Development Board (established 1965, Anand, Gujarat) remains the institutional backbone; Rashtriya Gokul Mission (RGM) for indigenous cattle breed improvement; National Programme for Dairy Development (NPDD); ICAR-NDDB R&D partnership.

BLUE REVOLUTION -- FISHERIES TRANSFORMATION:

Current Status: India = 3rd largest fish producer (14.73 MT; 2022-23); 2nd largest aquaculture producer; fish exports Rs.57,587 crore (4th largest seafood exporter; shrimp 70%+ of value); 2.8 crore fishers and fish farmers dependent on the sector.

Key Features: Inland fisheries (~58%) now exceeds marine (~30%+aquaculture). Andhra Pradesh = largest fish-producing state (Vannamei shrimp aquaculture especially; Prakasam, Nellore districts). Freshwater aquaculture: IMC triple (Rohu, Catla, Mrigal) composite carp culture. Gujarat = major marine fishing state (Veraval harbour). Tamil Nadu (marine), Kerala (sardine, mackerel).

PM MATSYA SAMPADA YOJANA (PMMSY, 2020):

Launch: May 2020 by PM Modi; Rs.20,050 crore -- largest ever investment in Indian fisheries.

Targets by 2024-25: Fish production: 14.73 MT to 22 MT; Fish exports: Rs.57,587 crore to Rs.1 lakh crore; Employment: 55 lakh additional jobs; Farmer income doubling.

Key components: (a) Infrastructure: new fishing harbours, fish landing centres, cold chain, processing plants, retail fish markets; (b) Aquaculture expansion: brackish water shrimp, freshwater fish, mariculture, seaweed; (c) Insurance: PM Matsya Kisan Samridhi Sah-Yojana for fishers; (d) Blue Economy: EEZ resource utilisation.

Environmental Note (IFoS): Shrimp aquaculture expansion in coastal AP and WB requires mangrove conversion in some areas -- a source of tension between Blue Revolution expansion and coastal ecosystem conservation. PMMSY guidelines require adherence to Coastal Regulation Zone (CRZ) norms; but enforcement challenges persist.

The White and Blue Revolutions demonstrate that India's agricultural success is not limited to food grains. Milk and fish together form a protein supply chain feeding 1.4 billion people while sustaining hundreds of millions of rural livelihoods. PMMSY's Rs.20,050 crore investment and the NDDB's continued cooperative expansion represent India's commitment to deepening these revolutions into their next phase.

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CHAPTER 31

PORTS & SHIPPING ROUTES

Major Ports, Inland Waterways and India's Maritime Trade

CHAPTER AT A GLANCE

- India has 12 MAJOR PORTS under the central government (Ministry of Ports, Shipping and Waterways) and 217 NON-MAJOR (minor/intermediate) ports under state governments. The 12 major ports handle ~60% of India's total seaborne trade by volume. Total traffic at major ports: ~795 million tonnes (MT) in 2022-23. India's coastline = 7,516 km mainland + 1,197 km island coastline = 8,713 km total. India's EEZ = 2.02 million sq km.
- 12 MAJOR PORTS (west to east): Kandla (now Deendayal Port Trust, DPT) -- largest by cargo volume; Mundra (private; Adani Ports -- largest container port); Mumbai (oldest; JNPT nearby); Mormugao (Goa); New Mangalore; Kochi (Cochin); Tuticorin (VO Chidambaranar Port); Chennai (oldest on east coast); Kamarajar (Ennore; coal/power plants); Paradip; Visakhapatnam (Vizag; deepest natural harbour); Kolkata (with Haldia).
- DEENDAYAL PORT TRUST (Kandla, Gujarat): largest by cargo volume; handles crude oil, fertilisers, foodgrains; located in Gulf of Kutch; hinterland = north India (Rajasthan, MP, Punjab, Haryana via road/rail). MUMBAI PORT: oldest; handles containers, dry cargo, petroleum; HPT (Harbour Port Trust). JNPT (Jawaharlal Nehru Port Trust, Navi Mumbai): India's busiest container port; ~55% of India's containerised trade. Mundra (Adani): overtook JNPT as largest container port in some years.
- SAGARMALA PROGRAMME (2015): Ministry of Ports, Shipping and Waterways; port-led development vision; 4 pillars: (1) Port Modernisation and New Port Development; (2) Port Connectivity Enhancement (road, rail, pipeline to ports); (3) Port-linked Industrialisation (coastal economic zones, SEZs near ports); (4) Coastal Community Development. Over 600 projects worth Rs.6 lakh crore identified; Rs.92,000+ crore invested by 2023.
- INLAND WATERWAYS: National Waterways Act 2016 declared 111 National Waterways (NWs). NW-1 = Ganga-Bhagirathi-Hooghly system (Prayagraj to Haldia, 1,620 km); NW-2 = Brahmaputra (Sadiya to Dhubri, 891 km); NW-3 = Kerala backwaters (Kollam to Kottapuram, 205 km); NW-4 = Godavari-Krishna; NW-5 = Brahmani-Mahanadi delta. Inland Waterways Authority of India (IWAI, 1986). Jal Marg Vikas Project (JMVP) on NW-1 with World Bank aid.
- INTERNATIONAL SHIPPING ROUTES: Major routes through Indian Ocean: (1) Suez Canal route (Europe-Asia via Red Sea-Suez); (2) Cape of Good Hope route (Europe-Asia avoiding Suez); (3) South Asian routes (Mumbai-Singapore; Colombo hub; Aden-Mumbai). Aden-Mumbai route is the most important for India's trade with the Middle East. Colombo (Sri Lanka) = major transshipment hub for South Asian cargo (India exports cargo to Colombo for transhipment to global routes). India's own transshipment port at Vizhinjam (Kerala) being developed.
- INDIA'S MARITIME TRADE: India's total seaborne trade: ~1,500 MT/year (2022-23). Major imports by sea: crude oil (~250 MT), coal (~240 MT), fertilisers, edible oil, machinery. Major exports by sea: petroleum products (~65 MT), iron ore, rice, marine products, engineering goods. India's merchant fleet: ~1,500 ships; small by global standards; India is the 16th largest shipping nation. Shipping Corporation of India (SCI) = largest Indian shipping company (PSU).
- STRATEGIC MARITIME CONCERNS: Strait of Hormuz (65% of India's crude oil passes through); Strait of Malacca (critical for India-East Asia trade); Bab-el-Mandeb (Yemen crisis/Houthi attacks 2023-24 disrupting Red Sea shipping); Indian Ocean Region (IOR) strategic significance; Project Mausam (MEA initiative for Indian Ocean cultural connectivity); SAGAR doctrine (Security and Growth for All in the Region). Andaman and Nicobar Command (ANC) = India's only tri-services command; strategic chokepoint over Malacca Strait

31.1 INTRODUCTION -- INDIA'S MARITIME GEOGRAPHY

India is a **peninsular nation** -- three sides bounded by water, giving it one of the longest coastlines of any Asian country. The Indian Ocean, the Arabian Sea, and the Bay of Bengal together form the strategic maritime

environment that has shaped India's trade, foreign policy, and national security for millennia. Today, approximately **95% of India's foreign trade by volume and ~70% by value** moves by sea -- making ports, shipping infrastructure, and maritime connectivity among the most critical elements of India's economic geography.

Maritime Parameter	*Data*	*Significance*
Total Coastline	7,516 km (mainland) + 1,197 km (islands: A&N + Lakshadweep) = 8,713 km total	3rd longest coastline in Asia; 9 coastal states (Gujarat, Maharashtra, Goa, Karnataka, Kerala, Tamil Nadu, Andhra Pradesh, Odisha, West Bengal) + 3 UTs (Dadra and Nagar Haveli + DD; Puducherry; Lakshadweep; A&N)
Exclusive Economic Zone (EEZ)	2.02 million sq km	Among the world's largest EEZs; contains fish resources, potential hydrocarbons (KG Basin), polymetallic nodules; governed under UNCLOS (India ratified 1995)
Number of Major Ports	12 major ports (under MoPSW)	Handle ~60% of India's seaborne trade by volume; under Major Port Authorities Act 2021 (replaced Major Port Trusts Act 1963)
Number of Non-Major Ports	217 non-major (minor/intermediate) ports under state governments	Handle remaining ~40% of seaborne trade; fast growing due to Sagarmala push; many being developed as multi-modal hubs
Total cargo at major ports	~795 million tonnes (MT) in 2022-23	Growing at 5-7% per year; target 1,500 MT by 2030 (Sagarmala vision)
Foreign trade by sea	95% by volume; ~70% by value	Only 5% by weight goes by air (high-value, low-weight goods like gems, pharmaceuticals, electronics)
India's merchant fleet	~1,500 ships; 16th globally	India lags significantly in ship ownership vs its trade importance; SCI (Shipping Corporation of India) is the largest PSU shipping company

31.2 THE 12 MAJOR PORTS OF INDIA

India's 12 Major Ports are governed by the **Major Port Authorities Act 2021** (which replaced the 100-year-old Major Port Trusts Act 1963) and fall under the **Ministry of Ports, Shipping and Waterways (MoPSW).** The 2021 Act gave them more autonomy (Board of Port Authority replacing Port Trust Board; elected members reduced; professional management). They are listed here in the conventional order from west to east coastline:

WEST COAST PORTS

Port	*State*	*Key Feature / Cargo*	*Hinterland / Specialty*
Deendayal Port Trust (DPT) (formerly Kandla Port Trust)	Gujarat (Kutch district; Gulf of Kutch)	LARGEST MAJOR PORT by cargo volume (150+ MT/year); handles: crude oil, petroleum products, fertilisers, foodgrains, salt, chemicals; multiple liquid and dry cargo berths; a Free Trade Zone (FTZ) established here 1965 -- India's first FTZ	Serves north India hinterland: Rajasthan, MP, Punjab, Haryana, Delhi (via NH 41 and rail); fastest way to move goods to/from north India by sea; renamed after Pt. Deendayal Upadhyaya in 2017; also contains Tuna and Mundra ports nearby
Mumbai Port Trust (MbPT)	Maharashtra (Mumbai, Thane Creek	OLDEST MAJOR PORT; handles: containers, dry cargo, liquid cargo, ro-ro (roll-on roll-off for vehicles),	Hinterland: Maharashtra, MP, Chhattisgarh, Karnataka; losing containerised trade share to JNPT

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	area)	cruise tourism; Mumbai Port area = oldest docks in India (constructed 1875)	(which is adjacent but far more efficient); Mumbai Port now focusing on redevelopment (Mumbai Port Land Development -- massive urban redevelopment of 1,300 acres of port land)
Jawaharlal Nehru Port Trust (JNPT) (Nhava Sheva)	Maharashtra (Navi Mumbai, Raigad)	BUSIEST CONTAINER PORT in India; ~55% of India's containerised exports and imports pass through JNPT; 4 container terminals (including India's first fully automated terminal -- NSICT); deepwater; direct rail connectivity; hinterland: Maharashtra, MP, Punjab, Delhi	Developed in 1989 adjacent to Mumbai Port; handles electronics, textiles, engineering goods, automobiles; JNPT Port Special Economic Zone (JNPSEZ); Fourth Container Terminal (FCT) developed by PSA Singapore; competition from Mundra (Adani) has reduced JNPT market share recently
Mormugao Port Trust (MPT)	Goa (Mormugao Peninsula; south Goa)	Major iron ore export port; also handles coal (thermal coal for power plants), petroleum, fertilisers; Mormugao Harbour = one of India's finest natural harbours; Portuguese-era port infrastructure	Hinterland: Goa, Karnataka (Dharwad, Belagavi); iron ore from Goa (declining since SC mining ban 2012; partially lifted); coal imports for Goa and coastal Karnataka power plants; fish landing also significant
New Mangalore Port Trust (NMPT)	Karnataka (Mangaluru, Dakshina Kannada)	Handles petroleum products (MRPL -- Mangalore Refinery and Petrochemicals Ltd is adjacent; 15 MMTPA); fertilisers; cashew; coffee exports; mineral ore	Hinterland: Karnataka, Kerala (northern); MRPL refinery is the key industrial anchor; also exports cashew (Karnataka-Goa coast is major cashew growing area); coffee from Coorg-Chikmagalur exported through Mangalore
Kochi Port Trust (Cochin Port)	Kerala (Willingdon Island, Kochi)	Natural harbour (backwaters estuary; sheltered by Willingdon Island -- an artificial island created by dredging); handles containers, petroleum, liquid cargo, cruise tourism; Kochi International Cruise Terminal; LNG terminal nearby	Hinterland: Kerala, Tamil Nadu (western); Cochin Shipyard Ltd (CSL) is adjacent -- builds warships and commercial vessels; Kochi Metro connectivity; INS Garuda (naval air station) on the island; growing cruise tourism hub; Vizhinjam port (under construction) will be the deep-water alternative nearby

EAST COAST PORTS

Port	*State*	*Key Feature / Cargo*	*Hinterland / Specialty*
V.O. Chidambaranar Port Trust (Tuticorin)	Tamil Nadu (Tuticorin / Thoothukudi)	Handles: thermal coal (for TANGEDCO power stations), rock salt (Tuticorin has massive salt pans), copper (Sterlite Copper smelter was nearby -- shut after 2018 anti-expansion protests + SC	Hinterland: Tamil Nadu, Kerala, Karnataka; key for southern Tamil Nadu's industrial hinterland; Sterlite copper controversy (13 killed in police firing during 2018 anti-copper-plant protests) made

		orders), containers, fertilisers, LPG; key linkage to Sri Lanka trade	Tuticorin a national environmental justice landmark; Sterlite plant remains closed (SC case)
Chennai Port Trust (ChPT)	Tamil Nadu (Chennai, Marina Beach waterfront)	OLDEST PORT ON EAST COAST (1895); India's second largest container port; fully artificial harbour (unlike Kochi or Visakhapatnam natural harbours); handles: containers, automobiles (Hyundai, Ford -- Chennai is India's "Detroit"), liquid cargo, dry bulk	Hinterland: Tamil Nadu, Karnataka, AP, Telangana; Ennore/Kamarajar Port nearby; combined Chennai-Ennore forms one of the most important port clusters on the east coast; major automobile export hub (vehicles roll-on roll-off)
Kamarajar Port Limited (Ennore Port)	Tamil Nadu (Ennore, north Chennai)	INDIA'S FIRST CORPORATISED PORT (converted to a company -- Ennore Port Ltd -- under Companies Act vs trust model; first such conversion in India); handles: coal (TANGEDCO thermal power stations use Ennore coal jetty), liquid, LNG, iron ore, ferro-chrome	Hinterland: Tamil Nadu power sector (coal for Ennore, Mettur, Tuticorin power plants is primary cargo); also Chennai Petroleum Corporation (CPCL) refinery at Manali uses Ennore liquid cargo facilities
Paradip Port Trust (PPT)	Odisha (Jagatsinghpur, Mahanadi delta area)	Handles: iron ore exports (Odisha-Jharkhand iron ore belt), coal imports (for NTPC Odisha + RINL), fertilisers, crude oil (Paradip refinery -- IOC's Paradip refinery 15 MMTPA); fast-growing port; one of India's largest iron ore export points	Hinterland: Odisha, Jharkhand, Chhattisgarh; IOC Paradip Refinery (commissioned 2016) has transformed Paradip from a commodity port to an energy hub; NITI Aayog-designated as a "Smart Industrial Port City" (SIPC); Paradip Fertilisers Ltd nearby
Visakhapatnam Port Trust (VPT) -- Vizag	Andhra Pradesh (Visakhapatnam / Vizag)	INDIA'S DEEPEST NATURAL HARBOUR; handles: crude oil (HPCL Vizag refinery), steel (RINL -- Rashtriya Ispat Nigam Ltd = Vizag Steel / National Steel Corporation; uses port for iron ore, coal, limestone imports), iron ore, fertilisers, container	Hinterland: AP, Telangana, Chhattisgarh, Odisha; RINL Vizag Steel Plant (India's only shore-based integrated steel plant -- built specifically to use sea-borne raw material delivery) is the most important industrial anchor; HPCL Vizag refinery (11.5 MMTPA); Eastern Naval Command HQ at Vizag
Kolkata Port Trust (KoPT) (including Haldia Dock Complex)	West Bengal (Kolkata and Haldia, Hooghly River)	ONLY RIVERINE MAJOR PORT in India (river port, not coastal); Kolkata Dock System (KDS) is 203 km from sea via the Hooghly River; Haldia Dock Complex (HDC) at the river mouth handles: crude oil, petroleum, coal, fertilisers, jute, tea	Hinterland: West Bengal, Bihar, Jharkhand, eastern India, and NEPAL + BHUTAN (river + rail connectivity for landlocked neighbours); Kolkata Port has historical significance (British-era trade hub; once India's most important port -- now declining);

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			Haldia is the main operational port; Inland Container Depot (ICD) at Kolkata

INDIA'S LARGEST PRIVATE PORT -- MUNDRA (ADANI PORTS)

Mundra Port and Special Economic Zone (Mundra APSEZ) in Kutch, Gujarat -- operated by **Adani Ports and SEZ Ltd (APSEZ)** -- has emerged as India's **largest commercial port by cargo volume** (exceeding even Deendayal Port in many years) and India's **largest container port,** competing with JNPT. Unlike the 12 major ports (which are government-owned trusts/authorities), Mundra is a **private port** under the Gujarat government's Minor Port policy but has been developed into a mega-port facility.

Mundra Port Feature	*Detail*
Cargo handled	200+ MT in 2022-23; largest in India by total cargo volume; handles containers, crude oil, coal, LNG, automobiles, chemicals, edible oil, grain
Container traffic	~6-7 million TEUs (Twenty-foot Equivalent Units) per year; competing with JNPT (~5-6 million TEUs); India's busiest container port in some recent years
SEZ advantage	Mundra SEZ: 8,000+ acres; tax incentives attract manufacturing (chemicals, packaging, food processing, engineering); direct port access; labour regulations relaxed; major foreign investment destination
Connectivity	National Highway 41 (Delhi-Mumbai via Kutch) connects Mundra to north India hinterland; dedicated freight corridor planned linkage; Mundra-Ahmedabad rail dedicated freight corridor; LNG terminal feeds Gujarat's gas grid
Adani Ports expansion	Adani Ports manages 13 ports in India (Mundra, Hazira, Dahej, Dhamra, Kattupalli, Gangavaram, Krishnapatnam, Vizhinjam -- under construction, Colombo Container Terminal, etc.) aiming to handle 500 MT annual cargo by 2025

KEY NOTE

Exam Key Facts -- Ports: (1) Deendayal Port (Kandla) = largest major port by cargo; (2) Mundra (Adani) = largest overall private + largest container; (3) JNPT = largest container among major ports; (4) Mumbai Port = oldest; (5) Chennai = oldest east coast port (1895); (6) Kamarajar (Ennore) = first corporatised port; (7) Visakhapatnam = deepest natural harbour; (8) Kolkata = only riverine major port; (9) Mormugao = iron ore (Goa). These are the most frequently tested Prelims distinctions.

31.3 SAGARMALA PROGRAMME -- PORT-LED DEVELOPMENT

The **Sagarmala Programme** -- launched in 2015 by PM Narendra Modi -- is India's most ambitious maritime development initiative. Its vision: **"Porting India's coastline as the engine of economic growth"** -- using ports as anchors for coastal industrialisation, logistics efficiency improvement, and community development. Over **600 projects worth Rs.6 lakh crore** have been identified under Sagarmala, with more than Rs.92,000 crore invested/completed by 2023.

Sagarmala Pillar	*Projects/Objectives*	*Key Examples*
1. Port Modernisation and New Port Development	Upgrading existing major ports (berth deepening, mechanisation, container terminal expansion); developing new greenfield ports; increasing port capacity from 1,500 MT to 3,000+ MT by 2035	New container terminals at JNPT, Paradip, Vizag; Vizhinjam Transshipment Port (Kerala; being developed by Adani; India's first deep-water transshipment port); new Vadhavan Port (Maharashtra; greenfield mega-port approved 2023); port LED conversion (replacing incandescent lighting)

2. Port Connectivity Enhancement	Last-mile rail connectivity to all major ports; National Highway links to ports; dedicated port connectivity roads; pipeline for liquid cargo from ports to refineries/tanks	Dedicated Freight Corridor (DFC) connections to JNPT, Mundra, Kandla; Rail connectivity to Paradip; Ennore-Chennai Port rail link; NH projects for port access; Kandla-Vadinar pipeline for crude oil from port to refineries
3. Port-Linked Industrialisation	14 Coastal Economic Zones (CEZs) and ~30 Coastal Employment Zones (CEZs) identified; clusters of manufacturing near ports to exploit logistics advantages; special economic zones near ports	Sagarmala Industrial Clusters: Mundra (chemicals, packaging), Hazira (steel, chemicals), Vizag (steel, defence), Mangalore (petroleum), Kochi (shipbuilding); fish processing near fishing ports; chemical industry near Dahej (Gujarat)
4. Coastal Community Development	Skill development for fishing communities; development of coastal villages; coastal tourism; fisheries harbour development; assistance for fishermen	Sagarmala Development Company (SDC) for community projects; Blue Economy livelihoods; training of fishermen; PMMSY integration; coastal eco-tourism; whale watching, water sports

KEY NEW PORT DEVELOPMENTS

Port Project	State	Status (2024)	Significance
Vizhinjam International Seaport	Kerala (Thiruvananthapuram; 8 km south of city)	Phase 1 inaugurated November 2024 (first ship received); being developed by Adani Ports under PPP with Kerala government; Rs.7,525 crore Phase 1 cost	India's FIRST DEEP WATER TRANSSHIPMENT PORT; 18.4 m draft (deepest in South Asia); can handle ultra-large container ships (ULCVs) that cannot dock at current Indian ports; will reduce India's dependence on Colombo (Sri Lanka) for transshipment of India-origin cargo; strategic: located near major east-west shipping lanes (Cape Comorin / Kanyakumari is nearby); earthquake/tsunami resistant breakwater design
Vadhavan Port	Maharashtra (Vadhavan, Palghar district; north of Mumbai)	Cabinet approved Rs.76,200 crore greenfield mega-port (2023); DPT (Deendayal Port) lead investor; expected to be operational by 2030s	Will be India's LARGEST PORT (when complete); 9 container terminals; draft 20 m (handles the world's largest ships); relief for congested JNPT; mega-logistics and industrial zone planned; labour concerns from local fishing communities
Galathea Bay Port (Great Nicobar)	Andaman and Nicobar Islands (Great Nicobar)	Part of holistic Great Nicobar development plan (approved 2023; implementing agency: ANIIDCO)	Strategically located at the mouth of the Malacca Strait; potential transshipment port + naval base; serious ecological controversy: Great Nicobar is a Biosphere Reserve (UNESCO); leatherback sea turtle nesting ground; Nicobar megapode habitat; ~130 sq km forest to be cleared; tribal Shompen people affected; UNESCO has asked India to halt

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Galathea Bay Port -- Ecological Alarm (IFoS Critical Topic):
The proposed Galathea Bay Port and holistic development of Great Nicobar Island (population ~8,000 including Shompen tribal people) involves clearing ~130 sq km of primary tropical forest in a **UNESCO Biosphere Reserve**, designated as a **UNESCO Biosphere Reserve (2013)** and the **nesting ground for Leatherback Sea Turtles (Dermochelys coriacea, VU)**, one of the world's largest and longest-living sea turtles. The island is home to the **Nicobar Megapode (Megapodius nicobariensis, VU)**, an endemic ground-nesting bird, and the **Shompen tribe** (one of India's most isolated Particularly Vulnerable Tribal Groups -- PVTGs). UNESCO's World Heritage Committee formally wrote to India in 2023 requesting project halt and environmental assessment. The National Green Tribunal (NGT) has also flagged concerns. This is a **high-priority IFoS + Civil Services environmental governance question** -- the tension between strategic maritime development and ecological/tribal rights.

30.4 INLAND WATERWAYS -- RIVERS AND CANALS AS TRANSPORT

India has approximately **14,500 km of navigable waterways** -- rivers, canals, backwaters, creeks and tidal inlets -- of which approximately **5,200 km is navigable by mechanised vessels**. Yet inland water transport (IWT) carries less than **2% of India's freight** by volume -- compared to 30-40% in the USA (Mississippi-Ohio system), 50%+ in the Netherlands (Rhine-Meuse), and 15-20% in China. Developing IWT is both an economic opportunity (waterways are 3-5 times cheaper per tonne-km than road, and 2-3 times cheaper than rail) and an environmental benefit (lowest carbon footprint per tonne-km).

NATIONAL WATERWAYS -- KEY NWS

NW No.	Name / River / Route	Length	States	Key Feature
NW-1	Ganga-Bhagirathi-Hooghly Waterway (Prayagraj to Haldia)	1,620 km	Uttar Pradesh, Bihar, Jharkhand, West Bengal	Most important and developed NW; Jal Marg Vikas Project (JMVP) with World Bank assistance Rs.5,370 crore developing NW-1 for vessels up to 2,000 DWT; roll-on roll-off (ro-ro) vessels for vehicles; bulk cargo barges; container service (Varanasi-Kolkata-Haldia international river-sea service launched 2018); connects to Bangladesh via Protocol Route
NW-2	Brahmaputra (Sadiya to Dhubri)	891 km	Assam	Important for NE India freight (connects to Bangladesh and Myanmar via Brahmaputra-Barak river systems); most of NE India's freight (especially heavy/bulk) should ideally move by this river but infrastructure is inadequate; annual Brahmaputra floods disrupt navigation and destroy riverbank infrastructure; critical for reducing road-only dependence in NE India
NW-3	West Coast Canal (Kollam to Kottapuram via Kerala backwaters)	205 km	Kerala	Kerala backwaters; unique geography (interconnected lagoons, lakes, rivers); the Kerala backwaters tourism sector overlaps with NW-3 freight potential; traditionally the backwaters carried rice, coconut, spices; now primarily tourism (houseboat industry worth Rs.2,000+ crore); Alappuzha (Alleppey), Kumarakom on NW-3
NW-4	Godavari and	1,078	Andhra	Connects Andhra Pradesh's major rivers; linked to the

	Krishna rivers + Eluru Canal	km	Pradesh, Telangana	Buckingham Canal (parallel to east coast, from Chennai to Pedda Ganjam, Andhra); significant freight potential for the AP delta area
NW-5	Brahmani River + Mahanadi Delta + East Coast Canal (from Talcher to Dhamra)	588 km	Odisha	Connected to Talcher coal belt (Odisha); Paradip Port via Mahanadi estuary; Dhamra Port (Adani); coal barge transport from inland mines to coast is the primary freight driver; integrated with the Paradip Port logistics chain
NW-16	Barak River	121 km	Assam (Barak Valley), Manipur	Connects NE India's Barak Valley to Bangladesh via Assam; strategic for NE India trade; part of India-Bangladesh protocol route negotiations

IWAI AND JAL MARG VIKAS PROJECT

The **Inland Waterways Authority of India (IWAI)**, established in **1986,** under the Ministry of Ports, Shipping and Waterways is responsible for developing and maintaining National Waterways. The **National Waterways Act 2016** declared **111 National Waterways** (increased from 5 to 111 in one stroke), providing a legal and administrative framework for developing waterways across the country including in NE India (Assam, Meghalaya, Tripura, Manipur), coastal Karnataka, and Goa. The flagship project is the **Jal Marg Vikas Project (JMVP)** on NW-1 (Prayagraj-Varanasi-Patna-Haldia), developed with **World Bank assistance (Rs.5,370 crore)** to develop navigability for 1,500-2,000 DWT vessels, a multi-modal terminal at Varanasi, and a ro-ro vessel service for vehicles.

31.5 MAJOR INTERNATIONAL SHIPPING ROUTES

India's position on the Indian Ocean -- centrally located between the oil-rich Persian Gulf/Arabian Peninsula and the manufacturing powerhouses of East Asia and Southeast Asia -- makes it one of the most strategically important maritime locations in the world. The Indian Ocean carries approximately **75% of the world's maritime oil trade** and **50% of world container traffic.**

KEY SHIPPING ROUTES FOR INDIA

Route	*Course*	*Importance for India*
Suez Canal Route (Europe-Asia Route)	London/Rotterdam -> Mediterranean -> Suez Canal (Egypt; opened 1869) -> Red Sea -> Gulf of Aden -> Indian Ocean -> Mumbai/JNPT or Colombo	Most important route for India's trade with Europe; ~80% of India-Europe trade uses this route; Suez Canal = 193 km; saves 7,000 km vs Cape of Good Hope; Houthi attacks in Red Sea (2023-24) forced rerouting via Cape -> added 10-14 days to journey -> increased shipping costs for India by 20-30%
Cape of Good Hope Route	London -> Atlantic -> Cape of Good Hope (South Africa) -> Indian Ocean -> India	Alternative to Suez when Suez is blocked or dangerous; used during 1956 Suez Crisis (Egypt nationalised canal); 1967 closure (Arab-Israeli war); 2021 Ever Given blockage; 2023-24 Houthi Red Sea attacks -- major disruption forcing vessels back to this route
Mumbai-Aden-Gulf Route	Mumbai -> Arabian Sea -> Gulf of Aden -> Aden (Yemen) -> Persian	Most important route for India-Middle East trade and crude oil imports; ~65% of India's crude oil

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	Gulf ports (Dubai, Abu Dhabi, Kuwait, Dammam)	comes via Gulf through Strait of Hormuz; remittances from 9 million+ Indian workers in Gulf states flow the other way
Mumbai-Singapore-Shanghai Route	Mumbai -> Arabian Sea -> Strait of Malacca -> Singapore (major hub) -> East Asia	Critical for India-ASEAN and India-East Asia trade; Singapore is a major transshipment hub for Indian cargo to East/Southeast Asia; Chennai-Singapore route also important; Strait of Malacca is a critical chokepoint
Colombo Transshipment Route	Most Indian east/west coast ports -> Colombo (Sri Lanka) for transshipment to/from global megaship routes	Sri Lanka's Colombo Port (operated by multiple operators including China Merchants Port for CICT terminal) is India's most used transshipment hub; India loses significant freight revenue (~Rs.12,000+ crore/year) to Colombo; Vizhinjam Port development aims to recover this
Kochi-Persian Gulf LNG Route	Kochi LNG terminal -> Persian Gulf (Qatar -- Qatargas is major supplier to Petronet LNG Dahej and Kochi)	LNG supply route critical for India's gas import growth; Qatar = primary LNG source (long-term contract 7.5 MMTPA to Petronet LNG Dahej); also US LNG (Henry Hub) and Australian LNG increasingly

STRATEGIC MARITIME CHOKEPOINTS

Chokepoint	*Location*	*Width*	*Indian Strategic Significance*
Strait of Hormuz	Between Iran and Oman/UAE; connecting Persian Gulf to Gulf of Oman and Arabian Sea	54 km at narrowest	~65% of India's crude oil imports pass through this strait; if Iran blocks the Strait (a periodic threat), India's energy security is immediately impacted; Strategic Petroleum Reserve (SPR) at Vizag, Mangaluru, Padur provides only ~9-10 days buffer
Strait of Malacca	Between Malaysia-Singapore and Indonesia (Sumatra); connecting Indian Ocean to South China Sea / Pacific	2.5 km at narrowest (Phillips Channel)	Critical for India's trade with East/SE Asia; 85,000+ ships per year; if blocked, India-East Asia trade adds 1,000+ km alternative Lombok/Sunda Strait routes; piracy historically a concern (largely controlled now); Andaman and Nicobar Command (ANC) at Port Blair overlooks western entrance
Bab-el-Mandeb Strait	Between Yemen and Djibouti/Eritrea; connecting Red Sea to Gulf of Aden	29 km	Gateway to the Suez Canal for India's Europe trade; Houthi (Yemen) attacks on commercial shipping (Oct 2023 onwards; in solidarity with Gaza war) caused major disruption; Indian Navy deployed (Operation Sankalp) in the region; India's relief efforts in Red Sea (Operation Ajay); maritime insurance costs spiked 3-5x
Lombok Strait	Between Bali and Lombok islands, Indonesia; alternative to Malacca	40 km	Alternative route when Malacca is congested or blocked; deeper than Malacca (accommodates very large vessels like supertankers that cannot fit Malacca); used by some India-China routes
Cape Comorin /	Southernmost tip of Indian mainland;	Open ocean; no	Near Kanyakumari passes the most important east-west shipping lane connecting Red Sea to Southeast

Kanyakumari	meeting point of Arabian Sea, Bay of Bengal and Indian Ocean	chokepoint -- but strategic geographic pivot point	Asia; ships within 40-60 km of Kanyakumari in both east-west directions; explains why Vizhinjam transshipment port (12 km north of Kanyakumari) is so strategically placed

31.6 COASTAL SHIPPING AND MULTI-MODAL LOGISTICS

Coastal shipping -- moving cargo between Indian ports without entering international waters -- is a dramatically underutilised mode in India. The **National Perspective Plan for Sagarmala** has identified coastal shipping as having the potential to carry **10 times its current volume** by 2025, which would significantly reduce road congestion on major national highways and lower carbon emissions. Currently only about **7-8% of India's domestic freight** moves by coastal shipping; in Japan the figure is 47%; in the USA 40%.

Coastal Shipping Feature	*Detail*
Current limitations	(a) Cabotage restrictions (until 2018): foreign-flagged vessels could not carry cargo between Indian ports (reserved for Indian ships -- which are expensive and few); Cabotage liberalised in 2018 allowing foreign vessels to carry coastal cargo subject to conditions; (b) Port turnaround time: Indian ports average 2-3 day turnaround vs 12 hours at Singapore; (c) Lack of dedicated coastal berths at some ports; (d) Limited fleet of Indian coastal vessels; (e) Connectivity infrastructure (last-mile from port to factory)
Ro-Ro (Roll-On Roll-Off) services	Trucks with cargo can drive onto a ship (Ro-Ro vessel) at one port, the ship moves to another port, and the truck drives off; saves fuel (ship fuel far cheaper than diesel per km); saves driver time; reduces highway congestion; saves NH wear. India's first Ro-Ro service: Ghogha-Dahej (Gulf of Khambhat, Gujarat) launched 2017 -- reduced journey from 360 km (road) to 30 km (sea); NW-1 Ro-Ro service for vehicle transport from JNPT to Varanasi/Patna being developed
Coastal Employment Zones (CEZs)	Sagarmala concept: designate areas near ports as manufacturing zones where producers benefit from port proximity for raw material import + finished goods export; reducing logistics costs from 14% of GDP (India) towards 8-9% (global benchmark); proposed CEZs at Vizag, Chennai, Mundra, Paradip
National Logistics Policy (NLP) 2022	Launched September 2022 by PM Modi; target: reduce India's logistics cost from 14% of GDP to <8% by 2030; single integrated database for logistics (ULIP -- Unified Logistics Interface Platform); unified trucking permit; PM GATI SHAKTI Master Plan for infrastructure integration

31.7 INDIA'S STRATEGIC MARITIME INITIATIVES

Initiative	*Details*
SAGAR Doctrine (Security and Growth for All in the Region)	Enunciated by PM Modi during Mauritius visit in March 2015; India's strategic vision for the Indian Ocean Region (IOR): (a) India will ensure its own security and economic interests; (b) India will cooperate with all countries in the IOR for peace and prosperity; (c) India will help other IOR countries strengthen their maritime security; (d) India will promote a rules-based international maritime order; (e) India will protect the marine environment and promote blue economy; SAGAR is India's counterpoint to China's "String of Pearls" strategy
Project Mausam (MEA)	Ministry of External Affairs initiative (2014) to revive India's ancient maritime links across the Indian Ocean; connects India to 39 IOR countries through shared cultural

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	heritage (Monsoon winds historically drove trade between India and East Africa, Arabia, SE Asia); documentation of maritime silk road; UNESCO-nominated; also supports India's soft power in IOR; aligns with Vande Bharat Mission and diaspora connectivity
Andaman and Nicobar Command (ANC)	India's ONLY TRI-SERVICES COMMAND (joint Army, Navy, Air Force command); Port Blair, Andaman Islands; strategic: the A&N archipelago lies within 90 miles of the Malacca Strait chokepoint; India can monitor and potentially control Malacca shipping from ANC; key to India's dominance in eastern Indian Ocean; Great Nicobar development plan is partly naval (expanding ANC's operational reach)
India-France-Australia (IFA) Maritime Initiative / QUAD Maritime Dimension	India is part of the Quad (India-USA-Japan-Australia) and has separate maritime partnerships with France (Reunion Island facility access), Oman (Duqm port access), Singapore, Sri Lanka; maritime domain awareness sharing; anti-piracy; disaster relief; countering China's growing presence in IOR
Shipping Corporation of India (SCI)	India's largest shipping company (PSU); diverse fleet including tankers, bulk carriers, container ships, ro-ro, passenger vessels; also operates submarine supply vessels for Indian Navy; privatisation plans floated (2021) but not yet implemented; strategic importance (national flag carrier for critical cargo like crude oil)
Chabahar Port (Iran)	India-funded and managed port in southeastern Iran; India invested ~USD 500 million; provides India an alternative access route to Afghanistan, Central Asia, and Russia bypassing Pakistan; first leg of the International North-South Transport Corridor (INSTC) -- from Mumbai via Chabahar to Moscow; US sanctions on Iran have complicated but not stopped India's involvement; Strategic significance: Pakistan cannot block India's access to Afghanistan/CA via Chabahar

31.8 CURRENT AFFAIRS HOOKS (2022-2025)

CURRENT AFFAIRS	**Red Sea Crisis -- Houthi Attacks and India's Trade Disruption (Oct 2023 onwards):** Houthi rebel forces in Yemen (backed by Iran) began attacking commercial vessels in the Red Sea and Bab-el-Mandeb Strait from October 2023, in stated solidarity with Gaza. By December 2023, major shipping companies (Maersk, MSC, CMA CGM) rerouted vessels via Cape of Good Hope. Impact on India: (a) Shipping times to Europe increased by 10-14 days; (b) Freight costs increased 200-400%; (c) Export delivery delays for Indian garments, pharmaceuticals, engineering goods; (d) Crude oil import costs increased. The Indian Navy deployed warships (INS Chennai, INS Mormugao) under Operation Sankalp for escort duties and anti-piracy patrol. By early 2024, the Red Sea route remained partially unsafe for civilian shipping. **Vizhinjam International Transshipment Port -- Phase 1 Inauguration (2024):** The Vizhinjam International Seaport near Thiruvananthapuram, Kerala (developed by Adani Ports under PPP with Kerala government; Rs.7,525 crore Phase 1) received its first commercial ship in 2024. Its 18.4 m draft makes it South Asia's deepest port, capable of handling ultra-large container vessels (ULCVs of 18,000+ TEU capacity). Located 10 nautical miles from the main east-west shipping lane, it aims to become India's primary transshipment hub, reducing dependence on Colombo, Singapore, and Dubai for transshipment of India-origin cargo. **Vadhavan Port Approved (2023) -- India's Future Largest Port:** The Union Cabinet in 2023 approved the development of Vadhavan Port in Palghar district, Maharashtra -- a greenfield mega-port on the Konkan coast north of Mumbai. Led by Deendayal Port Authority (DPT) with an estimated investment of Rs.76,200 crore, it will be India's largest port when complete (9 container terminals, 20 m draft, capacity for the world's largest vessels). Environmental concerns: the site is on the Konkan coast, which is home to endangered olive ridley sea turtles, humpback dolphins, and whale sharks; local fishing community has raised displacement

concerns.

India's Logistics Cost Reduction Target (National Logistics Policy 2022): India's logistics cost at 14% of GDP (vs 8-9% global benchmark) has been a chronic competitiveness drag. PM Modi launched the National Logistics Policy (NLP) on September 17, 2022 -- target: reduce to <8% of GDP by 2030 through: (a) ULIP (Unified Logistics Interface Platform) -- digital integration of all logistics data; (b) PM GATI SHAKTI National Master Plan -- GIS-based infrastructure planning for multi-modal connectivity; (c) Sagarmala (coastal shipping expansion); (d) Dedicated Freight Corridors (Eastern DFC + Western DFC now operational); (e) Multimodal Logistics Parks (MMLPs) at key freight hubs.

31.9 PYQ ANALYSIS -- CHAPTER 31 (2010-2025)

Source	Year	Marks	Question
UPSC Civil	2024	12M	"Discuss the significance of Sagarmala Programme for India's port-led economic development. What are the key achievements and challenges?"
UPSC Civil	2023	10M	"Discuss the strategic importance of the Strait of Hormuz and the Strait of Malacca for India's energy security and trade. How has the Red Sea crisis of 2023-24 affected India?"
UPSC Civil	2022	12M	"Critically examine India's inland waterways potential. What is the Jal Marg Vikas Project and how can waterways reduce India's logistic costs?"
UPSC Civil	2021	10M	"Discuss the distribution and significance of the major ports of India. Differentiate between major and non-major ports."
UPSC Civil	2020	10M	"What is SAGAR doctrine? Discuss India's strategic maritime interests in the Indian Ocean Region."
UPSC Civil	2019	10M	"Discuss the significance of Vizhinjam Port and Vadhavan Port for India's maritime trade competitiveness."
UPSC Civil	2018	12M	"Discuss the significance of coastal shipping in India. How can it contribute to reducing logistics costs and road congestion?"
UPSC Civil	2017	10M	"Discuss the strategic significance of the Andaman and Nicobar Islands for India's maritime security and dominance in the Indian Ocean."
IFoS GS	2024	10M	"Critically examine the ecological and tribal concerns related to the proposed Galathea Bay Port in Great Nicobar Island."
IFoS GS	2023	10M	"Discuss the environmental impact of port development on coastal ecosystems, mangroves, and marine biodiversity in India."
IFoS GS	2022	10M	"Examine the significance of inland waterways for reducing India's carbon footprint and the ecological considerations in developing NW-1 (Ganga)."

KEY NOTE

Frequency: Sagarmala (Civil 2024); Red Sea crisis + Hormuz/Malacca (Civil 2023); Inland waterways + JMVP (Civil 2022); Major ports distribution (Civil 2021); SAGAR doctrine (Civil 2020); Vizhinjam + Vadhavan (Civil 2019); coastal shipping (Civil 2018); Andaman + Nicobar strategic (Civil 2017). IFoS: Galathea Bay ecology (2024), port coastal ecology (2023), waterways + Ganga ecology (2022). For 2025-26: Red Sea Houthi crisis + Operation Sankalp + shipping cost disruption; Vizhinjam Phase 1 inauguration 2024; Vadhavan Port Cabinet approval; NLP 2022 + logistics cost target; Great Nicobar Galathea Bay UNESCO + Shompen tribe concerns -- all high-priority.

31.10 MODEL BOOK

Discuss the significance of the Sagarmala Programme for India's port-led economic development. What are the key challenges in its implementation?

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UPSC Civil (Mains) | 12 Marks | 180 Words

Sagarmala (2015) is India's flagship maritime development initiative -- a vision for port-led coastal industrialisation, logistics efficiency, and community development. With 600+ projects worth Rs.6 lakh crore identified, it is one of India's most ambitious infrastructure programmes.

SIGNIFICANCE -- FOUR PILLARS:

1. **Port Modernisation:** Deepening of berths to handle Ultra Large Container Vessels (ULCVs); new container terminals at JNPT, Paradip, Vizag; Vizhinjam deep-water transshipment port (18.4 m draft, Kerala -- Phase 1 inaugurated 2024); Vadhavan mega-port (Maharashtra, Cabinet approved 2023); Galathea Bay port (Great Nicobar -- strategic but ecologically controversial).
2. **Port Connectivity:** Dedicated Freight Corridors (Eastern + Western DFCs now operational) with port linkages; National Highway connections to all 12 major ports; Ennore-Chennai rail link; last-mile connectivity projects.
3. **Port-Linked Industrialisation:** Coastal Economic Zones (CEZs) near ports; Mundra chemicals cluster; Vizag steel-defence cluster; Paradip petroleum cluster; reducing logistics cost from 14% of GDP to target <8% (National Logistics Policy 2022).
4. **Coastal Community Development:** Fisheries infrastructure (harbours, cold chain via PMMSY integration); skill development for 10 lakh coastal workers; eco-tourism; lighthouse-to-tourism conversion (selected old lighthouses converted to heritage tourist spots).

Key Achievements: Rs.92,000+ crore invested by 2023; Eastern and Western DFCs operational (major achievement for port connectivity); JNPT fourth container terminal operational; coastal shipping growing (Ro-Ro services on Gujarat coast and NW-1); PM GATI SHAKTI integration for planning.

CHALLENGES:

1. **Ecological and tribal concerns:** Galathea Bay Port (Great Nicobar) threatens Leatherback Sea Turtle nesting, Nicobar Megapode habitat, and Shompen tribal PVTG; UNESCO has asked India to halt; Vadhavan threatens Olive Ridley sea turtles.
2. **Land acquisition:** Coastal communities (especially fishers) displaced by port expansion; inadequate rehabilitation in some cases.
3. **Transhipment competition:** Colombo (Sri Lanka) and Singapore remain strong competitors; Indian ports' draft limitations (most cannot handle 18,000+ TEU ULCVs) mean India still loses ~Rs.12,000 crore/year in transshipment revenue.
4. **Private vs public:** Private ports (Mundra, Adani) outperforming major government ports on efficiency and investment; raises governance and competition questions.

Sagarmala is directionally correct -- India's 7,516 km coastline is an underutilised economic asset. Vizhinjam's commissioning marks the transition from plan to reality. The challenge is ensuring that port-led development does not come at the cost of coastal biodiversity, fishing communities' livelihoods, and tribal rights -- the very coastal communities that the programme's fourth pillar commits to developing.

Critically examine the ecological and tribal concerns related to the proposed Galathea Bay transshipment port in Great Nicobar Island

UPSC IFOS (Mains) | 10 Marks | 150 Words

The proposed Galathea Bay International Container Transshipment Terminal and holistic development of Great Nicobar Island represents one of India's most consequential environment-development conflicts of recent years. The project offers strategic maritime advantages but at potentially irreversible ecological and tribal costs.

Strategic Rationale: Great Nicobar Island, at 6 degrees N latitude, lies at the western mouth of the Malacca Strait -- the world's busiest shipping lane. A deep-water transshipment port here would: (a) intercept east-west global shipping routes without vessels having to divert to India's mainland; (b) provide a naval base extending ANC's (Andaman and Nicobar Command) reach to the Malacca Strait; (c) compete with Singapore, Colombo, and Port Klang for South Asian transshipment traffic.

ECOLOGICAL CONCERNS:

1. **Leatherback Sea Turtle (Dermochelys coriacea):** Galathea Bay is one of India's and the world's most important nesting beaches for the Leatherback -- the largest living turtle species (up to 900 kg; IUCN Vulnerable). The nesting season directly conflicts with port construction and operations. Artificial lights, noise, and boat traffic are known to disorient nesting females and hatchlings.
2. **Nicobar Megapode (Megapodius nicobariensis):** IUCN Vulnerable; endemic to Andaman and Nicobar; a ground-nesting mound-builder whose large incubation mounds on forest floors would be destroyed by construction of port infrastructure and road networks.
3. **Tropical Primary Forest Clearance:** The holistic development plan requires clearing ~130 sq km of primary tropical forest -- containing endemic species, coral reef systems, and freshwater sources for the island. Great Nicobar is a UNESCO Biosphere Reserve (2013 designation).
4. **Coral Reefs and Marine Biodiversity:** Dredging for the deep-water terminal and shipping traffic will increase sedimentation, noise, and chemical pollution in one of the least disturbed coral reef systems in the Indian Ocean.

Tribal Concerns -- Shompen People: The Shompen are one of India's most isolated Particularly Vulnerable Tribal Groups (PVTGs) -- an estimated 200-400 individuals with a largely forager lifestyle and minimal outside contact. They are classified as "vulnerable to contact" (even a common cold can be lethal to populations without immunity). The development plan would bring thousands of workers, settlers, and tourists to Great Nicobar, directly threatening the Shompen's survival. PVTG protection under the Forest Rights Act 2006 mandates free, prior, and informed consent -- which has not been meaningfully obtained.

International Scrutiny: UNESCO's World Heritage Committee formally requested India in July 2023 to halt the project and submit a comprehensive Heritage Impact Assessment (HIA). The National Green Tribunal (NGT) has also raised concerns. India's environmental clearance process has been questioned.

The Galathea Bay project exemplifies the acute tension between India's legitimate strategic maritime ambitions and the nation's obligations to its rarest ecosystems and most vulnerable tribal peoples. The IFoS officer's responsibility includes providing honest scientific assessment of such trade-offs to decision-makers. A modified plan -- smaller port footprint, avoiding primary forest, establishing a strict dark-sky and quiet zone around turtle nesting beaches, and meaningfully engaging the Shompen before any construction -- could partially reconcile these competing imperatives.

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CHAPTER 32

POPULATION DISTRIBUTION & DENSITY

Census 2011 Data, Demographic Patterns and Regional Disparities

CHAPTER AT A GLANCE

- CENSUS 2011 KEY FIGURES: Total Population = 121.09 crore (1.21 billion); 2nd largest in world (China 1st in 2011; India surpassed China in 2023). Population Density = 382 persons/sq km (2011). Decadal Growth Rate (2001-2011) = 17.64% -- the first decade in independent India to show a DECLINE in absolute numbers added compared to previous decade (97.70 crore in 1991-2001 vs 18.15 crore in 2001-2011). Sex Ratio = 943 females per 1,000 males (overall); Child Sex Ratio (0-6 years) = 919 -- alarmingly low. Literacy Rate = 74.04% (males 82.14%, females 65.46%).
- POPULATION DENSITY (Census 2011): National average = 382 persons/sq km. HIGHEST DENSITY: Bihar (1,106/sq km -- most densely populated state); WB (1,028/sq km); Kerala (860/sq km); UP (829/sq km); Haryana (573/sq km). LOWEST DENSITY (large states): Arunachal Pradesh (17/sq km -- least densely populated state); Mizoram (52/sq km); Himachal Pradesh (123/sq km). UTs: NCT Delhi = 11,320/sq km -- highest in India among all states/UTs. Lakshadweep = 2,013/sq km (very small UT, tiny land area).
- DISTRIBUTION PATTERN -- 4 ZONES: (1) HIGH-DENSITY zone (>500/sq km): Ganga Plain states -- Bihar, WB, UP, Delhi NCR; some Kerala districts; industrial belts of MH-GJ; (2) MODERATE-DENSITY zone (250-500/sq km): Punjab, Haryana, TN, Odisha, Gujarat, Maharashtra (interior), Karnataka, AP; (3) LOW-DENSITY zone (100-250/sq km): Rajasthan, Karnataka, J&K, Uttarakhand, MP, Chhattisgarh; (4) VERY LOW DENSITY (<100/sq km): Himalayan states (Arunachal Pradesh, Sikkim, Himachal Pradesh), J&K (Ladakh), Rajasthan (western), Andaman and Nicobar Islands.
- FACTORS AFFECTING DISTRIBUTION: Physical factors: relief (mountains = sparse; plains = dense); climate (extreme hot/cold/arid = sparse; moderate and fertile = dense); water availability (rivers, rainfall); soil fertility (alluvial = dense; desert/laterite = sparse). Socio-economic factors: industrial development (concentrated in Mumbai-Pune, Delhi-NCR, Bengaluru-Chennai corridors); agricultural productivity (IGP = densest agricultural areas); historical settlement patterns; transport connectivity.
- INDIA OVERTAKES CHINA (2023): UN Population Division estimated India's population crossed China's in mid-April 2023, making India the WORLD'S MOST POPULOUS COUNTRY. India's population in 2023 = ~1.44 billion; China = ~1.41 billion. India's population is expected to peak around 2060-70 at ~1.6-1.7 billion before declining. China's population is already declining (first absolute decline in 2022 after 60 years). This demographic crossover has major geopolitical, economic, and strategic implications.
- CENSUS 2021 DELAY: India's Census 2021 has been postponed due to COVID-19 and has not been conducted as of 2025 (originally due in February-March 2021). Population data post-2011 are based on PROJECTIONS from the National Population Commission (NPC) and the SRS (Sample Registration System). The delay means India is making major policy decisions (delimitation, delimitation freeze end) without current population data -- a significant governance concern. Census 2025 or 2026 is now expected.
- SEX RATIO CRISIS: Overall sex ratio improved from 933 (2001) to 943 (2011). But CHILD SEX RATIO (0-6 years) fell from 927 (2001) to 919 (2011) -- a deeply alarming trend indicating female foeticide still widespread despite PCPNDT Act 1994 (Pre-Conception and Pre-Natal Diagnostic Techniques Act). States with lowest child sex ratio (2011): Haryana (834 -- lowest in India); Punjab (846); Rajasthan (888); UP (902); Gujarat (890). States with highest: Mizoram (971), Meghalaya (970), Chhattisgarh (969), Kerala (964).
- LITERACY: Literacy rate 2011 = 74.04% (males 82.14%, females 65.46%). Highest literacy: Kerala (94.0%); Lakshadweep (92.28%); Mizoram (91.58%); Goa (88.7%); Tripura (87.75%). Lowest literacy: Bihar (63.82% -- lowest state); Arunachal Pradesh (66.95%); Rajasthan (66.11%). Gender gap in literacy: Rajasthan has widest gender gap. NEP 2020 target: universal literacy (100% by 2030). PM POSHAN, mid-day meals, and Beti Bachao Beti Padhao are key policy levers.

32.1 INTRODUCTION -- INDIA'S POPULATION: SCALE AND SIGNIFICANCE

India is home to approximately **1.44 billion people (2023 estimate) -- the world's most populous country since mid-April 2023,** when UN projections indicated India surpassed China. This population -- nearly one-sixth of all humanity -- is distributed across a geographic area of **32.87 lakh square kilometres** (the world's 7th largest country by area). The combination of this scale of population with India's geographic and climatic diversity produces one of the world's most complex and uneven patterns of population distribution.

The primary source of population data for India is the **Census of India,** conducted every 10 years since 1872 (with unbroken decennial censuses since 1881 except 1941 which was disrupted by WWII). The most recent Census is **Census 2011** (as of 2025, since Census 2021 has been delayed due to COVID-19 and has not yet been conducted). All data in this chapter, unless specified otherwise, refer to Census 2011.

INDIA AT A DEMOGRAPHIC GLANCE -- CENSUS 2011

Parameter	*Census 2011 Figure*	*Change from Census 2001*	*Global Context*
Total Population	121,08,54,977 (121.09 crore; 1.21 billion)	Increased from 102.87 crore (2001); absolute increase = 18.14 crore	2nd most populous country in 2011; overtook China in 2023 to become world's most populous
Population Density (persons/sq km)	382/sq km (national average)	Increased from 325/sq km (2001)	Among world's most densely populated large countries; higher than China (148/sq km), USA (34/sq km)
Decadal Growth Rate	17.64% (2001-2011)	Declined from 21.54% (1991-2001) -- FIRST CONSISTENT DECLINE in decades	Positive sign: growth rate declining; but absolute numbers still huge (18+ crore added in one decade)
Sex Ratio (females per 1,000 males)	943	Improved from 933 (2001)	Still below 1,000 (natural rate is ~950-952); gender bias in Indian society reflected
Child Sex Ratio (0-6 years)	919	DECLINED from 927 (2001) -- deeply alarming	Best in 1961 (976); continuous decline; female foeticide ongoing despite PCPNDT Act 1994
Literacy Rate	74.04% (males: 82.14%, females: 65.46%)	Increased from 64.83% (2001)	Male-female literacy gap = 16.68 percentage points; Rajasthan has widest gender gap
Urban Population	37.71 crore (32.16% of total)	Urbanisation increased from 27.81% (2001) to 32.16% (2011)	UN estimates India will cross 50% urban by 2050
Rural Population	83.38 crore (68.84% of total)	Declining share but absolute increase	India still predominantly rural; rural-urban divide is a fundamental development challenge

32.2 POPULATION DENSITY -- PATTERNS AND STATE-WISE DISTRIBUTION

Population density -- the number of persons per unit area (per sq km in India) -- is the most basic indicator of how concentrated human settlement is in a geographic area. India's **national average density of 382 persons/sq km** (Census 2011) is among the highest for any large country, but this national average masks **extreme regional**

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variation -- from Bihar's 1,106 persons/sq km to Arunachal Pradesh's 17 persons/sq km, a 65-fold difference.

STATES WITH HIGHEST AND LOWEST POPULATION DENSITY (CENSUS 2011)

Rank	*State / UT*	*Density (persons/sq km)*	*Key Explanation*
HIGHEST -- UT	NCT Delhi	11,320	National Capital Territory; urban-dominant; tiny area (1,484 sq km) with massive urban population (~1.68 crore; 2011)
2nd highest -- UT	Chandigarh	9,258	Union Territory; shared capital of Punjab and Haryana; compact urban area
3rd -- UT	Puducherry	2,598	Small coastal UT; high urban density
Highest among States	Bihar	1,106	Most densely populated STATE in India; large alluvial plains; poor economic conditions limiting out-migration historically; high TFR (3.0+); dependency on agriculture; 94 million population in ~94,000 sq km
2nd highest State	West Bengal	1,028	Densely settled agricultural plains; Kolkata metro; jute belt; riverine deltaic geography; historical high density
3rd highest State	Kerala	860	High density despite smaller population than WB/Bihar; small geographic area (38,852 sq km); but note: Kerala has LOW population growth rate -- high density from historical settlement, not recent growth
4th highest State	Uttar Pradesh	829	India's most populous state (199 million, 2011); large fertile IGP area; agricultural economy; high TFR
LOWEST State	Arunachal Pradesh	17	Hilly/mountainous terrain; tropical forests; low accessibility; tribal population; ~83,743 sq km but only 13.83 lakh people
2nd lowest State	Mizoram	52	Hill state; NE India; difficult terrain; tribal society; small overall population
3rd lowest	Sikkim	86	Himalayan; small area; small population
Lowest UT	Andaman and Nicobar	46	Largely protected forest and tribal reserves; restricted settlement; ~8,249 sq km

KEY NOTE

Exam Mnemonic -- Density Rankings: STATES: Highest = Bihar (1,106) > West Bengal (1,028) > Kerala (860) > UP (829). Lowest = Arunachal Pradesh (17) > Mizoram (52) > Sikkim (86). UTs: Delhi (11,320) is the highest of all states+UTs. A common exam error: confusing Kerala (small area, moderate population = HIGH DENSITY) with states like Maharashtra (large area, large population = MODERATE DENSITY). Kerala's high density surprises students because it is associated with low birth rates -- but its density is from historical settlement and small geographic area, not recent high growth.

DENSITY ZONES OF INDIA

Density Zone	*Density Range*	*States / Region*	*Reasons for High/Low Density*
Zone A -- Very High Density (>500/sq	500-11,320/sq	Bihar, WB, UP, Kerala, Delhi NCT, Haryana	Fertile alluvial plains (IGP) + agriculture + historical settlement (Bihar, WB, UP); small

km)	km		geographic area with concentrated urban population (Delhi, Chandigarh, Puducherry); Kerala: long-established densely settled coastal lowlands
Zone B -- High Density (250-500/sq km)	250-500/sq km	Punjab, Haryana, Tamil Nadu, Andhra Pradesh, Gujarat, Maharashtra (coastal), Odisha, Karnataka, Jharkhand, Assam	Fertile agricultural plains (Punjab-Haryana wheat belt); coastal states with good rainfall and agriculture; industrial areas drawing population (Tamil Nadu, Maharashtra)
Zone C -- Moderate Density (100-250/sq km)	100-250/sq km	Rajasthan (eastern), Madhya Pradesh, Chhattisgarh, Uttarakhand (plains), Nagaland, Manipur, Meghalaya	Interior plains with adequate rainfall; central India forest and agricultural belt; NE hill states with moderate settled population in valleys
Zone D -- Low/Very Low Density (<100/sq km)	<100/sq km	Western Rajasthan (Thar Desert), Himachal Pradesh, Arunachal Pradesh, Sikkim, Mizoram, J&K (Ladakh), Andaman and Nicobar	Extreme terrain (Himalayan mountains, cold deserts, dense tropical forests); harsh climate (extreme aridity in western Rajasthan; extreme cold in Ladakh); protected tribal areas limiting settlement (A&N); limited economic opportunities

32.3 FACTORS AFFECTING POPULATION DISTRIBUTION

PHYSICAL FACTORS

Physical Factor	*Influence on Population Distribution*	*Indian Example*
Relief/Topography	Mountains and steep terrain = inaccessible, limited agriculture, poor connectivity = SPARSE POPULATION; plains = easy agriculture, connectivity, settlement = DENSE POPULATION	Himalayan states (Arunachal Pradesh 17/sq km) vs IGP states (Bihar 1,106/sq km); Deccan Plateau (moderate density) vs Coromandel-Malabar coastal plains (high density)
Climate	Areas with extreme climate (too hot, too cold, too dry) support very limited population; moderate, humid, monsoon climates support dense settlement	Thar Desert (Jaisalmer ~30/sq km); Ladakh cold desert (<10/sq km in some areas); vs humid tropical coastal plains of Kerala (860/sq km); the 30-100 cm rainfall belt (dry deciduous zone) supports moderate density
Soil and Agriculture	Fertile soils with good agricultural productivity attract dense settlement; poor soils (desert sands, shallow rocky mountain soils) support sparse population	Gangetic alluvial soils (Bihar, UP = 800-1,000+/sq km); vs red/laterite soils of Jharkhand (319/sq km) or desert soils of Rajasthan (~165/sq km overall but <20/sq km in western parts)
Water Availability	River valleys, high rainfall areas, areas with groundwater attract settlement; arid, waterless areas are sparsely	The Ganga-Yamuna Doab (between the two rivers) is one of the most densely populated agricultural areas on Earth; vs the waterless

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	populated	Thar Desert and the Rann of Kutch
Natural Resources and Minerals	Mineral-rich areas attract mining industry and associated settlement; forest areas may attract tribal settlement but restrict agricultural expansion	Jharkhand-Chhattisgarh-Odisha mineral belt = moderate density despite difficult terrain; coastal areas = fishing communities; forest-rich areas often have tribal settlements but lower overall density

SOCIO-ECONOMIC FACTORS

Socio-Economic Factor	Influence	Indian Example
Agricultural Productivity	High-yield, irrigated agriculture supports dense rural settlement; rain-fed, low-yield areas support sparser settlement	Irrigated Punjab-Haryana (Green Revolution) = 573 and 573/sq km; rain-fed Rajasthan interior = <50/sq km in desert areas
Industrialisation and Employment	Industrial clusters attract migrant workers and increase density dramatically; Mumbai, Delhi, Surat, Bengaluru, Chennai, Hyderabad are all high-density industrial/service hubs	Mumbai Metropolitan Region: ~14,000/sq km in the city proper; Surat (Gujarat) is one of India's fastest-growing cities due to diamond-cutting + textiles industry drawing UP-Bihar migrants
Transport Connectivity	Areas with good road/rail connectivity develop faster and attract more people; inaccessible areas remain sparsely populated	NE India's poor connectivity (Chicken Neck/Siliguri Corridor = only land connection) has limited development and kept density low; Grand Trunk Road and Delhi-Mumbai-Chennai rail corridors = linear density concentrations
Historical and Administrative Factors	Capital cities, administrative centers, ancient trade routes attract population over centuries; partition (1947) disrupted the historic Punjab-Sind population geography	Delhi (national capital), Patna (ancient Pataliputra), Varanasi (ancient religious center) = historically dense; former colonial ports (Mumbai, Kolkata, Chennai) = still mega-cities today
Migration Patterns	Intra-state and inter-state migration concentrates population in destination states/cities; source states (Bihar, UP) become relatively less dense as migrants leave, destination states (Maharashtra, Delhi, Gujarat) gain	Maharashtra alone receives 20+ lakh migrants/year (Census 2011 data); Delhi is India's largest migration destination; "BIMARU" states (Bihar, MP, Rajasthan, UP) are both densely populated AND high out-migration states

32.4 STATE-WISE POPULATION -- CENSUS 2011

Rank	*State*	*Population (2011)*	*% of India's Population*	*Key Note*
1	Uttar Pradesh	19,98,12,341 (19.98 crore)	16.51%	Most populous state; 1 in 6 Indians lives in UP; larger than Brazil's population; Allahabad (now Prayagraj), Lucknow, Kanpur, Agra, Varanasi = major cities
2	Maharashtra	11,23,74,333 (11.24 crore)	9.29%	2nd most populous; also richest state by GSDP; Mumbai metro area alone = ~2

				crore
3	Bihar	10,40,99,452 (10.41 crore)	8.60%	3rd most populous; also most dense (1,106/sq km); highest TFR (~3.0); poor economic development despite large population
4	West Bengal	9,12,76,115 (9.13 crore)	7.54%	2nd most dense (1,028/sq km); Kolkata is the 3rd largest metro; high literacy relative to other dense states
5	Andhra Pradesh (undivided)	8,45,80,777 (8.46 crore)	6.99%	Note: Telangana was carved out of AP in 2014; AP post-division = ~5.2 crore; Telangana ~3.5 crore
6	Madhya Pradesh	7,26,26,809 (7.26 crore)	6.00%	Large area (largest state by area until Rajasthan regained this after Chhattisgarh separation); moderate density
7	Rajasthan	6,86,21,012 (6.86 crore)	5.67%	Largest state by area (342,239 sq km); low overall density (201/sq km) despite being large; desert area sparsely populated; Aravalli belt moderately dense
8	Tamil Nadu	7,21,47,030 (7.21 crore)	5.96%	High literacy; rapid urbanisation; Chennai metropolitan region; demographically advanced (low TFR ~1.6)
9	Karnataka	6,10,95,297 (6.11 crore)	5.05%	Bengaluru IT hub; fastest-growing large city in India by absolute numbers in recent decades; migrant population from across India
10	Gujarat	6,03,83,628 (6.04 crore)	4.99%	High urbanisation; industrial development (Surat, Ahmedabad, Rajkot, Vadodara); high per-capita income
LEAST POPULOUS State	Sikkim	6,10,577 (6.1 lakh)	0.05%	Himalayan; smallest state by population; but growing due to tourism, NHPC projects

Population Concentration: Five states (UP, Maharashtra, Bihar, WB, Andhra Pradesh) account for approximately 48% of India's total population. The BIMARU states (Bihar, Madhya Pradesh, Rajasthan, Uttar Pradesh -- and some add "CU" for Chhattisgarh and Uttarakhand) account for ~37% of India's population but lag in most development indicators. The demographic dividend versus demographic burden debate hinges heavily on what happens with these high-fertility, low-development states.

32.5 SEX RATIO IN INDIA

The sex ratio in India is measured as **females per 1,000 males** (unlike most countries which use males per 1,000 females or another convention). A "natural" sex ratio at birth is approximately **943-952 females per 1,000 males** (accounting for the biological fact that slightly more males are born but males have higher mortality). India's

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overall sex ratio of **943 (Census 2011)** is now within the natural range -- but the **child sex ratio (0-6 years) of 919** indicates that **selective elimination of female children** continues through female foeticide (sex-selective abortion using PCPNDT technologies).

Sex Ratio Category	2011 Figure	States with HIGHEST	States with LOWEST	Key Note
Overall Sex Ratio (all ages)	943 females per 1,000 males (improved from 933 in 2001)	Kerala (1,084) -- highest in India; Puducherry (1,037); TN (996); Chhattisgarh (991); Odisha (979)	Haryana (879 -- lowest among all large states); J&K (889); Punjab (895); Sikkim (890); Delhi (868)	Kerala's high sex ratio = high female literacy, good healthcare, strong female agency; Haryana and Punjab's low ratio = strong son preference, history of female foeticide
Child Sex Ratio (0-6 years)	919 females per 1,000 males (DECLINED from 927 in 2001 and 976 in 1961)	Mizoram (971); Meghalaya (970); Chhattisgarh (969); Kerala (964); Andaman and Nicobar (966)	Haryana (834 -- lowest in India; alarmingly low); Punjab (846); Jammu and Kashmir (862); Rajasthan (888); Gujarat (890)	The DECLINE despite the PCPNDT Act 1994 (banning sex-determination tests for sex-selection purposes) indicates: (a) widespread violations of PCPNDT; (b) inadequate enforcement; (c) deep-rooted son preference; Beti Bachao Beti Padhao launched 2015 in 100 worst-affected districts (including Haryana districts)

UPSC CIVIL

Beti Bachao Beti Padhao (BBBP) -- 2015: Launched January 22, 2015 by PM Modi at Panipat, Haryana -- targeting the specific districts of Haryana (and Punjab) with the lowest child sex ratio. Three-ministry convergence: WCD (Women and Child Development), Health, Education. Key objectives: (a) prevent gender-biased sex-selective elimination; (b) ensure survival and protection of the girl child; (c) promote education of girls. The scheme expanded from 100 pilot districts (2015) to all 640 districts (2017). **Haryana's CSR improved from 834 (2011) to 930+ (by 2021 SRS estimates)** -- one of the most rapid CSR improvements in Indian history, indicating that targeted policy attention (plus changing social attitudes, economic incentives) can quickly change demographic outcomes.

32.6 LITERACY IN INDIA -- CENSUS 2011

Literacy is defined by the Census as the ability to read and write with understanding in any one language. Persons aged 7 years and above are counted for literacy (children below 7 are automatically excluded). The **National Literacy Rate (2011) = 74.04%** (males: 82.14%, females: 65.46%) represents a dramatic improvement from 18.33% at Independence (1951) to 74% in 2011 -- a testament to India's massive investment in primary education. However, **India still has the world's largest number of illiterate persons** in absolute terms (approximately **31.3 crore illiterates in 2011**) due to its large population base.

Literacy Parameter	Census 2011 Data	Best Performing	Worst Performing / Gender Gap
Overall Literacy Rate	74.04%	Kerala = 94.0% (highest state); Lakshadweep = 92.28% (highest UT); Mizoram = 91.58%; Goa = 88.7%; Tripura = 87.75%	Bihar = 63.82% (LOWEST state); Arunachal Pradesh = 66.95%; Rajasthan = 66.11%; Jharkhand = 66.41%; J&K = 68.74%

Male Literacy	82.14%	Kerala = 96.11%; Lakshadweep = 96.11%; Goa = 92.65%	Bihar = 73.39%; Rajasthan = 79.19%; Uttar Pradesh = 79.24%
Female Literacy	65.46%	Kerala = 92.07%; Mizoram = 89.27%; Lakshadweep = 88.25%	Rajasthan = 52.66% (lowest female literacy among large states); Bihar = 53.33%; Uttar Pradesh = 59.26%
Gender Gap in Literacy	16.68% (national male minus female literacy)	Mizoram = narrowest gap (~2%); Meghalaya = narrow; Kerala = narrow	Rajasthan = 26.53% (widest gender gap in literacy -- males 79.19%, females 52.66%); UP, Bihar also have wide gaps
Absolute Illiterates	~31.3 crore illiterates (2011)	--	UP alone = ~5 crore illiterates (largest absolute number); Bihar = ~3.7 crore; Rajasthan = ~2.3 crore -- these 3 states account for 35%+ of India's illiterates

Why is Kerala's literacy so high? Kerala's consistently high literacy (94%, the highest in India since at least 1991) is attributed to: (a) historical missionary and princely state investments in education (Travancore and Cochin princely states had Universal Education Acts even before Independence -- 1945 in Travancore); (b) strong Ezhava and Nair community emphasis on literacy; (c) Communist government investments in public education and health from 1957 onwards; (d) high female agency and participation; (e) strong civil society and mass literacy movements (Kerala Shastra Sahitya Parishad, Total Literacy Campaign in Ernakulam district 1990 -- first district to achieve total literacy).

32.7 DEMOGRAPHIC TRANSITION -- INDIA'S POPULATION JOURNEY

India's population history from Independence to the present can be understood through the **Demographic Transition Theory (DTT),** which proposes that all societies pass through four stages of demographic change as they develop:

Stage	*Birth Rate*	*Death Rate*	*Population Growth*	*India's Experience*
Stage 1 -- High Stationary	High (40-50/1,000)	High (35-45/1,000)	Low (near-zero; births and deaths nearly balance)	Pre-Independence India (before 1920-30 when modern medicine began reducing death rates); typical of traditional agrarian societies
Stage 2 -- Early Expanding	High (35-45/1,000)	Falling rapidly (20-30/1,000)	RAPID GROWTH (population explosion)	India 1951-1981: death rate fell dramatically with vaccination programmes, food availability, improved healthcare; but birth rate remained high; population DOUBLED in 35 years (36 crore in 1951 to 68 crore in 1981)
Stage 3 -- Late Expanding	Falling (20-30/1,000)	Low (10-15/1,000)	Moderate but slowing growth	India 1981-present: birth rates beginning to fall (family planning, female education, urbanisation); growth rate declining; India is in the LATE STAGE 3; some states (Kerala, TN, Goa, Delhi, HP, Uttarakhand) have already reached Stage 4
Stage 4 -- Low	Low (10-15/1,000)	Low (10-15/1,000)	Near-zero or slight growth;	KERALA, TAMIL NADU, GOA, DELHI, HIMACHAL PRADESH have reached Stage 4:

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Stationary			population stabilises	TFR at or below replacement (2.1); these states face aging population concerns rather than population growth concerns
Stage 5 (emerging concept)	Very low (<10/1,000)	Low or rising (aging effects)	Negative growth (population decline)	No Indian state has reached Stage 5; some European countries, Japan, South Korea, China are here; India's overall population will not begin declining until ~2060-70

India's TFR (Total Fertility Rate): The national TFR has fallen from ~6 at Independence to approximately **2.0 (SRS 2020 -- Sample Registration System),** which is **BELOW THE REPLACEMENT LEVEL OF 2.1** for the first time in India's demographic history. However, this national average conceals major state-level variation: Bihar TFR = ~3.0; UP = ~2.7 (well above replacement) vs Tamil Nadu = ~1.6; Kerala = ~1.7; Andhra Pradesh = ~1.7 (well below replacement). This means India's population growth is now almost entirely driven by the high-fertility states of the north (BIMARU + Assam + Jharkhand), while the south and some western states are approaching zero or sub-replacement growth.

32.8 INDIA AS WORLD'S MOST POPULOUS COUNTRY (2023)

In mid-April 2023, the **United Nations Population Division (UNPD)** estimated that India's population crossed China's, making India the **world's most populous country** -- a milestone that will have lasting demographic, economic, and geopolitical implications. According to the UNPD's *World Population Prospects 2022,* India's population in 2023 is approximately **1.44 billion,** while China's has begun declining (first absolute decline in 2022 for the first time since the Great Leap Forward famine of 1959-61).

India-China Demographic Comparison (2023)	*India*	*China*
Population (2023 est.)	~1.44 billion	~1.41 billion (declining)
TFR (Total Fertility Rate)	~2.0 (SRS 2020; slightly below replacement)	~1.09 (far below replacement; severe fertility crisis)
Population trajectory	Will continue growing until ~2060-70; peak at ~1.6-1.7 billion	Already declining; projected to fall to ~1.0-1.1 billion by 2100
Median age	~29 years (young population)	~39 years (rapidly aging)
Working-age population (15-64)	~68% of population (demographic dividend ongoing)	~68-70% but declining as baby boomers retire
Key demographic concern	Managing the demographic dividend (skill, jobs); high-fertility BIMARU states; gender imbalance in some states	Rapidly aging population; shrinking workforce; social security crisis; low fertility despite end of One Child Policy
Policy context	Population Commission of India; NDP targets; NEP 2020; Mission Shakti for women	China ended One Child Policy 2016; Two-Child Policy 2021; Three-Child Policy 2023; cash incentives for having children; not working

KEY NOTE

Census 2021 -- The Missing Census: India's Census 2021 was originally scheduled for February-March 2021 but was postponed due to COVID-19 (the notification to conduct Census was first issued in September 2019 for the Houselisting phase). As of 2025, Census 2021 has NOT yet been conducted. The government has announced Census 2025 or 2026 as the likely next timeline. This means India

has been governing without current Census data for over 14 years (since the 2011 Census). The postponement has significant policy implications: (a) Delimitation (redrawing of parliamentary constituency boundaries) was constitutionally frozen until 2026 based on 1971 Census data; the freeze was extended to 2031; (b) The actual 2023 population figure is based on PROJECTIONS not actual count.

32.9 HISTORICAL POPULATION GROWTH -- DECADAL DATA

Census Year	Population	Decadal Growth Rate	Key Context
1901	23.84 crore	--	Lowest population in India since reliable data; great plague epidemics; famines; high mortality
1921	25.13 crore	+0.97% (decadal)	Year of the GREAT DIVIDE -- near-zero growth due to 1918 Spanish Flu pandemic (killed 12-17 million Indians), WWI casualties, famine; LOWEST growth decade; population stability
1951	36.11 crore	+13.31%	Post-Independence; partition disrupted data; still pre-transition phase; death rates starting to fall with post-Independence public health measures
1961	43.92 crore	+21.51%	RAPID GROWTH begins; death rate falling sharply (vaccination: smallpox, cholera, tuberculosis); birth rate still high; first signs of population explosion
1971	54.82 crore	+24.80%	Peak growth rate approaches; Green Revolution provides food security; India feeds its growing population; Indira Gandhi government initiates family planning
1981	68.33 crore	+24.66%	Emergency (1975-77) had controversial forced sterilisation programme; growth rate barely changed; population doubled since 1951 in just 30 years
1991	84.64 crore	+23.87%	Growth rate slowly declining; female literacy improving; economic reforms beginning; TFR starting to fall in southern states
2001	102.87 crore	+21.54%	INDIA CROSSES 1 BILLION (October 11, 1999 -- "Day of 6 Billion" globally; "Baby of the Billion" in India); TFR declining nationally
2011	121.09 crore	+17.64%	First decade to show LOWER ABSOLUTE INCREASE than previous decade; demographic transition in progress; national TFR approaching replacement; policy success becoming visible
2023 (PROJECTION)	~144 crore	~+18.5% from 2011	India surpasses China as world's most populous; Census 2021 not yet conducted; figure is a UN projection

1921 -- The Year of the Great Divide: The decade 1911-1921 recorded the lowest population growth in the 20th century -- the population actually DECLINED slightly (from 25.2 crore in 1911 to 25.1 crore in 1921). The 1918 Spanish Influenza pandemic killed 12-17 million Indians -- proportionally one of the worst-affected countries in the world.

For this reason, 1921 is called the Year of the Great Divide or Demographic Turning Point. Before 1921, death rate was still high enough to suppress growth; after 1921, it began falling consistently while birth rate remained high, leading to accelerating population growth.

32.10 DEMOGRAPHIC DIVIDEND -- INDIA'S YOUTH BULGE

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The **demographic dividend** refers to the economic growth potential that can result from a shift in a country's age structure when the proportion of people in the working-age group (15-64 years) is higher than the proportion of dependents (children 0-14 years + elderly 65+). India's young population (median age ~29 years in 2023) represents this opportunity -- but it is also a **demographic burden** if the working-age population cannot find employment.

Demographic Dividend Feature	*Detail*
Window of opportunity	India's demographic dividend window is estimated at approximately 2020-2055; during this period the working-age population (15-64) constitutes 65-68% of total population -- a historically high ratio offering maximum economic output per dependent
Youth bulge statistics	India has ~600 million people below age 25 (2023); ~900 million below age 35; adding ~7-10 million new entrants to the workforce every year; needs to create ~8-10 million FORMAL JOBS PER YEAR to absorb this workforce (a target India has historically struggled to meet)
States at different stages	Southern states (Kerala, TN, AP, Karnataka, Telangana, Goa) have ALREADY passed their demographic dividend peak (low TFR means young population proportion declining); BIMARU states (Bihar, UP, Rajasthan, MP) are still at the EARLY stage of demographic dividend -- young populations, high dependency ratios in past, now entering working age; this creates a "dual India" demographic
BIMARU vs South contrast	The combination of a south that is aging and a north that is young means: (a) future economic activity must shift northward to where young workers are; (b) migration from BIMARU states to southern cities is already growing; (c) delimitation (redrawing of parliament seats based on population) after 2031 Census will shift political power northward (UP and Bihar will gain seats; TN and Kerala may lose); this is a major political economy issue in India
Challenges to realising dividend	(a) Education quality: large numbers of graduates are unemployable (National Employability Report); (b) Formal job creation: India's formal sector creates only ~3-4 million jobs/year; (c) Female labour force participation: FLFP is only ~25% in India (one of the world's lowest); (d) Health and nutrition: stunting (35% of children), malnutrition affect human capital; (e) Regional mismatch: youth in Bihar, UP; jobs in Maharashtra, Gujarat, Delhi -- migration required but infrastructure and social integration challenges
Policy response	Skill India Mission (target 40 crore skilled workers by 2022; behind schedule); Pradhan Mantri Kaushal Vikas Yojana (PMKVY); Startup India; Make in India (manufacturing jobs); National Education Policy 2020 (quality education reform); PM Mudra Yojana (micro-enterprise loans); Atmanirbhar Bharat -- all targeting the demographic dividend realization

32.11 CURRENT AFFAIRS HOOKS (2022-2025)

India World's Most Populous (April 2023): UNPD estimated India surpassed China in mid-April 2023 (India ~1.44 billion; China ~1.41 billion and declining). China's population declined in absolute terms in 2022 -- first decline since 1961 -- despite ending the One Child Policy in 2016. India's peak population: ~1.65-1.70 billion around 2060-70. Implications: world's largest workforce, consumer market, military recruitment pool; demographic divergence with China widening.

Census 2021 Still Pending (2025): India's Census was due in 2021 but postponed due to COVID-19. As of 2025, Census has not been conducted. Government expects Census 2025-26. Key implications: (a) No current demographic data for policy-making; (b) Delimitation of parliamentary constituencies delayed; (c) Scheme

targeting uses projected data; (d) Research community deprived of current data.

Beti Bachao Beti Padhao Results (2024): PM Modi highlighted BBBP progress. Haryana's Child Sex Ratio (CSR) improved from 834 (Census 2011) to ~930+ (SRS estimates 2023) -- one of the fastest CSR improvements recorded anywhere. India's overall CSR improved from 919 (2011) to estimated 930+ (2023). Government credits BBBP, Sukanya Samridhi Yojana, and Mahila Shakti Kendras.

Delimitation Controversy -- South vs North (2023-2026): The next delimitation (post-2031 Census) will increase Lok Sabha seats for high-population states (UP, Bihar, Rajasthan, MP) and may stagnate or reduce seats for low-growth states (Tamil Nadu, Kerala, Karnataka, AP). South Indian states argue they are penalised for successfully controlling population while north gains political power proportionally.

32.12 PYQ ANALYSIS -- CHAPTER 32 (2010-2025)

Source	Year	Marks	Question
UPSC Civil	2024	15M	"India has become the world's most populous country in 2023. Examine the implications of this demographic milestone for India's economy, society, and international standing."
UPSC Civil	2023	12M	"Discuss the concept of demographic dividend with reference to India. What are the challenges in realising the demographic dividend?"
UPSC Civil	2022	10M	"Discuss the distribution of population in India. What are the major factors responsible for the uneven distribution of population?"
UPSC Civil	2021	12M	"The decline in child sex ratio in India is alarming. Discuss the reasons and the policy measures taken to address this challenge."
UPSC Civil	2020	10M	"Discuss the significance of the 1921 census as a 'year of the great divide' in India's demographic history."
UPSC Civil	2019	12M	"Critically examine India's population density distribution. Why is Bihar the most densely populated state despite having low economic development?"
UPSC Civil	2018	10M	"Discuss the trend in literacy in India since 1951. What are the main determinants of high literacy in Kerala?"
UPSC Civil	2017	10M	"Discuss the demographic transition in India with reference to trends in birth rate, death rate and population growth rate."
IFoS GS	2024	10M	"Discuss the relationship between population density, forest cover, and environmental degradation in the densely populated states of India."
IFoS GS	2023	10M	"Examine how demographic pressure, particularly in the Indo-Gangetic Plain states, affects natural resource depletion and land-use change."
IFoS GS	2022	10M	"Discuss the environmental implications of India's emerging status as the world's most populous country."

KEY NOTE

Frequency: India most populous + implications (Civil 2024); demographic dividend + challenges (Civil 2023); population distribution (Civil 2022); child sex ratio + policy (Civil 2021); 1921 Great Divide (Civil 2020); density distribution + Bihar paradox (Civil 2019); literacy trends + Kerala (Civil 2018); demographic transition (Civil 2017). IFoS: density + forest cover (2024), IGP demographic pressure + resources (2023), India most populous + environment (2022). For 2025-26: Census 2021 delay and implications; Delimitation controversy north vs south; Beti Bachao results (CSR improvement); India-China demographic divergence; demographic dividend challenges (unemployment + FLFP); Population Policy 2023 -- all high-priority.

32.13 MODEL BOOK

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India has become the world's most populous country. Examine the implications of this demographic milestone for India's economy, society, and geopolitics.

UPSC Civil (Mains) | 15 Marks | 210 Words

In mid-April 2023, India surpassed China as the world's most populous country (~1.44 billion vs China's ~1.41 billion -- and declining). This is not merely a statistical milestone -- it is a demographic turning point with profound economic, social, and geopolitical implications.

ECONOMIC IMPLICATIONS:

1. **Demographic Dividend:** India has ~600 million people below 25 years; median age ~29 years; the working-age population (15-64) constitutes ~68% of total -- a historically high ratio. If India can skill and employ this workforce, it adds 1-2 percentage points to GDP growth annually (ADB estimates). This requires creating 8-10 million formal jobs/year -- a target India is struggling to meet.
2. **Largest Consumer Market:** With 1.44 billion consumers (growing middle class of 300-400 million), India is the world's most attractive consumer market for global companies; foreign FDI follows where consumers are.
3. **Demographic Burden Risk:** If the demographic dividend is not capitalised -- if young people cannot find jobs -- the same youth bulge becomes a **demographic burden:** social unrest, crime, economic stagnation. The gap between 8-10 million new workforce entrants and 3-4 million formal jobs created annually is India's most critical economic challenge.

SOCIAL IMPLICATIONS:

1. **Regional Asymmetry:** North India (Bihar, UP, Rajasthan, MP) has high TFR (2.5-3.0) and is STILL growing; South India (TN, Kerala, AP, Karnataka) has TFR below replacement (~1.6-1.8) and is facing an aging population. This creates a "dual demographic India" -- north young and growing; south aging and declining workforce.
2. **Delimitation and Political Power:** Post-2031 Census delimitation will shift Lok Sabha seats northward (UP and Bihar gain; TN and Kerala may stagnate or lose). Southern states feel penalised for population control success -- a deep fault line in Indian federal politics.
3. **Resource Pressure:** Every additional billion people means more pressure on water (groundwater depletion), land (shrinking farm sizes), forests (encroachment), and urban infrastructure.

GEOPOLITICAL IMPLICATIONS:

1. **Strategic Power:** World's largest population = world's largest military recruitment pool (active: 1.4 million; reserve: 1.2 million); largest diplomatic network; largest vote bank in geopolitical terms.
2. **India vs China -- Demographic Divergence:** China's population is declining (2022: first decline since 1961; TFR = 1.09 -- far below replacement); India's will peak at ~1.65-1.7 billion around 2060-70. This demographic divergence will widen the strategic gap between India and China over the 21st century -- India will have more workers, consumers, and soldiers as China's population ages and shrinks.
3. **Global South Leadership:** India leading the world's most populous country reinforces its claim to a permanent UN Security Council seat; G20 Presidency in 2023 was framed partly around India's demographic weight and "Voice of the Global South" narrative.

Being the world's most populous nation is simultaneously India's greatest opportunity (demographic dividend, market size, strategic power) and its most complex challenge (jobs, education, resources, regional equity). The next 30 years -- when India's working-age population is at its peak -- will determine whether 2023 is remembered as the beginning of India's century or as a warning about a demographic burden unmanaged.

Critically examine the distribution of population in India. Why is Bihar the most densely populated state despite low economic development?

UPSC Civil (Mains) | 12 Marks | 160 Words

India's population distribution is profoundly uneven -- ranging from Bihar's 1,106 persons/sq km (most densely populated state) to Arunachal Pradesh's 17 persons/sq km, a 65-fold difference within one country. This pattern reflects the interplay of physical geography, agricultural history, economic development (or its absence), and cultural factors.

DISTRIBUTION PATTERN -- FOUR ZONES:

1. **Very High Density (>500/sq km):** Bihar, WB, UP, Kerala, Delhi NCT. Fertile alluvial plains of the Ganga system support intensive agriculture and dense rural settlement; Kerala = long-established small landholding agriculture; Delhi = India's largest urban agglomeration by density.
2. **High Density (250-500/sq km):** Punjab, Haryana, Tamil Nadu, Gujarat, Maharashtra coast. Irrigated agriculture (Punjab-Haryana wheat-rice), coastal industrialisation (Gujarat, Maharashtra), high-service economy (TN).
3. **Moderate Density (100-250/sq km):** MP, Chhattisgarh, Rajasthan (east), Uttarakhand (plains). Central India agricultural zone; mixed terrain.
4. **Very Low Density (<100/sq km):** Arunachal Pradesh (17), Himachal Pradesh (123), Western Rajasthan (desert <20), Ladakh (<5), A&N islands (46). Himalayan terrain, desert, protected forests restrict settlement.

BIHAR'S HIGH DENSITY DESPITE LOW DEVELOPMENT -- THE PARADOX:

Historical reasons: Bihar was one of India's most prosperous and densely settled agricultural regions for millennia (Mauryan empire capital at Pataliputra/Patna; Buddhist monasteries at Nalanda). This historical density was never redistributed.

Fertile alluvial land: Bihar lies entirely on the Ganga-Ghaghara-Gandak-Kosi alluvial plain -- some of India's most fertile soil, capable of supporting dense agricultural populations even at subsistence levels.

High TFR (~3.0): Bihar has India's highest TFR (3.0 in SRS 2020) -- more than 50% above replacement. Without economic development providing alternatives to large families (female education, employment), birth rates remain high.

Low out-migration historically: Although Bihar is now one of India's largest out-migration states (sending workers to Delhi, Punjab, Haryana, Gujarat), historically out-migration was limited by caste barriers, language differences, and lack of information/networks -- so population accumulated on the land.

Poor economic development = trapped population: When economies industrialise, workers leave agriculture for factories and services -- reducing rural density (urbanisation). Bihar's limited industrialisation means most people remain in agriculture, maintaining high rural density.

Bihar's density paradox -- most dense but least developed -- reflects a poverty trap: density without development creates more poverty; poverty reduces incentives for family planning; more children maintain high density. Breaking this cycle requires investment in female education (which most reduces TFR), quality schools and healthcare, and industrial job creation in Bihar itself (rather than sending workers to other states). Bihar's density is a SYMPTOM of underdevelopment, not merely a CAUSE.

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CHAPTER 33

POPULATION GROWTH, MIGRATION AND LITERACY

Birth Rate, Death Rate, TFR, MMR, IMR, Migration Streams and Literacy Trends

CHAPTER AT A GLANCE

- POPULATION GROWTH COMPONENTS: Three components -- (1) Birth Rate (Crude Birth Rate / CBR): live births per 1,000 population per year; India CBR = 19.7 (SRS 2020); declined from 40.8 (1951) to 19.7 (2020). (2) Death Rate (Crude Death Rate / CDR): deaths per 1,000 population; India CDR = 6.0 (SRS 2020); declined dramatically from 27.4 (1951) to 6.0 (2020). (3) Natural Growth Rate = CBR - CDR; currently ~13.7/1,000 = ~1.37%/year (2020). Net Migration Rate is the 4th component.
- TOTAL FERTILITY RATE (TFR): Average number of children a woman would have over her lifetime at current age-specific fertility rates. National average TFR = 2.0 (SRS 2020) -- BELOW REPLACEMENT LEVEL of 2.1 for the first time. But state variation huge: Bihar TFR = 3.0; UP = 2.7 (above replacement); vs TN = 1.6; Kerala = 1.7; Delhi = 1.6 (well below replacement). Target of NHP 2017 (National Health Policy): TFR = 2.1 by 2025 -- already achieved nationally though not in all states.
- INFANT MORTALITY RATE (IMR) and MATERNAL MORTALITY RATIO (MMR): IMR = deaths of infants (below age 1) per 1,000 live births; India IMR = 28 (SRS 2020); declined from 146 (1951) to 28 (2020). MMR = maternal deaths per 1,00,000 live births; India MMR = 97 (SRS 2018-20); declined from 384 (2000) to 97 (2018-20). LOWEST IMR states: Kerala (4), Manipur (7), Delhi (10). HIGHEST IMR: Madhya Pradesh (48), Odisha (40), Uttar Pradesh (38). SDG target: IMR <25, MMR <70 by 2030.
- MIGRATION: Census 2011 counted 45.36 crore migrants (37.5% of population!). Migration types: (1) Internal migration (within India) -- dominant; rural-to-urban and rural-to-rural; (2) International migration -- emigration (to Gulf, USA, UK, Canada, Australia) and immigration (from Bangladesh). Largest migration streams: Bihar and UP are top SOURCE states; Maharashtra and Delhi are top DESTINATION states. Reasons: WORK (most common for males), MARRIAGE (most common for females by Census definition).
- MAJOR MIGRATION FLOWS IN INDIA: (1) Punjab-Haryana wheat belt attracts seasonal workers from Bihar, UP, Rajasthan for harvesting. (2) Mumbai attracts workers from UP, Bihar, Rajasthan, Andhra Pradesh. (3) Delhi attracts workers from UP, Bihar, Rajasthan, Haryana. (4) Surat (Gujarat) textile and diamond industry draws UP-Bihar migrants. (5) Kerala exports migrants to Gulf (highest per-capita Gulf migrants) and receives domestic migrants from NE India (healthcare, hospitality). (6) Kolkata-WB attract workers from UP, Bihar. Push factors: poverty, drought, lack of employment. Pull factors: employment, higher wages, better services.
- INTERNATIONAL MIGRATION (DIASPORA): India has the WORLD'S LARGEST DIASPORA -- approximately 3.2 crore (32 million) Non-Resident Indians and Persons of Indian Origin (NRI + PIO) globally (UN 2020). Top destination countries: UAE (3.5 million), USA (4.5 million), Saudi Arabia (2.5 million), Kuwait, Oman, Qatar (Gulf countries collectively ~9 million). Remittances: India is the WORLD'S LARGEST RECIPIENT OF REMITTANCES -- USD 125 billion in 2023 (World Bank); 3.3% of GDP. States receiving most remittances: Kerala (highest per capita), UP, Maharashtra, TN, Punjab. Ministry of External Affairs: Pravasi Bharatiya Divas (January 9, Pravasi Bharatiya Sammelan); e-Migrate portal; Pravasi Bharatiya Bima Yojana.
- LITERACY -- KEY TRENDS: Literacy rate improved from 18.33% (1951) to 74.04% (2011 Census). National Literacy Mission (NLM, 1988); Saakshar Bharat (2009-12 successor to NLM); NEP 2020 target: universal functional literacy by 2030. New Literacy Programme (2022): NIPUN Bharat (National Initiative for Proficiency in Reading with Understanding and Numeracy) for foundational literacy (Classes 1-3) by 2026-27. ULLAS (Understanding Lifelong Learning for All in Society) -- New India Literacy Programme (NILP) 2022-27 replacing Saakshar Bharat; target: 5 crore illiterates to be made literate.

- HEALTH INDICATORS AND POLICY: Life Expectancy at Birth: India = 69.7 years (2018; males 68.2, females 71.2 years); improved from 32 years (1951). National Family Health Survey 5 (NFHS-5, 2019-21) is the most recent comprehensive demographic health survey. NFHS-5 key findings: TFR = 2.0; IMR = 35.2; under-5 mortality = 41.9; stunting 35.5%; wasting 19.3%; anaemia in women 57%; institutional births 88.6% (major improvement from 79% in NFHS-4). Key schemes: PM Matru Vandana Yojana (PMMVY); Pradhan Mantri Surakshit Matritva Abhiyan (PMSMA); National Nutrition Mission / POSHAN Abhiyaan.
- NEP 2020 target: universal literacy (100% by 2030). PM POSHAN, mid-day meals, and Beti Bachao Beti Padhao are key policy levers.

33.1 COMPONENTS OF POPULATION CHANGE

Population change in any area over time is determined by four components: **Birth Rate, Death Rate, In-migration,** and **Out-migration.** The first two together determine the **Natural Growth Rate,** and the latter two determine the **Net Migration Rate.** In India, natural growth remains the dominant driver of population change, though migration is becoming increasingly important at the state and city level.

Component	*Formula / Definition*	*India Current Value (approx. SRS 2020)*	*Trend since 1951*
Crude Birth Rate (CBR)	Live births per 1,000 population per year	19.7 per 1,000	Declined from 40.8 (1951) to 19.7 (2020) -- more than halved; declining rapidly but some northern states still high
Crude Death Rate (CDR)	Deaths per 1,000 population per year	6.0 per 1,000	Declined from 27.4 (1951) to 6.0 (2020) -- remarkable fall driven by public health improvements; now at a low plateau
Natural Growth Rate (NGR)	CBR minus CDR	~13.7 per 1,000 (~1.37% per year)	Peaked in 1970s-80s (around 2.2%/year); now declining; population growth is slowing but still positive
Total Fertility Rate (TFR)	Average number of children per woman over lifetime	2.0 (SRS 2020; NFHS-5: 2.0)	Declined from ~6 (1950s) to 2.0 (2020); now at or slightly BELOW replacement level (2.1) nationally
Infant Mortality Rate (IMR)	Deaths below age 1 per 1,000 live births	28 per 1,000 live births (SRS 2020)	Declined from 146 (1951) to 28 (2020) -- major achievement of public health; but still higher than SDG target of 25
Maternal Mortality Ratio (MMR)	Maternal deaths per 1,00,000 live births	97 per 1,00,000 (SRS 2018-20)	Declined from 384 (2000) to 97 (2018-20); SDG target = 70 by 2030; some states already below 70
Life Expectancy at Birth (LEB)	Average years a newborn is expected to live	69.7 years (2015-19 SRS; males 68.2, females 71.2)	Increased from 32 years (1951) to 69.7 years (2015-19) -- one of the most dramatic health improvements in human history
Net Migration Rate	Net in-migrants minus out-migrants per 1,000 population	Varies by state; nationally near-zero (internal migration only redistributes)	Maharashtra, Delhi, Gujarat net in-migration states; Bihar, UP, Rajasthan net out-migration states

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BIRTH RATE -- STATE-WISE VARIATION

Category	*States*	*CBR (approx. SRS 2020)*	*Key Factor*
HIGHEST CBR (above-replacement fertility belt)	Bihar, Uttar Pradesh, Rajasthan, Madhya Pradesh, Jharkhand	Bihar ~26; UP ~24; Rajasthan ~23; MP ~22	Low female literacy, low FLFP (female labour force participation), high son preference, poverty, limited access to family planning; these are the "demographic momentum" states still driving national population growth
NEAR-REPLACEMENT CBR	Assam, Chhattisgarh, Haryana, Odisha, Gujarat, Maharashtra, Karnataka	18-22 per 1,000	Middle-ground states; some have recently brought TFR to ~2-2.5; in transition
BELOW-REPLACEMENT CBR	Kerala, Tamil Nadu, Andhra Pradesh, Telangana, Delhi, Himachal Pradesh, Sikkim, Goa, Punjab	Kerala ~13; TN ~14; Delhi ~14	High female literacy, urbanisation, good healthcare, women empowerment; these states have already completed demographic transition; facing aging population challenges

DEATH RATE AND IMR -- STATE DISPARITIES

State Category	States / IMR	CDR	Key Note
LOWEST IMR (best child health)	Kerala (4/1,000), Manipur (7), Delhi (10), Goa (8), Tamil Nadu (13)	Kerala CDR ~6.5 (slightly elevated due to older age structure)	Kerala's IMR = 4 is among the lowest in any developing country globally; comparable to many European nations; driven by universal institutional delivery, excellent ASHA programme, high female literacy
HIGHEST IMR (worst child health)	Madhya Pradesh (48), Odisha (40), UP (38), Assam (37), Rajasthan (30)	Higher CDR in many of these states (MP ~7.8; UP ~7.0)	MP's IMR of 48 means 48 babies die per 1,000 live births in the first year -- more than 10 times Kerala's rate; poor institutional delivery, malnutrition, distance from health centres, tribal areas poorly served
GENDER DISPARITY in IMR	Several states show higher female IMR than male IMR (contrary to natural expectation where male IMR is slightly higher)	Varies	WHERE female IMR > male IMR, it indicates FEMALE NEGLECT of sick infant girls (preference for male infants in seeking treatment); evidence of gender-biased health-seeking behaviour; seen in states like UP, Rajasthan, MP

KEY NOTE

National Family Health Survey 5 (NFHS-5, 2019-21) -- Key Findings: TFR = 2.0 (first time at replacement level); IMR = 35.2 per 1,000 live births; Under-5 Mortality Rate = 41.9; Neonatal mortality = 24.9; Stunting (children below 2 SD height for age) = 35.5%; Wasting = 19.3%; Anaemia in women 15-49 years = 57% (high and concerning -- linked to low dietary iron and nutritional deficiency); Anaemia in children 6-59 months = 67.1%; Institutional births = 88.6% (major improvement from 78.9% in NFHS-4); Full immunisation (12-23 months) = 76.4%. NFHS-5 is conducted by IIPS (International Institute for Population Sciences, Mumbai) for the Ministry of Health. It is the primary data source for demographic health analysis in India.

33.2 TOTAL FERTILITY RATE AND POPULATION POLICY

The Total Fertility Rate (TFR) is the **single most important indicator of a country's demographic future** -- it determines whether the population will grow, stabilise, or decline in the long run. India's achievement of a national TFR of **2.0 (SRS 2020)** -- the first time in history it has fallen at or below replacement level -- is a major milestone. However, the profound **north-south divide in TFR** means that India's population trajectory is now largely driven by the BIMARU states.

State	*TFR (SRS 2020 / NFHS-5)*	*Above/Below Replacement (2.1)*	*Implication*
Bihar	3.0	41% ABOVE replacement	Bihar alone adds ~30 lakh babies/year above replacement; the state's population is still growing rapidly; extreme strain on education, health, and job infrastructure
Uttar Pradesh	2.7	29% above replacement	UP is India's most populous state AND still above replacement; the state's young population will continue to enter the workforce for decades; demographic pressure vs potential dividend
Rajasthan	2.5	19% above replacement	Improving (was 2.9 in NFHS-4); desert state with limited water/resources -- above-replacement fertility creates severe resource pressure
Jharkhand	2.3	10% above replacement	Tribal-majority state; improving but still above replacement
MP / Assam / Gujarat	2.0 - 2.2	Near replacement	These states are in the transition zone; moving toward replacement
Maharashtra / Karnataka	1.8 - 1.9	Below replacement	Rapid urbanisation, high female education; demographic transition well advanced; Bengaluru-Mumbai corridor is demographically similar to Europe
Tamil Nadu	1.6	24% BELOW replacement	Tamil Nadu's TFR of 1.6 is lower than France (1.8) and approaching Japan (1.2); aging population concern is real; Tamil Nadu government has been resisting family planning messaging as it feels it has "done its job"
Kerala / Delhi / Andhra Pradesh	1.6 - 1.7	Below replacement	Kerala TFR (1.7) below replacement since 1990s; Delhi = most urbanised, lowest fertility; Kerala concerns: aging population (22%+ above 50 years), healthcare burden of aged, labour shortages in construction/domestic sectors

POPULATION POLICY -- HISTORICAL EVOLUTION

Policy / Programme	*Year*	*Key Feature*
India's First National Family Planning Programme	1952	WORLD'S FIRST NATIONAL FAMILY PLANNING PROGRAMME -- India launched this in 1952 as the first country to do so; initially focused on rhythm method and spacing; infrastructure-building phase; limited reach
Emergency Sterilisation Drive	1975-77 (Emergency period)	Indira Gandhi's Emergency (June 1975 - March 1977); Sanjay Gandhi drove a coercive male sterilisation programme (vasectomies); target of 8 million sterilisations in 1976-77; widely perceived as forced; political backlash contributed to Congress defeat in 1977 elections; permanent damage to

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		voluntary family planning programme credibility
National Population Policy (NPP)	2000	Comprehensive policy: Immediate objective = address unmet need for contraception and reproductive health; Medium-term = TFR at replacement level by 2010 (achieved by 2020); Long-term -- population stabilisation by 2045. Key targets: IMR < 30; MMR < 100; CBR < 21; universal access to contraception; 80% institutional deliveries; key role for ASHAs and ANMs
Janani Suraksha Yojana (JSY)	2005 (under NHM)	Cash incentive for institutional delivery; specifically targeting BPL women in rural areas; dramatically increased institutional delivery rates (from 38% in 2005 to 78% in NFHS-4 and 88.6% in NFHS-5); world's largest conditional cash transfer programme for maternal health; 1 crore+ deliveries supported annually
Mission Parivar Vikas	2016	Intensive programme in 146 high-fertility districts across 7 high-TFR states (UP, Bihar, MP, Rajasthan, Jharkhand, Chhattisgarh, Assam); free contraceptive delivery; community-level outreach; target: these districts to achieve TFR 2.1 by 2025
National Health Policy 2017 (NHP 2017)	2017	Sets TFR = 2.1 at national level as a health sector goal; emphasis on reproductive, maternal, newborn, child, and adolescent health (RMNCH+A); universal health coverage; AYUSHMAN BHARAT (PM-JAY) under NHP 2017 framework
Comprehensive Primary Health Care through HWCs	2017-2022 (under Ayushman Bharat)	Health and Wellness Centres (HWCs) -- transformation of 1.5 lakh Sub-Health Centres and Primary Health Centres into comprehensive primary health care providers; includes maternal health, family planning, chronic disease management; critical for rural family planning access

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Two-Child Policy Debate -- Constitutional and Legal Position: Several state governments (Rajasthan, Assam, Uttar Pradesh, Uttarakhand, Andhra Pradesh) have enacted or proposed laws that disqualify persons with more than two children from contesting panchayat/municipal elections, applying for government jobs, or accessing certain government benefits. The Supreme Court has upheld some of these laws (Javed vs State of Haryana, 2003) while noting that population control is a legitimate state interest. HOWEVER, demographic experts argue strongly that these laws are COUNTER-PRODUCTIVE: they tend to increase female child neglect and female foeticide (parents may kill a girl to stay under the limit while trying for a son), discriminate against the poor and less educated, and do not address the root causes of high fertility (female education, economic security, contraception access). National Commission for Women (NCW) and UNFPA have opposed such policies. The two-child policy debate is a live GS-2 and GS-3 question.

33.3 MIGRATION IN INDIA -- TYPES, STREAMS AND PATTERNS

Migration -- the movement of people from one place to another with a change of residence -- is one of India's most powerful socio-economic forces. The **Census 2011** counted approximately **45.36 crore migrants** (37.5% of India's total population) who had moved from their place of birth or last residence. This remarkable statistic makes India one of the world's most internally mobile large societies.

TYPES OF MIGRATION

Migration Type	*Definition*	*India Examples*
RURAL-TO-URBAN (R-U)	Movement from villages to cities; the classic "push-pull" migration; driven by agricultural distress (push) and urban employment opportunity (pull)	Bihar/UP villagers moving to Delhi, Mumbai, Surat, Ludhiana, Bhopal; this is the dominant migration stream in India and is accelerating with urbanisation; also drives rapid growth of slums (Dharavi in Mumbai, Govindpuri in Delhi, Dharavi equivalent in Bengaluru)
RURAL-TO-	Movement from one village to	Women migrating due to marriage (largest category

RURAL (R-R)	another; most common for FEMALE MIGRATION (marriage) -- women moving to husband's village; also seasonal agricultural labour movement	in Census marriage migration); seasonal harvest workers moving between agricultural regions (Bihar harvesting workers in Punjab kharif season; north India workers in Karnataka/AP harvest); tribal migration from hills to plains for seasonal work
URBAN-TO-URBAN (U-U)	Movement between cities; skilled professionals, transferable government/PSU jobs; corporate transfers	IT professionals moving Bengaluru-Hyderabad-Pune-Chennai; government employees transferred; management trainees joining companies in metro cities; less numerous than R-U but higher income mobility
URBAN-TO-RURAL (U-R)	Return migration to villages (counter-urbanisation); rare but observed during crises	COVID-19 reverse migration (March-May 2020): estimated 1-2 crore migrant workers returned to home states (Bihar, UP, Rajasthan, Odisha, Jharkhand) from cities when factories and construction sites shut; images of walking migrants became a defining image of India's COVID-19 crisis; Shramik Special Trains organised to facilitate return
INTERNAL MIGRATION	All migration within India; Census measures: Intra-district, Inter-district, Inter-state, and Intra-state migration	Inter-state migration = most studied; Bihar-UP to Maharashtra-Delhi-Gujarat is the dominant flow; Inter-district = largest category by volume (people moving within the same state for short-distance work or marriage)
INTERNATIONAL EMIGRATION	Indian citizens moving to other countries for work, study, or residence	Two streams: (a) Low-skilled/semi-skilled to Gulf countries (historically Kerala, now UP/Bihar/Rajasthan/AP/TN also); (b) Highly skilled/professionals to USA, UK, Canada, Australia, Europe (IT engineers, doctors, academics, students -- brain drain or brain gain depending on perspective)

PUSH AND PULL FACTORS OF MIGRATION

Factor Type	*PUSH Factors (why people leave)*	*PULL Factors (why people go to destination)*
Economic	Agricultural distress (low productivity, monsoon failure, debt, small landholdings in Bihar/UP with 0.3-0.5 ha average); unemployment; low wages in origin	Higher wages (Delhi construction worker earns 3-4x Bihar village wage); formal employment; diverse industries; entrepreneurial opportunities; better access to markets
Social	Caste discrimination; lack of social mobility; limited educational/career opportunities; dowry burden; domestic violence for women	Better social anonymity; merit-based opportunities (urban context more meritocratic); higher quality education; hospitals; better social services; escaping social constraints
Environmental	Droughts (Rajasthan, Bundelkhand); floods (Assam, Bihar Kosi belt); sea-level rise (Sundarbans islands); deforestation and forest loss reducing tribal livelihoods	Stable environment; irrigation and water security; lower disaster risk in destination
Forced/Conflict	Ethnic conflict (NE India; Manipur	Safety; peace; legal protection; refugee camps or

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	violence 2023 drove large-scale internal displacement); religious violence; partition; AFSPA-related insecurity	host communities
Marriage (female-specific)	Cultural norm of patrilocal marriage (bride moves to husband's house); the Census shows marriage as the most common reason for female migration	Husband's family location; better household conditions in destination; no explicit economic pull (female marriage migration is normative, not economic choice)

MAJOR MIGRATION CORRIDORS IN INDIA (CENSUS 2011)

Migration Corridor	*Volume / Significance*	*Key Characteristics*
Bihar / UP --> Delhi-NCR	Largest inter-state migration stream; estimated 30-40 lakh migrants from Bihar+UP in Delhi-NCR area	Construction, domestic workers, factory workers, small trade; Bihari and Bhaiyya communities form distinct enclaves; seasonal and permanent mix; remittances to Bihar via mobile money and bus/train cash transfers
Bihar / UP / Rajasthan --> Mumbai-Pune	Second largest stream; 20-30 lakh migrants from these states	Textile mills (declining), construction, domestic work, small trade, informal sector; Dharavi (Mumbai) = India's most famous slum = home to migrants from across India; Sion-Kurla area = UP-Bihar migrant hub
UP / Bihar / Rajasthan --> Surat (Gujarat)	Surat = one of India's fastest-growing cities due to: (a) diamond cutting and polishing industry (controlled by Saurashtra Patels but employs UP-Bihar-Rajasthan migrants); (b) Textile industry (power looms, saree manufacturing)	Estimated 6-8 lakh UP-Bihar migrants in Surat; social tensions periodically (2018 anti-UP riots in Surat after diamond industry slump); language-identity conflicts; COVID reverse migration hit Surat textile workers hardest
Bihar / UP / Odisha / NE --> Ludhiana-Jalandhar (Punjab)	Seasonal and semi-permanent for kharif and rabi harvesting; also Punjab's hosiery, bicycle, textile industries	Seasonal workers come for wheat harvest (April-May) and paddy transplanting (June-July); estimated 10-15 lakh workers seasonally; important for Punjab's agricultural economy which cannot function without migrant labour despite high-tech farming
All states --> Bengaluru, Hyderabad, Chennai, Pune	IT and tech industry professionals; construction workers; domestic workers; students	Bengaluru = India's fastest-growing large city in 2001-2011; 40%+ of Bengaluru residents were born outside Karnataka; Hyderabad (post-bifurcation = Telangana capital) = major IT hub; inter-state migrants face language and cultural integration challenges
Kerala --> Gulf Countries (UAE, Saudi Arabia, Kuwait, Qatar, Oman, Bahrain)	Approximately 2+ million Keralites work in Gulf countries; Gulf remittances = 30-35% of Kerala's GSDP	Kerala emigration culture since 1970s oil boom; nurses (Kerala trains 25%+ of India's nursing graduates), construction workers, professionals; "Gulf Malayali" as a cultural phenomenon; money sent home funds Kerala's housing boom and education

COVID-19 REVERSE MIGRATION AND ITS IMPACT (2020)

The **COVID-19 pandemic lockdown of March 24-May 31, 2020** triggered one of India's largest reverse migration

events since Partition. When PM Modi announced a nationwide lockdown with 4-hour notice, an estimated **1-2 crore migrant workers** in cities suddenly lost their jobs and income, were unable to pay rent, and began walking, cycling, or using any available transport to return to their home states. The images of thousands of migrants walking on highways became a defining image of the COVID lockdown.

COVID Migration Impact	***Detail***
Scale	Estimated 1-2 crore migrants displaced from cities; Shramik Special Trains (1,060 trains) transported 14.5 lakh workers between May 1-31, 2020; many walked hundreds of kilometres
Hardship	Workers who had been in Delhi, Mumbai, Surat, Ahmedabad found: no savings; no food; no shelter if they couldn't pay rent; landlords evicting; police harassment on roads; lack of registration in destination states made them ineligible for local food distribution (ration cards are issued for home state PDS)
Systemic exposure	The COVID crisis exposed the complete lack of social protection for India's ~50 crore informal sector workers; no formal employment, no PF, no ESI, no ration entitlement at destination, no housing security; the Migrant Labour problem became a national policy debate
Policy response	Atma Nirbhar Bharat package (May 2020) included: PM Garib Kalyan Ann Yojana (free grain at origin state); One Nation One Ration Card (ONORC) rolled out to enable migrants to use ration card in any state; Supreme Court intervened (suo moto) to direct states to provide transport, food, shelter to migrants
Post-COVID return	Many migrants returned to cities as industries reopened (August-November 2020); but some stayed in home states (took up MGNREGS work, started local businesses); MGNREGS demand peaked in 2020-21 (389 crore person-days) as returning migrants used it as income support

33.4 INTERNATIONAL MIGRATION -- INDIA'S DIASPORA AND REMITTANCES

India has the **world's largest diaspora** -- approximately **3.2 crore (32 million) people of Indian origin** living outside India (combining NRIs -- Non-Resident Indians -- and PIOs -- Persons of Indian Origin). The Indian diaspora is also the **world's most economically significant diaspora,** sending approximately **USD 125 billion in remittances to India in 2023** -- the largest remittance flow to any single country globally (World Bank 2024).

Diaspora Feature	***Detail***
Total size	~3.2 crore (32 million) combined NRI + PIO (UN Department of Economic and Social Affairs, 2020); India has sent the largest number of international migrants cumulatively of any country
Top destination countries	USA: ~4.5 million (largest, highest skilled, highest earners); UAE: ~3.5 million (largest in Gulf region; blue-collar + professional mix); Saudi Arabia: ~2.5 million; Kuwait, Oman, Qatar, Bahrain (Gulf countries collectively ~9 million); UK: ~1.8 million; Canada: ~1.5 million (fastest growing); Australia: ~0.8 million
Two streams	HIGH-SKILL stream: IT professionals (Hyderabad, Bengaluru, Pune, Chennai migrants to USA, UK, Canada, Australia); doctors (Indian-origin doctors = largest foreign medical graduate group in USA and UK); academics; students (India sends the most international students to USA annually in many years). LOW/MEDIUM-SKILL stream: construction workers, domestic workers, nurses to Gulf countries (Kerala, UP, Bihar, Rajasthan, AP, TN origin)
REMITTANCES	USD 125 billion (2023) -- world's largest; USD 100 billion (2022); growing at 12-15% per year; equal to ~3.3% of India's GDP; larger than India's FDI inflows; larger than India's total defence budget; states receiving most: Kerala (~USD 30 billion = 30-35% of state GSDP), Maharashtra,

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	UP, Tamil Nadu, Punjab; Telangana (growing rapidly with Hyderabad IT professionals)
Impact on source states	POSITIVE: poverty reduction; construction boom (Gulf money finances Kerala housing; UP/Bihar rural house construction); education funding; healthcare access; female empowerment (wives left behind often manage finances and gain independence); NEGATIVE: brain drain (best trained doctors, engineers, IT professionals leave); social disruption (left-behind families, abandoned wives); Gulf dependency (Kerala economy crashes when Gulf slows -- as in 2015-16 Gulf oil price crash)
Policy framework	Pravasi Bharatiya Divas (PBD): January 9 (day Mahatma Gandhi returned to India from South Africa in 1915); annual or biennial convention for diaspora engagement; e-Migrate portal (for GCC migrant worker registration); Pravasi Bharatiya Bima Yojana (PBBY) -- mandatory insurance for ECR category (Emigration Check Required) passport holders going to notified countries; Overseas Citizenship of India (OCI) card -- gives near-citizen rights except voting and government jobs; merged PIO card with OCI in 2015

33.5 LITERACY -- TRENDS, DISPARITIES AND POLICY

India's literacy journey from **18.33% (Census 1951)** to **74.04% (Census 2011)** represents one of the most remarkable expansions of human capability in the modern world. Yet in 2011, India still had approximately **31.3 crore illiterates** -- the world's largest absolute number -- primarily concentrated in UP, Bihar, and Rajasthan. Understanding literacy trends, gender gaps, and policy initiatives is essential for UPSC GS-2 and GS-3 aspirants.

LITERACY RATE TRENDS -- DECADAL PROGRESS

Census Year	*Overall Literacy*	*Male Literacy*	*Female Literacy*	*Gender Gap*	*Key Policy / Context*
1951	18.33%	27.16%	8.86%	18.30%	Near-total illiteracy at Independence; 82% of India could not read/write; limited schooling infrastructure
1961	28.30%	40.40%	15.35%	25.05%	Post-independence school expansion; still very low female literacy; expansion of elementary schools
1971	34.45%	45.96%	21.97%	24.00%	Slow progress; rural schools inadequate; female education still socially discouraged in many areas
1981	43.57%	56.38%	29.76%	26.62%	National Adult Education Programme (1978); pace of improvement slow; female literacy still very low
1991	52.21%	64.13%	39.29%	24.84%	National Literacy Mission (NLM) 1988; Total Literacy Campaigns in districts; female literacy improving
2001	64.83%	75.26%	53.67%	21.59%	Sarva Shiksha Abhiyan (SSA) for universal elementary education; mid-day meal scheme (1995) increasing enrolment; significant improvement
2011	74.04%	82.14%	65.46%	16.68%	Right to Education Act 2009 (RTE); gender gap narrowing; but 31.3 crore illiterates remain; highest absolute illiteracy in world
Projected (2021-22)	~77-80% (ASER, SRS estimates)	~85%	~72%	~13%	Census 2021 not conducted; ASER reports show mixed results on learning outcomes vs enrolment; NIPUN Bharat 2021; ULLAS 2022

STATE-WISE LITERACY DISPARITIES (CENSUS 2011)

Category	State	Literacy Rate	Female Literacy	Key Note
HIGHEST OVERALL	Kerala	94.0%	92.07%	Highest in India since 1991; among highest in any developing country; Ernakulam district = first district in India to achieve total literacy (1990 Total Literacy Campaign)
2nd Highest	Lakshadweep (UT)	92.28%	88.25%	Small island UT; high female literacy
3rd Highest	Mizoram	91.58%	89.27%	NE state; traditional Baptist Christian church emphasis on literacy; Mizo script; 19th century missionaries established schools
Lowest Overall State	Bihar	63.82%	53.33%	Lowest state literacy; despite progress, 4 crore+ Bihari citizens illiterate; Bihar's low literacy is a major constraint on development and fertility reduction
Lowest Female Literacy	Rajasthan	52.66% female	52.66%	Only state where female literacy is below 55%; patriarchal culture; girls pulled from school early for marriage; child marriage historically high (though declining)
Widest Gender Gap	Rajasthan	66.11% overall (male 79.19%, female 52.66%)	52.66%	Gender gap = 26.53 percentage points; most extreme gender literacy divide in India; Beti Bachao Beti Padhao and Rajasthan Saraswati Yojana targeting this
Best improvement 2001-11	Rajasthan, Bihar, UP, Jharkhand	10-12% improvement in decade	Largest gains in female literacy	High base of illiteracy paradoxically allows larger percentage gains; SSA and mid-day meal scheme driving enrolment in these states

KEY LITERACY PROGRAMMES AND SCHEMES

Programme	Period	Key Feature
National Literacy Mission (NLM)	1988-2009	First major adult literacy programme; Total Literacy Campaigns (TLCs) approach; mobilised volunteers; Ernakulam TLC (1990) = world's first district to achieve total literacy; by 2009, NLM had made ~12 crore persons literate
Saakshar Bharat	2009-12 (extended to 2017)	Successor to NLM; focused on 51 million adult non-literates, especially rural women aged 15+; target districts = those with <50% female literacy; 167 districts covered; achieved limited success vs targets
Sarva Shiksha Abhiyan (SSA) / PM POSHAN	2001 (SSA); 2021 renamed PM POSHAN	Universal Elementary Education; free and compulsory education for classes 1-8; mid-day meals (PM POSHAN) incentivising school attendance; dropout reduction; enrollment near universal for

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		primary (6-11 years); secondary retention still a challenge
Right to Education Act (RTE) 2009	2009 (came into force April 1, 2010)	Fundamental Right to free and compulsory education for ages 6-14 (Article 21-A inserted by 86th Amendment 2002; RTE Act 2009 operationalises it); private unaided schools must reserve 25% seats for economically weaker sections (EWS); neighbourhood school concept; no detention policy (since modified)
NIPUN Bharat (National Initiative for Proficiency in Reading with Understanding and Numeracy)	2021; target 2026-27	Foundational Literacy and Numeracy (FLN) for Classes 1-3; ensure all children can read and do basic arithmetic by end of Grade 3; NIPUN = skill target; major national initiative as ASER data showed only 50% of Grade 5 students could read Grade 2 text; NEP 2020 also emphasises FLN
ULLAS (New India Literacy Programme / NILP)	2022-27	Understanding Lifelong Learning for All in Society; successor to Saakshar Bharat; Rs.1,037.90 crore; target to make 5 crore non-literates literate in 5 years (2022-27); focuses on adults 15+ especially women, SC, ST, minorities; uses volunteer educators (Vidya Prerak); app-based and digital tools; "Jan Andolan" (mass movement) approach
National Education Policy (NEP) 2020	Approved July 2020	Comprehensive education reform: 5+3+3+4 school structure replacing 10+2; mother tongue instruction in early grades; flexibility in subject choices; vocational integration from Grade 6; emphasis on foundational literacy and numeracy (FLN/NIPUN); targets functional literacy for all by 2030; teacher training reform

33.6 CURRENT AFFAIRS HOOKS (2022-2025)

NFHS-5 (2019-21) -- TFR Below Replacement: The National Family Health Survey 5 (NFHS-5) released in 2021 confirmed India's TFR at 2.0 -- the first time in history at or below replacement level (2.1). Key concerning finding: Anaemia in women 15-49 years increased from 53.1% (NFHS-4) to 57.0% (NFHS-5) -- a reversal suggesting nutritional deficiency is worsening. NFHS-5 IMR = 35.2; under-5 mortality = 41.9. Institutional births increased to 88.6%.

One Nation One Ration Card (ONORC) -- Full Roll-out (2021): Following the COVID migrant crisis (2020), the ONORC scheme was rolled out to all states and UTs by 2021. By 2024, over 80 crore NFSA beneficiaries can access their PDS entitlement from ANY ration shop in India using Aadhaar authentication. This directly addresses the most critical welfare gap for inter-state migrants -- the inability to use their home-state ration card when working in a different state.

Manipur Violence and Internal Displacement (2023): Ethnic violence between the Meitei and Kuki-Zo communities in Manipur (starting May 3, 2023) caused one of India's largest post-Independence internal displacement events. Approximately 60,000-70,000 people were displaced within Manipur (relief camps in Imphal Valley and hill districts). Properties and churches destroyed; army and CRPF deployed. The crisis highlighted how ethnic conflict drives forced internal migration and long-term demographic change.

ULLAS -- New India Literacy Programme (2022-27): Launched 2022-23, ULLAS aims to make 5 crore non-literate adults literate by 2027. Uses a "Jan Andolan" (mass movement) approach involving community volunteers (Vidya Preraks), digital tools (DIKSHA platform), and convergence with PM POSHAN, MGNREGS, and SHG networks. The National Literacy Day (September 8) is used for annual campaign rallies. Early results: approximately 90 lakh adults registered and beginning literacy training as of 2024.

33.1 PYQ ANALYSIS -- CHAPTER 33 (2010-2025)

Source	Year	Marks	Question
UPSC Civil	2024	15M	"Critically examine India's demographic transition with reference to the TFR, IMR, and MMR data. What are the policy implications of the north-south fertility divide?"
UPSC Civil	2023	12M	"Discuss the causes, patterns, and socio-economic consequences of internal migration in India. What is the significance of One Nation One Ration Card?"
UPSC Civil	2022	10M	"Analyse the push and pull factors of migration in India. How has COVID-19 changed the understanding of migrant vulnerability in India?"
UPSC Civil	2021	12M	"India is the world's largest recipient of remittances. Discuss the significance of the Indian diaspora and remittances for the Indian economy."
UPSC Civil	2020	10M	"Discuss the trends in literacy in India from 1951 to 2011. What are the key factors explaining the gender gap in literacy?"
UPSC Civil	2019	10M	"Critically evaluate India's population policy since 1952. What are the arguments for and against a two-child policy?"
UPSC Civil	2018	12M	"Discuss the causes and consequences of rural-to-urban migration in India. What policy interventions are needed to manage urbanisation and migration better?"
UPSC Civil	2017	10M	"What are the main demographic indicators? Discuss the trends in IMR, MMR, and Life Expectancy in India since Independence."
IFoS GS	2024	10M	"Discuss the relationship between migration, deforestation, and forest cover change in India with specific reference to NE India and tribal regions."
IFoS GS	2023	10M	"Examine the environmental and ecological impacts of rapid urbanisation driven by rural-to-urban migration in India."
IFoS GS	2022	10M	"Discuss the relationship between female literacy, fertility rate, and environmental sustainability in India."

KEY NOTE

Frequency: Demographic transition + TFR + north-south divide (Civil 2024); internal migration + ONORC (Civil 2023); COVID reverse migration + vulnerability (Civil 2022); diaspora + remittances (Civil 2021); literacy trends + gender gap (Civil 2020); population policy + two-child (Civil 2019); R-U migration (Civil 2018); IMR + MMR + LEB trends (Civil 2017). IFoS: migration + deforestation NE India (2024), R-U migration urbanisation ecology (2023), female literacy + TFR + environment (2022). For 2025-26: NFHS-5 TFR 2.0 milestone + anaemia concern; ULLAS 5 crore target; ONORC post-COVID; Manipur displacement; India largest remittance recipient USD 125 billion (2023); two-child policy constitutional debate -- all high-priority.

33.8 MODEL BOOK

Critically examine the north-south fertility divide in India. What are the policy implications of states having very different TFRs?

UPSC Civil (Mains) | 15 Marks | 210 Words

India's national TFR of 2.0 (SRS 2020 / NFHS-5) -- at or below replacement level for the first time in history -- masks one of the most consequential demographic asymmetries in the world: the north-south TFR divide. Some states have completed demographic transition while others are still in Stage 2 of population growth, and this divide has profound economic, political, and social implications.

THE DIVIDE -- DATA:

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HIGH-TFR North: Bihar (3.0), UP (2.7), Rajasthan (2.5), MP/Jharkhand (~2.3); the BIMARU+J states are still significantly above replacement and driving virtually all of India's national population growth.

LOW-TFR South: Tamil Nadu (1.6), Kerala (1.7), Delhi (1.6), Andhra Pradesh (1.7), Karnataka (1.8); below replacement since the 1990s-2000s; facing aging population concerns rather than growth concerns.

CAUSES OF THE DIVIDE:

1. **Female literacy:** Kerala female literacy = 92%; Bihar female literacy = 53%; the single strongest predictor of fertility -- educated women marry later, space children, and have more agency to refuse additional pregnancies.
2. **Female Labour Force Participation (FLFP):** South India's higher FLFP means women have economic alternatives to full-time motherhood; economic opportunity cost of each additional child is higher.
3. **Healthcare access:** Institutional delivery 98% in Kerala vs 68% in UP (NFHS-5); Kerala's ASHA-ANM network is vastly more effective; better family planning counselling and access to contraception.
4. **Urbanisation:** South India is more urbanised; urban TFR is uniformly lower than rural; Chennai, Bengaluru, Hyderabad have near-European fertility rates.
5. **Historical culture and reform:** Kerala's matrilineal Nair tradition; Travancore-Cochin's early female education; Tamil Nadu's Dravidian movement emphasis on social reform; contrasts with Rajasthan-UP patriarchal systems, purdah, early marriage.

POLICY IMPLICATIONS:

1. **Delimitation (Political):** The post-2031 Census delimitation will increase Lok Sabha seats for high-TFR states (UP and Bihar may gain 15-20 seats together) while low-TFR states (TN, Kerala) may lose proportional representation. South India (which has contributed most to India's demographic transition success) will be politically penalised for that success -- a deeply problematic dynamic.
2. **Federal finance (Economic):** Finance Commission devolution formula that includes population as a factor will transfer more resources to high-population northern states, which low-TFR states see as a "reward for failure to control population."
3. **Migration necessity:** Kerala faces labour shortages in construction and domestic work (compensated by NE India and Bengal migrants to Kerala); Tamil Nadu faces similar issues. The surplus young workers of Bihar and UP will need to migrate southward -- making north-south migration integration politically and culturally important.
4. **Aging in the South:** Tamil Nadu and Kerala already have 15-22% of population above 50 years; healthcare systems must prepare for a massive aging population surge; elderly care burden; pension systems.

BIMARU Investment Imperative: The highest-impact policy intervention for the north-south divide remains: female education (especially secondary and higher), women's economic empowerment, and improving reproductive healthcare access in UP, Bihar, Rajasthan, and MP. Mission Parivar Vikas (146 high-TFR districts targeted) is the current focused effort.

India's north-south TFR divide is not merely a health statistic -- it is a political earthquake in slow motion. If unchecked, it will shift political power northward (where governance is weaker) and create labour deficits in the economically more dynamic south. Managing this divergence through education, employment, and judicious migration policy is one of India's most complex governance challenges of the next 25 years.

Discuss the causes, patterns and consequences of internal migration in India. What does the COVID-19 crisis reveal about migrant workers' vulnerability?

UPSC Civil (Mains) | 12 Marks | 170 Words

Census 2011 counted 45.36 crore migrants -- 37.5% of India's population. India's internal migration is one of the largest migration systems in the world, fundamentally reshaping both source and destination regions.

CAUSES -- PUSH AND PULL:

Push (Origin): Agricultural distress (farm fragmentation -- Bihar average 0.4 ha); drought and floods (Bundelkhand, Assam Brahmaputra plain); unemployment; caste discrimination; low wages.

Pull (Destination): Higher wages (Delhi construction = 3-4x Bihar farm wage); diverse employment in informal sector; urban services (hospitals, schools); anonymity enabling social mobility.

PATTERNS AND STREAMS:

1. **Source states:** Bihar, UP, Rajasthan, Odisha, Jharkhand, MP -- high out-migration states driven by agricultural poverty.
2. **Destination states:** Maharashtra (Mumbai-Pune), Delhi-NCR, Gujarat (Surat, Ahmedabad), Punjab (Ludhiana), Karnataka (Bengaluru) -- industrialised, high-wage destinations.
3. **Gender:** Males migrate primarily for WORK; females migrate primarily for MARRIAGE (by Census definition -- most female migration is to husband's village; significant female work migration is undercounted in Census methodology).
4. **Duration:** Seasonal (harvest workers, Diwali construction rush); circular (alternate between city and village); permanent.
5. **Major corridors:** Bihar/UP to Delhi-NCR (construction, domestic, trade); Bihar/UP to Mumbai (construction, textile, service); UP/Bihar/Rajasthan to Surat (diamond, textile); Bihar/UP to Punjab (harvest labour); All India to Bengaluru/Hyderabad (IT + construction).

CONSEQUENCES:

1. **Source states:** Remittances (Bihar received ~Rs.20,000 crore in remittances from migrants); reduction of rural poverty; left-behind families (women managing household alone); "feminisation of agriculture" as women take over farming; social disruption; brain drain of educated youth.
2. **Destination cities:** Labour supply for construction, domestic work, factories, gig economy; slum growth (50%+ of Mumbai's population in informal settlements); pressure on civic infrastructure; social tensions (Marathi Manoos vs Bihari migrants; Gujaratis vs UP workers in Surat).

COVID-19 and Migrant Vulnerability: The March 2020 lockdown stripped away the illusion that India's economy functions with social protection. When factories shut overnight, ~2 crore migrant workers had no savings, no ration entitlement in destination state (ration cards issued by home state), no formal employment record (they work in informal sector), and no employer to protect them. Images of families walking hundreds of kilometres -- some dying on the highway -- revealed: (a) Zero social security for 50 crore informal workers; (b) Ration card portability gap (ONORC scheme since fixed this); (c) Lack of data on migrants at district level making relief targeting impossible; (d) Migrant children not in local school records.

Policy Response and Lessons: ONORC (One Nation One Ration Card) -- the single most important migrant welfare reform: portability of ration entitlement nationally. Also: e-Shram portal (registering informal workers), PM Shram Yogi Maandhan Yojana (pension for informal workers), Building and Other Construction Workers (BOCW) welfare fund (construction workers' welfare -- poorly implemented but exists). The fundamental fix: formalisation of employment (PM's vision of 1 crore formal jobs/year under Atmanirbhar Bharat).

Internal migration in India is simultaneously an economic necessity (source of GDP growth, poverty reduction via remittances), a social phenomenon (marriage migration, identity transformation), and a governance challenge (social protection portability, urban infrastructure, conflict management). COVID-19 was a stress test that revealed deep systemic failures in India's social protection architecture for its most mobile and most vulnerable workers.

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CHAPTER 34

URBANISATION & MAJOR CITIES

Urban Growth, Metropolitan Areas, Smart Cities & Urban Challenges

CHAPTER AT A GLANCE

- URBANISATION DATA (Census 2011): Urban Population = 37.71 crore (31.16% of India). Number of Urban Agglomerations (UAs) and Towns = 7,935 (Census 2011; up from 5,161 in 2001). Million-plus cities = 53 (cities with population above 10 lakh). Megacities (above 40 lakh) = 8: Mumbai, Delhi, Kolkata, Chennai, Bengaluru, Hyderabad, Ahmedabad, Pune. India is expected to cross 50% urbanisation by 2047-50 (UN estimate).
- DEFINITION: Census of India defines an URBAN AREA as: (a) All statutory places with municipality, corporation, cantonment board or notified area council; OR (b) Places satisfying all three criteria: (i) population >= 5,000; (ii) at least 75% of male working population in non-agricultural occupations; (iii) population density >= 400 persons/sq km. These are called "Census Towns" when they meet criteria (b) but are not statutory towns.
- METROPOLITAN AREAS (Top Cities): 1. Delhi NCR: ~3.2 crore (UA 2011; estimated 3.5 crore+ by 2024); 2. Mumbai UA: ~2.07 crore (2011); 3. Kolkata UA: ~1.42 crore; 4. Chennai UA: ~87 lakh; 5. Bengaluru UA: ~84 lakh (fastest growing major city 2001-2011); 6. Hyderabad UA: ~77 lakh; 7. Ahmedabad UA: ~63 lakh; 8. Pune UA: ~50 lakh. These 8 megacities contain approximately 25% of all urban India population.
- URBANISATION PATTERN: India's urbanisation is characterised by: (1) PRIMACY -- excessive concentration in a few large cities (Delhi, Mumbai dominate); (2) GROWING MEDIUM TOWNS -- smaller cities (1-10 lakh) growing faster than megacities in many states; (3) CENSUS TOWNS -- a new category that grew dramatically 2001-2011 (from 1,362 to 3,894 Census Towns; many are actually large rural settlements reclassified); (4) PERI-URBAN SPRAWL -- metros expanding into surrounding areas (NCR; MMR; Bengaluru-Mysuru corridor); (5) COASTAL URBANISATION -- port cities and coastal tourism driving fast growth.
- SMART CITIES MISSION (2015): PM Modi; 100 cities selected through "Challenge Method" (competition); Rs.2.05 lakh crore investment (central + state + ULB); aims for: core infrastructure (water 24x7, sanitation, power, mobility), Smart IT management (integrated command and control centres -- ICCCs), citizen participation. 100 cities include: Bhopal, Indore, Pune, Ahmedabad, Surat, Kochi, Chandigarh, Visakhapatnam, Bhubaneswar (first city selected), Coimbatore, Jabalpur, Gwalior. Critics: "island of excellence" -- improving small parts of cities while neglecting larger areas.
- PM AWAS YOJANA (URBAN): Housing for All by 2022 (since extended); target 1.12 crore urban houses for EWS/LIG beneficiaries; 4 components: (1) In-situ slum redevelopment; (2) Credit Linked Subsidy Scheme (CLSS) -- interest subsidy for home loans; (3) Affordable Housing in Partnership (AHP); (4) Beneficiary-Led Construction (BLC). By 2024: ~1 crore houses sanctioned, ~80 lakh completed; largest affordable housing programme in India's history.
- URBAN CHALLENGES: (1) Slums: 65.49 million (6.5 crore) slum dwellers in India (Census 2011; 17.4% of urban population); Maharashtra has most absolute slum dwellers (11.8 million); Dharavi (Mumbai) = Asia's largest slum with 700,000-1 million people in 2.1 sq km. (2) Urban transport: gridlock; 8 cities with metro rail (Delhi, Mumbai, Bengaluru, Kolkata, Chennai, Hyderabad, Kochi, Ahmedabad); PM e-Bus Sewa. (3) Water crisis: cities drawing from shrinking groundwater tables; Day Zero fears for several cities. (4) Air pollution: Delhi = one of world's most polluted cities in winter.
- AMRUT (Atal Mission for Rejuvenation and Urban Transformation): 2015 (AMRUT); AMRUT 2.0 (2021-26, Rs.2.99 lakh crore); 500 cities with population above 1 lakh; water supply, sewerage, green spaces, urban transport; 100% coverage of water and sewerage in all AMRUT cities by 2026 target. SBM-U (Swachh Bharat Mission Urban): ODF (Open Defecation Free) status achieved by 4,320+ cities; toilet construction; solid waste management; SBM-U 2.0 (2021-26) targets total sanitation and solid waste management.

34.1 INTRODUCTION -- INDIA'S URBAN TRANSITION

India is in the midst of the largest urban transition in human history -- not the fastest (China urbanised much faster in the 1990s-2010s) but the largest in absolute numbers. Adding approximately **25-30 million urban residents every year** (equivalent to adding a city the size of Delhi every 3-4 years), India's urban population will reach approximately **600 million by 2031** and cross **50% of total population by 2047-50.** Managing this urbanisation -- ensuring that cities provide jobs, housing, clean water, clean air, and dignity to their residents -- is among India's most complex governance challenges.

India's urbanisation is unique in several ways: it is **slower than expected** given India's level of economic development (India is only 31.16% urban at ~USD 2,500 per capita income -- other countries reached this income level at 50-60% urbanisation); it is **geographically uneven** (megacities grow but many small towns stagnate); it is **informality-driven** (most urban jobs are in the informal sector; most urban housing is self-built or slum); and it is producing **severe environmental stress** (air pollution, groundwater depletion, heat island effect) in major cities.

DEFINING URBAN IN INDIA

Urban Definition Type	*Criteria*	*Example*
Statutory Towns (Urban Local Bodies -- ULBs)	All places with a municipality, city corporation (Nagar Nigam), town committee, cantonment board, or notified area committee regardless of population or density	Mumbai Municipal Corporation (BMC); Delhi Municipal Corporation; even small towns with a municipality are "urban" regardless of their character
Census Towns	Places NOT covered by a municipal body BUT satisfying ALL THREE: (1) Population >= 5,000; (2) At least 75% of male working population employed in non-agricultural occupations; (3) Population density >= 400 persons/sq km	Peri-urban villages near major cities that have functionally become urban (shops, non-farm jobs, density) but have not been given municipal status; Census 2011 showed massive jump in Census Towns (1,362 in 2001 to 3,894 in 2011) -- much of India's urban growth was actually reclassification of large villages
Urban Agglomeration (UA)	A city with its continuous urban spread beyond municipal limits + outgrowths -- all counted together as one UA	Mumbai UA (includes BMC area + Thane + Navi Mumbai + suburban extensions); Delhi UA (includes Delhi + NDMC + Delhi Cantonment + parts of NCR beyond Delhi boundary in Census terms)
Metropolitan Area / Megacity	Colloquially: city agglomeration above 10 lakh = million city; above 40 lakh = megacity; above 1 crore = mega-metro	Delhi NCR (~3.2 crore UA 2011 = mega-metro); Mumbai UA (~2.07 crore); Kolkata UA (~1.42 crore) = also mega-metro

34.2 URBANISATION TRENDS -- HISTORICAL AND CURRENT

Census Year	*Urban Population*	*% Urbanisation*	*No. of Urban Areas*	*Key Event / Context*
1901	2.58 crore	10.84%	1,827	Pre-Independence low baseline; largely trade and administrative towns; limited industrial urbanisation

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1941	4.45 crore	13.86%	2,250	Wartime urbanisation (WWII industrial expansion); Bombay, Calcutta textile and jute mills growing
1951	6.23 crore	17.29%	2,843	Post-Partition urbanisation; Lahore, Karachi lost to Pakistan; Delhi/Amritsar gained refugees; Nehru's planned industrial cities (Chandigarh, Bhilai, Rourkela, Durgapur)
1971	10.91 crore	19.91%	3,060	Post-Green Revolution; rural income rise; some migration to cities; Maharashtra and Gujarat industrialisation
1981	15.94 crore	23.34%	3,378	Industrial expansion; Bombay and Calcutta peak; New Bombay/Navi Mumbai planned as satellite city
1991	21.75 crore	25.72%	3,768	Economic liberalisation beginning; IT sector seeds being sown in Bengaluru; service economy emerging
2001	28.61 crore	27.81%	5,161	IT boom; Bengaluru, Hyderabad, Pune, Chennai becoming tech hubs; BPO sector; new middle class
2011	37.71 crore	31.16%	7,935	Fastest absolute increase in any decade (9.1 crore added); Census Towns tripled (1,362 to 3,894); 53 million-plus cities; 8 megacities
2031 (projected)	~60 crore	~40%	--	UN projection; Smart Cities, AMRUT, PM Awas driving planned urban growth; NCR, MMR, Bengaluru-Chennai corridor as mega-urban regions

KEY NOTE

Key Urban Transitions -- 2001 to 2011 Decade: The 2001-2011 decade showed the most dramatic urban change in India's recorded history: (a) Urban population added = 9.1 crore -- the largest absolute addition in any decade; (b) Number of urban areas jumped from 5,161 to 7,935 (+2,774 new urban areas -- primarily Census Towns reclassified from large villages); (c) 53 million-plus cities vs 35 in 2001; (d) 8 megacities (above 40 lakh) vs 5 in 2001. Importantly, much of India's measured "urbanisation" in 2001-2011 was reclassification of settlements rather than actual migration -- large villages that crossed the Census Town threshold were counted as "new urban areas," inflating the urban count.

34.3 INDIA'S MAJOR CITIES -- PROFILE AND SIGNIFICANCE

DELHI -- NATIONAL CAPITAL AND LARGEST CITY

Feature	*Detail*
Population	UA 2011: 1,67,53,235 (1.68 crore); NCT of Delhi (political) = 1.68 crore; NCR (National Capital Region) planning area = 3.2 crore+ (2011); by 2024 estimated 3.5-4.0 crore making it world's 2nd largest urban agglomeration after Tokyo (37 million)
Economic character	India's largest service economy city; central government, PSUs, defence services HQ; retail and wholesale trade hub for North India; IT parks in Gurugram (Gurgaon) and Noida (UP); Delhi-NCR = India's largest metropolitan economy

Urban sprawl	NCR covers 4 states: NCT Delhi + Haryana (Gurugram, Faridabad, Ghaziabad, Sonipat, Panipat, Rohtak, Rewari, Bahadurgarh) + UP (Noida, Greater Noida, Ghaziabad, Meerut, Hapur) + Rajasthan (Alwar, Bharatpur); planned under NCR Planning Board
Pollution crisis	Delhi consistently ranks among world's most polluted cities (AQI peaks >500 in winter); causes: (a) Stubble burning (Punjab-Haryana Oct-Nov); (b) Vehicle emissions (1.3 crore+ registered vehicles); (c) Construction dust; (d) Cold weather trapping pollutants (temperature inversion); (e) Power plant emissions; GRAP (Graded Response Action Plan) scheme; odd-even car rationing; artificial rain (cloud seeding) attempts; Supreme Court-mandated environment protection measures
Urban transport	Metro: Delhi Metro Rail Corporation (DMRC) -- 349 km (2023; world's 6th largest metro network); 9 colour-coded lines; ~60 lakh daily ridership; Phase 4 expansion underway. Road: BRTS (Bus Rapid Transit System) largely failed; DTC buses; Ring Road and expressways; NH 48 (Delhi-Mumbai) passes through NCR. Airport: Indira Gandhi International Airport (IGIA) -- busiest in India (7.5 crore+ passengers/year); Terminal 3 (T3)
Key issues	Water: Yamuna river = one of world's most polluted urban rivers (black, toxic, frothy); Delhi's water supply crisis (DJB -- Delhi Jal Board; acute water stress in summer; 40% non-revenue water loss); Land: DDA (Delhi Development Authority) manages land; inadequate housing drives slum growth; 49+ unauthorised colonies regularised; JJ (Jhuggi-Jhopdi) clusters = 1.8 million slum dwellers

MUMBAI -- FINANCIAL CAPITAL

Feature	*Detail*
Population	UA 2011: 2,07,48,395 (2.07 crore); Greater Mumbai (BMC area) = 1.24 crore; Mumbai Metropolitan Region (MMR) = ~2.07 crore + suburbs; by 2024 estimated 2.2-2.3 crore (slowing growth vs Bengaluru)
Economic character	India's financial capital: Bombay Stock Exchange (BSE, 1875 -- Asia's oldest stock exchange); National Stock Exchange (NSE, 1992); Reserve Bank of India HQ; SEBI HQ (temporarily shifted to Delhi but functionally Mumbai); largest corporate HQ concentration; film industry (Bollywood; 1,000+ Hindi films/year; Rs.18,000+ crore industry); port and international trade; largest MIDC (Maharashtra Industrial Development Corporation) industrial zones
Unique geography	Built on 7 islands originally (Bombay = Portuguese corruption of "Bom Bahia" = good bay); islands progressively reclaimed and connected; Nariman Point, BKC (Bandra-Kurla Complex), Dharavi all on reclaimed/low-lying land; highly vulnerable to storm surges (July 26, 2005 floods killed 1,094 people); sea-level rise threat
Dharavi	Asia's (previously "world's") largest slum in 2.1 sq km between Mahim and Sion; estimated 700,000-1 million residents; annual turnover of economic activity estimated at USD 1 billion+ (leather, pottery, recycling, garments -- informal industries); Dharavi Redevelopment Plan (Adani Group selected 2022 as developer; Rs.20,000 crore project; will rehouse slum dwellers in free apartments; critics concerned about displacement and loss of existing livelihood ecosystems)
Urban transport	Mumbai Suburban Railway (CST/Western/Harbour lines): 3 lines; 7.5 million daily passengers = world's busiest commuter rail system; Metro: Mumbai Metro (operational: Lines 1, 2A, 7; Lines 3, 6, 9 under construction); Mumbai-Pune Expressway and Mumbai-Ahmedabad National High Speed Rail Corridor (NHSRC/Bullet Train) under construction
Key issues	Housing: 42% of Mumbai's population lives in slums (Census 2011); chronic housing deficit; high real estate prices (Nariman Point commercial area = among world's most expensive per sq ft);

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	Water: Brimstowad drainage upgrade (Rs.6,000 crore) to handle extreme rainfall; Mumbai faces coastal flooding risk

OTHER MAJOR METROPOLITAN CITIES

City	UA Population (2011)	Economic Character	Key Feature / Issue
Kolkata	1,41,12,536 (1.41 crore)	Traditional trade and jute hub; second-oldest IT cluster; port logistics; creative economy; education (Presidency University, JU, IIT-Kgp nearby)	Once India's largest city (until 1990s); now declining in relative rank; population growth slower than western and southern metros; Howrah Bridge (1943; cantilever suspension; 100,000 vehicles/day); Kolkata Metro = India's first metro (1984; officially 1991 full service); Kolkata is India's most walkable major city with dense tram network (150-year-old); aging infrastructure challenge
Chennai	86,96,010 (87 lakh)	India's "Detroit" -- automobile manufacturing (Hyundai, Ford, BMW, Nissan, Renault, Daimler trucks); IT/ITES (OMR -- Old Mahabalipuram Road = "Rajiv Gandhi Salai"); health tourism (Apollo Hospitals originated here); film industry (Tamil cinema)	Water crisis: Chennai "Day Zero" June 2019 (city reservoirs completely dried up; water trucked in); excessive groundwater extraction; erratic NE monsoon; Ponneri lake restoration; Cauvery water dependency; 2021 floods (NE monsoon + cyclone Nivar); Cyclone vulnerability (Bay of Bengal cyclone belt)
Bengaluru	84,99,399 (85 lakh)	India's Silicon Valley / IT capital; Electronic City, Manyata Tech Park, Whitefield; Infosys, Wipro, TCS, IBM, Microsoft, Amazon, Google India HQ; HAL (Hindustan Aeronautics Ltd), ISRO headquarters; fastest-growing major city in India 2001-2011 (+49%)	Water crisis: Bengaluru ground zero for India's urban water crisis; Cauvery water allocation limited (Karnataka-TN dispute); 10,000+ bore wells; water table declining; lakes dying (from 262 lakes in 1960s to 81 in 2023); startup ecosystem No. 1 in India (5th globally by Startup Genome); severe traffic congestion (4th worst globally, Tomtom 2023); Namma Metro expanding
Hyderabad	77,49,334 (77 lakh)	HITEC City (Hyderabad Information Technology Engineering Consultancy City); Genome Valley (biotech); Pharma City (world's largest pharmaceutical manufacturing cluster -- Genome Valley + Hyderabad Pharma City combined); Fab City (semiconductor); defence	Post-bifurcation capital controversy: Hyderabad = capital of both Telangana AND residuary Andhra Pradesh for 10 years (2014-2024) -- AP was to get its own capital (Amaravati, Andhra Pradesh capital city development controversy; Jagan Reddy cancelled Amaravati project then revived it); Osman Sagar and Himayat Sagar = lake reservoirs for water; Hussain Sagar lake

		electronics (DRDO, BDL)	in city centre; Pearl City; biryani culture
Ahmedabad	63,57,693 (64 lakh)	Textiles (historic "Manchester of India" -- though mills mostly defunct now); diamond cutting and polishing (Surat is bigger for diamonds); chemical and pharmaceutical industry; Sabermatic City; GIFT City (Gujarat International Finance Tec-City) -- first IFSC in India (2015); Dholera SIR (Special Investment Region)	UNESCO World Heritage City (2017) -- India's first UNESCO Heritage City; walled city with "pols" (traditional neighbourhood clusters); Sabarmati Ashram (Gandhi heritage); Sabarmati Riverfront Development (12 km beautified urban river front); Metro Phase 1 operational; extremely hot summers; AC adoption; urban heat island; BRTS (Bus Rapid Transit System) relatively successful
Pune	50,49,968 (50 lakh)	Automobile (Tata Motors, Bajaj Auto, Force Motors, Mahindra); IT (Hinjewadi IT Park; Infosys, Wipro, IBM); education hub (Pune University, Symbiosis, Fergusson College); defence (College of Military Engineering, Armoured Corps Centre and School)	Fastest-growing city for urban sprawl (merging with Mumbai region to form a mega-corridor); Deccan Plateau location at ~560 m altitude = pleasant climate vs Mumbai; massive peri-urban expansion; PMC (Pune Municipal Corporation) + PCMC (Pimpri-Chinchwad) as twin cities; Poona reflected in Bollywood as the "intellectual Maharashtra city"

34.4 URBAN CHALLENGES -- THE DARK SIDE OF URBANISATION

SLUMS

India's **6.5 crore slum dwellers** (Census 2011 -- 65.49 million; 17.4% of total urban population) represent one of the most urgent human development challenges. Slums are characterised by: inadequate housing (kutcha or semi-pucca structures), lack of piped water supply, lack of sanitation (open defecation, inadequate toilets), insecure tenure (threat of eviction), and inadequate waste management. Yet slums are also **economic engines** -- Dharavi's USD 1 billion+ annual economy, Surat's diamond workshops, Delhi's manufacturing clusters -- that provide essential goods and services to urban economies.

Slum Challenge	*Scale / Data*	*Policy Response*
Slum population	6.5 crore (Census 2011); 17.4% of urban population; states with most slum dwellers: Maharashtra (1.18 crore), AP (1.04 crore), WB (1.1 crore), UP (0.73 crore), Rajasthan (0.44 crore)	PM Awas Yojana-Urban (PMAY-U): targets 1.12 crore urban houses for EWS/LIG by 2024; In-situ slum redevelopment component; ~1 crore houses sanctioned by 2024
Sanitation deficit	40-50% of India's urban population had no access to individual household toilets (Census 2011); open defecation in cities contributing to disease burden and dignity violation, especially for women	Swachh Bharat Mission-Urban (SBM-U): 10 lakh+ individual household latrines (IHHLs) + community and public toilets (CPTs/PTs); ODF status declared by 4,320+ cities; SBM-U 2.0 (2021-26) targeting total sanitation and solid waste management
Water access	43% of India's urban households without piped water supply within premises (Census 2011); most urban poor and	AMRUT (Atal Mission for Rejuvenation and Urban Transformation): 500 cities; water and sewerage infrastructure; AMRUT 2.0 (2021-26): target 100%

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	slum dwellers dependent on tanker water, public standposts, or polluted groundwater	water supply coverage in all AMRUT cities; Jal Jeevan Mission Urban
Urban poverty	Urban poverty rate ~7.5% (Tendulkar method); in absolute terms = ~2.8 crore urban poor; urban homeless = estimated 10-15 lakh (Night Shelter Scheme for urban homeless)	National Urban Livelihoods Mission (NULM / DAY-NULM -- Deendayal Antyodaya Yojana NULM): skill development, SHG formation, vendor market support, shelter for homeless
Eviction and tenure	Approximately 6.5 crore slum dwellers live in insecure tenure (only ~49% of slum households in notified slums; rest in non-notified/unrecognised slums with higher eviction risk)	PM Awas Yojana In-situ slum redevelopment; Delhi Slum Rehabilitation Authority; Dharavi Redevelopment (Adani 2022); JNNURM predecessor had Basic Services to Urban Poor (BSUP) for slum upgrading

URBAN AIR POLLUTION

Urban air pollution is India's most visible and politically charged urban environmental crisis. India has **21 of the world's 30 most polluted cities** by PM2.5 annual average (IQAir World Air Quality Report 2023), with Delhi, Gurugram, Faridabad, Noida, and Ghaziabad consistently in the top 5-10 most polluted cities globally. The health burden is enormous: air pollution kills an estimated **1.6-2 million Indians annually** (IHME data), making it India's 2nd largest risk factor for premature death after malnutrition.

Source of Urban Air Pollution	*Contribution (Delhi, winter, approximate)*	*Policy Response*
Crop residue burning (Punjab-Haryana)	25-35% of PM2.5 in Delhi winter (October-November); stubble burning from paddy harvest in Punjab and Haryana	GRAP (Graded Response Action Plan): tiers of actions based on AQI levels; Pusa Decomposer (IARI biodecomposer for stubble); Happy Seeder (mechanisation); compensation to farmers to not burn; limited success to date
Vehicular emissions	20-30% year-round; Delhi has 1.3 crore+ registered vehicles; India adopted BS-VI (Bharat Stage VI = Euro 6 equivalent) emission standards from April 2020 for all new vehicles	Odd-Even scheme (Delhi, seasonal); EV push (Delhi EV Policy 2020 -- target 25% EVs by 2024); DTC electric bus fleet; FAME II scheme for EVs nationally; NCR clean fuel zone
Industrial and construction dust	15-25%; massive construction activity in NCR (infrastructure, housing, highways)	Construction dust control: sprinklers mandatory; green net on buildings; anti-smog guns; periodic construction halts during extreme AQI
Power plants	10-20%; coal-fired power plants near NCR (Jhajjar, Badarpur -- now closed, Dadri)	Badarpur Thermal Power Station (Delhi) closed permanently 2018; NTPC and state plants required to install Flue Gas Desulphurisation (FGD) systems
Biomass burning and firecrackers	5-15% (spikes on Diwali night: AQI crosses 1000 in some Delhi areas)	SC-mandated firecracker ban/restrictions in Delhi; "green crackers" policy (limited enforcement)

URBAN WATER CRISIS

Multiple Indian cities face an acute and worsening urban water crisis -- driven by population growth, groundwater overextraction, climate variability (extreme rainfall events alternating with droughts), inadequate water infrastructure, and very high water losses in distribution networks (non-revenue water = 30-60% in most

Indian cities).

City	Water Challenge	Scale / Event
Chennai	Demand outstrips supply; extreme dependence on 4 reservoirs (Chembarambakkam, Red Hills, Poondi, Sholavaram); variable NE monsoon	June 2019 "Day Zero": all 4 reservoirs at near-zero capacity; water tankers at Rs.3,000/trip; offices asked to work from home; apartments drilling illegal bore-wells; Chennai Metrowater (CMWSSB) in crisis
Bengaluru	Over 10,000 bore-wells; lakes disappearing (81 lakes in 2023 vs 262 in 1960s); Cauvery water limited (Karnataka-TN dispute)	Predicted "Day Zero" risk by 2025-2030; IISc study projected Bengaluru faces severe water stress; groundwater 400+ feet deep in many areas; BWSSB (Bengaluru Water Supply and Sewerage Board) supplies only 50% of Bengaluru's needs; rest from groundwater
Delhi	Yamuna water + Ganga Canal + groundwater; 40% NRW (Non-Revenue Water = leakage + theft)	Delhi Jal Board (DJB) under political controversy; water tanker mafia; supply inequity (south Delhi gets 200+ lpcd; JJ clusters get 20-30 lpcd); Yamuna river Delhi stretch = virtually dead river (fecal coliform 3,500x safe limit at some monitoring points)
Hyderabad	Musi River pollution; Krishna and Godavari water; rapid urbanisation exceeding supply	Hyderabad Disaster Risk Management; new Godavari water pipeline; Musi Riverfront Development project to clean and beautify the Musi (the river was badly polluted by pharmaceutical and dye industries)

34.5 URBAN POLICY -- KEY MISSIONS AND SCHEMES

Scheme / Mission	Year	Target Cities	Budget	Key Feature
JNNURM (Jawaharlal Nehru National Urban Renewal Mission)	2005-2014	65 large cities (mission cities)	Rs.66,000 crore	First major urban renewal programme; two sub-missions: Basic Services to Urban Poor (BSUP) and Urban Infrastructure and Governance (UIG); criticism: city plans required but planning capacity weak; large fund underutilisation
Smart Cities Mission (SCM)	June 2015	100 cities (Challenge selection over 4 rounds)	Rs.2.05 lakh crore (central + state + ULB contribution)	Unique feature: CHALLENGE METHOD -- cities competed; presented city improvement plans (SCP); 100 selected. Pan-city and Area-Based Development (ABD). Integrated Command and Control Centres (ICCCs) = nerve centres with real-time city data. Bhubaneswar = first city selected. Indore = most successful implementation (also India's cleanest city 7 consecutive years in Swachh Survekshan). Criticism: "island of excellence" -- only ABD zone improved, rest neglected
AMRUT (Atal Mission for	June 2015 (AMRUT	500 cities (>1 lakh	AMRUT 1.0: Rs.50,000	Water supply, sewerage, stormwater drains, urban transport, green spaces. AMRUT 2.0

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Rejuvenation and Urban Transformation)	1.0); October 2021 (AMRUT 2.0)	population) for AMRUT 1.0; all ULBs for AMRUT 2.0	crore; AMRUT 2.0: Rs.2.99 lakh crore	targets: 100% water supply coverage; 100% sewerage coverage in all AMRUT cities; waterlogging free cities; clean rivers in cities; urban forestry
Smart Cities Mission -- ICCC	2015-2023	100 Smart Cities	Part of SCM budget	Integrated Command and Control Centres: single platform integrating traffic management, flood monitoring, power outage, crime tracking, solid waste management, public address system; Surat ICCC managed COVID monitoring (city surveillance + health data integration)
PM Awas Yojana -- Urban (PMAY-U)	June 2015	All urban areas (ULBs)	Rs.2.03 lakh crore	Housing for All by 2022 (extended); 1.12 crore houses sanctioned; 4 components: (1) In-situ slum redevelopment (ISSR) using land as resource; (2) Credit Linked Subsidy Scheme (CLSS) -- interest subsidy 3-6.5% for home loans; (3) Affordable Housing in Partnership (AHP); (4) Beneficiary-Led Construction/Enhancement (BLC/BLE)
Swachh Bharat Mission -- Urban (SBM-U)	2014 (1.0); 2021 (2.0)	All ULBs	Rs.1.41 lakh crore (SBM-U 2.0)	SBM-U 1.0 (2014-21): ODF (Open Defecation Free) status for cities; 63 lakh IHHLs (individual household latrines) constructed; 4,320+ cities declared ODF. SBM-U 2.0 (2021-26): ODF+ (sustaining ODF + toilet maintenance) and ODF++ (solid waste management); target: 100% solid waste processing in all cities; scientific landfill management; legacy waste clearance from old dumpsites; stars rating (3-star, 5-star, 7-star cities for waste management)
National Urban Livelihoods Mission (NULM / DAY-NULM)	2013	All ULBs (urban poverty focus)	Rs.3,550 crore (12th Plan)	Livelihood support for urban poor: (a) Social mobilisation and institution development (SHGs for women); (b) Training for market-oriented skills; (c) Shelter for urban homeless; (d) Support to urban street vendors (PM SVANidhi -- see below)
PM SVANidhi (PM Street Vendor's AtmaNirbhar Nidhi)	2020	All urban areas	Rs.700 crore (initial)	Micro-credit for street vendors: Rs.10,000 initial loan (extendable to Rs.20,000, Rs.50,000 on repayment); digital transactions incentivised; 40+ lakh loans disbursed by 2023; one of most visible COVID economic recovery schemes; addressed urban informal economy directly

34.6 URBAN ENVIRONMENT -- ECOLOGY AND SUSTAINABILITY

IFoS FOCUS	**IFOS -- URBAN ECOLOGY CONNECTIONS:** (1) **Urban Heat Island (UHI) Effect:** Concrete and asphalt absorb and re-emit heat; lack of vegetation; anthropogenic heat from vehicles and AC; Delhi summer temperatures can be 5-6 deg C higher than surrounding rural areas; Bengaluru (historically "Garden City of India" at 920 m) has lost 88% of tree cover since 1973 (IISc study) and temperatures have risen 2-3 deg C. (2) **Urban Biodiversity:** Despite urbanisation, urban green spaces (parks, urban forests, water bodies) support significant biodiversity; Sanjay Gandhi National Park (SGNP), Mumbai = world's only national park inside a megacity (inside BMC limits) with leopards (40+ leopards in SGNP); Aravalli biodiversity park in Gurugram; Delhi Ridge Forest (remnant Aravalli Ridge). (3) **Urban Lakes and Wetlands:** Bengaluru's lakes (Hebbal, Ulsoor, Sankey Tank) historically recharged groundwater; now most are polluted, encroached, or dead; Bellandur Lake (now Varthur) -- notorious for toxic foam eruptions (caused by detergents + algae blooms) that periodically caught fire; NGT has mandated restoration. (4) **Urban Trees and Air Quality:** NITI Aayog Urban Heat Action Plan (2022) recommends urban forestry, green roofs, cool pavements; Delhi has Ridge Forest and Central Ridge biodiversity park; Mumbai has Aarey Colony forest (metro car shed controversy -- High Court halted tree felling 2019, Supreme Court reviewed). (5) **Aarey Colony controversy (Mumbai):** 2019: BMC approved felling of 2,700+ trees in Aarey Milk Colony for Mumbai Metro Line 3 car shed; massive citizen protest; HC dismissed petition; SC stayed tree-felling (Nov 2019); final resolution: car shed shifted to Kanjurmarg (2020); Aarey designated as "forest" by Maharashtra government (2020) -- controversy highlighted urban forest vs infrastructure tension.

34.7 CURRENT AFFAIRS HOOKS (2022-2025)

Smart Cities Mission Completion (March 2024): The Smart Cities Mission deadline was originally 2020, then extended to June 2023, and finally to March 2024. By March 2024, approximately 90%+ of projects worth Rs.1.64 lakh crore (of Rs.2.05 lakh crore planned) had been completed or were in advanced stages. ICCCs in all 100 cities became operational -- these became especially important during COVID-19 for surveillance, vaccination tracking, and hospital bed monitoring. However, the "island of excellence" critique persists: the selected ABD zones were improved while the rest of the city remained neglected.

Indore -- 7 Consecutive Times Cleanest City (Swachh Survekshan 2023): Indore, Madhya Pradesh won the Swachh Survekshan Award for the 7th consecutive time in 2023, cementing its reputation as India's cleanest city. Indore's model: (a) 100% door-to-door waste collection; (b) segregation at source (wet + dry + hazardous + domestic hazardous); (c) biogas from wet waste (Trident city biogas plant producing CNG for buses); (d) Gobardhan plant converting cow dung to biogas; (e) construction waste recycling; (f) citizen participation and monitoring; other cities (Surat, Navi Mumbai, Visakhapatnam) also consistently high-ranking.

Bengaluru Water Crisis (2024): Bengaluru faced its worst water crisis in March-April 2024, with reservoir levels critically low (Cauvery water at historical lows due to 2023 poor southwest monsoon; Karnataka-Tamil Nadu Cauvery dispute limiting releases). Tanker water prices spiked 4-5x; companies asked employees to work from home; borewells being drilled to 600+ feet. The Bengaluru water crisis became the defining urban environmental story of early 2024, focusing attention on unsustainable groundwater dependence and the need for lake restoration, rainwater harvesting mandates, and water-use efficiency.

Delhi Pollution and GRAP-IV Actions (Winter 2023-24): Delhi's winter AQI crossed 400 (Hazardous category) multiple times in November-December 2023. The CAQM (Commission for Air Quality Management in NCR and Adjoining Areas) implemented GRAP-IV (Stage 4 -- most severe): (a) Ban on all diesel trucks in Delhi (except essential commodities); (b) Construction ban; (c) WFH for government offices; (d) School closure for Classes 1-5; (e) Odd-even car rationing. India's SC monitored real-time AQI data and issued directions. The stubble burning contribution peaked at 35% during this period.

34.8 PYQ ANALYSIS -- CHAPTER 34 (2010-2025)

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Source	Year	Marks	Question
UPSC Civil	2024	15M	"Critically examine the challenges of rapid urbanisation in India. Discuss the specific problems of housing, water, and air pollution in major cities."
UPSC Civil	2023	12M	"Discuss the Smart Cities Mission -- its objectives, implementation approach, achievements and criticisms."
UPSC Civil	2022	10M	"What is the significance of slums in Indian cities? Discuss the policy responses for slum rehabilitation and housing for urban poor."
UPSC Civil	2021	12M	"Discuss the causes and consequences of the urban air pollution crisis in Delhi. What policy measures have been taken to address it?"
UPSC Civil	2020	10M	"Discuss the pattern of urbanisation in India. What are the main causes and consequences of rapid urbanisation?"
UPSC Civil	2019	10M	"Critically examine the PM Awas Yojana (Urban). How does it address the housing needs of the urban poor?"
UPSC Civil	2018	12M	"Examine the major urban environmental challenges in Indian cities with specific reference to water scarcity, solid waste management and urban heat islands."
UPSC Civil	2017	10M	"Discuss the significance of the AMRUT scheme for transforming India's small and medium towns."
IFOS GS	2024	10M	"Critically examine the ecological impact of rapid urbanisation on biodiversity and green spaces in Indian metropolitan cities."
IFOS GS	2023	10M	"Discuss the Urban Heat Island Effect in Indian cities and the role of urban forests in mitigating it."
IFOS GS	2022	10M	"Examine the ecological significance of urban wetlands and lakes in India with specific reference to Bengaluru's lake crisis."

KEY NOTE	**Frequency:** Urban challenges + housing + water + pollution (Civil 2024); Smart Cities Mission (Civil 2023); slums + PM Awas (Civil 2022); Delhi air pollution (Civil 2021); urbanisation pattern (Civil 2020); PMAY-U (Civil 2019); urban environment + water + solid waste (Civil 2018); AMRUT (Civil 2017). IFoS: urbanisation + biodiversity + green spaces (2024), UHI + urban forests (2023), Bengaluru lake crisis (2022). For 2025-26: SCM completion March 2024; Bengaluru water crisis 2024; Delhi GRAP-IV 2023-24; Indore 7th cleanest city award; Dharavi redevelopment Adani 2022 controversy; Aarey Colony forest designation -- all high-priority.

34.9 MODEL BOOK

Critically examine the challenges of rapid urbanisation in India. Discuss specific problems of housing, water supply and air pollution in major cities.

UPSC Civil (Mains) | 15 Marks | 210 Words

India's urban population grew from 28.61 crore (2001) to 37.71 crore (2011) -- adding 9.1 crore urban residents in a decade. Projected to reach 60 crore by 2031 and cross 50% urbanisation by 2047-50, India's urban transition is one of history's largest demographic shifts. But this transition is producing severe housing, water, and air quality crises in major cities.

PATTERN OF URBANISATION: 31.16% urban (2011); 8 megacities (above 40 lakh); 53 million-plus cities; Delhi (3.2 crore NCR), Mumbai (2.07 crore UA), Bengaluru (fastest-growing 2001-2011, +49%). Two distinct India: rapidly growing metros vs stagnating small towns.

CHALLENGE 1 -- HOUSING AND SLUMS:

Scale: 6.5 crore slum dwellers (17.4% of urban population; Census 2011); 42% of Mumbai in slums; Dharavi = 700,000-1 million people in 2.1 sq km; Delhi's 1.8 million JJ cluster residents.

Causes: Rural-to-urban migration; inadequate affordable housing supply; high real estate prices (market failure in housing for EWS/LIG); inadequate urban land supply (DA/DDA restrictions); weak urban planning enforcement.

Policy: PM Awas Yojana-Urban (PMAY-U): 1.12 crore houses sanctioned; In-situ slum redevelopment; Credit Linked Subsidy Scheme (CLSS); Dharavi redevelopment (Adani, 2022); criticism: tenure security often not addressed.

CHALLENGE 2 -- URBAN WATER CRISIS:

Scale: 43% urban households without piped water within premises (Census 2011); Chennai "Day Zero" June 2019 (all reservoirs empty; water tankers deployed); Bengaluru 2024 water crisis (10,000+ borewells; water table 400+ feet; lakes reduced from 262 to 81).

Causes: Population growth outpacing supply infrastructure; groundwater overextraction (30-60% NRW in distribution networks); climate variability (irregular monsoon patterns); inter-state water disputes (Cauvery limiting Chennai and Bengaluru supply).

Policy: AMRUT 2.0 (Rs.2.99 lakh crore; 100% water supply target); Jal Jeevan Mission Urban; rainwater harvesting mandates; lake restoration in Bengaluru (NGT orders); water recycling for non-potable use.

CHALLENGE 3 -- URBAN AIR POLLUTION:

Scale: 21 of world's 30 most polluted cities in India (IQAir 2023); Delhi's AQI regularly crosses 400 (Hazardous) in winter; 1.6-2 million air pollution deaths annually in India (IHME). Delhi's worst contributors: stubble burning (25-35% in Oct-Nov), vehicles (20-30%), dust and construction.

Policy: GRAP (Graded Response Action Plan): 4 tiers from Moderate to Emergency; BS-VI emission standards (April 2020); Delhi EV Policy; Odd-Even scheme; Punjab Preservation of Subsoil Water Act (delays paddy harvest = delays stubble burning start); CAQM (Commission for Air Quality Management for NCR).

STRUCTURAL REFORMS NEEDED: All three crises share a common structural cause: urban growth has massively outpaced infrastructure and institutional capacity. Solutions require: (a) Metropolitan governance reform (single authority for MMR, NCR vs current fragmentation); (b) Land market reform (affordable housing supply); (c) Investment in water infrastructure (AMRUT 2.0 is a step); (d) Decentralisation of urban functions to elected ULBs (74th Constitutional Amendment empowerment).

India's cities are the engines of its economic growth (70%+ of GDP from urban areas) but also the sites of its most acute environmental and human development failures. The Smart Cities Mission, PMAY-U, AMRUT 2.0, and SBM-U are directionally correct but insufficiently funded relative to the scale of the challenge. India needs to spend 1-2% of GDP annually on urban infrastructure (vs current 0.5%) to avoid its cities becoming development liabilities rather than assets.

Examine the ecological impact of urbanisation on biodiversity and green spaces in Indian metropolitan cities.

UPSC IFOS (Mains) | 10 Marks | 150 Words

Indian metropolitan cities are among the world's most ecologically stressed urban environments -- expanding concrete footprints are eliminating urban green spaces, wetlands, and wildlife corridors, with direct consequences for biodiversity, microclimate, groundwater recharge, and human well-being.

1. **URBAN HEAT ISLAND (UHI) EFFECT:** Bengaluru has lost 88% of its tree cover since 1973 (IISc RSST study), contributing to a 2-3 deg C temperature rise in the city vs surrounding areas. Delhi's ridge forests (last remnant of the Aravalli range in Delhi) experienced 4,000+ tree loss in 2016-17 due to infrastructure

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projects. Heat waves intensified by UHI now regularly kill urban residents (2022 North India heat wave; 2024 record May temperatures in several cities).

2. **URBAN WETLAND AND LAKE DESTRUCTION:** Bengaluru had 262 lakes in the 1960s; only 81 functional lakes remain (2023). Lakes have been filled for layouts, drained for real estate, or polluted beyond recovery. Bellandur lake (now Varthur lake) periodically catches fire due to toxic foam caused by detergents and algae. NGT has mandated restoration of Bengaluru lakes; BBMP (civic authority) is slow to implement. In Chennai, Pallikaranai marsh (India's only remaining natural wetland near a large city; Ramsar designation advocated) has been progressively encroached for the IT corridor (OMR).
3. **WILDLIFE CORRIDORS FRAGMENTED:** Sanjay Gandhi National Park (SGNP) in Mumbai -- world's only national park within a megacity -- has 40+ leopards and 270+ bird species. But the metro rail expansion (Line 3 Colaba-SEEPZ-Aarey), the Aarey car shed (proposed for metro; 2,700 trees to be felled; subsequently relocated after SC intervention 2019-20; Aarey designated forest 2020), and urban sprawl have fragmented the wildlife corridors connecting SGNP to the Sahyadri Western Ghats. Leopards increasingly venture into residential areas (human-leopard conflict in Aarey, Borivali, Thane).
4. **URBAN BIODIVERSITY POTENTIAL VS REALITY:** Several cities retain significant biodiversity: Delhi's ridge harbours 450+ plant species and 150+ bird species; Mumbai's Thane Creek Flamingo Sanctuary (TCFS) hosts 25,000+ Greater and Lesser Flamingos annually; Hyderabad's Osman Sagar and Himayat Sagar lakes support migratory waterfowl. But all are under increasing pressure from encroachment, pollution, and urbanisation.

POLICY RESPONSE: AMRUT 2.0 urban forestry component; NITI Aayog Urban Heat Action Plan 2022 (urban forests, cool pavements, green roofs); Bengaluru lake restoration (BBMP + NGT); Wetland Conservation Rules 2017 (protecting urban wetlands); Delhi Urban Art Commission (tree cover norms for developments). The key challenge: urban development authorities (DDA, BBMP, MCGM) prioritise infrastructure over ecology; green space preservation requires political will and stronger enforcement.

Urban biodiversity is not a luxury -- it is essential infrastructure. Lakes and wetlands recharge groundwater; trees reduce temperatures by 2-8 deg C locally; urban forests support mental health; wildlife corridors allow adaptation to climate change. The IFoS officer has a specific responsibility to defend urban forests and wetlands against development pressure -- providing scientific evidence, participating in environmental impact assessments, and mobilising civil society for conservation of the last natural spaces in India's rapidly expanding cities.

CHAPTER 35

MINERALS AND MINING IN INDIA

35.1 INTRODUCTION -- INDIA'S MINERAL WEALTH

India is among the world's most well-endowed nations in terms of mineral resources -- a consequence of its ancient and varied geological formations. The **Peninsular Shield (Deccan Plateau)** -- composed of Precambrian crystalline and metamorphic rocks among the world's oldest geological formations -- contains some of the world's richest deposits of iron ore, manganese, bauxite, chromite, and mica. The **Gondwana sedimentary basins** of central and eastern India hold vast coal reserves. The **coastal placers** of Kerala, Tamil Nadu, and Andhra Pradesh contain valuable heavy mineral sands (ilmenite, titanium, monazite with rare earth elements).

India's total value of mineral production (excluding fuel minerals) is approximately **Rs.2.1 lakh crore per year (2022-23; IBM data)**, and the sector (including fuel minerals) contributes approximately **2.5% of India's GDP.** Mining provides direct employment to approximately **11 lakh workers** (formal sector) plus several times that number in informal and ancillary roles. The challenge for India is to exploit its mineral wealth for development while **protecting the rights and livelihoods of tribal communities** who predominantly live in the mineral-rich areas of Jharkhand, Odisha, Chhattisgarh, and Andhra Pradesh.

35.2 MASTER MINERAL DISTRIBUTION TABLE -- PRELIMS QUICK REFERENCE

Mineral	*Type / Use*	*Rank-1 Producer State*	*Rank-2*	*Rank-3*	*Key Mine / Site / Note*
Iron Ore	Haematite (primary); Magnetite (Karnataka); Used for steel	Odisha (57%+ of national production; Joda-Barbil-Keonjhar-Sundargarh belt; Kiriburu mine)	Chhattisgarh (Bailadila mines, NMDC; export grade ore)	Karnataka (Bellary-Hospet-Sandur; Kudremukh for magnetite)	4th largest reserves globally; NMDC = largest iron ore company; SC ban on Bellary-Sandur (2011-12, CEC); Goa mines also significant (SC ban 2012, partially lifted)
Coal	Bituminous/coking (Jharia); Sub-bituminous; Lignite (Neyveli, TN)	Jharkhand (Damodar Valley; Jharia coking coal; Raniganj nearby WB border)	Odisha (Talcher-IB Valley coalfields; Mahanadi Coalfields Ltd)	Chhattisgarh (Korba-Surguja; South Eastern Coalfields)	4th largest reserves; 3rd largest producer; 98% = Gondwana age; CIL = world's largest coal producer; Neyveli Lignite (TN) = 3rd largest lignite after RJ and GJ
Bauxite	Lateritic; used for aluminium (Al2O3)	Odisha (#1; Koraput-Kalahandi-Bolangir; NALCO Damanjodi smelter)	Jharkhand (#2; Lohardaga -- best quality; Netarhat plateau)	Gujarat (#3; Jamnagar, Kutch areas)	5th largest reserves globally; Niyamgiri Hills (Vedanta-Sterlite case, SC 2013 = gram sabha right); NALCO (CPSE under MoM); Hindalco

					(Birla); Vedanta
Manganese	Used in steel (deoxidiser/desulphuriser); also batteries, fertilisers	Odisha (#1; Keonjhar, Koraput, Sundargarh)	Maharashtra (#2; Nagpur-Bhandara belt; MOIL Balaghat largest single mine in India)	Karnataka (#3; Sandur, Dharwad-Uttara Kannada)	MOIL Ltd (Manganese Ore India Ltd; CPSE); Madhya Pradesh (Balaghat = Manganese ore + Copper); also Goa, AP
Copper	Used in electrical wiring, electronics, construction	Rajasthan (#1; Khetri -- "Copper City of India"; Jhunjhunu district)	Jharkhand (#2; Singhbhum -- Mosabani, Baharagora)	Madhya Pradesh (#3; Malanjkhand; Balaghat district -- one of Asia's largest open-cast copper mines)	India is COPPER DEFICIT (imports 80%+); HCL (Hindustan Copper Ltd) = only PSU copper miner; Malanjkhand mine operated by HCL; Khetri complex (HCL)
Mica	Muscovite (best quality; used in electrical insulators, cosmetics); Phlogopite (brown mica)	Jharkhand (#1; Koderma-Giridih-Hazaribagh = "Mica Triangle of India"; best muscovite quality globally)	Rajasthan (#2; Ajmer-Bhilwara-Nagor belt)	Andhra Pradesh (#3; Nellore district = Nellore Mica Belt)	India = world's LARGEST mica producer; child labour in mica mining = major human rights concern (Jharkhand, RJ); Responsible Mica Initiative (industry voluntary); also Bihar mica (Munger)
Gold	Used in jewellery, electronics, currency reserves	Karnataka (#1; Kolar Gold Fields KGF -- now closed after 120 years operation; Hutti Gold Mines -- still operational; Hutti-Maski belt)	Jharkhand (#2; Ichagarh area; Sonua)	Rajasthan (#3; Banswara -- small production)	KGF = once Asia's deepest mine (3.2 km); closed 2001 due to declining grade and cost; HGML (Hutti Gold Mines Ltd) operates Hutti; India imports ~800-1,000 tonnes gold/year; UP (Sonbhadra 2020 claim of 3,000 tonnes revised to 160 kg by IBM)
Silver	Often found with lead-zinc (galena); also copper mining byproduct	Rajasthan (#1; Jawhar-Maton lead-zinc mines at Udaipur = among world's largest ZnPb mines; silver is byproduct)	Karnataka (#2; Hutti gold mine byproduct)	Jharkhand (#3; minor)	Hindustan Zinc Ltd (Vedanta subsidiary) = India's only primary zinc-lead-silver producer; Rampura Agucha mine (Bhilwara, RJ) = world's largest zinc-lead mine by reserves
Lead-Zinc	Lead (PbS	Rajasthan (#1;	Andhra	Bihar/Jharkh	Hindustan Zinc Ltd (HZL,

	galena) for batteries, paints; Zinc (ZnS sphalerite) for galvanising steel, alloys	Zawar mines, Rampura Agucha mine -- Bhilwara; Dariba-Kayad mine)	Pradesh (#2; Agnigundala, Lomo mines)	and (minor)	Vedanta subsidiary) = operates ALL Rajasthan mines; India imports zinc (insufficient domestic supply); Rampura Agucha = world's largest open-pit zinc mine
Chromite	Chromium ore; used in stainless steel, plating, refractory materials	Odisha (#1; Sukinda Valley, Jajpur district -- 98%+ of India's chromite and 95%+ of South Asia's chromite; world's 2nd largest chromite reserve concentration)	Karnataka (#2; Hassan, Mysore -- small)	Maharashtra (#3; minor)	Sukinda Valley = one of world's most polluted places (hexavalent chromium Cr6+ leaching into Brahmani River; toxic; carcinogenic; groundwater contaminated; MOEF has flagged but cleanup slow); OMC (Odisha Mining Corporation) main producer
Titanium (Ilmenite and Rutile)	Titanium ore; used in aerospace, paints (TiO2 = white pigment), military	Kerala (#1; Chavara, Kollam -- "mineral sands beach"; highest ilmenite concentration in coastal sands)	Tamil Nadu (#2; Manavalakurichi, Kanyakumari; also Vairavanpatti in TN)	Andhra Pradesh (#3; Bheemunipatnam, Srikakulam)	India = 2nd largest ilmenite reserves globally (after Australia); IREL (Indian Rare Earths Ltd, a DAE company under Dept of Atomic Energy) controls monazite mining (radioactive thorium) in beach sands; KMML (Kerala Minerals and Metals Ltd) = TiO2 pigment producer
Thorium / Rare Earth Elements	REE (lanthanum, cerium, neodymium, praseodymium etc.) from monazite sand; Thorium from monazite (Stage 3 nuclear fuel)	Kerala (Chavara beach sands = highest REE+Th)	Andhra Pradesh (Nellore-Srikakulam coast)	Tamil Nadu (Manavalakurichi)	India = 5th largest REE reserves (2.9 million tonnes); DAE controls thorium/monazite (strategic); IREL mines and processes; REEs critical for EVs (NdFeB magnets), wind turbines, electronics
Limestone / Cement	Calcium carbonate (CaCO3); used	Rajasthan (#1; Jodhpur-Bikaner-Barmer-Sirohi;	Andhra Pradesh (#2; Kurnool,	Madhya Pradesh (#3; Satna-Rewa	Rajasthan + AP + MP together = 70%+ of India's cement

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grade	for cement, iron smelting, paper, chemicals	cement capital of India)	Kadapa, Guntur -- large deposits)	-- cement hub of India; also Jabalpur)	limestone; India = 2nd largest cement producer (after China); ACC, UltraTech, Ambuja, Shree Cement = major companies; Satna-Rewa = "Cement City" cluster
Petroleum and Natural Gas	Crude oil; Natural gas	Gujarat/Maharashtra (Bombay High offshore -- ONGC)	Rajasthan (Barmer onshore -- Cairn/Vedanta)	Assam (Digboi; Naharkatia -- oldest; OIL India)	Covered in Ch 26 (Energy Resources); included here for completeness; India produces ~30 MT crude/year vs ~250 MT consumption; import-dependent

KEY NOTE

Ultimate Prelims Mnemonic -- State-wise Minerals: "JOCKG" = Jharkhand-Odisha-Chhattisgarh-Karnataka-Gujarat = mineral powerhouses. JHARKHAND: Coal (Jharia coking), Mica (Koderma), Iron ore (Singhbhum), Copper (Singhbhum), Bauxite (Lohardaga). ODISHA: Iron ore (Joda-Barbil #1 nationally), Bauxite (#1), Manganese (#1), Chromite (#1 -- Sukinda 98%), Coal (Talcher). CHHATTISGARH: Iron ore (#2 -- Bailadila NMDC), Coal (Korba). KARNATAKA: Gold (Kolar-Hutti), Iron ore (#3 -- Bellary), Magnetite (Kudremukh), Manganese (#3 Sandur). RAJASTHAN: Copper (Khetri), Silver+Zinc+Lead (Jawhar-Maton-Rampura Agucha), Mica (#2), Limestone (#1). KERALA-TN: Ilmenite+REE+Thorium (coastal beach sands; IREL).

35.3 IRON ORE -- BACKBONE OF STEEL INDUSTRY

India has the **4th largest iron ore reserves** in the world (after Australia, Brazil, and Russia) estimated at approximately **33.2 billion tonnes** (IBM 2022; including all grades). India is also the **4th largest iron ore producer** and among the **top 5 iron ore exporters** globally. Iron ore is the foundation of India's steel industry and has been central to the country's industrial development since the Tata Steel plant opened at Jamshedpur in 1907.

Iron Ore Feature	*Detail*
Types	HAEMATITE (Fe2O3): Red-coloured; 60-70% Fe content; highest grade; found in Jharkhand, Odisha, Chhattisgarh, Goa, Karnataka, AP. MAGNETITE (Fe3O4): Black colour; 60-72% Fe content; highly magnetic; most value but needs beneficiation; primarily Karnataka (Kudremukh, Hassan district). LIMONITE (Fe2O3.nH2O): Yellow/brown; lower grade (~40-60%); found in NE India and some Deccan areas. SIDERITE (FeCO3): Lowest grade; not commercially significant in India.
Reserve distribution	Odisha = 28% of reserves; Jharkhand = 25%; Chhattisgarh = 18%; Karnataka = 14%; Goa = 5%; Others (AP, TN, MP) = 10%. Odisha + Jharkhand + CG together hold ~71% of India's iron ore reserves.
Production distribution	Odisha = 57%+ (#1 -- fastest growing; Keonjhar, Sundargarh, Joda-Barbil belt); Chhattisgarh = ~17% (#2 -- Bailadila; NMDC's largest operation); Karnataka = ~15% (#3 -- Bellary-Hospet; Bellary mining ban by SC-CEC 2011); Jharkhand = ~5%; Goa = ~3%; AP = ~2%.
Major mines	BAILADILA (Dantewada, CG): World's finest export-grade iron ore (67-68% Fe); NMDC (National Mineral Development Corporation) operates; exported to Japan (SAIL-NMDC-NSC joint; historical JTC treaty from 1966); 10 deposits identified; 4 operational. JODA-BARBIL belt (Keonjhar-Sundargarh, Odisha): Largest iron ore production cluster; private mines (Tata Steel,

	ArcelorMittal-Nippon, SAIL) + OMC. KIRIBURU-MEGHAHATUBURU (Singhbhum, Jharkhand): SAIL mines; IISCO Steel Plant Burnpur uses ore. KUDREMUKH (Hassan-Chikmagalur, KA): Magnetite; National Mineral Policy restricted further mining (forest area); KIOCL (Kudremukh Iron Ore Company Ltd) now only does pelletisation.
Export and Controversy	India was a major iron ore exporter to China (2004-2012: 100+ MT/year). ILLEGAL MINING in Goa (Parrikar-era CAG report 2012), Karnataka (B Sreenivasulu Reddy "Mining scam"; CEC 2011 ban; partial lifting under conditions), and Odisha led to Supreme Court interventions and mining bans. Goa SC ban (2012); partly lifted 2014; new cap system. Karnataka Bellary-Sandur ban (2011): 166 illegal mines identified; revenue loss Rs.16,085 crore alleged; "Reddy Brothers" (BSR -- Janardhan Reddy + Karunakara Reddy + Somashekhara Reddy -- former ministers) jailed. These cases established precedents for SC oversight of state-level mining governance.

35.4 BAUXITE AND ALUMINIUM -- THE NIYAMGIRI STORY

Bauxite -- the primary ore for aluminium -- forms by intense laterisation of aluminium-rich parent rocks under tropical conditions. India has the **5th largest bauxite reserves** globally (~3.9 billion tonnes). Aluminium is crucial for aerospace, electrical wires, automobile bodies, packaging, and defence equipment -- hence bauxite is increasingly classified as a "critical mineral."

The most significant recent story in India's bauxite sector involves the **Niyamgiri Hills of Odisha (Kalahandi-Rayagada districts),** where **Vedanta/Sterlite Industries'** proposal to mine bauxite atop the Niyamgiri plateau -- sacred to the **Dongria Kondh tribal community** (who worship these hills as the home of their deity Niyam Raja) -- was rejected by the Supreme Court in 2013 after all 12 gram sabhas (village councils) of the Dongria Kondh voted against the mining project. This landmark judgment established the principle of **gram sabha consent for mining in tribal and forest areas** and is globally recognised as a landmark case in indigenous peoples' rights and natural resource governance.

35.5 CRITICAL MINERALS -- INDIA'S NEW FRONTIER

The global energy transition -- from fossil fuels to electric vehicles, solar panels, wind turbines, and energy storage batteries -- is creating unprecedented demand for a new set of **"critical minerals"** whose supply chains are currently concentrated in a few countries (China dominates REE processing; Congo dominates cobalt; Indonesia dominates nickel). India has recognised this as both a vulnerability (it imports most critical minerals) and an opportunity (it has significant reserves of some).

Critical Mineral	*Global Significance*	*India's Position*	*Key Policy*
Lithium	Lithium-ion batteries (EVs, phones, laptops, grid storage); demand to grow 40x by 2040 (IEA)	NEW DISCOVERY: J&K (Salal-Haimana area, Reasi district): GSI announced ~5.9 million tonnes inferred resource in 2023 -- potentially world's largest lithium deposit IF confirmed (needs detailed exploration); also Rajasthan (Degana, Nagaur -- small); India currently imports 100% lithium from Australia, Chile, Argentina	Critical Minerals Mission (2024); Rs.34,300 crore; lithium exploration in J&K being fast-tracked; bilateral agreements with Australia (Critical Minerals Partnership), Chile, Argentina
Cobalt	Lithium-ion battery cathodes; critical for EV revolution	Very limited domestic reserves; India imports from DRC (Democratic Republic of Congo); strategic	KABIL (Khanij Bidesh India Ltd -- JV of NALCO, HCL, MECL): seeks overseas mineral assets;

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		partnership with DRC being explored	acquired stakes in cobalt mines abroad
Rare Earth Elements (REE)	NdFeB permanent magnets (wind turbines, EV motors); phosphors (LED); catalysts; 17 elements	India = 5th largest REE reserves globally (~2.9 million tonnes; USGS 2022); mainly monazite in coastal beach sands of Kerala (Chavara), Tamil Nadu (Manavalakurichi), AP, Odisha, WB; also Jharkhand alkaline complexes	IREL (Indian Rare Earths Ltd, DAE company) = sole authorised miner of monazite (radioactive due to thorium); India separates REE but has NOT developed domestic processing into magnets (key gap); China processes 90%+ of world's REEs; India-Australia Critical Minerals Investment Partnership
Titanium	Aerospace (Ti alloys -- lightest structural metal); military (armour); TiO2 white pigment (paints, cosmetics)	India = 2nd largest ilmenite (FeTiO3) reserves globally (after Australia); ~770 million tonnes; Kerala (Chavara) + TN (Manavalakurichi) + AP (Bheemunipatnam) coastal sands	IREL + KMML (Kerala Minerals and Metals Ltd) mine and process; India exports crude ilmenite but imports high-purity TiO2 and Ti metal -- need to move up value chain
Graphite	Lithium-ion battery anodes; lubricants; nuclear reactors (graphite moderator)	India has graphite deposits in Tamil Nadu (Salem), Jharkhand, Odisha, Rajasthan; not currently a major producer	Exploration under Critical Minerals Mission; currently imports from China and Mozambique
Nickel	EV batteries (NMC cathode = nickel-manganese-cobalt); stainless steel	Very limited domestic reserves; Sukinda Valley (Odisha) has some lateritic nickel; not commercially developed	Critical mineral for India EV ambitions; entirely import-dependent; Indonesia and Philippines are major sources
Vanadium	Vanadium Redox Flow Batteries (grid storage); steel alloy	Rajasthan (Rajpura-Dariba zinc mine has vanadium byproduct); Andhra Pradesh; Karnataka	Critical Minerals Mission targeting exploration

CURRENT AFFAIRS

Critical Minerals Mission (2024) -- Key Details: The Union Budget 2024-25 announced the National Critical Mineral Mission (NCMM) with Rs.34,300 crore outlay. Objectives: (a) Intensive domestic exploration (GSI, MECL) for lithium, cobalt, nickel, REEs; (b) Setting up processing and refining facilities domestically (reduce China dependence on REE processing); (c) International mining acquisitions via KABIL (Khanij Bidesh India Ltd) -- to acquire stakes in mines in mineral-rich countries (Australia, Chile, Argentina, DRC, Zambia); (d) Battery recycling to recover critical minerals from end-of-life EVs and electronics; (e) R&D for mineral processing technology. This mission is directly linked to India's EV targets, Net Zero 2070 commitment, and MAKE IN INDIA for defence and aerospace.

J&K Lithium Discovery (2023) -- Cautionary Note: GSI (Geological Survey of India) announced in February 2023 that it had identified ~5.9 million tonnes of lithium inferred resources in Salal-Haimana area, Reasi district, J&K. If confirmed as a reserve (not yet at reserve stage -- currently only "inferred resource"), this would be one of the world's largest lithium concentrations (Chile's Atacama has ~9.8 million tonnes). However, Indian media overhyped this as a "done deal" -- in reality, the resource is at early exploration stage; economic viability, grade, extraction feasibility, and J&K's complex terrain and security environment all need assessment. The critical

minerals sector requires several years of assessment between "resource" announcement and actual mining. Also, even if mined, lithium ore still needs processing -- and India currently has no lithium processing capacity.

35.6 MINING POLICY, REGULATION AND ENVIRONMENTAL IMPACT

KEY LEGISLATION AND POLICY

Law / Policy	*Year*	*Key Provision*
Mines and Minerals (Development and Regulation) Act -- MMDR Act	1957; amended 2015 and 2021	Fundamental legislation governing all mining (except petroleum and coal); grants mining leases; royalty rates set here; 2015 amendment: auction of mineral blocks (replacing discretionary grant); Mineral Auction Rules; Star Rating of Mines; 2021 amendment: composite licences (prospecting + mining in one step); captive vs merchant mines distinction
District Mineral Foundation (DMF) / PMKKKY	2015 (created by MMDR Amendment 2015)	DMF = trust set up in each district having mining operations; funded by contribution from mining companies (10-30% of royalty); PMKKKY (Pradhan Mantri Khanij Kshetra Kalyan Yojana) = scheme to use DMF funds for development of mining-affected communities; education, health, livelihood, infrastructure for tribal/affected communities; Rs.60,000+ crore in DMF funds collected by 2023 nationally
National Mineral Policy 2019	2019	Replacing NMP 2008; promotes sustainable mining; ensures tribal rights; promotes value addition in India (processing of raw minerals domestically); addresses illegal mining; technology adoption; offshore seabed mining exploration
Forest Conservation Act 1980 / FCAA 2023	1980; amendment 2023	Forest land diversion for mining requires FC (Forest Clearance) from central government; FCAA 2023 controversially exempted 100 km border areas from FC requirement -- affects some mining near border regions; EIA required for Stage 2 FC
Environment Protection Act 1986 / EIA Notification 2006	1986; 2006	Environmental Impact Assessment (EIA) mandatory for all mining projects above threshold size; prior environmental clearance (EC) from MoEFCC required before mining can begin; EIA Draft 2020 proposed diluting public consultation -- faced massive criticism and was not finalised
PESA (Panchayats Extension to Scheduled Areas) 1996 and FRA 2006	1996; 2006	PESA: Scheduled (tribal) Area gram sabhas have rights over minor minerals and natural resources; FRA: Community Forest Rights (CFR) protects community forest areas including those with minerals; Niyamgiri SC judgment 2013 established gram sabha veto over mining in tribal areas
Offshore Areas Mineral Development Regulation Act 2002	2002	Governs mining in India's Offshore areas (EEZ and continental shelf); Deep-sea mining potential (polymetallic nodules, ferromanganese crusts in Indian Ocean); NCPOR (National Centre for Polar and Ocean Research) and ISRO-NIO (National Institute of Oceanography) coordinate; India has Pioneer Investor status with ISA (International Seabed Authority) for polymetallic nodule mining area in Central Indian Ocean Basin

ENVIRONMENTAL AND SOCIAL IMPACTS OF MINING

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Impact Category	Description	Specific Indian Examples
Deforestation	Mining requires clearing forest for: mine pits (open-cast); overburden dumps; roads; processing plants; tailings ponds; housing; all require Forest Clearance under FCA 1980 -- a process mining companies often try to expedite or circumvent	Chhattisgarh Hasdeo Arand forest (one of central India's most biodiverse dry deciduous forests; 170,000 ha; home to 23 coal blocks; tribal community protests since 2011 against coal mining allocation; Supreme Court and NGT cases ongoing); Odisha bauxite mining threatening plateau-top forests of Niyamgiri, Gandhamardan
Tribal displacement	Most mineral-rich areas in India are Schedule V areas (tribal majority); mining projects cause large-scale displacement of indigenous communities who are rarely rehabilitated adequately; the "resource curse" paradox: states with most minerals have worst tribal welfare indicators	Jharkhand: "Jharkhand was carved out as a tribal state in 2000; its minerals now displace the very tribal people the state was created to protect." Odisha: Sukinda Valley chromite mines (Jajpur district) -- 97% of India's chromite in an area with ~2 lakh tribal and non-tribal residents; Cr6+ contamination of ground and surface water
Water pollution	Acid mine drainage (AMD): sulfide minerals (pyrite, chalcopyrite) exposed to water and oxygen form sulfuric acid + heavy metals leaching into water; heavy metal contamination of rivers; tailings dam failures	Sukinda Valley (Odisha): hexavalent chromium (Cr6+) in Brahmani River -- UNEP and Blacksmith Institute declared it one of world's most polluted places (2007, 2013); Khetri Copper Complex (Rajasthan): copper tailings in Kantli River; Damodar River: coal mine drainage + ash pond seepage
Air and dust pollution	Mining (especially open-cast blasting + excavation + truck movement) creates massive dust plumes; fine PM2.5 and silica dust cause occupational diseases (silicosis, pneumoconiosis); coal dust causes pneumoconiosis (black lung) in miners	Dhanbad (Jharkhand) = one of world's most polluted cities partly due to coal mining; Joda-Barbil (Odisha) iron ore mining area: roads and settlements covered in red iron dust; Koraput bauxite area: dust from NALCO smelter
Land subsidence and ground instability	Underground mining causes surface subsidence; Jharia underground coal fire has caused ground subsidence threatening Jharia township; earthquake risk in mining areas	Jharia (Dhanbad, Jharkhand): coal fires burning since 1916 in subsurface; ground cracking; gas emissions; ~27,000 families need evacuation; BCCL (Bharat Coking Coal Ltd) responsible; JADA (Jharia Development Authority) managing slow relocation
Sea-floor disruption (emerging)	Deep-sea mining for polymetallic nodules in Indian Ocean could disturb unique deep-sea ecosystems (cold seep communities, deep-sea fish, sediment communities); irreversible disturbance; international governance gap	India has Pioneer Investor Status from ISA for 75,000 sq km in Central Indian Ocean Basin; exploration ongoing by NCPOR; commercial mining timeline uncertain; environmental baseline studies required by ISA before any mining authorised

ENV ALERT

Hasdeo Arand Forest -- Mining vs Tribal Rights (IFoS Critical Case):
The Hasdeo Arand forest in northern Chhattisgarh (Surguja, Korba, and Korea districts) is one of central India's largest and most biodiverse contiguous forests (~170,000 ha of Northern Tropical

Moist Deciduous and Dry Deciduous forest; home to elephants, leopards, sloth bears, diverse birdlife). It has been designated as a "No-Go Zone" for coal mining by MoEFCC in 2009-10. However, 23 coal blocks have been allocated in or adjacent to this forest, of which 4-5 have received clearances despite expert committee and villager opposition. Adani Group's Parsa East and Kanta Basan mines (PECB coal block) have been operational in the Hasdeo area, with continued tribal protest (Adivasi Janajagriti Samiti). The NGT, High Court, and Supreme Court have all been approached by tribal communities. For IFoS aspirants: Hasdeo Arand = the defining current case of forest-mining conflict; involve: NTFP (non-timber forest produce) rights; elephant corridor; Fifth Schedule tribal rights; FRA 2006 community rights; PESA compliance; State government collusion with mining interests.

35.7 CURRENT AFFAIRS HOOKS (2022-2025)

Critical Minerals Mission Announced (Budget 2024-25): The National Critical Mineral Mission (NCMM) announced in Union Budget 2024-25 with Rs.34,300 crore outlay is India's most comprehensive response to the global critical mineral challenge. Focus: domestic exploration for lithium, cobalt, nickel, REEs; processing capacity; KABIL international acquisitions; battery recycling (urban mining). Directly linked to India's 30% EV penetration target by 2030 and net-zero 2070 commitment.

J&K Lithium Resource Announcement (February 2023): GSI announced ~5.9 million tonnes inferred lithium resource in Reasi district, J&K. If confirmed, potentially world's largest deposit. However, it is currently only at "inferred resource" stage -- not "reserve." Extraction feasibility, terrain challenges (Himalayan geology), and J&K security environment add uncertainty. India-Australia Critical Minerals Partnership (2023) and India-Argentina MoU on lithium and copper are related diplomatic developments.

MMDR Amendment Act 2021 -- Captive vs Merchant Mining: The MMDR Amendment Act 2021 allowed captive mine owners (those mining for in-house use in steel/aluminium/power plants) to sell up to 50% of their production in the open market. This was aimed at increasing mineral availability. The amendment also removed end-use restrictions for private mines auctioned, making them merchant mines (selling to highest bidder). Critics: this could cause ore to go abroad rather than stay in India for domestic value addition; government argues it increases supply and reduces illegal mining.

NMDC Green Steel and Iron Ore Export Policy (2022-2024): NMDC (National Mineral Development Corporation) -- India's largest iron ore producer -- has been developing plans for "green steel" using hydrogen-based direct reduced iron (DRI) to replace coking coal in steel production. NMDC's Nagarnar Steel Plant (Chhattisgarh, 3 MMTPA) commissioned in 2023 -- India's newest steel plant, developed by NMDC and divested to NMDC Steel Ltd. India's iron ore export policy has been volatile: export duty on iron ore imposed/removed based on domestic steel industry needs and international price cycles.

35.8 PYQ ANALYSIS -- CHAPTER 35 (2010-2025)

Source	*Year*	*Marks*	*Question*
UPSC Civil	2024	12M	"Discuss the distribution of critical minerals in India. How does India's critical mineral policy address the challenges of energy transition and strategic dependence?"
UPSC Civil	2023	10M	"Discuss the significance of the District Mineral Foundation (DMF). How does it address the social and environmental costs of mining in tribal areas?"
UPSC Civil	2022	10M	"Discuss the distribution and significance of iron ore in India. What are the major issues associated with iron ore mining in Odisha, Jharkhand, and Karnataka?"

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UPSC Civil	2021	12M	"What is the Niyamgiri case? Discuss the significance of the Supreme Court judgment on tribal rights and mining."
UPSC Civil	2020	10M	"Discuss the distribution of bauxite and the aluminium industry in India. What are the environmental concerns associated with bauxite mining?"
UPSC Civil	2019	10M	"Discuss the distribution of mica, copper, and gold in India and the challenges faced by these sectors."
UPSC Civil	2018	12M	"Critically examine the environmental and social impacts of mining in India with specific examples from coal and iron ore sectors."
UPSC Civil	2017	10M	"Discuss the distribution of manganese ore in India and its significance for the steel industry."
IFoS GS	2024	10M	"Critically examine the environmental impact of coal mining in the Damodar Valley with specific reference to air pollution, water contamination, and forest loss."
IFoS GS	2023	10M	"Discuss the Hasdeo Arand forest controversy. What are the ecological and tribal rights dimensions of coal block allocation in this region?"
IFoS GS	2022	10M	"Discuss the ecological significance of Sukinda Valley (Odisha) chromite deposits and the chromium (Cr6+) pollution crisis."

KEY NOTE

Frequency Pattern: Critical minerals (Civil 2024); DMF tribal rights (Civil 2023); iron ore distribution + Bellary (Civil 2022); Niyamgiri judgment (Civil 2021); bauxite + aluminium + environment (Civil 2020); mica/copper/gold (Civil 2019); mining environmental impacts (Civil 2018); manganese distribution (Civil 2017). IFoS: Damodar Valley coal ecology (2024), Hasdeo Arand forest + tribal rights (2023), Sukinda Cr6+ pollution (2022). For 2025-26: Critical Minerals Mission Rs.34,300 crore (Budget 2024); J&K lithium 5.9 MT (2023); MMDR 2021 amendment; NMDC Nagarnar Steel Plant (2023); KABIL international acquisitions -- all high-priority.

35.9 MODEL BOOK

Discuss the distribution of major minerals in India. Critically examine the environmental and social impacts of mining in tribal areas.

UPSC CIVIL (Mains) | 15 Marks | 210 Words

India is among the world's most mineral-rich countries -- a consequence of its ancient Precambrian shield geology. The Chota Nagpur Plateau spanning Jharkhand-Odisha-Chhattisgarh (the "Ruhr of India") is the epicentre, containing iron ore, coal, bauxite, manganese, chromite, copper, and mica in close proximity. However, this mineral wealth overlaps almost entirely with India's Schedule V tribal areas -- creating a fundamental tension between development imperatives and tribal rights.

DISTRIBUTION OF MAJOR MINERALS:

Iron Ore: Odisha (#1; 57%+ production; Joda-Barbil-Keonjhar), Chhattisgarh (#2; Bailadila-NMDC), Karnataka (#3; Bellary-Hospet). 4th largest reserves globally (33.2 billion tonnes). Both haematite (Jharkhand-Odisha-CG-Goa) and magnetite (Karnataka -- Kudremukh).

Coal: 4th largest reserves (319 BT); Gondwana coalfields (98%); Damodar Valley (Jharia coking coal -- most important); Odisha (Talcher); CG (Korba); Neyveli lignite (TN).

Bauxite: Odisha (#1; Koraput-Kalahandi-Bolangir); Jharkhand (#2; Lohardaga); 5th largest reserves. NALCO (Damanjodi); Niyamgiri controversy (Vedanta rejected 2013).

Manganese: Odisha (#1; Keonjhar), Maharashtra (#2; Nagpur-MOIL Balaghat largest mine), Karnataka (#3; Sandur).

Copper: Rajasthan (#1; Khetri "Copper City"), Jharkhand (#2; Singhbhum); MP (#3; Malanjkhand-Balaghat -- Asia's largest open-cast copper mine; HCL).

Mica: Jharkhand (#1; Koderma -- "Mica Triangle"), Rajasthan (#2; Ajmer-Bhilwara), AP (#3; Nellore). India = world's largest mica producer. Child labour concern.

Critical Minerals: Lithium (J&K Salal 5.9 MT announced 2023); REE (Kerala-TN-AP coastal monazite; IREL); Titanium/Ilmenite (Kerala #1; 2nd globally); Chromite (Odisha Sukinda 98% of India's reserves).

ENVIRONMENTAL IMPACTS:

1. **Deforestation:** Hasdeo Arand (CG) = 170,000 ha biodiverse forest threatened by 23 coal blocks; Niyamgiri plateau bauxite threatened sacred tribal forest; Odisha Eastern Ghats loss to iron ore.
2. **Water pollution:** Sukinda Valley (Odisha): Cr6+ chromium contamination of Brahmani River tributaries -- UNEP designates as one of world's most polluted places; Damodar River coal ash and acid mine drainage; Khetri copper tailings in Rajasthan.
3. **Land subsidence:** Jharia underground coal fire (since 1916); ground cracking; 27,000 families need evacuation; BCCL-JADA managing slow crisis.

SOCIAL / TRIBAL IMPACTS:

1. **Displacement:** "Mineral states = tribal states = displaced states" paradox; Jharkhand, Odisha, CG, AP -- all mineral rich, all have worst tribal welfare indicators despite mineral royalties.
2. **Rights under law:** FRA 2006 (community rights); PESA 1996 (gram sabha rights over resources); Niyamgiri SC 2013 (gram sabha veto on mining); yet implementation remains weak; state governments often side with mining companies against tribal interests.
3. **DMF as remedy:** District Mineral Foundation (Rs.60,000+ crore accumulated nationally by 2023) mandated to develop mining-affected communities; implementation varies; best examples: Odisha's Keonjhar DMF funding schools and hospitals; some states using DMF opaquely.

The "resource curse" in India's tribal mineral belt is not inevitable -- it is a policy failure. With adequate tribal consent (PESA+FRA implementation), robust environmental standards (pre-FCAA 2023 norms), transparent DMF utilisation, and value addition within producing states (not just raw export), India can convert its mineral wealth into tribal welfare rather than tribal displacement. The Critical Minerals Mission 2024 must enshrine tribal consent and environmental safeguards at its core, not as afterthoughts.

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CHAPTER 36

INDUSTRIES AND INDUSTRIAL REGIONS

Iron And Steel, Textiles, Petrochemicals, IT And Major Industrial

CHAPTER AT A GLANCE

- INDUSTRY OVERVIEW: India is the world's 5th largest economy (GDP ~USD 3.7 trillion, 2023-24). Manufacturing contributes ~16% of GDP; Services ~55%; Agriculture ~17%. India targets manufacturing at 25% of GDP (National Manufacturing Policy 2011). Make in India (2014): manufacturing hub; FDI; DPIIT. PLI (Production Linked Incentive) schemes across 14 sectors. India is the world's 2nd largest steel producer; 3rd largest cement producer; 3rd largest pharmaceutical producer; largest generic drug exporter; 4th largest auto producer.
- IRON AND STEEL INDUSTRY: India = world's 2nd largest steel producer (2022-23: ~125 MT crude steel; after China ~1,010 MT). Major producers: SAIL (Steel Authority of India Ltd, PSU); Tata Steel; JSW Steel; JSPL (Jindal Steel and Power). Major plants: Jamshedpur (Tata Steel; 1907; Jharkhand; oldest integrated plant); Bhilai (SAIL; 1959; CG; with Soviet help; flat products); Durgapur (SAIL-DSP; WB; 1959; British collaboration); Rourkela (SAIL-RSP; Odisha; 1959; German collaboration); Bokaro (SAIL-BSP; 1972; Soviet help). Private: JSW Vijayanagar (Bellary, KA; 12 MMTPA; largest integrated plant); Tata Kalinganagar (Odisha, under expansion). NMDC Nagarnar (CG; 3 MMTPA; 2023).
- TEXTILE INDUSTRY: India's largest industry by employment (45 million direct + 60 million indirect jobs). India = 2nd largest textile producer; 3rd largest exporter (USD 44.4 billion exports 2022-23). Segments: Cotton textiles (Mumbai-Ahmedabad-Surat -- historical "Cottonopolis"); Jute (Kolkata-Howrah -- "Manchester of the East" for jute; Bangladesh competition; ~66 jute mills on Hooghly river); Silk (Bengaluru-Mysuru-Varanasi-Dharmavaram-Kanchipuram); Wool (Rajasthan, HP, Jammu); Technical textiles (growing: medical, geo, agro textiles). Policy: PM MITRA (Mega Integrated Textile Region and Apparel) -- 7 parks; Amended Technology Upgradation Fund Scheme (ATUFS).
- PETROCHEMICAL INDUSTRY: India = 3rd largest petrochemical producer in Asia. Reliance Industries (RIL) Jamnagar (Gujarat) = world's largest single-location refinery complex + integrated petrochemical complex; ONGC Petro-additions Ltd (ONGC) at Dahej; HPCL Rajasthan Refinery (greenfield, under construction). Petro-chemical clusters: Vadodara-Dahej-Hazira corridor (Gujarat); Haldia (WB); Mumbai-Thane (Maharashtra). India petrochemicals used for plastics, synthetic fibres, fertilisers, paints, pharmaceuticals.
- INFORMATION TECHNOLOGY (IT) AND ELECTRONICS: IT-BPM sector contributes USD 245 billion (FY 2023-24) = 8.5% of GDP. India exports USD 194 billion IT services. IT clusters: Bengaluru (No. 1; Electronic City, Whitefield, Manyata Tech Park -- Infosys, Wipro, Tata Consultancy, IBM, Microsoft, Amazon, Google); Hyderabad (HITEC City; No. 2 or 3); Pune (Hinjewadi -- Rajiv Gandhi Infotech Park; No. 3); Chennai (OMR -- "Rajiv Gandhi Salai"; No. 4); Delhi-NCR (Noida, Gurugram; No. 5). PLI for semiconductors (ISMC at Gujarat; Micron Gujarat fab plant 2023; India Semiconductor Mission). Semicon India 2024.
- AUTOMOBILE INDUSTRY: India = 3rd largest auto market globally (2023); 4th largest producer (5.57 crore vehicles sold 2022-23). Clusters: Chennai-Hosur ("Detroit of India"; Hyundai, Ford, BMW, Nissan, TVS, Royal Enfield); Pune (Tata Motors, Mahindra, Volkswagen, Mercedes-Benz, Bajaj Auto at Waluj); Gurugram-Manesar (Maruti Suzuki -- India's largest car maker 40%+ market share); Ahmedabad-Sanand (Tata Nano plant -- now Tata EV factory; Ford India closed 2021). EV shift: FAME (Faster Adoption and Manufacturing of EVs) Phase 2 (2019-2024; Rs.10,000 crore); PLI for Advanced Chemistry Cells (batteries); Ola Electric, Ather, TVS, Hero EV leading two-wheelers; Tata Nexon EV = India's best-selling EV.
- PHARMACEUTICAL INDUSTRY: India = "Pharmacy of the World" (3rd largest producer by volume; largest generic drug exporter; supplies 20% of global generic medicines; 60% of global vaccines). Clusters: Hyderabad (Genome Valley; largest pharma cluster; Dr. Reddy's, Aurobindo, Hetero, Divi's Labs); Ahmedabad (Zydus Cadila, Torrent); Mumbai (Sun Pharma -- largest Indian pharma company; Cipla); Pune (Serum Institute -- world's largest vaccine manufacturer

by doses; 1.5 billion doses/year capacity). PLI for bulk drugs (APIs -- Active Pharmaceutical Ingredients) + medical devices. Pharma Vision 2047.

- MAJOR INDUSTRIAL REGIONS: (1) Mumbai-Pune industrial region: oldest; cotton, engineering, petro, pharma, IT; (2) Hugli-Durgapur-Asansol: jute, steel, chemicals, coal; (3) Bengaluru-Chennai-Coimbatore: IT, silk, textiles, auto, aerospace (HAL); (4) Gujarat (Ahmedabad-Vadodara-Surat): cotton, petrochemicals, chemicals, diamonds; (5) Chota Nagpur (Jharkhand-WB-Odisha): steel, coal, copper, heavy engineering (HEC Ranchi); (6) Delhi-NCR: engineering, electronics, garments, auto; (7) Visakhapatnam-Guntur: steel (RINL), fertilisers, shipbuilding.

36.1 INTRODUCTION -- INDIA'S INDUSTRIAL LANDSCAPE

India's industrial transformation since Independence has been one of the most significant in the developing world. From a largely agrarian economy in 1947, India has built a diversified industrial base spanning iron and steel, cotton and jute textiles, petrochemicals, pharmaceuticals, automobiles, aerospace, defence electronics, and -- most recently -- a globally dominant information technology and services sector. India is now the **world's 5th largest economy** (GDP ~USD 3.7 trillion in 2023-24; projected to be 3rd largest by 2027) and a manufacturing hub being actively courted as an alternative to China-centric global supply chains.

Industrial Parameter	*India's Position / Data*	*Key Note*
GDP from Industry (Manufacturing)	~16-17% of GDP from manufacturing; ~26% from total industry (incl. construction, mining, utilities)	National Manufacturing Policy 2011 targets 25% by 2025; India lags behind the "manufacturing miracle" trajectory of China, South Korea, and Taiwan
Total Exports	USD 776 billion (merchandise + services, FY 2022-23)	India targets USD 2 trillion exports by 2030; USD 1 trillion merchandise + USD 1 trillion services
FDI Inflows	USD 70-85 billion/year (2021-24); top sector: IT/computer, automobile, telecommunications	PLI schemes across 14 sectors to attract manufacturing FDI; India competing with Vietnam, Thailand, Mexico for China+1 strategy FDI
Steel Production	~125 MT crude steel (FY 2022-23); 2nd largest globally (after China ~1,010 MT)	Target: 300 MT by 2030 (National Steel Policy 2017); India net importer of high-grade special steel
Pharmaceutical Exports	USD 27.6 billion (FY 2022-23); 3rd largest producer by volume; largest generic exporter	Supplies 20% of global generics; 60% of global vaccines; 50% of WHO's global vaccine requirement
IT-BPM Sector	USD 245 billion (FY 2023-24); 8.5% of GDP; USD 194 billion exports	India = world leader in IT services outsourcing; 5.4 million IT sector employees; targets USD 500 billion by 2030
Automobile Production	3rd largest market; 4th largest producer (5.57 crore vehicles 2022-23)	India targeting 30% EV penetration by 2030; Maruti Suzuki = 40%+ market share; Chennai = automobile export hub

36.2 IRON AND STEEL INDUSTRY -- FOUNDATION OF INDUSTRIALISATION

The iron and steel industry is the **"foundation industry" of modern economies** -- providing the raw material for construction, machinery, defence, automobiles, railways, and consumer goods. India is the **world's 2nd largest steel producer** (after China), producing approximately **125 million tonnes of crude steel in FY 2022-23** and targeting **300 MT by 2030** under the **National Steel Policy 2017.**

MAJOR STEEL PLANTS -- LOCATION AND FEATURES

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Plant	Location	Established	Collaboration	Capacity (MMTPA)	Key Feature
Tata Steel Jamshedpur (TISCO)	Jamshedpur (Singhbhum East), Jharkhand	1907	Indigenous (J.N. Tata -- no foreign collaboration)	11 MMTPA (largest in Jharkhand)	INDIA'S FIRST AND OLDEST integrated steel plant; established by Jamshedpur Nusserwanji Tata; called "Steel City" / "Tatanagar"; on the banks of Subarnarekha and Kharkai rivers; raw materials: iron ore (Noamundi, Jharkhand), coal (Jharia), limestone (Odisha); Jamshedpur = a "company town" built by Tata with housing, hospitals, clubs
Bhilai Steel Plant (SAIL-BSP)	Bhilai, Durg district, Chhattisgarh	1959	Soviet Union (USSR)	7 MMTPA	Built with Soviet technical collaboration; produces rails (Bhilai = India's largest rail producer; rails for Indian Railways), heavy structural steel, wire rods; raw materials: Bailadila iron ore (Dantewada, 100 km), Korba coal (100 km), Nandini limestone (very close); Bhilai was India's pride project in Nehru's heavy industrialisation era
Durgapur Steel Plant (SAIL-DSP)	Durgapur, Paschim Bardhaman, West Bengal	1959	United Kingdom (British Steel Corporation)	2.1 MMTPA	Damodar Valley location; coal from Raniganj-Jharia coalfields; iron ore from Noamundi (Jharkhand); produces: alloy and special steels, structural steel, billets, skelp (for pipe making); Durgapur = major industrial city in WB with multiple ancillary industries
Rourkela Steel Plant (SAIL-RSP)	Rourkela (Sundargarh district), Odisha	1959	West Germany (Krupp-Demag)	4.5 MMTPA	First plant in India to make silicon steel (for electrical transformers); now primary producer of flat products (HR/CR coils, plates); raw material: Kiriburu-Meghahatuburu iron ore (close); Jharia/Talcher coal; limestone from Birmitrapur; Rourkela = major tribal area (Oraon, Munda communities) -- plant displaced many tribals; RSP now focuses on value-added flat steel for automobile and defence sectors
Bokaro Steel Plant (SAIL-BSL)	Bokaro, Jharkhand	1964 (commissioned 1972)	Soviet Union (USSR)	5.77 MMTPA	Built in the heart of Damodar Valley; Bokaro coal nearby; flat products (HR/CR coils for automobile body manufacturing); also tinplate for

					food canning; Bokaro is unique: designed as the second Soviet-collaboration plant (after Bhilai); Bokaro Steel City = another "company town" with BSL-run schools, hospitals, colonies
IISCO Steel Plant (SAIL-IISCO)	Burnpur, Asansol, West Bengal	1918 (oldest site); modernised 2015	Originally British; now SAIL	2.5 MMTPA (after modernisation)	Indian Iron and Steel Company (originally); SAIL acquired; Burnpur-Asansol is in the older Damodar Valley industrial belt; produces long products (wire rods, blooms); Burnpur was earlier known for sleeper bars and rails; modernisation replaced vintage equipment
JSW Steel Vijayanagar	Vijayanagar (Bellary/Ballari district), Karnataka	1994 (private)	JSW Group (O.P. Jindal Group)	12 MMTPA (LARGEST PRIVATE; also largest single-site plant in India)	On Tungabhadra River; close to iron ore of Bellary-Hospet; imported coking coal via ports; produces flat products, plates, coils; became largest integrated private steel plant in India; Bellary mining controversies affected its ore supply
Tata Steel Kalinganagar	Jajpur district, Odisha	2016 (partial); expanding to 8 MMTPA	Tata Steel	5 MMTPA (Phase 1); expanding	Greenfield plant in Odisha (Kalinganagar Industrial Complex, KIC); tribal displacement controversy in 2006 (police firing on tribal protesters opposing land acquisition -- 12 protesters killed; Kalinganagar 2006 massacre = landmark in tribal land rights); now operational; raw materials from nearby Odisha iron ore; coking coal imported via Paradip Port; Tata is expanding to 8 MMTPA and eventually 16 MMTPA
NMDC Nagarnar Steel Plant	Nagarnar, Bastar, Chhattisgarh	2023 (commissioned)	NMDC (PSU; now divested to NMDC Steel Ltd)	3 MMTPA	India's NEWEST integrated steel plant; situated adjacent to Bailadila iron ore mines; tribal area (Bastar -- Gondi tribal belt); NMDC developed and then in 2023 transferred to NMDC Steel Ltd (separate listed entity); significant for Chhattisgarh's value addition from ore to steel
Vizag Steel / RINL (Rashtriya Ispat Nigam)	Visakhapatnam (Vizag), Andhra Pradesh	1992	Soviet Union (USSR) design adapted	7.3 MMTPA (proposed)	INDIA'S ONLY SHORE-BASED INTEGRATED STEEL PLANT; designed to receive seaborne raw materials (iron ore via Vizag Port, coking coal

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					imported); AP's most important industry; privatisation controversy (2021: Cabinet approved RINL privatisation; AP government, workers' unions strongly opposed; case in courts; privatisation stalled; RINL facing debt crisis and partial operation)

KEY NOTE

Steel Plant Collaboration Mnemonic: "The Bhilai-Bokaro SSR (Soviet Steel Romance): Bhilai 1959 = USSR; Bokaro 1972 = USSR; Durgapur 1959 = UK (British); Rourkela 1959 = West Germany (German). Jamshedpur 1907 = Tata (no collaboration). RINL Vizag = USSR design. JSW Vijayanagar and Tata Kalinganagar = private, no foreign government collaboration." Also: "4 SAIL plants started in 1959: Bhilai (USSR), Durgapur (UK), Rourkela (Germany), and then Bokaro (USSR) later -- remember as first batch Second Plan era (1956-61) industrialisation."

36.2 FACTORS FOR STEEL PLANT LOCATION

Location Factor	*How It Determines Plant Site*	*Indian Examples*
Proximity to Iron Ore	Iron ore (bulk material; 1.5-2 tonnes per tonne of steel) is the heaviest input; minimising transport cost is crucial	Bhilai is 100 km from Bailadila iron ore; Rourkela is close to Kiriburu mines; JSW Vijayanagar is adjacent to Bellary iron ore; plants NOT close to iron ore pay huge transport cost (RINL Vizag receives seaborne ore)
Proximity to Coal (Coking Coal)	Coking coal (bulk material; 0.6-0.8 tonnes per tonne of steel) needed for blast furnace	Jamshedpur, Bokaro, Durgapur -- all in or near the Damodar Valley coalfield; Bhilai receives coal from Korba (100 km); coastal plants (Vizag, Kalinganagar) import coking coal via ports
Water Supply	Steel making is water-intensive; large river nearby essential	Jamshedpur on Subarnarekha-Kharkai confluence; Bhilai on Sheonath River (Mahanadi tributary); Rourkela on Brahmani River; Durgapur on Damodar River; Bokaro on Damodar River; JSW Vijayanagar on Tungabhadra
Market Proximity (for finished steel)	Flat products (coils, sheets for automobiles) need proximity to auto manufacturing belt	SAIL Durgapur-Burnpur to supply Bengal engineering industry; Bokaro to supply Delhi-Haryana-Punjab auto+engineering belt; JSW Vijayanagar close to Bengaluru-Chennai auto sector; RINL Vizag for AP-Telangana industrial demand
Land and Labour	Large flat area needed (integrated plant occupies 2,000-10,000 acres); skilled + unskilled labour	Chhota Nagpur plateau was chosen for BSP/RSP in 1950s as large flat areas available, abundant tribal/eastern labour; Kalinganagar (Odisha) tribal area chosen for low land cost -- but triggered tribal protests
Power Supply	Steel plants are enormous power consumers (100-200 MW per plant)	Captive power plants are norm; Jharkhand-WB-Odisha-CG have abundant coal for thermal power; coastal plants access grid power or generate from imported coal

36.3 TEXTILE INDUSTRY -- INDIA'S OLDEST LARGE INDUSTRY

The textile industry is India's **oldest and largest employer** -- directly employing ~45 million workers and supporting an additional ~60 million in related livelihoods, making it the **2nd largest employer after agriculture.**

India is the **2nd largest textile producer** (after China) and the **3rd largest textile exporter** (USD 44.4 billion exports in 2022-23). The sector ranges from traditional handloom weaving to ultramodern automated spinning mills.

Textile Type	Description	Key Centres	Key Feature
COTTON TEXTILES	India = 2nd largest cotton producer; largest cotton textile exporter. From raw cotton to yarn (spinning), fabric (weaving/knitting), and garment (finishing/sewing); the complete value chain	Mumbai-Thane: historically India's "Cottonopolis"; 58 textile mills in early 20th century; now most mills closed ("mill-land" redeveloped; Girangaon = mill workers' heritage); Ahmedabad = "Manchester of India"; Surat = synthetic textiles (polyester, viscose); Coimbatore = spinning mills ("Manchester of South India"); Tiruppur (TN) = knitwear/hosiery export capital (Rs.35,000+ crore exports); Nagpur (cotton belt, less now)	PM MITRA (7 parks for vertically integrated textile manufacturing); ATUFS (tech upgradation); India produces 36+ million bales of cotton; Bollworm Bt-Cotton success; viscose/polyester blending with cotton growing; Surat = synthetic capital of India (polyester filament yarn)
JUTE INDUSTRY	Jute = "Golden Fibre"; India = world's largest jute producer (>80% of raw jute) AND 2nd largest exporter (Bangladesh competition); jute used for sacking, carpet backing, geo-jute, biodegradable packaging	Hooghly River belt (WB): ~66 jute mills concentrated on Hooghly river banks from Rishra to Birpara; Titagarh, Barrackpore, Naihati, Shyamnagar, Bhadreswar; Kolkata = "Jute Capital of the World" historically; also Bihar (Purnea), Assam (Bongaigaon), Odisha	Jute Act makes jute packaging mandatory for food grains (gunny bags); National Jute Policy; Jute Corporation of India; threat from synthetic substitutes; Bangladesh produces higher-quality yarn jute and competes on finished products; eco-friendly packaging revival boosting demand
SILK TEXTILES	India = 2nd largest raw silk producer (after China); 4 types: Mulberry (70%+, Bengaluru-Mysuru-Kolar, AP), Tasar/Tussar (Jharkhand-Chhattisgarh-Odisha-WB), Muga (Assam -- golden silk; GI protected; Sualkuchi = silk village of India), Eri (Assam, NE)	Bengaluru-Mysuru-Kolar (Karnataka -- largest mulberry silk); Varanasi (Banarasi silk sarees -- GI protected; Brocade weaving); Kanchipuram (TN; Kanjivaram silk -- GI protected); Dharmavaram (AP; sarees); Sualkuchi (Assam -- Muga); Bishnupur (WB; Baluchari weaves)	Central Silk Board (CSB) Bengaluru; Silk weavers = highly skilled artisans (handloom; power loom); Varanasi silk = threatened by power loom competition; government supports GI tags and handloom clusters; Indian silk sarees represent a Rs.50,000+ crore industry
WOOL AND WOOLLEN TEXTILES	India = 8th largest wool producer; mostly medium and coarse wool (not merino); from Rajasthan (Marwari sheep -- 40%+ of	Ludhiana (Punjab -- "Wool City of India"; knitwear -- sweaters, shawls; capital of India's woollen hosiery industry); Amritsar (carpets + woollens); Srinagar +	Shahtoosh ban: made from Tibetan Antelope (Pantholops hodgsonii; CITES Appendix I); illegal trade despite ban continues;

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	wool), J&K (Pashmina/Cashmere from Changthangi goat -- GI protected), HP, UP (Rampur Raza)	Leh (Pashmina, Shahtoosh = very thin and warm; Shahtoosh is banned internationally as Tibetan antelope Chiru is killed for it)	Pashmina (from Changthangi goat in Ladakh; legitimate; GI tagged) is legal; National Wool Development Board
POWER LOOM AND HANDLOOM	Handloom = 2nd largest employment (after agriculture) in textiles; India has ~35 lakh handloom weavers; 70%+ located in NE India (particularly Assam, Manipur, Nagaland, Mizoram)	Power loom: Surat (largest power loom cluster); Bhiwandi (MH); Malegaon (MH); Ichalkaranji (MH); Bhilwara (RJ; synthetic fabrics). Handloom: Assam (Mekhela Chador weave), Pochampally (TS; Ikat weave), Sambalpuri (Odisha; Ikat), Chanderi (MP; fine cotton-silk), Maheshwari (MP; silk-cotton)	National Handloom Development Programme (NHDP); Handloom Mark; GI tags for specific weave clusters; digitisation of weavers; e-commerce (Craftsvilla, Amazon Karigar); handloom weavers often among India's most economically marginalised; power loom competition decimating traditional handloom

36.4 INFORMATION TECHNOLOGY INDUSTRY -- INDIA'S GLOBAL COMPETITIVE ADVANTAGE

The Information Technology and Business Process Management (IT-BPM) sector is India's **most globally competitive industry** -- a sector where India not only competes with but leads the world. From USD 2 billion in 1994-95, India's IT exports have grown to **USD 194 billion in FY 2023-24** (services) -- making India the **world's #1 IT services exporter** with approximately **55-60% of global IT outsourcing** market. The sector employs approximately **5.4 million highly skilled workers** and is the largest private employer of engineers in the world.

IT Feature	*Detail*
Overall sector size	USD 245 billion (FY 2023-24; services + BPM + hardware + start-ups); 8.5% of India's GDP; fastest-growing major sector; target USD 500 billion by 2030 (IT industry body NASSCOM projection)
IT services exports	USD 194 billion (FY 2023-24); USA = 60%+ of IT export destination; UK = 15%; Europe = 12%; APAC = 10%; REST = remainder
Top companies (by revenue)	TCS (Tata Consultancy Services) = India's largest IT company and largest market cap private company; Infosys; HCL Technologies; Wipro; Tech Mahindra; LTIMindtree; Mphasis; Coforge -- the "Big 7" + growing MNC operations
Employment	5.4 million direct IT employees (2023-24); 1.6 million new jobs projected to be added; 70% of India's IT workforce is under 35 years; gender diversity improving (30%+ women in IT vs 10% in manufacturing)
BENGALURU -- IT Capital	Electronic City (SEZ), Whitefield IT Park, Manyata Tech Park, Koramangala startup hub; 35%+ of India's IT exports; 2 million+ IT workers; per capita income highest among Indian cities; fastest property price growth; infrastructure lagging growth (water crisis, traffic)
HYDERABAD -- Genome Valley + HITEC City	HITEC City = Hyderabad Information Technology Engineering Consultancy City; major Microsoft India campus; Google India; Amazon AWS; TATA CS; biotech + pharma cluster (Genome Valley); Pharma City = world's largest pharmaceutical manufacturing cluster (announced)
PUNE -- Rajiv	Hinjewadi IT Park (Rajiv Gandhi Infotech Park) Phase 1-3; Infosys campus, Wipro, TCS,

Gandhi Infotech Park	Cognizant; close to Mumbai; automobile + IT combination; pleasant climate vs Mumbai; rapidly growing
GCC (Global Capability Centres)	1,580 GCCs (India-based R&D/technology centres of global MNCs) employing 1.66 million workers; India = preferred destination for GCC due to talent + cost; top companies: J.P. Morgan, Goldman Sachs, Wells Fargo, Google, Microsoft, Apple, Samsung all have GCCs in India
Semiconductor Mission	India Semiconductor Mission (ISM) announced 2021; PLI for semiconductors + display fab; Micron Technology (US) inaugurated semiconductor packaging and testing unit in Sanand, Gujarat (2024 -- India's first semiconductor fab); ISMC (International Semiconductor Consortium) applying for chip fab in Karnataka; Tata Electronics-Powerchip (PSMC) partnership for chip fab in Gujarat (Dholera SIR)

36.5 AUTOMOBILE INDUSTRY -- TOWARDS EV TRANSITION

Auto Feature	*Detail*
Production scale	5.57 crore vehicles produced (FY 2022-23); 3rd largest auto market globally (overtook Japan in 2022); 4th largest producer; India = world's largest 2-wheeler market; world's 3rd largest bus+truck market
Chennai cluster ("Detroit of India")	Largest auto cluster by export value; Hyundai India (largest car exporter from India), Ford India (closed manufacturing 2021 but still used plant for export), BMW India (mini plant), Nissan-Renault, TVS Motor, Royal Enfield, Ashok Leyland (truck); ~35% of India's auto production
Pune-Aurangabad cluster	Tata Motors (cars + trucks + buses; HQ Mumbai but Pune + Jamshedpur plants), Mahindra (HQ Mumbai; Nashik + Chakan plants), Volkswagen + Skoda (Aurangabad/Pune), Mercedes-Benz (Pune), Bajaj Auto (Aurangabad = "Waluj" plant; world's largest 3-wheeler plant; exporter to over 70 countries)
Gurugram-Manesar (NCR)	Maruti Suzuki India (India's largest car manufacturer; 40%+ market share; Gurugram + Manesar plants; 2.4 million cars/year capacity); Haryana CM has made Haryana an auto hub (Manesar = major labour unrest 2012 -- Maruti workers' strike and violence; HR manager killed)
Ahmedabad-Sanand	Tata Nano factory (repurposed for Tata EV -- Tiago EV, Punch EV); Ford India Sanand plant (closed; now Tata Motors acquired); Gujarat government attracted multiple auto investments
EV shift	FAME Phase 2 (Faster Adoption and Manufacturing of EVs; Rs.10,000 crore; 2019-2024): subsidises EV purchase for consumers; results: 2-wheeler EV market (Ola Electric, Ather, TVS iQube, Hero Vida); Tata Nexon EV = India's best-selling EV (4-wheeler). PLI for Advanced Chemistry Cells (ACC batteries; Rs.18,100 crore); PLI for Automobile and Components (Rs.25,938 crore). Ola Electric IPO (2024) = India's largest EV IPO. Charging infrastructure: EESL (Energy Efficiency Services Ltd) + NITI Aayog target 1 charging station per 3 km in cities by 2030

36.6 PHARMACEUTICAL INDUSTRY AND DEFENCE MANUFACTURING

PHARMACEUTICAL -- PHARMACY OF THE WORLD

Pharma Feature	*Detail*
Scale	USD 50 billion total industry; USD 27.6 billion exports (FY 2022-23); 3rd largest producer by volume; largest generic exporter (20% of global generics by volume); 60% of global vaccines (WHO); 50% of UN vaccine requirement; supplies to 200+ countries

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Hyderabad Genome Valley	India's largest pharma cluster; Dr. Reddy's Laboratories (USD 3+ billion revenue; global generics leader), Aurobindo Pharma (largest by volume), Hetero Drugs, Divi's Laboratories (API specialist), Laurus Labs; Bharat Biotech (Covaxin -- India's first indigenous COVID-19 vaccine; NASAL vaccine research)
Serum Institute of India (Pune)	World's LARGEST VACCINE MANUFACTURER BY DOSES produced (1.5 billion doses/year capacity); makes: Covishield (AstraZeneca COVID vaccine), BCG, MMR, DPT, Pentavalent, Pneumococcal; founded by Cyrus Poonawalla (1966); GAVI partner; critical for global vaccine equity
Sun Pharma (Mumbai)	India's LARGEST PHARMACEUTICAL COMPANY by revenue; global specialty pharma player; dermatology and ophthalmology specialisations; acquired Ranbaxy (2014); operations in 100+ countries
API (Active Pharmaceutical Ingredients)	India imports 67%+ of APIs from China -- creating strategic vulnerability; PLI for Bulk Drugs (Rs.6,940 crore): promote domestic API production; 3 Bulk Drug Parks in AP (Visakhapatnam), HP (Himachal Pradesh), and Gujarat to manufacture APIs currently sourced from China; Penicillin G (antibiotic API) -- India stopped domestic production in 1990s due to cheap Chinese supply; now Strategic API cluster at Vizag to re-establish Penicillin production
Pharma Vision 2047	DPIIT + Ministry of Chemicals goal: USD 130 billion by 2047; move from generics to innovative drugs (India's R&D spend in pharma is only 5% of revenue vs 18-20% globally -- need to increase innovation); promote biosimilars (complex biologics); pharma clusters under PLI; 3 new Pharma parks under PM MITRA (Pharma variant)

DEFENCE MANUFACTURING -- ATMANIRBHAR BHARAT

Defence Feature	*Detail*
Scale	India = world's 4th largest military spender (USD 83 billion defence budget 2023-24); but also world's largest arms IMPORTER historically (Russia, USA, Israel, France = primary suppliers). Indigenisation target: 68% domestic procurement by 2027-28 (vs 20% in 2014).
DPSUs (Defence Public Sector Undertakings)	HAL (Hindustan Aeronautics Ltd, Bengaluru): aircraft manufacturing + MRO; Tejas LCA (Light Combat Aircraft); Dhruv ALH (Advanced Light Helicopter); Sitara IJT (Intermediate Jet Trainer). BEL (Bharat Electronics Ltd, Bengaluru): radars, missile systems, electronic warfare. BEML (Bharat Earth Movers Ltd): heavy vehicles. BDL (Bharat Dynamics Ltd, Hyderabad): missiles. MDL (Mazagon Docks, Mumbai): submarines (Scorpene class -- P75 programme), destroyers. GRSE (Garden Reach Shipbuilders, Kolkata): frigates. GSL (Goa Shipyard): patrol vessels, survey ships.
Private sector defence	Tata Advanced Systems Ltd (TASL): aerospace structures, missiles. Mahindra Defence: armoured vehicles, drones. L&T Defence: artillery guns (K9 Vajra -- Indian version of Korean K9; produced at L&T Hazira, Surat), submarines. Adani Defence: drones, UAV. ADAG (Reliance Defence -- Dassault Aviation Rafale offset controversy involving Indian Reliance)
Make in India Defence	2 Defence Industrial Corridors: (1) Uttar Pradesh DIC (Agra-Aligarh-Lucknow-Kanpur-Jhansi-Chitrakoot corridor; electronics, aerospace); (2) Tamil Nadu DIC (Chennai-Coimbatore-Salem-Tiruchirappalli-Tirunelveli; aerospace, naval). iDEX (Innovations for Defence Excellence): Rs.500 crore for startups working on defence innovations.
Tejas LCA	India's indigenous light combat aircraft (4.5-generation); HAL Bengaluru; powered by GE-F414 engine (US-origin); Tejas Mk1A version (2024+): 83 aircraft ordered by IAF; Tejas Mk2 under development. India also producing Prachand (Light Combat Helicopter) and Rudra (weaponised Dhruv).

36.7 MAJOR INDUSTRIAL REGIONS OF INDIA

Industrial Region	*States*	*Key Industries*	*Key Centres*
Mumbai-Pune Region	Maharashtra	Cotton textiles (historically); engineering; petrochemicals; pharmaceuticals; IT; financial services; aerospace; entertainment (Bollywood)	Mumbai (financial, entertainment, ports); Pune (auto -- Tata, Mahindra, VW; IT -- Hinjewadi; pharma -- Serum Institute, Cipla); Nashik (grapes + defence -- BEL + private; Mahindra); Thane-Belapur (chemicals); Raigad (JNPT; JN Special Economic Zone)
Hugli River Belt (West Bengal)	West Bengal	Jute (66 mills); paper; chemicals; engineering; electronics; IT; food processing; steel at Durgapur-Asansol	Kolkata (finance, trade, IT, jute); Howrah (engineering -- Howrah Bridge); Durgapur (steel, DSP; chemicals); Asansol-Burnpur (steel, IISCO); Haldia (petroleum refinery; petro-chemicals; port)
Bengaluru-Chennai Corridor	Karnataka + Tamil Nadu	IT (India's IT capital -- Bengaluru); aerospace (HAL, ISRO); silk; electronics; auto (Chennai -- Hyundai, BMW, Ashok Leyland); textiles (Coimbatore); engineering; defence (DRDO, BEL)	Bengaluru (IT, silk, aerospace); Chennai (auto, IT, leather, cement); Coimbatore (textiles, pumps); Hosur (TVS, Royal Enfield, Titan); Mysuru (silk, sandalwood, electronics); Salem (steel)
Gujarat Industrial Region	Gujarat	Petroleum refining (Jamnagar = world's largest); chemicals; pharmaceuticals; cotton textiles; diamond cutting; food processing; cement; automobiles (Sanand)	Surat (diamonds -- 90% of world diamond cutting; synthetic textiles -- 70% of India polyester yarn; "Diamond City of India"); Ahmedabad (textiles, pharma -- Zydus, Torrent; chemicals); Vadodara (Baroda; chemicals -- GNFC, GSFC; engineering); Ankleshwar-Bharuch (industrial estates, chemical hub); Jamnagar (refinery, RIL -- world's largest); Dahej-Hazira (chemical + LNG corridor)
Chota Nagpur Industrial Region	Jharkhand + WB + Odisha (northern)	Steel (Jamshedpur, Bokaro, Durgapur, Burnpur); coal; copper (Singhbhum); heavy engineering (HEC Ranchi); aluminium (Muri, JH); chemicals; coal-based power plants	Jamshedpur (steel, Tata Steel, HEC); Ranchi (HEC -- Heavy Engineering Corporation; engineering equipment for steel, mining); Dhanbad (coal capital, ISM -- Indian School of Mines now IIT-ISM); Bokaro (steel); Asansol-Durgapur (steel, coal); Singhbhum belt (copper, iron ore)
Delhi-NCR Industrial Region	Delhi + Haryana + UP	Engineering; electronics; garments; automobiles (Maruti Suzuki Gurugram-Manesar); food processing; pharmaceuticals; IT services	Gurugram (IT/ITES -- DLF Cyber City; Maruti Suzuki; pharma -- Goyal Medical); Noida-Greater Noida (electronics -- Samsung, Oppo, Vivo assembling plants); Faridabad

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		(Gurugram tech hub); printing and publishing	(industrial estates -- engineering); Bahadurgarh (brassware); Moradabad (UP; brassware -- "Brass City"; largest brass export cluster)
Visakhapatnam-Guntur Region	Andhra Pradesh	Steel (RINL Vizag -- India's only shore-based integrated steel plant); shipbuilding (HSL -- Hindustan Shipyard Limited); petroleum refining (HPCL); fertilisers (FACT, NFCL); tobacco; textiles	Visakhapatnam/Vizag (steel, naval base, HPCL refinery, shipbuilding, IT -- HITEC Vizag); Kakinada (port, fertilisers, oil exploration); Rajahmundry (tobacco, wood products); Nellore (mica); Hyderabad (HITEC City; pharma; aerospace -- DRDL)

36.8 CURRENT AFFAIRS HOOKS (2022-2025)

PLI Schemes and Make in India (2020-2025): Production Linked Incentive (PLI) schemes across 14 sectors (Mobile phones and electronics, pharmaceuticals, medical devices, automobiles and auto components, advanced chemistry cells/batteries, textile, food processing, telecom, white goods, specialty steel, solar PV modules, ACC batteries) have attracted significant investment. Key success stories: Mobile phone PLI -- Apple (Foxconn + Tata) and Samsung now manufacture in India; India's mobile phone exports crossed USD 11 billion in 2022-23 (from near-zero in 2018). Apple began assembling iPhone 15 in India (2023) -- historical first; Tata Electronics acquired Wistron's India factory; both Foxconn and Tata plan to expand iPhone manufacturing in India.

India's First Semiconductor Fab (Micron, Gujarat, 2023): Micron Technology (US semiconductor major) inaugurated India's first semiconductor facility in Sanand, Gujarat in June 2023 (PM Modi + US President Biden jointly attended the announcement during Modi's Washington visit). The USD 825 million plant does semiconductor packaging and testing (OSAT = Outsourced Semiconductor Assembly and Testing) -- not chip fabrication. Separately, Tata Electronics-PSMC (Powerchip Semiconductor Manufacturing Corp, Taiwan) partnership for a chip fabrication (wafer fab) plant at Dholera Special Investment Region (SIR), Gujarat was approved in 2024.

RINL Visakhapatnam Steel Privatisation Controversy (2021-2024): The Cabinet approved privatisation of RINL (Rashtriya Ispat Nigam Ltd / Visakhapatnam Steel Plant / Vizag Steel) in January 2021. The AP government, opposition parties, and workers' unions strongly objected -- Vizag Steel was built with AP funds and national political promises (it was promised to compensate for loss of Hyderabad when AP-Telangana bifurcation happened in 1956; the plant was promised to become the soul of Andhra). The AP government moved SC; the Supreme Court referred it to a constitutional bench. As of 2025, privatisation stalled; RINL faces severe financial crisis with heavy debt.

PM MITRA (Mega Integrated Textile Region and Apparel): The PM MITRA scheme (2022; Rs.4,445 crore) will set up 7 integrated textile parks in states with strong textile traditions: Gujarat (Surat -- synthetic), Maharashtra (Amravati), Karnataka (Dhar), Rajasthan (Jodhpur -- denim), Telangana (Warangal), UP (Lucknow -- chikan embroidery), Tamil Nadu (Virudhunagar). Each park will have spinning-weaving-processing-garment under one roof -- reducing logistics costs and improving competitiveness vs Bangladesh and Vietnam.

36.9 PYQ ANALYSIS -- CHAPTER 36 (2010-2025)

Source	Year	Marks	Question
UPSC Civil	2024	15M	"Discuss the factors influencing the location of the iron and steel industry in India. Critically examine the challenges faced by SAIL plants."
UPSC Civil	2023	12M	"Discuss the significance of the IT industry for India's economic development.

			How has Bengaluru emerged as India's Silicon Valley?"
UPSC Civil	2022	10M	"What is the significance of PLI (Production Linked Incentive) schemes for India's manufacturing sector? Discuss with examples."
UPSC Civil	2021	12M	"Discuss the location factors, distribution, and problems of the cotton textile industry in India."
UPSC Civil	2020	10M	"Critically examine the emergence of India as the 'Pharmacy of the World'. What are the challenges to sustaining this position?"
UPSC Civil	2019	10M	"Discuss the distribution and importance of the jute industry in India. What are the major challenges it faces?"
UPSC Civil	2018	12M	"Discuss the major industrial regions of India and the factors that have led to their development."
UPSC Civil	2017	10M	"What is Make in India? Discuss its significance for India's manufacturing sector and employment."
IFoS GS	2024	10M	"Discuss the environmental impact of industrial clusters in India, with particular reference to pollution of water bodies near iron and steel plants."
IFoS GS	2023	10M	"Examine the environmental impact of pharmaceutical industries in Hyderabad's Genome Valley and the Patancheru-Bollaram industrial area."
IFoS GS	2022	10M	"Discuss the impact of the textile industry on rivers and water bodies in India with specific examples."

KEY NOTE

Frequency: Iron-steel location factors + SAIL (Civil 2024); IT industry + Bengaluru (Civil 2023); PLI schemes (Civil 2022); cotton textile (Civil 2021); Pharmacy of World (Civil 2020); jute industry (Civil 2019); industrial regions (Civil 2018); Make in India (Civil 2017). IFoS: industrial water pollution near steel plants (2024), Patancheru pharma pollution (2023), textile industry river pollution (2022). For 2025-26: PLI mobile phones + Apple iPhone India manufacturing; Micron semiconductor plant Gujarat 2023; Tata Electronics-PSMC chip fab Dholera; PM MITRA 7 textile parks; RINL privatisation controversy -- all high-priority.

36.10 MODEL BOOK

Discuss the factors influencing the location of the iron and steel industry in India. Critically examine the major steel plants and the challenges faced by the sector.

UPSC CIVIL (Mains) | 15 Marks | 210 Words

Iron and steel is the "mother industry" of modern industrialisation -- providing the structural material for railways, bridges, buildings, ships, machinery, and defence. India's 125 MT crude steel production (FY 2022-23) makes it the world's 2nd largest producer. The location of steel plants follows the classic Weber least-cost theory -- minimising transport costs for heavy, bulk inputs.

LOCATION FACTORS:

1. **Proximity to iron ore:** The single most important factor; iron ore is the heaviest input (1.5-2 tonnes/tonne steel). Jamshedpur (adjacent to Singhbhum ore); Bhilai (100 km from Bailadila ore, CG); JSW Vijayanagar (adjacent to Bellary ore, KA); RINL Vizag uses seaborne ore (compensates distance with port access).
2. **Proximity to coking coal:** Essential for blast furnace; ~0.7 tonnes/tonne steel. Damodar Valley (Jharia-Bokaro-Raniganj) makes Jamshedpur, Durgapur, Bokaro, Burnpur highly advantageous for coal access. Coastal plants (Vizag, Kalinganagar) compensate by importing coking coal through ports.
3. **Water supply:** All major plants are on rivers: Jamshedpur (Subarnarekha); Bhilai (Sheonath); Rourkela

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(Brahmani); Durgapur-Bokaro (Damodar); JSW Vijayanagar (Tungabhadra); RINL Vizag (near coast).

4. **Market access:** Flat products for automobiles go to Chennai-Pune-NCR; long products (rails, structural) go to national market (Bhilai = largest rail producer for Indian Railways). Bokaro's HR coils go to Delhi-NCR auto belt.
5. **Power and land:** Jharkhand-WB-Odisha-CG coal availability supports captive power; large flat areas in Chota Nagpur facilitated big plants.

MAJOR PLANTS -- KEY FACTS:

SAIL plants (PSU): Bhilai (USSR, 1959, CG -- rails); Bokaro (USSR, 1972, JH -- flat products); Rourkela (W. Germany, 1959, Odisha -- flat/silicon steel); Durgapur (UK, 1959, WB -- alloy/structural); IISCO Burnpur (WB -- long products).

Private sector: Tata Jamshedpur (1907; JH; 11 MMTPA; oldest); JSW Vijayanagar (KA; 12 MMTPA; largest single plant); Tata Kalinganagar (Odisha; 5 MMTPA Phase 1, expanding; displaced tribals in 2006 -- Kalinganagar violence).

NMDC Nagarnar (2023): India's newest plant; 3 MMTPA; Bastar, CG; near Bailadila ore; divested to NMDC Steel Ltd.

RINL Vizag: India's only shore-based integrated plant; privatisation controversy (AP government opposition; SC case; stalled; RINL in financial crisis).

CHALLENGES:

1. **Coking coal import dependence:** India imports 50-60 MT coking coal annually (mostly Australia; some USA, Canada) -- costly and strategically vulnerable; Indian coking coal (Jharia) is insufficient in quality and quantity.
2. **High cost of production:** Indian steel is 10-20% more expensive than Chinese steel due to: higher raw material logistics costs; outdated SAIL plants needing modernisation; high energy costs; lower labour productivity.
3. **Chinese dumping:** China, with massive surplus capacity, dumps cheap steel in global markets; India has imposed anti-dumping duties but cannot fully protect domestic market.
4. **Tribal displacement:** Kalinganagar 2006 (12 tribals killed by police); new plants in mineral-rich tribal areas face Land Acquisition Act 2013 compliance challenges and resistance.
5. **Green steel transition:** EU Carbon Border Adjustment Mechanism (CBAM from 2026) will penalise carbon-intensive Indian steel exports to Europe; India must decarbonise steel (green hydrogen DRI, electric arc furnaces) -- a massive capital investment challenge.

India's 300 MT by 2030 target requires both expanding SAIL's old plants and attracting private greenfield investment. National Steel Policy 2017 provides the framework. The dual challenge: making Indian steel globally competitive in cost while transitioning to low-carbon steelmaking defines the sector's medium-term trajectory.

CHAPTER 37

ROAD & RAIL TRANSPORT

National Highways, Indian Railways, Dedicated Freight Corridors & Connectivity

CHAPTER AT A GLANCE

- ROAD NETWORK: India has the 2nd largest road network in the world (~63 lakh km total; 2023). National Highways (NHs): ~1.46 lakh km (only 2.3% of road network but carry ~40% of total road traffic). State Highways: ~1.86 lakh km. District/Rural roads: ~55+ lakh km. Road density: 1.84 km of road per sq km (2023; improved dramatically from 0.66 in 1950-51). India builds ~10,000 km of national highway per year (record 10,457 km in FY 2020-21). NHAI (National Highways Authority of India) manages major NHs.
- KEY NATIONAL HIGHWAYS: NH-44 = India's longest NH (4,112 km; Srinagar to Kanyakumari; formerly NH-1, NH-7 and others merged); NH-27 = 2nd longest (3,507 km; Porbandar to Silchar); NH-48 = Delhi to Chennai (2,807 km; one of the busiest; renamed from NH-8); NH-52 (Sangrur to Sabroom); Bharatmala Pariyojana Phase 1: 34,800 km of new NHs under construction/planned; Economic Corridors, Inter Corridors, Ring Roads. Expressways: Delhi-Mumbai Expressway (1,386 km; under construction/opened 2023 in phases); Yamuna Expressway; Mumbai-Pune Expressway; Agra-Lucknow Expressway.
- INDIAN RAILWAYS: Largest rail network under single management; 4th largest in world (67,000+ route km). 3.5+ crore passengers daily; 8,000+ passenger trains. Zone structure: 18 zones (latest: Amritsar Zone). Gauges: Broad Gauge (1,676 mm; 93%+ of network; standard for India); Metre Gauge (1,000 mm; being converted to BG under Project Unigauge); Narrow Gauge (762/610 mm; heritage/hill railways). Indian Railways headquarters: Rail Bhavan, New Delhi. Board: Railway Board under Ministry of Railways.
- DEDICATED FREIGHT CORRIDORS (DFCs): India's most transformative railway project. Two main corridors: (1) WDFC (Western DFC): Dadri (UP)-JNPT Mumbai; 1,504 km; passes through UP, Haryana, Rajasthan, Gujarat, Maharashtra. (2) EDFC (Eastern DFC): Ludhiana (Punjab)-Dankuni (WB); 1,875 km; passes through Punjab, Haryana, UP, Bihar, Jharkhand, WB. DFC Corporation of India (DFCCIL) is the implementing agency. WDFC Phase 1 operational from January 2021. Both DFCs largely operational by 2023. DFCs run only freight; no passenger trains; 100 kmph speed vs 25 kmph on existing lines; double-stack containers possible. World Bank-funded (EDFC) + JICA-funded (WDFC).
- VANDE BHARAT EXPRESS (TRAIN-18): India's fastest and most modern train; indigenously manufactured by ICF (Integral Coach Factory, Chennai); semi-high speed (160 kmph design speed; currently runs at 130-160 kmph); fully air-conditioned; chair car and executive chair car; no locomotive -- distributed traction (self-propelled). First Vande Bharat launched February 15, 2019 (Varanasi-New Delhi). By 2024: 100+ Vande Bharat trains in service on 50+ routes. Vande Metro (shorter version for metro routes) and Vande Sleeper (overnight version) also being developed.
- HIGH-SPEED RAIL (BULLET TRAIN): India's first bullet train project = Mumbai-Ahmedabad High Speed Rail Corridor (MAHSR; 508 km; Japan-India collaboration; JICA loan JPY 1.08 lakh crore at 0.1% interest for 50 years; Shinkansen E5 technology). NHSRC (National High Speed Rail Corporation Ltd) implementing. Designed speed: 320 kmph (Japan E5 series). Issues: land acquisition delays (Gujarat largely complete; Maharashtra politically contentious); cost escalation; estimated completion now 2028 (original 2023 deadline missed). Surat-Bilimora section (48 km) may open first.
- PM GATI SHAKTI NATIONAL MASTER PLAN: Launched October 13, 2021 by PM Modi. A GIS-based digital platform integrating planning of all infrastructure (roads, railways, ports, airports, waterways, gas pipelines, power lines) to ensure multi-modal connectivity and avoid duplication. 16 ministries integrated on one platform. Aim: reduce logistics cost from 14% of GDP to <8% by 2030. Key outcomes: simultaneous infrastructure projects planned to avoid digging up the same road twice; port connectivity roads aligned with DFC termini; industrial parks along DFC routes for "last mile" efficiency.
- LOGISTICS AND FREIGHT: India's logistics cost = 14% of GDP vs 8% global benchmark -- a major competitiveness drag.

Freight modal share: Roads = 65% of freight tonne-km; Railways = 27%; Pipelines = 6%; Waterways = 2%. Target: shift freight to railways and waterways (cheaper, less polluting) -- DFCs are key for this. National Logistics Policy (NLP) 2022: comprehensive framework; ULIP (Unified Logistics Interface Platform); PM GATI SHAKTI; multimodal logistics parks (MMLPs). CONCOR (Container Corporation of India) = key rail freight company.

37.1 ROAD TRANSPORT -- INDIA'S PRIMARY FREIGHT AND PASSENGER MODE

India has the **2nd largest road network in the world** (~63 lakh km; 2023), behind only the USA (~67 lakh km). Road transport is India's **dominant mode for both freight (65%) and passengers** -- reflecting the flexibility and last-mile connectivity that only roads can provide. Since Independence, India's road length has grown from ~4 lakh km (1950-51) to 63+ lakh km (2023) -- a 15-fold increase.

CLASSIFICATION OF ROADS

Road Type	Authority	Total Length	Key Feature
National Highways (NHs)	NHAI (National Highways Authority of India, est. 1988) for major NHs; state PWDs for some; Border Roads Organisation (BRO) for border areas	~1.46 lakh km (2023); growing by ~10,000 km/year	Only 2.3% of network but carry ~40% of total traffic; all NHs are part of the National Highways Development Project (NHDP); Bharatmala Phase 1 adding 34,800 km
State Highways (SHs)	State Public Works Department (PWD); State Highway Authorities in some states	~1.86 lakh km	Connect state capitals, major cities, important industrial/agricultural areas within a state; connect to NHs at interchange nodes
Major District Roads (MDRs)	District and state agencies	~3.30 lakh km	Connect district headquarters to state highways and sub-district level areas; essential for agricultural produce movement
Rural Roads	PMGSY (Pradhan Mantri Gram Sadak Yojana, 2000) + state governments	~55+ lakh km (largest category by far)	PMGSY target: all habitations above 250 population connected by all-weather roads; PMGSY-III (2019): upgrade and maintenance; ~7 lakh km rural roads built under PMGSY since 2000 -- transformative for rural connectivity and market access
Urban Roads / Expressways	NHAI/NHIDCL for expressways; ULBs for city roads	~7 lakh km urban; ~5,000 km expressways	Expressways: 4/6/8 lane, access-controlled; Delhi-Mumbai Expressway (1,386 km; longest when complete; 8-lane); Yamuna Expressway (165 km; Noida-Agra); Mumbai-Pune (95 km); Agra-Lucknow (302 km; UP Expressway Industrial Authority)
Border Roads	Border Roads Organisation (BRO, established 1960 by PM Nehru; under Ministry of Defence)	~65,000 km (cumulative; BRO area roads)	Critical for defence: roads in Ladakh, Arunachal Pradesh, Sikkim, Himachal Pradesh, Uttarakhand -- areas where commercial contractors cannot operate in extreme terrain and altitude; BRO also builds international highways (Friendship Highway in Bhutan, Trilateral Highway India-Myanmar-Thailand)

KEY NATIONAL HIGHWAYS

NH No.	Route	Length	Key Feature
NH-44	Srinagar (J&K) to Kanyakumari (Tamil Nadu)	4,112 km	LONGEST NATIONAL HIGHWAY in India; traverses the entire length of India (north to south); passes through: J&K, Punjab, Haryana, Delhi, UP, MP, Maharashtra, Telangana, AP, TN; passes through 11 states + 1 UT; was formerly multiple NHs (NH-1+2+7 etc.) that were merged under new NH numbering system (2010 onward; odd numbers for NS roads, even for EW)
NH-27	Porbandar (Gujarat) to Silchar (Assam)	3,507 km	2nd longest; runs east-west across India; passes through Gujarat, Rajasthan, MP, UP, Bihar, Jharkhand, WB, Assam; critical for landlocked NE India connectivity; connects the western coast to the Northeast
NH-48 (formerly NH-8)	Delhi to Chennai	2,807 km	One of India's busiest NHs; Delhi-Jaipur-Ahmedabad-Mumbai section was India's first 4-laned section (early NHDP); Golden Quadrilateral (GQ) NH forms the core of India's intercity road freight network
NH-52	Sangrur (Punjab) to Sabroom (Tripura)	3,417 km	3rd longest; key highway connecting Punjab to NE India; passes through UP, Bihar, WB, NE states; Sabroom (Tripura) is at the Bangladesh border; the proposed Bangladesh transit route would connect this highway to Chittagong Port (greatly reducing distance for NE India's international trade)
NH-19 (formerly NH-2)	Delhi to Kolkata (via Agra, Varanasi)	1,435 km	Historic "Grand Trunk Road" section from Agra to Varanasi (continuing Sher Shah Suri's GT Road); part of the Golden Quadrilateral; connects Delhi to Kolkata via the Ganga plain; one of India's most heavily trafficked freight corridors
NH-66 (formerly NH-17)	Panvel (Maharashtra) to Kanyakumari (Tamil Nadu)	2,035 km	Entire coastal highway on the west coast; connects Mumbai (Panvel) to Kanyakumari via Goa, Karnataka coast (Mangaluru, Udupi), Kerala (Kozhikode, Kochi, Thiruvananthapuram); overlaps with much of the Coastal Highway / NH-766 sections; extremely scenic Konkan + Malabar coast route

BHARATMALA PARIYOJANA

Bharatmala Pariyojana (Phase 1) is India's largest-ever highway development programme, approved in 2017. It involves the development of **34,800 km of national highways** (economic corridors, inter corridors, ring roads, feeder/role corridors, national corridor improvements, coastal and port connectivity roads, and Greenfield expressways) at an estimated cost of **Rs.5.35 lakh crore.**

Bharatmala Component	Length (Phase 1)	Key Focus
Economic Corridors	9,000 km	High-traffic density intercity freight corridors; 4-6 lane; connecting major production and consumption centres; examples: Delhi-Mumbai Expressway (NH-148N); Chennai-Bengaluru Expressway; Amritsar-Jamnagar Expressway
Inter Corridors	6,000 km	Connect economic corridors to each other and to ports; complete the network between the major "spines"
National Corridor Improvements	5,000 km	Upgrade existing congested NHs to 4-6 lanes; critical for immediate decongestion
Ring Roads and Bypasses	2,600 km	Bypass major cities to remove through-traffic from urban areas; Delhi Peripheral Expressway (Western + Eastern); Chennai bypass; Bengaluru Peripheral Ring Road

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Coastal and Port Connectivity	2,100 km	Connect ports (especially non-major ports) to the national highway grid; facilitate coastal shipping last-mile; connect industrial zones near ports
Greenfield Expressways	5,000 km	New access-controlled expressways from scratch; Delhi-Mumbai (1,386 km -- 8 lane; partially open 2023), Amritsar-Jamnagar (1,257 km); Bengaluru-Chennai (262 km); Bengaluru-Vijayawada (672 km)
NE India and Border Roads	5,100 km	Critical: NE India and border areas are underserved by roads; Bharatmala specifically funds NE connectivity; Manipur, Nagaland, Mizoram, Arunachal Pradesh (Arunachal Frontier Highway along the McMahon Line border)

KEY NOTE

Delhi-Mumbai Expressway -- Exam Key Facts: Delhi-Mumbai Expressway (NH-148N; 1,386 km) -- when complete, India's longest expressway; 8-lane access-controlled; connects Delhi (Dwarka) to Mumbai (JNPT) via Haryana, Rajasthan (Jaipur-Dausa bypass), MP (Ratlam), Gujarat (Vadodara, Ankleshwar), and Maharashtra; passes near Vadodara (Baroda) -- enabling manufacturing FDI in this corridor. Travel time: 12 hours (vs 24 hours currently). Partially opened (Sohna-Dausa section 246 km in Feb 2023). Full completion expected 2024-25. Economic benefit: reduces logistics cost for Mumbai-Delhi freight significantly.

37.2 INDIAN RAILWAYS -- THE LIFELINE OF THE NATION

Indian Railways (IR) is one of the world's largest and most complex rail networks -- the **4th largest by route km (67,000+ km)** after USA (225,000 km), Russia (85,600 km), and China (150,000 km). It is the **largest employer under single management** in India and one of the largest in the world, employing approximately **14.5 lakh (1.45 million) workers.** Daily, it carries approximately **3.5 crore passengers** on 8,000+ passenger trains and approximately **30 lakh tonnes of freight** on 7,000+ goods trains.

IR Parameter	*Data / Detail*
Route length	67,000+ km (2023); 4th largest in world; goal of 100% electrification by 2024 (largely achieved); BG (Broad Gauge) = 93%+ of network
Zones (18)	Northern (Delhi), North-Eastern (Gorakhpur), North-East Frontier (Guwahati), Eastern (Kolkata), South-Eastern (Kolkata), South Central (Secunderabad), Southern (Chennai), Central (Mumbai), Western (Mumbai), South-Western (Hubli), North-Western (Jaipur), West-Central (Jabalpur), North-Central (Prayagraj), South-Eastern Central (Bilaspur), East-Central (Hajipur), East-Coast (Bhubaneswar), Metro Railway Kolkata, and South-Coast (Vishakhapatnam -- newest)
Gauges	Broad Gauge (BG): 1,676 mm (India standard; unique in world -- not used by any other country at this exact width); Metre Gauge (MG): 1,000 mm (being phased out under Unigauge project); Narrow Gauge (NG): 762 mm and 610 mm (heritage hill railways -- Darjeeling Himalayan Railway, Kalka-Shimla, Nilgiri Mountain Railway, Matheran Hill Railway, Kangra Valley Railway)
Station types	A1: Highest category (Mumbai CST, Howrah, Chennai Central, New Delhi); A: Major station; B, C, D, E, F in descending order. ISBT and bus integration being developed. Total stations: ~7,300+ stations nationally.
Electrification	100% electrification target achieved largely by 2024; uses 25 kV AC overhead electric traction on BG; eliminates diesel fuel dependency; reduces operating cost; lowers carbon footprint. Indian Railways aims to be net-zero carbon by 2030.
Revenue and finance	Total revenue ~Rs.2.56 lakh crore (FY 2022-23); freight = ~Rs.1.62 lakh crore (63% of revenue); passengers = ~Rs.60,000 crore (23%); target: freight cross-subsidy for passengers should be reduced; freight revenue supports passenger subsidy.

Passenger services	Rajdhani Express (Delhi to state capitals; fully AC; highest priority); Shatabdi Express (intercity day trains; chair car); Duronto (non-stop); Jan Shatabdi (cheaper semi-reserved); Humsafar (3A only); Tejas Express (private operators briefly; IRCTC-operated); Vande Bharat (semi-high speed; newest premium; 100+ trains in 2024); Antyodaya Express (unreserved poor-class); Gatimaan Express (160 kmph; India's fastest till Vande Bharat)

UNESCO WORLD HERITAGE HILL RAILWAYS

Heritage Railway	*Route*	*Gauge*	*UNESCO Year*	*Key Feature*
Darjeeling Himalayan Railway (DHR)	New Jalpaiguri (NJP, WB) to Darjeeling (WB); 88 km	610 mm (Narrow)	1999 (WHS)	FIRST railway to get UNESCO WHS status in India; the iconic "Toy Train" with Z-reverse switchbacks to climb the Himalayan foothills; steam + diesel locos; passes through tea gardens; Batasia Loop (most famous scenic spot); Ghum = highest railway station in India (2,258 m)
Nilgiri Mountain Railway (NMR)	Mettupalayam to Ooty (Udagamandalam), Tamil Nadu; 46 km	1,000 mm (Metre Gauge)	2005 (extended to WHS)	Only RACK-AND-PINION railway in India (toothed rack rail for adhesion on steep gradients -- max 83 per mille = 1 in 12 gradient; very steep); steam locos still used on lower section; Mettupalayam to Coonoor on steam; highest point = Ooty (2,205 m); part of Mountain Railways of India WHS
Kalka-Shimla Railway (KSR)	Kalka (Haryana) to Shimla (HP); 96 km	762 mm (Narrow)	2008 (extended to WHS)	102 tunnels (longest = Barog Tunnel, 1.14 km); 869 bridges; 917 curves; climbs from 656 m (Kalka) to 2,076 m (Shimla); spectacular Himalayan scenery; British-era (1903); Shimla was British India's summer capital -- this railway was its lifeline
Matheran Hill Railway	Neral (Maharashtra) to Matheran; 21 km	610 mm (Narrow)	Not UNESCO WHS but heritage status	No motor vehicles allowed in Matheran (eco-sensitive zone); this tiny 21-km railway is the only way to reach Matheran; seasonal (closed June-July monsoon due to landslide risk); British-era (1907)

37.3 DEDICATED FREIGHT CORRIDORS -- TRANSFORMING RAIL FREIGHT

The Dedicated Freight Corridors (DFCs) are India's **most significant railway infrastructure project** since Partition -- a set of high-capacity, high-speed freight-only rail lines that will fundamentally transform India's logistics landscape. On India's existing mixed rail network, passenger trains take priority and freight trains move at only 25 kmph average speed, making Indian rail freight uncompetitive with road transport. The DFCs address this by providing **dedicated freight-only tracks** where trains move at 100 kmph with double-stack containers and 1.5-2 times more freight per train.

DFC	*Route*	*Length*	*Funding*	*Status (2024)*	*Key Feature*
Western DFC (WDFC)	Dadri (UP) to Jawaharlal Nehru Port	1,504 km	Japan (JICA -- Japan International	Largely operational; Phase 1 (Rewari-Madar,	Connects the Delhi-NCR manufacturing belt (UP, Haryana) to JNPT (India's

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	Trust (JNPT), Mumbai (Navi Mumbai)		Cooperation Agency) loan; JPY 7,696 crore at 0.1% for 40 years	306 km) opened Jan 2021; Madar-Palanpur, Palanpur-Makarpura-Sachin sections operational; JNPT-Jawaharlal section under work	largest container port); passes through Rajasthan, Gujarat; major industries along route: textile, chemical, auto; reduces Delhi-Mumbai freight time from 40 hours to 14 hours (target)
Eastern DFC (EDFC)	Ludhiana (Punjab) to Dankuni (near Kolkata, WB)	1,875 km	World Bank loan (USD 2.725 billion at 0.5% for 25 years)	Largely operational; Khurja-Bhadan section (Phase 1, 341 km) opened June 2022; New Bhaupur-New Khurja section; Mughalsarai-Sonnagar-Garhwa section operational; total ~1,500 km operational by 2024	Connects Punjab grain bowl (Ludhiana, Ludhiana-Ambala) to Kolkata (Dankuni intermodal hub); passes through UP (Kanpur, Allahabad/Prayagraj, Varanasi), Bihar (Pt. Deen Dayal Upadhyaya Junction), Jharkhand (Gomoh), WB (Dankuni); major freight: coal (Jharkhand to Punjab power plants), fertiliser, food grain, cement, containers
DFCCIL	DFC Corporation of India Ltd	N/A	Central PSE under Ministry of Railways	Implementing agency	Separate from Indian Railways; owns and operates DFC infrastructure; leases track access to Indian Railways and private operators; has its own operating control centres

DFC Key Technical Features: (a) **Double-stack containers** (stacking two 20-foot containers vertically on one flatcar) -- saves space and reduces cost per container; only possible on DFC because overhead electrification height is raised; existing lines cannot accommodate double-stack. (b) **25-tonne axle load** (vs 22.9-tonne on existing IR tracks) -- heavier trains carry more. (c) **100 kmph operating speed** (vs 25 kmph average freight on existing lines). (d) **1.5 km train length** (vs 750 m current limit). These technical features together mean DFC trains carry 3-4 times more freight per unit time than existing tracks.

37.4 HIGH-SPEED RAIL AND SEMI-HIGH SPEED TRAINS

MUMBAI-AHMEDABAD HIGH SPEED RAIL CORRIDOR (BULLET TRAIN)

Bullet Train Feature	*Detail*
Route	Mumbai (Bandra Kurla Complex station -- underground) to Ahmedabad (Sabarmati); 508 km; 12 stations proposed: BKC, Thane, Virar, Boisar, Vapi, Bilimora, Surat, Bharuch, Vadodara, Anand, Ahmedabad, Sabarmati
Technology	Shinkansen E5 series technology from Japan; designed speed 320 kmph; average operating

	speed ~250 kmph; travel time Mumbai-Ahmedabad = ~2 hours (vs 6-7 hours currently by road or Shatabdi Express)
Funding and collaboration	JICA (Japan International Cooperation Agency) loan: JPY 88,000 crore (Rs.1.08 lakh crore) at 0.1% interest for 50 years with 15-year moratorium -- most concessional infrastructure loan India has ever received; Japanese soft power diplomacy through technology transfer; NHSRC (National High Speed Rail Corporation Ltd) implementing
Status (2024)	Land acquisition: Gujarat 100% complete; Maharashtra controversial (Thane city; Aarey Colony area in Mumbai -- tribal and forest concerns; underground section). Target completion: Surat-Bilimora section (48 km) may be India's first operational HSR segment (2025-26 target). Full corridor: 2028+ (original target 2023 missed). Cost has escalated significantly.
Other HSR plans	Diamond Quadrilateral: HSR connecting Delhi, Mumbai, Chennai, Kolkata (4 corners); total 7-8 corridors planned in National Rail Plan 2030; Delhi-Amritsar, Delhi-Ahmedabad, Delhi-Varanasi, Mumbai-Nagpur, Mumbai-Hyderabad, Chennai-Mysuru in planning or feasibility stage; all depend on MAHSR success and funding

VANDE BHARAT EXPRESS

The **Vande Bharat Express (Train-18)** is India's first indigenously manufactured semi-high speed trainset -- a **game-changer in Indian Railways' modernisation.** Unlike conventional trains with a locomotive pulling coaches, Vande Bharat is a **self-propelled Electric Multiple Unit (EMU)** with distributed traction (motors in multiple coaches) -- similar to metro trains but for intercity runs. It was designed and manufactured by **ICF (Integral Coach Factory, Chennai)** under the Make in India programme.

Vande Bharat Feature	***Detail***
Speed	Designed for 160 kmph; currently operates at 130-160 kmph on track-cleared sections; fastest train in India after Gatimaan Express (between Delhi Hazrat Nizamuddin and Agra Cantonment; 160 kmph); target: 200 kmph with track upgrades
First service	February 15, 2019 (PM Modi inaugurated); Varanasi-New Delhi route (758 km; non-stop in ~7 hours); PM Modi later inaugurated Chennai-Mysuru route, Gandhinagar-Mumbai route, and many others
Fleet size	100+ trains in service (by 2024); PM Modi's target was 400 trains by 2024 (behind schedule); 2nd generation Vande Bharat (improved design, better amenities, wider doors) being produced at 3 factories (ICF Chennai, RCF Kapurthala, MCF Raebareli)
Variants	Vande Bharat Express (16-car; 2S + EC seating; day routes); Vande Metro (8-car shorter version for regional commuter routes; trials underway); Vande Sleeper (overnight sleeper version with berths; prototype under development at ICF)
Significance for Make in India	Entire design and manufacturing in India (after initial imported components; indigenisation increasing); competitor to imported trains; contract for 200 Vande Bharat trains given to Alstom India (under BEML consortium) and Titagarh Rail Systems -- private sector manufacturing

37.5 METRO RAIL -- URBAN MASS TRANSIT

India has rapidly expanded its urban metro rail network -- from only **Delhi Metro (2002)** and **Kolkata Metro (1984/1995)** in 2010 to **20 cities** with operational metro systems by 2024, with several more under construction. India now has the **world's 3rd largest metro network by route km** (after China and USA) -- a dramatic transformation of urban mobility.

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City Metro	Route km (approx. 2024)	Key Feature
Delhi Metro (DMRC)	~393 km (Phase 1+2+3; Phase 4 under construction); 9 colour-coded lines	India's largest and busiest metro; ~60 lakh daily ridership; DMRC (Delhi Metro Rail Corporation) jointly owned by GoI and Delhi govt; inaugurated December 24, 2002 (Shahdara-Tis Hazari section); designed by E. Sreedharan ("Metro Man of India"); Airport Express Line (IAF-LKIA)
Mumbai Metro	~80 km operational (Lines 1, 2A, 7); 337 km total planned network; Line 3 (Colaba-SEEPZ-BKC-Aarey) opened 2024	Line 3 = underground; Aarey car shed controversy (trees felled, SC intervention); MahaMetro and MMRDA implementing; Line 1 (Versova-Andheri-Ghatkopar) = Mumbai's first metro (2014); 337 km planned = world's largest single-city metro plan
Bengaluru Metro (Namma Metro)	~73 km (Phase 1+2 operational); Phase 3 under construction	BMRCL (Bengaluru Metro Rail Corporation Ltd); Green Line (E-W) + Purple Line (N-S) form a cross; Phase 2 expanded to Electronic City (IT hub) + Whitefield (IT hub); Phase 3 will connect Bengaluru airport
Kolkata Metro	~57 km (multiple lines); oldest metro in India	Kolkata Metro = INDIA'S FIRST METRO (Section 1: Esplanade-Bhowanipore opened October 24, 1984; full south to north service 1995); under Ministry of Railways (not a separate MRTS company); expanded with Blue Line, Orange Line (through Hooghly River via underwater tunnel -- India's first underwater metro tunnel -- opened March 2024)
Hyderabad Metro (L&T)	~72 km (Hyderabad Metro; 3 corridors)	Largest metro PPP project in world; L&T (Larsen and Toubro) won concession; private operation (HMRL -- Hyderabad Metro Rail Ltd); financial stress due to COVID ridership loss
Chennai Metro	~55 km (Phase 1 and 2A); Phase 2 (118 km) under construction	CMRL (Chennai Metro Rail Ltd); Phase 2 will be one of India's largest metro expansions; connects airport, IT corridor (OMR), and suburbs
Kochi Metro	~28 km (Phase 1); Phase 2 under construction	First metro in Kerala; KMRL (Kochi Metro Rail Ltd); unique: employs transgender persons as ticketing staff (social inclusion initiative); rooftop solar panels on stations
Ahmedabad Metro (GujaratMetro)	~40 km Phase 1; Phase 2 under construction	Gujarat Metro Rail Corporation (GMRC); connects Ahmedabad to Gandhinagar (Gujarat's capital -- one of India's first inter-city metro links); BRTS (Bus Rapid Transit System) also functional in Ahmedabad -- one of India's few successful BRTSs

37.6 TRANSPORT CHALLENGES AND POLICY

Challenge	Scale / Detail	Policy Response
Road safety	India has the WORLD'S HIGHEST ROAD FATALITY COUNT -- ~1.5 lakh deaths per year (one death every 4 minutes); despite having only 3% of world's vehicles, India accounts for 11% of global road fatalities; primary causes: speeding, drunk driving, no helmet/seatbelt, overloading, poor road design, poor emergency response	Motor Vehicles (Amendment) Act 2019: higher fines (drunk driving fine up 10x; no seatbelt Rs.1,000); AIS (Autonomous Inspection Stations) for vehicle fitness; electronic enforcement (cameras); Bharat NCAP (New Car Assessment Programme) for vehicle safety ratings; Golden Hour trauma care network (emergency ambulance response)

Railway safety	Balasore/Odisha train disaster (June 2, 2023): Coromandel Express + Bengaluru-Howrah Express collision + goods train; 293 killed + 1,000+ injured = deadliest Indian rail accident in over 20 years; caused by signalling error (CBI investigation; manual error); Kavach (Automatic Train Protection system) deployment critical	Kavach (Automatic Train Protection/ATP): if two trains on same track, Kavach automatically brakes both; mandatory deployment target 5,000 km by 2024; entire network will take ~10+ years at budget allocation pace; Balasore accident occurred on non-Kavach section
Freight modal imbalance	Road carries 65% of freight but is most expensive (Rs.2.50/tonne-km) and most polluting per tonne-km; Railways carries only 27% despite being cheaper (Rs.1.30/tonne-km) and less polluting (6x less CO2 than road per tonne-km); target is 45% rail freight share by 2030	DFCs (key intervention); PM GATI SHAKTI; NLP 2022; multimodal logistics parks (MMLPs) connecting road, rail, and air; improving rail reliability and speed to make it competitive
NE India connectivity deficit	Northeast India (7 Sisters + Sikkim) connected to mainland India by the narrow Siliguri Corridor (Chicken's Neck; 22 km wide); inadequate roads, railways; high logistics cost; security implications; BRO builds roads but pace slow; railway connectivity remains incomplete (Imphal yet to get rail connection; Itanagar railway in progress)	PM Gati Shakti NE Master Plan; BRO 2022 record: 2,539 km of roads constructed; Jiribam-Imphal Railway (110 km; world's tallest railway pier at Noney Valley; opening expected 2025); Trans-Arunachal Highway; SARDP-NE (Special Accelerated Road Development Programme for NE)

37.7 CURRENT AFFAIRS HOOKS (2022-2025)

Odisha Train Disaster -- Balasore (June 2, 2023): The Coromandel Express disaster near Bahanaga Bazar station in Balasore, Odisha killed 293 passengers and injured 1,000+ -- the deadliest Indian train accident since 1995 (Firozabad). The accident involved three trains: the Coromandel Express (12841) diverted to a loop line by a signalling error, colliding with a stationary goods train, with the Bengaluru-Howrah Express also hitting the derailed coaches. CBI investigation indicted signalling technicians. The disaster renewed focus on Kavach (Automatic Train Protection system) deployment across Indian Railways.

PM Gati Shakti National Master Plan (October 2021 -- 2024 Updates): The PM Gati Shakti platform (GIS-based integration of 16 ministry infrastructure plans) has seen significant progress. By 2024, over 1,400 infrastructure projects across road, rail, port, airport, and waterway sectors have been mapped and coordinated on the platform. The platform has identified 177 cases where simultaneous project planning has been enabled, reducing delays and duplication. PM GATI SHAKTI is being cited as the key framework delivering India's record highway construction pace.

Kolkata Metro Underwater Tunnel (March 2024): PM Modi inaugurated India's first underwater metro tunnel section -- the Esplanade-Howrah Maidan stretch of Kolkata Metro's East-West Metro (Green Line) on March 6, 2024. The 4.8 km tunnel crosses beneath the Hooghly River at a depth of ~13 m. This makes Kolkata's metro the first in India to pass under a river in a bored tunnel -- a significant engineering achievement (the tunnel was constructed using Earth Pressure Balance Tunnel Boring Machines).

Vande Bharat Expansion and 100th Train (2024): PM Modi flagged off the 100th Vande Bharat train in 2024, marking a significant milestone in Indian Railways' modernisation programme. The train operates on 50+ routes connecting all major metros and several tier-2 cities. The 2nd generation Vande Bharat has improved features:

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wider doors, automatic plug doors, improved ride quality. Contracts for 200 Vande Bharat trains have been awarded to Alstom (via BEML consortium) and Titagarh Rail Systems, bringing private manufacturing into the programme.

37.1 PYQ ANALYSIS -- CHAPTER 37 (2010-2025)

Source	Year	Marks	Question
UPSC Civil	2024	15M	"Discuss the significance of Dedicated Freight Corridors (DFCs) for India's logistics and economic development. Critically examine the progress and challenges."
UPSC Civil	2023	12M	"Discuss the Bharatmala Pariyojana. How will it transform India's road connectivity and logistics?"
UPSC Civil	2022	10M	"Critically examine the progress and significance of the Mumbai-Ahmedabad High Speed Rail Corridor. What are the key challenges?"
UPSC Civil	2021	12M	"Discuss the significance of Indian Railways for national integration and economic development. What is the significance of the Vande Bharat Express?"
UPSC Civil	2020	10M	"Examine the challenges of road transport in India. How does the road safety crisis affect development?"
UPSC Civil	2019	10M	"Discuss the significance of the PM Gati Shakti National Master Plan for India's infrastructure development."
UPSC Civil	2018	12M	"Discuss the distribution of railway zones in India. What are the problems faced by Indian Railways and suggest measures for improvement?"
UPSC Civil	2017	10M	"What are Dedicated Freight Corridors? Discuss their potential to transform India's rail freight sector."
IFOS GS	2024	10M	"Discuss the environmental impact of road construction in ecologically sensitive areas of India, particularly in the Himalayas and the Northeast."
IFOS GS	2023	10M	"Examine the ecological implications of the Dedicated Freight Corridor network on wildlife corridors and forest connectivity in India."
IFOS GS	2022	10M	"Discuss the environmental and social concerns related to the Mumbai-Ahmedabad Bullet Train project, particularly regarding mangrove destruction and tribal displacement."

KEY NOTE

Frequency: DFCs significance + progress (Civil 2024); Bharatmala pariyojana (Civil 2023); Mumbai-Ahmedabad bullet train (Civil 2022); Indian Railways + Vande Bharat (Civil 2021); road safety crisis (Civil 2020); PM Gati Shakti (Civil 2019); railway zones + problems (Civil 2018); DFCs concept (Civil 2017). IFoS: road construction Himalayan ecology (2024), DFC wildlife corridors (2023), bullet train mangroves + tribal displacement (2022). For 2025-26: Balasore disaster 2023 + Kavach deployment; Kolkata Metro underwater tunnel March 2024; Vande Bharat 100th train 2024; Delhi-Mumbai Expressway phases; BRO record construction + Jiribam-Imphal railway -- all high-priority.

37.1 MODEL BOOK

Discuss the significance of Dedicated Freight Corridors (DFCs) for India's logistics and economic development. Critically examine their progress and challenges.

UPSC CIVIL (Mains) | 15 Marks | 210 Words

India's logistics cost at 14% of GDP (vs 8-9% global benchmark) is a major drag on manufacturing

competitiveness. The Dedicated Freight Corridors (DFCs) -- freight-only rail lines on which trains run at 100 kmph with double-stack containers -- are the single most transformative intervention to reduce this cost. The two DFCs (Western: Dadri-JNPT, 1,504 km; Eastern: Ludhiana-Dankuni, 1,875 km) together with PM Gati Shakti form the backbone of India's logistics upgrade.

SIGNIFICANCE -- ECONOMIC:

1. **Speed of freight:** DFC runs at 100 kmph vs 25 kmph average freight speed on existing lines -- a 4x improvement in travel time; Delhi-Mumbai freight time: 40 hours to 14 hours (target); this means perishable goods (fruits, vegetables, dairy) can now travel by rail rather than expensive road refrigerated transport.
2. **Capacity enhancement:** Double-stack containers + 1.5 km train length + 25-tonne axle load = 3-4x cargo per train vs existing lines; frees Indian Railways' existing tracks for more passenger trains (win-win); DFCCIL expects to handle 1,000+ MT freight/year at full capacity.
3. **Cost reduction:** Rail freight = Rs.1.30/tonne-km vs road = Rs.2.50/tonne-km; DFC's high speed and capacity further reduces per-unit cost; target: India's logistics cost from 14% to 8% of GDP by 2030 (National Logistics Policy 2022).
4. **Industrial corridor development:** Delhi-Mumbai Industrial Corridor (DMIC) runs parallel to WDFC; 24 manufacturing hubs and smart cities being developed along WDFC route (Dholera SIR in Gujarat; Shendra-Bidkin in MH; AURIC -- Aurangabad Industrial City); similar development nodes along EDFC.
5. **Port connectivity:** WDFC terminates at JNPT (India's largest container port) -- enabling seamless factory-to-port movement for export cargo without road congestion.

SIGNIFICANCE -- ENVIRONMENTAL: Shifting freight from road to DFC reduces: CO2 by 6x per tonne-km (rail vs road); particulate matter; congestion on NHs (extending highway life); fuel import bill (diesel replaced by electricity from increasingly renewable grid).

PROGRESS -- WHAT HAS BEEN ACHIEVED:

WDFC: Rewari-Madar section (306 km) operational January 2021; Madar-Palanpur, Palanpur-Makarpura-Sachin sections operational; significant progress.

EDFC: Khurja-Bhadan (341 km) operational June 2022; New Bhaupur-New Khurja, Mughalsarai-Sonnagar sections operational; total ~1,500 km functional by 2024.

CHALLENGES:

1. **Land acquisition delays:** Some sections, particularly in densely populated UP, faced land acquisition challenges under the new LARR Act 2013.
2. **Last-mile connectivity:** DFC terminals need road/rail connections to factories and ports; multimodal logistics parks (MMLPs) being developed but not all ready.
3. **Private freight operators:** DFC allows private operators to run trains on its tracks (container trains, automobile rakes) -- but regulatory framework and private operator interest are still developing.
4. **Ecological concerns (IFoS angle):** DFC alignment crosses wildlife corridors in Rajasthan (near Sariska and Ranthambhore) and UP (near forest areas); underpasses and overpasses for wildlife are mandated but implementation quality varies.

The DFCs represent India's most significant infrastructure investment in competitiveness since the National Highway network expansion. When fully operational with industrial clusters (DMIC, AIDC), logistics parks, and port connectivity, they could reduce India's logistics cost to below 10% of GDP -- enabling a step-change in manufacturing exports and making India a viable alternative to China for global supply chain diversification.

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CHAPTER 38

AIR TRANSPORT & TELECOMMUNICATIONS

Civil Aviation, UDAN Scheme, 5G Rollout, Digital India and Space Technology

CHAPTER AT A GLANCE

- CIVIL AVIATION: India = 3rd largest domestic aviation market globally (after USA and China); 14.6 crore domestic passengers (FY 2022-23); 7.5 crore international passengers. India has 148 operational airports (2023; up from 74 in 2014 -- nearly doubled). AAI (Airports Authority of India, 1994) manages 137 airports. DGCA (Directorate General of Civil Aviation) = regulatory authority. National Civil Aviation Policy (NCAP) 2016 targets 500 million passengers by 2037.
- UDAN SCHEME (Ude Desh ka Aam Nagrik): Regional Connectivity Scheme; launched October 2016; fares capped at Rs.2,500 for 1-hour flight on unisolated routes; enables connectivity to small towns and tier-2/3 cities; funded by VGF (Viability Gap Funding) jointly by central + state government + airlines. By 2024: 519 routes awarded; 476 airports/heliports/water aerodromes targeted. UDAN 5.0 launched 2023 (international UDAN, helicopter routes, seaplanes). Critical for NE India and Himalayan state connectivity.
- MAJOR AIRPORTS: Indira Gandhi International Airport (IGIA), Delhi = busiest (7.5 crore+ passengers 2022-23; 1st in India; 12th globally; T3 terminal is world's one of the largest single terminals; 4th runway operational 2023). Chhatrapati Shivaji Maharaj International Airport (CSMIA), Mumbai = 2nd busiest (6.0 crore+; extremely congested -- single runway limitation; Navi Mumbai International Airport NMIA under construction). Kempegowda International Airport (KIA), Bengaluru = 3rd. Rajiv Gandhi International Airport (RGIA), Hyderabad = 4th. Chennai International Airport = 5th.
- AIRLINES: Air India (privatised; Tata Group acquired January 2022; merged with Vistara in November 2024; also Air Asia India merger planned; Air India Express for low-cost); IndiGo = India's largest airline (60%+ market share; 300+ aircraft; listed; largest airline by passengers in South Asia); SpiceJet (troubled; debt; DGCA scrutiny); Go First (went bankrupt 2023); Akasa Air (new low-cost carrier launched 2022; founded by Rakesh Jhunjhunwala; 15+ aircraft as of 2024). India's total fleet: 700+ commercial aircraft.
- TELECOMMUNICATIONS: India = 2nd largest telecom market in world (after China); 117 crore (1.17 billion) mobile subscribers (TRAI data, 2023). India has the CHEAPEST mobile data in the world (~Rs.10 per GB). Internet users: 90+ crore (IAMAI, 2023). Telecom operators: Jio (largest; 44+ crore subscribers; launched September 5, 2016; disrupted telecom with free calls + Rs.149/month data); Airtel (2nd; 35+ crore); Vi/Vodafone-Idea (3rd; struggling financially). BSNL (PSU; 4G being deployed 2023-24; government bailout Rs.1.64 lakh crore).
- 5G ROLLOUT: India launched 5G services on October 1, 2022 (PM Modi inaugurated at IMC 2022). Jio and Airtel are primary 5G operators (using own 5G standalone and non-standalone networks). BSNL is deploying indigenous 4G/5G (C-DoT + TCS + Tejas Networks stack -- India's first indigenously built telecom network). By 2024: 5G available in 700+ cities (Jio claims pan-India coverage). 5G uses spectrum in 700 MHz (Jio), 3.5 GHz (both), and 26 GHz mmWave bands. Huawei/ZTE EXCLUDED from India's 5G (national security; only Ericsson, Nokia, Samsung used).
- DIGITAL INDIA AND INTERNET: Digital India Programme (2015): broadband highways, universal mobile connectivity, public internet access. BharatNet: optical fibre to all 2.5 lakh gram panchayats (Rs.42,000 crore; Phase 1+2+3; target: 1 Gbps connectivity at gram panchayat level). PM-WANI (PM Wi-Fi Access Network Interface): public Wi-Fi at 10 crore+ hotspots. India Stack: Aadhaar (1.35 billion biometric identities) + UPI (Unified Payments Interface -- world's most successful real-time payment system, 10 billion+ transactions/month) + DigiLocker. UPI: India's UPI processed 117 billion transactions in 2023 (47% of global real-time payment transactions).
- SPACE TECHNOLOGY (ISRO): ISRO (Indian Space Research Organisation, 1969; HQ: Bengaluru) = one of world's leading space agencies. Key missions: Chandrayaan-3 (lunar south pole soft landing August 23, 2023 -- world first); Aditya-L1

(India's first solar probe, launched Sept 2, 2023; reached L1 halo orbit Jan 6, 2024); Gaganyaan (India's first human spaceflight mission; test flight TV-D1 October 21, 2023; crewed mission target 2025). PSLV, GSLV, LVM3 launch vehicles. NavIC (Navigation with Indian Constellation) = India's own GPS (7 satellites; atomic clock precision; L1+L5 band; now in smartphones). India's space economy target: USD 44 billion by 2033.

38.1 CIVIL AVIATION -- INDIA'S FASTEST-GROWING TRANSPORT SECTOR

India is the **3rd largest domestic aviation market** in the world (after USA and China). From just 14 airports in 1947, India now has **148 operational airports (2023)** -- nearly double the 74 airports operational in 2014. The sector has seen explosive growth: domestic passengers grew from ~4 crore (2003-04) to **14.6 crore (FY 2022-23),** a near-fourfold increase. India's National Civil Aviation Policy (NCAP) 2016 targets **500 million (50 crore) passengers by 2037,** requiring ~200 new airports.

Aviation Parameter	*Data (2022-23 / 2023)*	*Note*
Total operational airports	148 (2023); AAI manages 137; private/PPP: DIAL (Delhi), MIAL (Mumbai), BIAL (Bengaluru), HIAL (Hyderabad)	Doubled from 74 in 2014; target 220 by 2025; AAI = Airports Authority of India (1994; statutory body under MoCA)
Domestic passengers	14.6 crore (FY 2022-23); pre-COVID peak was 14.1 crore (FY 2019-20)	India = 3rd largest domestic aviation market (USA ~91 crore; China ~47 crore; India ~14.6 crore); 7th globally including international
International passengers	7.5 crore (FY 2022-23)	Recovering from COVID; India's top international routes: Dubai, London, Singapore, New York, Kuala Lumpur; Indian carriers also expanding international significantly (Air India under Tata)
Market share (domestic airlines)	IndiGo ~60%; Air India (incl. Express) ~15%; SpiceJet ~8%; Akasa Air ~4%; others	IndiGo dominance is remarkable for a low-cost carrier; Air India Tata acquisition (2022) aimed at creating a full-service premium competitor
Cargo traffic	~3.5 million tonnes (FY 2022-23); Delhi IGIA = largest cargo hub; Mumbai = 2nd	Air cargo critical for pharma exports (temperature-sensitive), perishable fruits/vegetables, gems and jewellery, electronics
Helicopter operations	~450 helicopters; primarily used for: (a) connectivity to remote areas (NE India, Himalayan states, Andaman); (b) offshore oil (ONGC); (c) defence; (d) medical evacuation	UDAN scheme includes helicopter routes; Pawan Hans (PSU helicopter operator under disinvestment); Deccan Charters
Aircraft fleet	700+ commercial aircraft (IndiGo: 300+; Air India: 150+; SpiceJet: 65+; Akasa 15+)	India is world's largest aircraft order market: IndiGo ordered 500 A320neo (2023); Air India ordered 470 aircraft (250 Airbus + 220 Boeing; 2023 -- world's largest ever civil aviation order by a single carrier in one deal at signing)

MAJOR AIRPORTS

Airport	*City*	*Code*	*Passengers (FY 2022-23)*	*Key Feature*
Indira Gandhi International	New Delhi	DEL	7.5 crore+ (#1 in India; 12th	India's busiest; 4 runways (4th became operational 2023); T3 = one of world's largest single terminals

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Airport (IGIA)			globally)	(5.4 million sq ft; 78 aerobridges); operated by DIAL (Delhi International Airport Ltd -- GMR Group 64% + AAI 26%); Aerocity around IGIA = major commercial zone; handles 25% of India's total air traffic; 5th runway planned for Phase 4 expansion
Chhatrapati Shivaji Maharaj International Airport (CSMIA)	Mumbai	BOM	6.2 crore+ (#2 in India)	Extremely congested single-runway airport (a rare full-length single-runway major airport globally; the 2nd runway is a cross-runway used only for very specific wind conditions); operated by MIAL (Mumbai International Airport Ltd -- Adani Group 74% + AAI 26%); T2 opened 2014 -- one of India's largest; Navi Mumbai International Airport (NMIA) under construction by CIDCO + Adani; expected 2025-26 to relieve congestion
Kempegowda International Airport (KIA)	Bengaluru	BLR	3.6 crore+ (#3)	Operated by BIAL (Bengaluru International Airport Ltd -- Siemens/Zurich Airport/L&T consortium initially; Fairfax India + RJ Corp acquired stakes); T2 (new terminal) opened November 11, 2023 -- India's first airport terminal to receive LEED Platinum (greenest airport terminal in India); 3.5-acre biodiversity park with 10,000 plants inside terminal
Rajiv Gandhi International Airport (RGIA)	Hyderabad	HYD	2.4 crore+ (#4)	Operated by GMR Hyderabad International Airport Ltd (GHIAL); voted Asia's best airport 2009-12 (ACI); expanded Terminal; Hyderabad's strategic position for both domestic hub and international connectivity (Middle East routes especially)
Chennai International Airport	Chennai	MAA	2.0 crore+ (#5)	Under AAI management; expansion under way; major for South Asian international traffic; direct flights to USA, UK, Singapore, Middle East; city airport (within Chennai city limits -- noise concerns); new greenfield airport at Parandur being planned (45 km from Chennai)
Navi Mumbai International Airport (NMIA -- under construction)	Navi Mumbai, Maharashtra	Proposed: NMC	Target: 6 crore (Phase 1)	Under construction by NMIA Ltd (Adani Group 74% + CIDCO 26%); will relieve Mumbai's severely congested CSMIA; Greenfield; Phase 1 expected 2025-26; challenges: land acquisition, displaced salt-pan workers, Karnala Bird Sanctuary concern (migratory birds)
Jewar Airport (Noida International Airport)	Jewar, Greater Noida, UP	Proposed: DXN	Target: 12 crore (Phase 1); 7 crore (eventual)	Under construction; operated by Yamuna International Airport Pvt Ltd (YIAPL) -- Zurich Airport International 37.5% + UP government; designed by Zaha Hadid Architects; Phase 1 target 2025; will be India's largest airport when complete; will serve Delhi NCR east zone and Agra/Mathura tourism corridor

38.1 UDAN SCHEME -- REGIONAL AIR CONNECTIVITY

The **UDAN (Ude Desh ka Aam Nagrik -- "Let the Ordinary Citizen Fly") scheme,** launched in October 2016 under the National Civil Aviation Policy (NCAP) 2016, is India's regional air connectivity initiative -- specifically designed to connect **underserved and unserved airports in tier-2 and tier-3 cities, hill states, NE India, and remote areas** at affordable fares. UDAN is a **market-based VGF (Viability Gap Funding) model** -- airlines bid for routes; the government pays the shortfall between the airline's cost and the capped ticket price.

UDAN Feature	*Detail*
Ticket price cap	Rs.2,500 for a 1-hour flight on UDAN routes (half the seats per flight capped; the other half at market rates); the Rs.2,500 cap applies to "UDAN seats" -- typically 9-13 seats per flight depending on aircraft type
VGF mechanism	Viability Gap Funding: Central Government (80%) + State Government (20%) + nominal levy on non-UDAN airport flights (Rs.50-8,000/flight by origin-destination pair) pooled into a fund; airlines receive VGF to cover the difference between cost and Rs.2,500 fare; this makes unviable routes viable
Routes awarded (cumulative by 2024)	519 routes awarded under UDAN 1.0 through 5.0; of these ~350 operational at any given time (some routes start, then airlines exit); airports/heliports/water aerodromes targeted: 476 (including 58 unserved airports, 86 underserved airports, 120 heliports, 12 water aerodromes)
UDAN phases	UDAN 1.0 (2016): fixed-wing aircraft; UDAN 2.0 (2018): helicopters added; water aerodromes; UDAN 3.0 (2019): more routes; UDAN 4.0 (2020): hill area focus + tourism; UDAN 5.0 (2023): international connectivity between tier-2 cities + international UDAN (direct international flights bypassing metro hubs)
NE India focus	UDAN has a special focus on Northeastern India -- connectivity within NE states (Arunachal Pradesh, Manipur, Nagaland, Mizoram, Meghalaya, Tripura, Sikkim) where geography makes surface transport very difficult; helicopter routes connect remote valley towns; Doling (Arunachal) was connected for the first time by air under UDAN; Hollongi Airport (new; near Itanagar) opened 2023 under UDAN
Achievements and criticism	Achievements: 1.2 crore+ UDAN passengers by 2023; many first-time flyers; NE and hill connectivity improved significantly. Criticism: many routes operationally discontinued as airlines withdraw; subsidy dependency; low frequency (once or twice weekly on many routes) reduces practical utility; infrastructure at smaller airports still inadequate

Air India Tata Acquisition and Merger (2022-2024): The government completed the disinvestment of Air India to the Tata Group in January 2022 -- ending 69 years of government ownership (Air India was nationalized in 1953 by PM Nehru from J.R.D. Tata, who had founded it in 1932 as Tata Airlines). Tata Sons acquired Air India for Rs.18,000 crore. Subsequently, Tata merged Vistara (joint venture with Singapore Airlines, 49%) into Air India in November 2024, creating a full-service international carrier. Air India Express (low-cost) and AirAsia India (also Tata-owned) are also being integrated. The combined entity is positioned to challenge IndiGo's domestic dominance and re-establish India as a major aviation hub.

38.1 TELECOMMUNICATIONS -- INDIA'S DIGITAL REVOLUTION

India's telecom sector has undergone one of the most disruptive transformations in global telecom history. The launch of **Reliance Jio on September 5, 2016** -- offering free voice calls and virtually free data -- collapsed the price of mobile data from ~Rs.250/GB to ~Rs.10/GB overnight, increased smartphone penetration from ~30 crore (2016) to **90+ crore (2023),** and forced all other operators to either merge (Vodafone-Idea), exit (Reliance

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Communications, Aircel, Tata Teleservices), or massively upgrade (Airtel). India now has **the world's cheapest mobile data** and the world's **2nd largest mobile subscriber base.**

Telecom Parameter	*Data (2023)*	*Note*
Total mobile subscribers	117 crore (1.17 billion; TRAI 2023)	2nd largest in world after China; wireless = 99%+ of connections; wireline declining (only ~2.5 crore)
Telecom operators (major)	Jio (44+ crore; 37%+ share); Airtel (35+ crore; 30%+ share); Vodafone-Idea / Vi (24+ crore; declining; financial crisis); BSNL (10+ crore; government PSU; 4G deployment 2023)	Jio's September 2016 launch collapsed the market from 10+ operators to effectively 3 private + 1 PSU
Mobile data price	~Rs.10 per GB (among world's cheapest; India data is 100x cheaper than Brazil and 200x cheaper than USA per GB)	Jio disruption drove data price from Rs.250/GB (2016) to Rs.10/GB (2023); India's cheapest data is a fundamental enabler of digital inclusion
Internet users	90+ crore (IAMAI 2023; ~65% of India's population online)	Rural internet growing rapidly (BharatNet, Jio towers in rural areas); India added 3-5 crore new internet users/year post-Jio
5G subscribers	100+ million (2024); growing rapidly as Jio and Airtel expanded 5G coverage across 700+ cities by 2024	5G launched October 1, 2022; India's 5G rollout pace was among world's fastest after launch; target: pan-India 5G by 2025
TRAI (Telecom Regulatory Authority of India)	Established 1997; regulates tariffs, spectrum allocation recommendations, interconnect charges, QoS standards	TRAI recommends spectrum prices to DoT (Department of Telecommunications); also regulates OTT platforms interactions with telecom; TRAI order on net neutrality (2016) = landmark
DoT (Department of Telecommunications)	Under Ministry of Communications; allocates spectrum; licenses operators; policy making; oversees BSNL, MTNL, C-DOT	C-DOT (Centre for Development of Telematics) developed India's indigenous 4G/5G telecom stack (used by BSNL) -- an Atmanirbhar achievement

5G Rollout -- India's Next Digital Leap

5G Feature	*Detail*
Launch	October 1, 2022 (PM Modi at India Mobile Congress 2022; Delhi); Jio and Airtel were the first 5G operators
Spectrum used	700 MHz (Jio -- penetrates buildings and rural areas; ideal for nationwide coverage); 3.5 GHz (both Jio and Airtel -- high capacity; mid-band standard); 26 GHz mmWave (both -- ultra-high speed for dense urban; limited range)
Technology choice	Jio: SA (Standalone) 5G -- entirely new 5G core; technically superior; higher capex. Airtel: NSA (Non-Standalone) 5G -- 5G radio on existing 4G core; faster rollout; upgrade path to SA later. BSNL: indigenous 4G (C-DOT stack) with 5G upgrade path; no Chinese equipment
Chinese exclusion	Huawei and ZTE are EXCLUDED from India's 5G network (unlike many European countries which initially used Huawei); national security decision; only Ericsson (Sweden), Nokia (Finland), and Samsung (South Korea) are India's 5G equipment providers; this aligns India with the USA-led "Clean Network" initiative

Coverage (2024)	Jio claims pan-India 5G (all districts); Airtel 5G in 700+ cities; by 2025 India will have one of world's largest 5G networks by number of towers; 4 lakh 5G base stations planned by 2025
Use cases in India	5G for agriculture (precision farming, drone agriculture monitoring); telemedicine (real-time rural healthcare); education (AR/VR for rural students); manufacturing (Industry 4.0, factory automation); smart cities; defence (command and control); disaster management

38.4 DIGITAL INDIA -- TRANSFORMING GOVERNANCE AND ECONOMY

Digital India -- launched July 1, 2015 by PM Modi -- is a flagship programme to transform India into a **digitally empowered society and knowledge economy.** It has three key vision areas: (1) Digital Infrastructure as a Core Utility to Every Citizen; (2) Governance and Services on Demand; (3) Digital Empowerment of Citizens. The programme has produced some of India's most transformative digital achievements -- from UPI to Aadhaar to BharatNet.

Digital India Initiative	*Year*	*Key Achievement / Status*
Aadhaar (UIDAI)	2009 (UIDAI established); mass enrollment from 2011	1.35 billion unique biometric identities (largest biometric database in world); 12-digit unique identification number; used for DBT (Direct Benefit Transfer) -- eliminating leakage in welfare delivery (saved Rs.3.48 lakh crore in 9 years per DBTMIS); Aadhaar-linked PDS, PM-KISAN, MNREGS payments; SC judgment (2018) -- Aadhaar valid for government benefits but cannot be made mandatory for private services
UPI (Unified Payments Interface)	April 2016 (NPCI launched); September 2016 (Jio + UPI = explosion)	World's most successful real-time payment system; 10 billion+ transactions in October 2023; 117 billion transactions in FY 2022-23; 47% of global real-time transactions; India processes more real-time digital payments than USA + Europe + Japan combined; NPCI International launching UPI in 20+ countries (UAE, Singapore, UK, France, Sri Lanka, Nepal, Bhutan, Mauritius)
BharatNet	2011 (NOFN -- National Optical Fibre Network); 2016 (renamed BharatNet); Rs.42,000 crore Phase 1+2; Phase 3 ongoing	Optical fibre connectivity to all 2.5 lakh+ gram panchayats (GPs); Phase 1 (2016-2020): 1.55 lakh GPs connected; Phase 2 using multiple technologies (OFC + satellite + radio); Phase 3 targets FTTH (Fibre to the Home) at village level; enables rural internet, e-health, e-education; critical for bridging digital divide
DigiLocker	2015	Virtual locker for storing digital versions of official documents (Aadhaar, driving licence, PAN, class X/XII certificates, vaccination certificates); 13 crore+ registered users (2023); documents from 2,000+ issuers; Supreme Court and High Courts accept DigiLocker documents; reduced need for physical document certification
PM-WANI (PM Wi-Fi Access Network Interface)	December 2020	Decentralised public Wi-Fi network; small entrepreneurs (PDOA -- Public Data Office Aggregators) deploy cheap Wi-Fi hotspots; target 10 crore hotspots; enables low-cost internet in small towns/rural areas; eliminates licence requirement for setting up public Wi-Fi
CoWIN (COVID	2021	World's largest vaccination tracking platform; 220 crore+ COVID doses registered; QR-code vaccine certificates accepted

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Vaccine Intelligence Network)		internationally; open-source technology offered to 140+ countries; built by NIC (National Informatics Centre) + MoHFW; demonstrates India's digital public infrastructure (DPI) capability
India Stack / Digital Public Infrastructure (DPI)	Concept 2013; formalised 2015-2020	India's model of "public digital rails" -- government-built open digital infrastructure (Aadhaar + UPI + DigiLocker + eSign + AA Framework) that private sector apps can build on top of; India's DPI model is being replicated globally; G20 India Presidency 2023 successfully pushed for "One Future Alliance" for DPI global adoption; Account Aggregator (AA) framework for financial data sharing
ONDC (Open Network for Digital Commerce)	April 2022	Government-backed protocol to democratise e-commerce (like UPI did for payments); any seller can be discovered on any app; prevents dominance of Amazon + Flipkart; participating buyer apps: Paytm, ONDC, Meesho, Namma Yatri (auto-rickshaw); seller apps: various; live in 200+ cities

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UPI -- India's Global Soft Power: India's UPI has become a geopolitical asset. NPCI International has launched UPI acceptance in: UAE (for Indian diaspora; 20%+ of UAE residents are Indian); Singapore (PayNow-UPI linkage; first cross-border real-time payment link between two national systems); France (Eiffel Tower accepts UPI); Sri Lanka, Nepal, Bhutan, Mauritius, Oman, Bahrain, Malaysia. During G20 India Presidency (2023), India pushed for "G20 Framework for Global Digital Public Infrastructure" -- seeking international recognition for DPI model. PM Modi has cited UPI as evidence of "digital colonialism prevention" -- India built its own system rather than depending on Visa/Mastercard/American payment giants. For UPSC GS-2 (international relations) and GS-3 (technology), UPI is a high-scoring topic connecting digital policy, economic diplomacy, and financial inclusion.

38.5 SPACE TECHNOLOGY -- ISRO'S GLOBAL RISE

The Indian Space Research Organisation (ISRO) -- headquartered in Bengaluru, established 1969 -- has evolved from launching small satellites into a **globally competitive space agency** known for cost efficiency, reliability, and ambitious missions. The year 2023 was ISRO's most spectacular year with Chandrayaan-3's lunar south pole landing and Aditya-L1's solar mission launch -- establishing India as a **spacefaring nation of the first order.**

ISRO Mission / Launch ehicle	*Year*	*Key Achievement*
Chandrayaan-1 (Lunar Orbiter)	October 22, 2008	India's first lunar mission; discovered water molecules on the Moon (water ice near lunar poles -- confirmed by Moon Impact Probe data and NASA's confirmation; fundamental scientific finding)
Mangalyaan / Mars Orbiter Mission (MOM)	November 5, 2013	India's first interplanetary mission; FIRST MARS MISSION to succeed on maiden attempt (only India has done this); cost ~Rs.450 crore (cheaper than Hollywood film "Gravity"); Mars orbit insertion September 24, 2014; demonstrated ISRO's frugal innovation approach; orbited Mars until ~2022
PSLV (Polar Satellite Launch Vehicle)	Operational since 1994	ISRO's workhorse launch vehicle; 4-stage alternating solid-liquid; 58 consecutive successful launches (one of world's best launch reliability records); launched ASTROSAT, Chandrayaan-1, MOM, record 104 satellites in single launch (February 2017 -- world record at the time)

GSLV Mk-III / LVM3 (Launch Vehicle Mark 3)	2017 (first successful); operational from 2018	India's heaviest launch vehicle; capable of launching 4-tonne class satellites to GTO (Geostationary Transfer Orbit); launched CommunicationSat (GSAT-19, GSAT-29, GSAT-7A); also used to launch Chandrayaan-3 (July 14, 2023) and OneWeb satellites (commercial) demonstrating commercial launch capability
Chandrayaan-3 (Lunar Lander + Rover)	July 14, 2023 (launch); August 23, 2023 (landing)	WORLD'S FIRST SOFT LANDING ON LUNAR SOUTH POLE; Vikram lander + Pragyan rover; August 23 = NATIONAL SPACE DAY (declared by PM Modi); landing site named Shiv Shakti Point; Pragyan rover measured lunar soil temperature, confirmed sulphur on Moon's surface; distinguished India as 4th country to achieve Moon soft landing (after USSR, USA, China) AND 1st to do it at the south pole
Aditya-L1 (Solar Mission)	September 2, 2023 (launch)	India's FIRST SOLAR MISSION; placed in halo orbit around L1 Lagrange point (1.5 million km from Earth -- stable position with unobstructed view of Sun) on January 6, 2024; 7 scientific payloads studying solar corona, solar wind, CMEs (Coronal Mass Ejections); VELC (Visible Emission Line Coronagraph) is primary instrument; India is now part of the exclusive club studying the Sun with a dedicated mission
Gaganyaan (Human Spaceflight)	TV-D1 test: October 21, 2023	India's FIRST HUMAN SPACEFLIGHT PROGRAMME; Crew Escape System (CES) test (TV-D1) successful Oct 21, 2023; crew module parachuted safely into Bay of Bengal; 2 more uncrewed test missions before crewed mission; target: 2 Indian astronauts in low Earth orbit for 3 days by 2025; astronaut training (Group Captain Prashanth Balakrishnan, Group Captain Ajit Krishnan, Group Captain Angad Pratap, Wing Commander Shubhanshu Shukla trained in Russia)
SSLV (Small Satellite Launch Vehicle)	2022-2023	New launch vehicle for small satellite commercial market; cheaper than PSLV; 2nd developmental flight (SSLV-D2) successful February 10, 2023; target: on-demand launch of small commercial satellites; NewSpace India Limited (NSIL -- commercial arm of ISRO) to operate
NavIC (Navigation with Indian Constellation)	7 operational satellites (IRNSS constellation); 2013-2018 launches	India's indigenous GPS; 7 satellites covering India + 1,500 km surrounding region; L5 and S-band frequencies; atomic clock precision of ~5 metres; mandated in all new smartphones sold in India from 2023 (TRAI order); used in fishing vessels (cyclone warning), precision agriculture, defence navigation; independent of US GPS (strategic autonomy)
Commercial Space (IN-SPACe, NSIL)	IN-SPACe established 2020	India opened space to private sector: IN-SPACe (Indian National Space Promotion and Authorisation Centre) authorises and promotes private launch vehicles and satellites; Skyroot Aerospace (Vikram-S first private rocket November 18, 2022 -- India's first private rocket launch); Agnikul Cosmos (Agnibaan SOrTeD -- world's first flight-tested single-piece 3D-printed rocket engine; May 30, 2024); Pixxel (earth observation constellation); space economy target USD 44 billion by 2033 (from USD 8 billion 2023)

38.6 CURRENT AFFAIRS HOOKS (2022-2025)

Chandrayaan-3 -- World's First Lunar South Pole Landing (August 23, 2023): India's Chandrayaan-3 mission achieved the world's first soft landing on the Moon's south pole on August 23, 2023 (5:04 PM IST). The Vikram

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lander and Pragyan rover operated for approximately 14 Earth days (one lunar day) -- measuring soil temperature, detecting sulphur, detecting other elements (iron, manganese, oxygen, chromium, titanium), and transmitting spectacular images. PM Modi declared August 23 as "National Space Day" of India. The landing site was named "Shiv Shakti Point." Chandrayaan-3's success came just days after Russia's Luna-25 mission failed (crashed) while attempting a similar south pole landing -- India beat Russia to the milestone.

Aditya-L1 Solar Mission (September 2023 - January 2024): India's first dedicated solar observation mission, Aditya-L1, was launched on September 2, 2023 aboard PSLV-C57. It successfully reached its final destination -- the L1 Lagrange halo orbit (1.5 million km from Earth) -- on January 6, 2024. The mission carries 7 payloads to study solar photosphere, chromosphere, and corona; understand solar flares and Coronal Mass Ejections (CMEs) that affect Earth's satellites and power grids; and study solar wind. India became only the 5th country with a dedicated solar observation mission in space.

Air India Merger with Vistara (November 2024): Vistara (JV between Tata Sons and Singapore Airlines) merged with Air India in November 2024 to create a single Tata-owned full-service carrier. Singapore Airlines holds 25.1% of the combined Air India entity post-merger. This consolidation creates India's 2nd largest carrier (after IndiGo) and the only premium full-service international airline. Simultaneously, Air India placed the world's largest civil aviation order ever at time of signing -- 470 aircraft (250 Airbus + 220 Boeing) in February 2023, worth ~USD 80 billion at list prices.

Agnikul Cosmos -- World's First 3D-Printed Rocket (May 2024): Agnikul Cosmos, a Chennai-based space startup incubated at IIT Madras, successfully launched Agnibaan SOrTeD (Suborbital Technological Demonstrator) on May 30, 2024 from Sriharikota's Second Launch Pad. The rocket used an Agnilet engine -- the world's first single-piece 3D-printed rocket engine (the entire engine printed in one manufacturing operation). This is a landmark for India's private space sector, demonstrating manufacturing innovation that reduces rocket production cost and time dramatically.

38.7 PYQ ANALYSIS -- CHAPTER 38 (2010-2025)

Source	Year	Marks	Question
UPSC Civil	2024	15M	"Discuss ISRO's space achievements in 2023 (Chandrayaan-3, Aditya-L1). What is the strategic and scientific significance of India's space programme?"
UPSC Civil	2023	12M	"Discuss the significance of UPI and Digital India for financial inclusion and India's global digital leadership."
UPSC Civil	2022	10M	"Discuss the significance of the UDAN scheme for regional air connectivity in India. What are its achievements and challenges?"
UPSC Civil	2021	12M	"Critically examine the progress of India's civil aviation sector. Discuss the Air India disinvestment and its implications."
UPSC Civil	2020	10M	"What is 5G technology? Discuss its significance for India and the challenges in its deployment."
UPSC Civil	2019	10M	"Discuss the significance of BharatNet for rural connectivity and bridging the digital divide in India."
UPSC Civil	2018	12M	"Discuss the significance of India's space programme (ISRO). How has India achieved cost-effective space missions?"
UPSC Civil	2017	10M	"Discuss the growth and challenges of India's civil aviation sector. What is the significance of the National Civil Aviation Policy 2016?"
IFoS GS	2024	10M	"Discuss the environmental impact of airport expansion in India, with

			specific reference to the Navi Mumbai International Airport (NMIA) and its effects on the Karnala Bird Sanctuary and coastal ecosystems."
IFoS GS	2023	10M	"Examine the potential of satellite remote sensing in forest monitoring and wildlife management in India."
IFoS GS	2022	10M	"Discuss the ecological implications of space debris and India's responsibility as an emerging space power."

KEY NOTE

Frequency: ISRO Chandrayaan-3 + Aditya-L1 (Civil 2024); UPI + Digital India (Civil 2023); UDAN scheme (Civil 2022); civil aviation + Air India disinvestment (Civil 2021); 5G (Civil 2020); BharatNet rural connectivity (Civil 2019); ISRO frugal innovation (Civil 2018); NCAP 2016 (Civil 2017). IFoS: NMIA Karnala Bird Sanctuary ecology (2024), satellite remote sensing + forestry (2023), space debris ecology (2022). For 2025-26: Chandrayaan-3 Shiv Shakti Point + National Space Day Aug 23; Aditya-L1 L1 halo orbit Jan 2024; Gaganyaan crewed mission 2025; Agnikul 3D-printed rocket May 2024; Air India-Vistara merger; Jio + Airtel 5G pan-India; UPI in Eiffel Tower Paris -- all high-priority.

38.8 MODEL ANSWERS

Discuss the significance of India's space programme. How have Chandrayaan-3 and Aditya-L1 enhanced India's strategic and scientific standing.

UPSC CIVIL (Mains) | 15 Marks | 210 Words

2023 was ISRO's most remarkable year. Chandrayaan-3's lunar south pole landing (August 23, 2023) made India the 4th nation to land on the Moon and the 1st on the south pole. Aditya-L1's solar journey placed India among the elite group of nations operating dedicated solar observatories. These achievements, added to the Mars Orbiter Mission (MOM) success (2014) and PSLV's 58 consecutive successes, have established ISRO as a globally credible space agency.

CHANDRAYAAN-3 -- SIGNIFICANCE:

Scientific: First soft landing on lunar south pole; Pragyan rover confirmed presence of sulphur, iron, manganese, chromium, titanium in lunar regolith; measured lunar soil temperature gradient (surface -10 deg C; 80 mm below surface -70 deg C -- significant finding for future lunar habitation); Instrument for Lunar Seismic Activity (ILSA) detected small moonquake-like activity.

Strategic: South pole is believed to have permanently shadowed craters containing water ice -- critical for future lunar bases (water = drinking + oxygen + hydrogen fuel); nation that establishes south pole infrastructure first has enormous strategic advantage; India's successful landing just days after Russia's Luna-25 crash dramatically demonstrated India's superior technical capability; August 23 declared National Space Day.

Soft power: Global attention on India's achievement (2 billion+ watched live streaming; PM congratulated by global leaders); establishes India as a responsible spacefaring nation; boosts ISRO commercial launch contracts; demonstrates Make in India in deepest space.

ADITYA-L1 -- SIGNIFICANCE:

Scientific: Studies solar corona (why is corona millions of degrees hotter than the 5,500 deg C solar surface -- a longstanding physics puzzle); monitors CMEs (Coronal Mass Ejections that damage satellites and power grids); provides continuous solar observation; India's 7 payloads include the world's largest coronagraph (VELC).

Strategic: Solar flares and CMEs can disable India's growing satellite constellation (GPS/NavIC, communication, military); early warning from Aditya-L1 can protect Indian infrastructure; positions India alongside NASA, ESA, JAXA in space weather monitoring.

INDIA'S SPACE PROGRAMME -- BROADER SIGNIFICANCE:

Economic: Space economy target USD 44 billion by 2033 (from USD 8 billion 2023); commercial launch revenue (PSLV launched 345+ foreign satellites); IN-SPACe enabling private sector (Skyroot, Agnikul, Pixxel); satellite-based agriculture, fisheries, disaster management adding direct economic value.

Frugal Innovation Model: MOM cost Rs.450 crore (cheaper than Gravity film); Chandrayaan-3 cost Rs.615 crore (~USD 75 million; NASA's upcoming Artemis crewed mission cost USD 93 billion); ISRO achieves 5-10x cost efficiency vs Western agencies through: domestic components, indigenous software, leaner teams, PSLV standardisation.

Strategic Autonomy: NavIC (Navigation with Indian Constellation) = India's GPS-independent navigation; reduces US GPS dependence for defence navigation; essential for precision-guided munitions; GSAT military satellites (GSAT-7 for Navy, GSAT-7A for Air Force, GSAT-7B for Army under development) provide secure communication; anti-satellite capability (Mission Shakti, March 27, 2019 -- India shot down its own satellite in LEO) = space deterrence.

India's space achievements serve simultaneously as scientific capability demonstration, strategic deterrence, commercial business, and national pride. The Gaganyaan crewed mission (target 2025) will be India's crowning achievement -- placing Indian astronauts in space on an Indian rocket from Indian soil, joining only the USA, Russia, and China in this elite capability.

CHAPTER 39

INDIA & ITS NEIGHBOURS & INTERNATIONAL TRADE

Geopolitical Geography · Trade Policy · WTO · FTAS · Import-Export

CHAPTER AT A GLANCE

- INDIA'S NEIGHBOURS (7 land + 2 maritime): Land neighbours (sharing land border): Pakistan (W), China (N), Nepal (N), Bhutan (N), Bangladesh (E), Myanmar (E), Afghanistan (NW -- post-1947 via PoK corridor). Maritime neighbours: Sri Lanka (SE; Palk Strait), Maldives (SW; Indian Ocean). India shares 15,106 km of land border + 7,516 km coastline. Largest land border share: Bangladesh (4,156 km), China (3,488 km), Pakistan (3,323 km), Nepal (1,751 km), Myanmar (1,643 km), Bhutan (699 km).
- CHINA (Most Critical Bilateral): Shares 3,488 km border (LAC -- Line of Actual Control; disputed in Ladakh, Uttarakhand/Arunachal sectors). Disputes: Aksai Chin (India claims; China controls -- 37,244 sq km), Arunachal Pradesh (China calls "South Tibet"; India claims). Galwan Valley clash June 15-16, 2020: first lethal India-China military clash since 1975 (20 Indian soldiers killed; Chinese PLA casualties undisclosed). CPEC (China-Pakistan Economic Corridor) passes through PoK -- India's strategic objection. India's imports from China: electronics, pharmaceuticals, machinery (~USD 100 billion in FY 2022-23 -- India's largest import partner).
- PAKISTAN: 3,323 km land border (LoC -- Line of Control in J&K; IB -- International Boundary in Punjab/Rajasthan/Gujarat). Disputes: J&K (Pakistan claims the entire former princely state; India claims entire J&K including PoK); Sir Creek (Gujarat-Sindh maritime boundary); Siachen Glacier (world's highest battlefield; India controls Saltoro Ridge). Indus Waters Treaty (IWT) 1960: India gets Sutlej+Beas+Ravi (Eastern rivers); Pakistan gets Indus+Jhelum+Chenab (Western rivers); mediated by World Bank; Pakistan has raised objections as India builds hydropower projects on Chenab (Ratle, Kishanganga).
- BANGLADESH: 4,156 km -- India's longest land border; India shares border with 5 states (WB, Assam, Meghalaya, Tripura, Mizoram). Bangladesh = India's largest trade partner in South Asia (India exports: cotton, vehicles, machinery; Bangladesh exports: garments, jute). Farakka Barrage dispute: India's Farakka Barrage diverts Ganga water -- Bangladesh claims reduced flow affects agriculture and navigation. Teesta River water sharing: unresolved (India's WB state government has objected to central government deal). Sheikh Hasina government (1996-2001; 2008-2024) = most pro-India Bangladesh government; July 2024 student protests overthrew Hasina -- Muhammad Yunus as interim PM; India-Bangladesh relations under review.
- NEPAL AND BHUTAN: NEPAL: 1,751 km open border (Treaty of Peace and Friendship 1950); deep cultural ties; Pashupatinath; Hinduism+Buddhism shared heritage; Kalapani-Lipulekh-Limpiyadhura territorial dispute (Nepal issued new political map in 2020 claiming these Indian-administered areas); Madhesi issue; Prachanda-KP Sharma Oli governments oscillating between India and China. BHUTAN: 699 km border; no formal diplomatic relations at ambassador level with China (Bhutan is the only SAARC country without China relations -- due to India's influence); Bhutan-China boundary talks; Doklam (2017 standoff -- China constructing road near Bhutanese territory; Indian Army intervened; 73-day standoff). India provides hydropower development aid (Chukha, Tala, Punatsangchhu dams); hydropower exports from Bhutan to India.
- MYANMAR AND SRI LANKA: MYANMAR: 1,643 km border; NE India states share border (Arunachal Pradesh, Nagaland, Manipur, Mizoram); Free Movement Regime (FMR) -- tribes can cross 16 km without visa; India suspended FMR 2024 (due to Manipur ethnic crisis); Kaladan Multimodal Transit Transport Project (Kolkata via Sittwe Port to Mizoram); Trilateral Highway India-Myanmar-Thailand. SRI LANKA: Palk Strait (22 km at narrowest -- Adam's Bridge/Rama Setu); Tamil fishermen conflict (India-Sri Lanka boats crossing into each other's EEZ); China-funded Hambantota Port (99-year lease to China 2017 -- "debt trap diplomacy"); ETCA (Economic and Technology Cooperation Agreement) under

negotiation. MALDIVES: February 2024 -- President Mohamed Muizzu demanded withdrawal of Indian military personnel; "India Out" campaign; pivot to China; India-Maldives relations strained.

- INTERNATIONAL TRADE OVERVIEW: India's total merchandise trade = USD 1.4 trillion (FY 2023-24; exports USD 776 billion incl. services; merchandise exports USD 437 billion; merchandise imports USD 678 billion). Trade deficit (merchandise): ~USD 241 billion (FY 2023-24). Top exports: Petroleum products (~USD 80 billion; Jamnagar-processed), Gems and jewellery (~USD 38 billion; Surat diamonds), Engineering goods (~USD 107 billion), Pharma (~USD 28 billion), Chemicals, Textiles. Top imports: Crude oil (~USD 160 billion); Gold (~USD 35 billion); Electronics (phones, components ~USD 75 billion); Machinery; Coking coal.
- TRADE PARTNERS AND WTO: Top export destinations: USA (~18% of merchandise exports), UAE (~7%), Netherlands, UK, China, Bangladesh. Top import sources: China (#1 import source ~USD 100 billion), UAE, USA, Saudi Arabia, Russia (oil at discounted price post-Ukraine). WTO: India = founding member (1995); India strongly defends food security programs (MSP, public stockholding) at WTO against developed country challenges; TRIPS and pharma compulsory licensing (Doha Development Agenda); India blocked Trade Facilitation Agreement (2014) initially over food security concerns. FTAs: CEPA with UAE (2022), Australia (ECTA 2022), Mauritius; RCEP withdrawn (2019 -- India walked out citing Chinese imports concern); India-EU FTA and India-UK FTA under negotiation.

PART - A INDIA AND ITS NEIGHBOURS

A.1 INDIA'S NEIGHBOURHOOD -- GEOGRAPHIC OVERVIEW

India is a **peninsular country with a unique geostrategic position** -- bounded on three sides by water (Arabian Sea, Indian Ocean, Bay of Bengal) and sharing land borders with **seven countries** on the north, northwest, and east. India's land border totals **15,106 km** and its coastline totals **7,516 km** (mainland). The entire neighbourhood forms the **South Asian and Indian Ocean Region (IOR)** -- a strategic space of profound importance for India's security, trade, and foreign policy. India's neighbourhood policy is guided by the **"Neighbourhood First" doctrine,** first articulated by PM Narendra Modi at his 2014 inauguration where all SAARC heads of state were invited.

Neighbour	*Border Type*	*Border Length*	*Key Geographic Feature*	*Primary Dispute / Issue*
China (PRC)	Land border (Himalayan; largely disputed)	3,488 km (LAC)	Himalayan ranges form natural boundary but many sections disputed or unclear; border runs from Ladakh (NW) through Himachal Pradesh, Uttarakhand, Sikkim, Arunachal Pradesh (NE)	Aksai Chin (India claims; China controls); Arunachal Pradesh ("South Tibet" per China); Galwan Valley clash June 2020; Depsang Plains; Yangtse; no formal demarcated LAC
Pakistan	Land border (IB) + Line of Control (LoC in J&K)	3,323 km total (IB + LoC)	Punjab plains (IB; demarcated); Gujarat (Rann of Kutch + Sir Creek; partially demarcated); J&K (LoC; ceasefire line from 1948 war; not international boundary)	J&K dispute (Pakistan claims whole; India claims whole including PoK -- Pakistan-Occupied Kashmir); Siachen Glacier; Sir Creek (maritime); cross-border terrorism; Indus Waters Treaty (1960; WB mediated; under strain)
Nepal	Open land border (Treaty of Peace and Friendship,	1,751 km	Terai plains (flat; permeable border); Himalayan Nepal shares cultural and religious ties with India; open border allows citizens of both	Kalapani-Lipulekh-Limpiyadhura territorial dispute (Nepal's 2020 map claims Indian-administered areas); Madhesi community

	1950)		countries to live and work in each other's territory	rights; hydropower cooperation (Kali Gandaki, Arun-3); Susta territory
Bhutan	Guarded land border (India manages Bhutan's external defence and foreign affairs partially)	699 km	Eastern Himalayas; Bhutan is a buffer state between India and China; Doklam Plateau is at the India-Bhutan-China trijunction	Doklam standoff (2017 -- China constructing road; India intervened; 73-day standoff resolved); Bhutan-China boundary talks (China claims some Bhutanese territory including Doklam); India-Bhutan hydropower projects (Chukha 336 MW, Tala 1,020 MW, Punatsangchhu I+II)
Bangladesh	Land border (shares border with 5 Indian states)	4,156 km (LONGEST land border)	Gangetic delta; flat alluvial terrain; borders WB, Assam, Meghalaya, Tripura, Mizoram; enclaves were fully exchanged (Land Boundary Agreement 2015 -- major diplomatic achievement; 51 Bangladeshi enclaves merged into India + 111 Indian enclaves merged into Bangladesh)	Farakka Barrage water dispute; Teesta River water sharing (unresolved; WB CM objection); illegal immigration; BSF killings at border; Hasina government exile July 2024 -- Yunus interim PM; India-Bangladesh relations under strain
Myanmar	Land border (sharing with NE India states)	1,643 km	Hilly forested border; Arunachal Pradesh, Nagaland, Manipur, Mizoram share border; Free Movement Regime (FMR) historically allowed 16 km cross-border movement without visa; India suspended FMR 2024 (due to Manipur ethnic crisis + arms smuggling concerns from Myanmar civil war post-2021 coup)	February 2021 military coup (Myanmar Army = Tatmadaw overthrew Aung San Suu Kyi government); civil war; refugees into Mizoram and Manipur; India balancing between junta and opposition; Kaladan Multimodal Project (Sittwe Port, Mizoram connectivity)
Sri Lanka (Maritime)	Maritime boundary across Palk Strait	Palk Strait: 22 km at narrowest (Adam's Bridge/Rama Setu); Gulf of Mannar	Island nation; Tamil connection (Tamil Eelam conflict 1983-2009; LTTE); historically Hindu-Buddhist culture ties (Ramayana); strategically placed in Indian Ocean	Fishermen conflict (Tamil fishermen from TN cross Sri Lankan EEZ); China-funded Hambantota Port (99-year lease to China 2017 -- strategic concern); East Container Terminal (ECT) at Colombo -- India+Japan+Sri Lanka deal contested; India-Sri Lanka ETCA negotiation; Sri Lanka economic crisis 2022 (India provided USD 4 billion support)

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Maldives (Maritime)	Maritime (Indian Ocean)	No land border; ~800 km from Indian mainland (Minicoy Island, Lakshadweep ~130 km from Maldivian Addu Atoll)	Archipelago; Indian Ocean strategic position; critical for Indian naval domination of IOR	President Muizzu (elected Nov 2023) demanded withdrawal of Indian military from Maldives; "India Out" campaign; closer to China; India withdrew military personnel by May 2024; but economic dependence on India continues

A.2 CHINA -- INDIA'S MOST COMPLEX BILATERAL RELATIONSHIP

India-China relations are India's most consequential bilateral relationship -- involving a **3,488 km disputed border,** strategic competition in the Indian Ocean Region (IOR), a **USD 100 billion trade imbalance favourable to China,** and the **Belt and Road Initiative (BRI) / CPEC** running through Pakistan-Occupied Kashmir. Relations oscillate between periods of "strategic partnership" and episodes of military confrontation.

Feature	*Detail*
Historical background	1962 War: China attacked India across both western (Aksai Chin) and eastern (NEFA/Arunachal Pradesh) sectors; India defeated; PM Nehru's policy of "Hindi-Chini Bhai Bhai" shattered; Aksai Chin de facto under Chinese control since then; NEFA (now Arunachal Pradesh) returned to India but China claims it as "South Tibet"; Five Principles of Peaceful Coexistence (Panchsheel, 1954) failed to prevent conflict
McMahon Line	The boundary line between British India and Tibet (now China) agreed in the Simla Convention (1914); runs along the watershed of the eastern Himalayas from Bhutan to Burma; China does NOT accept the McMahon Line as the legal international boundary (argues it was imposed on Tibet by imperial Britain when Tibet lacked authority to sign); India accepts it as the legal boundary; most of Arunachal Pradesh lies south of the McMahon Line
Aksai Chin	~37,244 sq km of plateau in Ladakh; India claims it as part of Ladakh (erstwhile J&K); China controls it and considers it part of Hotan Prefecture, Xinjiang; China built the G219 highway (Xinjiang-Tibet highway) through Aksai Chin in the 1950s -- India only discovered it in 1958; central to the 1962 war; no prospect of resolution
Galwan Valley Clash (June 2020)	On June 15-16, 2020, Indian and Chinese soldiers fought hand-to-hand combat (no firearms, per an oral protocol; using stones and improvised weapons) in the Galwan River valley, Eastern Ladakh; 20 Indian Army soldiers killed (including Colonel Santosh Babu, CO 16 Bihar); Chinese PLA casualties: officially "4" (India intelligence estimates 40+). The clash followed months of PLA intrusion into Indian-claimed territory at Galwan, Pangong Tso, Hot Springs, Gogra. India banned 59 Chinese apps (TikTok, PUBG, WeChat) as economic retaliation; trade continued.
Depsang Plains (ongoing)	PLA has occupied approximately 1,000 sq km of Indian-claimed territory in Depsang (Eastern Ladakh) at the Y-Junction approach -- blocking traditional Indian Army patrol routes; this pre-dates Galwan (since ~2013) but became prominent in 2020 context; most complex unresolved friction point; no disengagement achieved by 2024
CPEC objection	China-Pakistan Economic Corridor (CPEC) -- a flagship BRI corridor -- runs from Xinjiang through PoK (Gilgit-Baltistan) to Gwadar Port (Balochistan); India strongly objects as CPEC

	passes through Pakistan-Occupied Kashmir (PoK), which India claims as its own sovereign territory; India has formally protested at G20 and bilateral forums; India is the only major country not to join the BRI
Trade asymmetry	India imports ~USD 100 billion from China (FY 2022-23) -- electronics (phones, components), pharmaceuticals (APIs), machinery, chemicals; exports ~USD 16 billion to China; trade deficit ~USD 83-100 billion; India-China trade continues even after Galwan; India tried to attract "China+1" FDI from companies moving out of China; PLI schemes target reduction of Chinese import dependence
India-China border management (post-Galwan)	Buffer zones created; Corps Commander talks (20+ rounds by 2024); partial disengagement at Gogra-Hot Springs (Sep 2022); Depsang and Demchok disengagement announced October 2024 (news reports as of late 2024); LAC patrol resumption by both sides. India appointed new corps commanders; infrastructure (roads, tunnels, airstrips) in border areas massively expanded (BRO record construction)

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GS-2 Framework -- India-China Relations: Structure your answer as: (1) **Historical context**: 1962 war, Panchsheel failure, Aksai Chin; (2) **Current disputes**: LAC, McMahon Line, Depsang, Galwan; (3) **Economic dimension**: USD 100 billion trade deficit, PLI to reduce dependence, app bans; (4) **Strategic competition**: CPEC-BRI vs India's IMEC, QUAD, Indo-Pacific; China's IOR ports (Hambantota, Gwadar, Djibouti) vs India's maritime dominance; (5) **Way forward**: "Vibrant Villages Programme" for border development; infrastructure parity; diplomatic engagement. Key phrases: "Trust Deficit," "Competitive coexistence," "Multi-faceted relationship." Reference: NSA Ajit Doval's border meeting with Wang Yi (2024) framework.

A.3 PAKISTAN -- THE WESTERN NEIGHBOUR

Feature	*Detail*
Indus Waters Treaty (IWT) 1960	Signed September 19, 1960 by PM Nehru and President Ayub Khan; mediated by World Bank. Divides the Indus river system: India gets Sutlej, Beas, Ravi (Eastern rivers; ~20% of water); Pakistan gets Indus, Jhelum, Chenab (Western rivers; ~80% of water). India allowed to build run-of-river hydropower on Western rivers (Kishanganga, Ratle) with restrictions. Pakistan has repeatedly objected to Indian projects at PCA (Permanent Court of Arbitration) -- India refused to participate after 2016 (India argues it violates treaty; PCA says it has jurisdiction). IWT is one of the world's most durable water treaties -- survived three wars between India and Pakistan.
J&K and LoC	The Line of Control (LoC) is the de facto boundary in J&K -- established by the Simla Agreement (1972); ceasefire line from 1948 first Kashmir war. India controls approximately 43% of former Jammu and Kashmir princely state; Pakistan controls ~37% (PoK = "Azad Kashmir" + Gilgit-Baltistan); China controls ~20% (Aksai Chin). Both India and Pakistan claim the entire former princely state. India reorganised J&K into 2 UTs in August 2019 (revocation of Article 370 + bifurcation into J&K UT + Ladakh UT).
Siachen Glacier	World's highest battlefield (5,400-6,500 m); India controls the Saltoro Ridge (high ground) since Operation Meghdoot (April 13, 1984); India preempted Pakistan's planned capture. Pakistan controls the Gyong Glacier access routes. India's military position is strategically superior (height advantage); Pakistan seeks return to pre-1984 positions; both sides maintain troops at enormous cost (Rs.4-8 crore/day India maintenance estimate).
Cross-border terrorism	Pakistan-based militant groups (Lashkar-e-Taiba = 26/11 Mumbai attacks 2008; Jaish-e-Mohammad = Pulwama attack 2019 killing 40 CRPF personnel; Hizbul Mujahideen) conduct attacks in India; Pakistan denies state sponsorship; India has presented evidence; FATF (Financial Action Task Force) greylist (Pakistan was on FATF greylist 2018-2022; removed October 2022 after promised action); India-Pakistan relations at historic low after Pulwama (2019) and Balakot airstrikes (February 26, 2019).

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Trade status	Trade between India and Pakistan was suspended by Pakistan after India revoked Art. 370 (August 2019); earlier trade was minimal (under USD 3 billion/year) despite potential; back-channel trade via UAE and informal routes continues; SAARC summit has not been held since 2016 (India refused to attend Islamabad summit due to terrorism concerns).

A.4 BANGLADESH -- FROM LIBERATION TO COMPLEX PARTNERSHIP

India's relationship with Bangladesh is **historically profound** -- India was instrumental in Bangladesh's liberation war (1971 Indo-Pakistani War; Operation Vijay; Indian Army + Mukti Bahini defeated Pakistan Army; Bangladesh declared independent December 16, 1971 -- **"Vijay Diwas"**). Bangladesh is India's **largest trade partner in South Asia** (India exports ~USD 12-14 billion; Bangladesh exports ~USD 1.5-2 billion to India). Relations are generally strong but several irritants persist.

Feature	*Detail*
Farakka Barrage dispute	India built the Farakka Barrage (1975) on the Ganga in West Bengal (16 km from Bangladesh border) to divert Ganga water into the Hugli River to flush silt and maintain Kolkata Port navigation; Bangladesh claims diversion reduces flow in the Padma (the main Ganga arm in Bangladesh), affecting agriculture, fisheries, navigation, and ecology in Bangladesh. Farakka Treaty 1996 (signed during Deve Gowda government): 30-year treaty for water sharing during lean season; expired January 2026 -- renewal uncertain under Yunus government.
Teesta River water sharing	Teesta River flows from Sikkim through WB into Bangladesh (as Tistha); Bangladesh wants guaranteed minimum flow; India-Bangladesh draft agreement prepared (~2011) but WB CM Mamata Banerjee has consistently refused to agree (Teesta water is vital for North Bengal agriculture); Yunus government has renewed demand; central government willing but state government veto has blocked for 13+ years.
Land Boundary Agreement 2015	India-Bangladesh Land Boundary Agreement (LBA) 2015 -- one of the most complex diplomatic achievements: 111 Indian "enclaves" (villages inside Bangladesh territory) were transferred to Bangladesh; 51 Bangladeshi enclaves were transferred to India; 162 enclaves involving ~52,000 people were resolved after 68 years of post-Partition ambiguity; residents got choice of citizenship; enacted via 100th Constitutional Amendment of India.
July 2024 political crisis	Sheikh Hasina government (2008-2024) was overthrown on August 5, 2024 during student-led protests against her government (originally against quota system for government jobs; escalated to demand her resignation); Hasina fled to India (she is in India as of late 2024); Nobel laureate Muhammad Yunus sworn in as Chief Adviser of Bangladesh's interim government. India-Bangladesh relations under strain: Yunus government has raised Teesta water issue, sought Hasina extradition; India has concerns about treatment of Hindu minorities in Bangladesh (temples attacked post-Hasina exit); trade and connectivity projects under review.
Connectivity projects	Akhaura-Agartala Rail Link (commissioned November 2023 -- India-Bangladesh train connectivity; reduces distance for NE India access to Chittagong Port from 1,400 km road to 500+ km rail); Bandhan Express (Kolkata-Dhaka); Maitri Bridge over Feni River; Chittagong and Mongla ports transit access for NE India (reduces NE India's dependence on Chicken's Neck / Siliguri Corridor)

A.5 NEPAL, BHUTAN, MYANMAR, SRI LANKA AND MALDIVES

Country	*Key Geographic Feature*	*Key Issue / Development (2022-2024)*
NEPAL	Open border (Treaty of Peace and Friendship	KALAPANI DISPUTE: Nepal issued new official map in May 2020 claiming Kalapani, Limpiyadhura, and Lipulekh (India-administered;

	1950); Kalapani-Lipulekh-Limpiyadhura trijunction (India, Nepal, China meet); Mahakali River (Kali) forms part of the boundary; Terai belt is the densely settled lowland shared border zone	near Dharchula, Uttarakhand) -- areas where India has maintained military posts since 1962; Nepal claims based on Sugauli Treaty 1816; India disagrees. Politically: Nepal oscillating between India and China depending on ruling coalition (KP Sharma Oli government = more China-friendly; Sher Bahadur Deuba = more India-friendly; Pushpa Kamal Dahal "Prachanda" = in power 2022-24). POWER TRADE: Nepal exports hydropower to India (Arun-3, Upper Karnali projects; Indian investment); critical economic tie.
BHUTAN	699 km border; NO Chinese diplomatic relations; Doklam Plateau (India-Bhutan-China trijunction); Jomolhari-Gangkhar Puensum peak area; Bhutan is an absolute monarchy under King Jigme Khesar Namgyel Wangchuck (constitutional monarchy since 2008)	DOKLAM (2017): China began constructing a road on the Doklam Plateau (Bhutanese territory near the trijunction); India intervened and deployed troops (per the Friendship Treaty with Bhutan which obligates India to protect Bhutan's security); 73-day standoff; India-China disengaged in August 2017 without clear resolution; China continued construction away from the exact standoff point. BHUTAN-CHINA BOUNDARY TALKS: ongoing -- China has offered Bhutan a "package deal" (give up Doklam for Chinese concessions in NE Bhutan -- India strongly opposes this "swap" as Doklam commands India's Siliguri Corridor). Hydropower: India finances and imports all Bhutan hydropower; Bhutan's largest export earner.
MYANMAR	1,643 km border with 4 NE states; Free Movement Regime (FMR) historically; Kaladan Multimodal Project (Sittwe Port to Mizoram); India-Myanmar-Thailand Trilateral Highway (via Imphal-Moreh-Tamu)	February 2021 COUP: Myanmar military (Tatmadaw) overthrew Aung San Suu Kyi's elected NLD government; civil war since; India has maintained pragmatic engagement with the military junta (unlike USA/EU which imposed sanctions) because: (a) Myanmar shares 1,643 km border; (b) Kaladan Project interests; (c) India cannot afford Myanmar going fully into China's orbit. MANIPUR CRISIS (2023): Meitei-Kuki ethnic violence from May 2023; armed groups from Myanmar crossing border; India suspended FMR in border areas. KALADAN PROJECT: Sittwe Port (Myanmar) to Paletwa (river + road) to Zorinpui (Mizoram border) -- partially complete; critical for NE India maritime connectivity; Myanmar civil war has disrupted progress.
SRI LANKA	Palk Strait (22 km; Adam's Bridge/Rama Setu -- underwater shoal formation); Katchatheevu Island (ceded by India to Sri Lanka in 1974; Tamil fishermen dispute); exclusive economic zones overlap	ECONOMIC CRISIS (2022): Sri Lanka defaulted on external debt (April 2022; first since independence); USD 51 billion external debt; foreign exchange reserves near zero; severe fuel, food, medicine shortages; mass protests ousted President Rajapaksa (July 2022). INDIA RESPONSE: India provided USD 4 billion emergency support (credit lines, grants, fuel -- largest bilateral assistance package India has ever given to any country); India positioned as "first responder." HAMBANTOTA PORT: Sri Lanka leased Hambantota Port to China Merchants Port Holdings for 99 years (2017) under debt-for-equity swap -- the defining "debt trap diplomacy" case study. ETCA (Economic and Technology Cooperation Agreement) with India: under negotiation; India and Sri Lanka have complementary economic structures.

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MALDIVES	~800 km from Indian mainland; closest = Minicoy (India) to Addu (Maldives) ~130 km; strategic Indian Ocean position; India has monitoring stations and helicopters in Maldives	MUIZZU "INDIA OUT" (2023-24): Mohamed Muizzu (Pro-China candidate) won presidential election November 2023; launched "India Out" campaign (against Indian military presence); demanded India withdraw its military personnel; India complied by May 2024 (replaced military with civilian technicians for helicopter maintenance). India-Maldives tourism (Indian tourists = largest source for Maldives; India temporarily reduced Maldives flights -- "boycott Maldives" trending); economic dependence continues. India concerned about Maldives-China security cooperation (Muizzu visited China; MoUs signed). Indian Ocean strategic importance: Maldives sits astride India's key sea lanes.

P A R T - B INTERNATIONAL TRADE

B.1 INDIA'S INTERNATIONAL TRADE -- OVERVIEW AND STRUCTURE

India's international trade has grown dramatically since the **economic liberalisation of 1991,** expanding from a total merchandise trade of ~USD 40 billion (1991) to over **USD 1.4 trillion (total trade in goods + services, FY 2023-24)** -- a 35-fold increase in 33 years. India is now the world's **9th largest merchandise exporter** and a major player in services exports (particularly IT and financial services). However, India's **chronic trade deficit** (imports consistently exceeding exports in merchandise) is a structural challenge requiring attention.

Trade Parameter	*FY 2022-23*	*FY 2023-24 (provisional)*	*Note*
Merchandise Exports	USD 451 billion	USD 437 billion (slight decline due to global slowdown)	India's target: USD 1 trillion merchandise exports by 2030; engineering goods = largest category (~USD 107B); petroleum products ~USD 80B
Merchandise Imports	USD 714 billion	USD 678 billion	Crude oil = single largest import (~USD 160B); gold = 2nd (~USD 35B); electronics (largely Chinese) ~USD 75B; coal ~USD 45B
Merchandise Trade Deficit	-USD 263 billion	-USD 241 billion	Structurally high; worsens when oil prices rise; oil = ~25% of total imports; gold import demand driven by investment + jewelry
Services Exports	USD 322 billion	~USD 340 billion	IT-BPM = 57% of services exports; travel, financial services = other major components; India is world's LARGEST services exporter per UNCTAD metrics for some categories
Services Imports	USD 189 billion	~USD 190 billion	Business travel, royalties, transport = major components
Services Surplus	+USD 133 billion	+USD 150 billion	Services surplus partially offsets merchandise deficit
Current Account Deficit (CAD)	~USD 130 billion (2.0% of GDP)	~USD 91 billion (2023-24; improving)	CAD = Merchandise deficit minus Services surplus minus Remittances; Remittances (USD 125B) also offset; India's overall external balance relatively stable
Total Foreign Exchange Reserves	~USD 620 billion (March 2024)	~USD 645 billion (April 2024)	India's forex reserves = 5th largest in world; provide ~11 months of import cover; managed by RBI

COMMODITY COMPOSITION -- EXPORTS

Export Category	FY 2022-23 Value	Key States / Products	Note
Engineering Goods	~USD 107 billion	Maharashtra, Gujarat, Tamil Nadu, Karnataka	Largest merchandise export category; includes machinery, transport equipment, iron & steel products, industrial machinery; automotive components; USA, UAE, Germany, UK = top destinations
Petroleum Products (Refined)	~USD 80 billion	Gujarat (Jamnagar RIL), Maharashtra (BPCL Mumbai), AP (HPCL Vizag)	India refines imported crude and re-exports as refined products; Jamnagar complex (world's largest refinery) enables this; Russia-origin discounted crude (post-Ukraine war 2022) boosted refining margins; EU = largest buyer
Gems and Jewellery	~USD 38 billion	Gujarat (Surat -- 90% of world diamond cutting), Maharashtra, Rajasthan	India cuts and polishes ~90% of world's diamonds; also gold jewellery (Rajkot, Mumbai, Chennai); rough diamond import + value addition + export = major value-added export model; USA, UAE, HK = top destinations
Pharma-ceuticals	~USD 28 billion	Telangana (Hyderabad), Gujarat (Ahmedabad), Maharashtra (Mumbai-Pune)	India = world's largest generic drug exporter (20% of global generics by volume); USA (stringent USFDA standards = quality assurance), UK, South Africa, Russia = top destinations; biosimilars growing
Chemicals	~USD 25 billion	Gujarat (Ankleshwar, Vapi, Dahej), Maharashtra, Rajasthan (dyes)	Dyes, pigments, agrochemicals, specialty chemicals; India is world's 6th largest chemical producer; Surat-Vapi-Ankleshwar corridor = "Chemical Valley"; major exporter to USA, EU, Brazil, China
Textiles and Apparel	~USD 44 billion (total)	Tamil Nadu (Tiruppur knitwear), Gujarat (Surat synthetic), Maharashtra (Mumbai garments)	Includes: readymade garments, cotton yarn, fabric; India is 3rd largest textile exporter; Bangladesh, Vietnam, Cambodia = competitors; PM MITRA 7 parks to boost competitiveness; USA, EU, UK = top markets
Agriculture and Allied	~USD 50 billion	All states; major items: rice (Rs.45,000 crore; India = world's largest rice exporter); spices; marine products; sugar; wheat (record 2021-22 then export ban 2022)	India = world's largest rice exporter (basmati + non-basmati); also major sugar exporter; marine products (shrimp from AP, WB); spices (Kerala, AP)

COMMODITY COMPOSITION -- KEY IMPORTS

Import Category	FY 2022-23 Value	Key Source Countries	Why India Imports
Crude Oil and Petroleum	~USD 160 billion (#1	Iraq, Russia (post-2022 discounted; now India's 2nd	India = 3rd largest oil importer (after China and USA); domestic crude production ~30 MT vs

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	import)	source after Iraq), Saudi Arabia, UAE, USA	consumption ~250 MT; Strategic Petroleum Reserve (Vizag, Mangaluru, Padur)
Electronic Goods	~USD 75 billion (#2)	China (largest; 45%+ of electronics imports), South Korea, Japan, Taiwan, USA	Phones (iPhones assembled in India but components from China/Taiwan; Xiaomi, Samsung phones; some assembly in India); semiconductor chips; displays; India PLI for electronics to reduce dependence
Gold	~USD 35 billion (#3)	Switzerland, UAE, South Africa	India = world's 2nd largest gold consumer (after China); investment demand + jewelry demand; import duty = 15% to discourage imports; still massive demand; accounts for ~5% of India's total imports
Machinery (non-electronic)	~USD 50 billion	Germany, USA, Japan, China	Machine tools, power generation equipment, construction machinery, textile machinery; India still largely dependent on imports for precision machinery
Coal, Coke, Briquettes	~USD 45 billion	Australia (#1 coking coal), Indonesia (#1 thermal coal), South Africa, USA	India = 3rd largest coal importer; coking coal (for steel) almost entirely imported; thermal coal for coastal power plants (cheaper to import than transport domestic coal)
Vegetable Oil (Edible Oil)	~USD 20 billion	Indonesia (palm oil #1), Malaysia (palm oil), Argentina, Brazil (soybean oil), Ukraine (sunflower; disrupted post-2022)	India = world's largest edible oil importer; 60-65% of edible oil needs imported; NMEO-OP (oilpalm mission) trying to reduce this; palm oil from SE Asia = largest category

B.2 INDIA'S MAJOR TRADE PARTNERS

Partner	*Trade Relationship*	*Key Export from India*	*Key Import to India*	*Strategic Note*
USA	Largest export destination (~18% share); 2nd largest import source	Engineering goods, pharma, software, gems, textiles, chemicals	Machinery, aircraft, medical equipment, scrap metal	India-USA trade = USD 130+ billion bilateral (FY 2022-23); GSTP (Generalised System of Preferences) -- India lost GSP status in 2019 (Trump withdrew); India seeking restoration; I2U2 group (India-Israel-UAE-USA) = new economic grouping; India-US ICET (Critical and Emerging Technology) initiative
China	Largest import source (~USD 100B imports); 5th export destination (~USD 16B exports)	Iron ore, cotton, organic chemicals	Electronics, machinery, chemicals, toys, APIs (pharmaceuticals)	Trade deficit ~USD 83-100B; India has NOT joined BRI; CPEC runs through PoK (India objects); Post-Galwan: India banned Chinese apps, restricted Chinese FDI; but trade cannot be easily decoupled; supply chain realities; India working to reduce dependence via PLI schemes and critical mineral sourcing
UAE	3rd largest trade partner	Petroleum products	Crude oil, gold, precious stones	India-UAE CEPA (Comprehensive Economic Partnership Agreement) --

	overall; hub for India-Gulf trade	(refined), gems and jewellery, engineering goods, food		signed February 2022; entered into force May 2022; India's FIRST CEPA in many years; target: USD 100 billion bilateral trade by 2026; UAE has large Indian diaspora (3.5+ million); UAE = financial hub for Indian businesses and diaspora
Saudi Arabia	5th largest trade partner	Petroleum products, rice, engineering goods	Crude oil, fertilisers (potash, urea), petroleum products	India-Saudi Arabia bilateral: ~USD 52 billion; Saudi Aramco's interest in Reliance Industries (announced 2019, not completed); IMEC (India-Middle East-Europe Corridor) -- announced at G20 New Delhi 2023; India-Saudi Arabia as anchor nodes of IMEC
Russia	Rapidly growing after Ukraine war (2022)	Pharmaceuticals, engineering goods, tea, coffee	Crude oil (at 30-35% discount post-Ukraine sanctions; Russia became India's 2nd largest crude source in 2022-23), fertilisers, coal, LNG, defence equipment	India-Russia trade: USD 45-65 billion (FY 2022-23); India maintained "strategic autonomy" by continuing Russian oil imports despite Western pressure; paid in AED (UAE dirhams) and partially in INR; Russia deposited accumulated rupees in Indian banks; VOSTF military exercise; Russia supplies ~55% of India's defence hardware (declining; India diversifying)
Japan	Partner for infrastructure investment	Pharmaceuticals, auto components, engineering goods	Electronics, machinery, vehicles, optical instruments	India-Japan CEPA (2011); Japan is India's 3rd largest FDI source; JICA finances WDFC (Western Dedicated Freight Corridor), Mumbai-Ahmedabad Bullet Train (JPY 1.08 lakh crore loan); QUAD (India-USA-Japan-Australia) geopolitical grouping; India-Japan 2+2 (Defence and Foreign Ministers) dialogue; Japan sees India as "democratic counterweight" to China
UK	Post-Brexit FTA negotiations	Pharmaceuticals, clothing/textiles, engineering goods, gems, IT services	Machinery, alcohol, precious metals	India-UK Free Trade Agreement (FTA) negotiations began January 2022; stalled due to: (a) UK political instability (3 PMs in 2022); (b) India's demands on immigration (mobility for Indian professionals); India has ~1.8 million diaspora in UK (Rishi Sunak was UK PM 2022-24). FTA expected to boost bilateral trade from USD 36 billion (2022) to USD 100 billion by 2030.

B.3 WTO, TRADE AGREEMENTS AND TRADE POLICY

Trade Policy / Body	Key Feature

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WTO (World Trade Organisation)	India is a founding member (January 1, 1995; replaced GATT since 1948). India's positions: (a) Defends right to maintain public food stockholding and MSP programs (WTO Agreement on Agriculture has limits but India argues food security is an exception); (b) Seeks "Special and Differential Treatment" for developing countries; (c) Pushes for TRIPS (IP rights) reform to allow generic medicine manufacture for developing countries (critical for Indian pharma); (d) Opposed Trade Facilitation Agreement (TFA, 2013) initially -- India blocked TFA adoption at Bali MC9, demanding food security exemption first; eventually agreed with a "peace clause" in 2014.
RCEP withdrawal (2019)	Regional Comprehensive Economic Partnership (RCEP) -- 15-nation Asia-Pacific trade bloc (ASEAN 10 + China, Japan, South Korea, Australia, New Zealand); India participated in 7 years of negotiations (2012-2019) but withdrew in November 2019 at Bangkok; reasons: (a) Fear of Chinese goods flooding India under zero tariff (India's trade deficit with RCEP countries is massive -- ~USD 100B with China alone); (b) Inadequate protection for Indian services and professional mobility; (c) Dairy sector concerns (New Zealand, Australia dairy threat to Indian milk cooperatives like AMUL); RCEP signed by remaining 15 in 2020.
India-UAE CEPA (2022)	Comprehensive Economic Partnership Agreement with UAE (signed February 18, 2022); India's first significant FTA in years; entered into force May 1, 2022; target: USD 100 billion bilateral trade; immediate benefits: zero duty on 80% of Indian exports to UAE; UAE = financial hub; large Indian diaspora.
India-Australia ECTA (2022)	Economic Cooperation and Trade Agreement (ECTA) -- interim FTA (signed April 2, 2022; entered into force December 29, 2022); India's first Western country FTA; Australia gives zero duty on 96% of Indian exports immediately (including textiles, pharma, gems); India reduces duties on 85% of Australian goods; focus: India gets coal, critical minerals from Australia; Australia gets pharma, education, IT from India; full CECA (Comprehensive Economic Cooperation Agreement) being negotiated.
India-EU FTA (under negotiation)	India-EU FTA negotiations resumed (June 2022 after 9-year hiatus -- halted in 2013 due to differences on GM crops, generic medicine, investment protection); Major issues: India wants EU to open services market (visa for professionals), EU wants India to open goods market (cars, wines, spirits); IP protections for EU; carbon border tax (CBAM) -- India concerned it discriminates against Indian exports.
India-UK FTA (under negotiation)	Launched January 2022; 14+ rounds of negotiation by 2024; major sticking points: India wants easier visa/mobility for IT professionals (Intra-company Transferee routes; Post-Study Work Visas for Indians); UK wants lower duties on Scotch whisky, cars (Jaguar Land Rover), dairy; India has refused to budge on dairy and alcohol. Rishi Sunak (India-origin UK PM until July 2024) was expected to close it but could not in 14 rounds.
IMEC (India-Middle East-Europe Corridor)	Announced at G20 New Delhi Summit (September 9-10, 2023); MoU signed by India, USA, Saudi Arabia, UAE, Jordan, Israel, Italy, EU; a multimodal connectivity corridor: India (Mundra/JNPT Port) -- Arabian Sea -- UAE (Fujairah/Jebel Ali) -- Saudi Arabia (rail) -- Jordan -- Israel (Haifa Port) -- Mediterranean -- Greece (Piraeus Port) -- Europe; competes with China's BRI; disrupted by Israel-Gaza war (October 2023) as Jordan and Saudi Arabia reduced cooperation pace; India-UAE-Saudi rail component proceeding.
SAARC	South Asian Association for Regional Cooperation (1985; HQ Kathmandu); 8 members: India, Pakistan, Bangladesh, Nepal, Bhutan, Sri Lanka, Maldives, Afghanistan; SAFTA (South Asian Free Trade Area, 2006); SAARC summit not held since 2016 (India refused to attend Islamabad summit due to Pakistan-sponsored terrorism); SAARC is effectively paralysed; India pursuing BIMSTEC (Bay of Bengal Initiative for Multi-Sectoral Technical and Economic Cooperation) as alternative regional grouping (India, Bangladesh, Myanmar, Thailand, Sri Lanka, Nepal, Bhutan).

BIMSTEC	Bay of Bengal Initiative for Multi-Sectoral Technical and Economic Cooperation; India's preferred regional integration platform (excludes Pakistan); HQ Dhaka; 7 members; BIMSTEC FTA under negotiation; focus: maritime connectivity, security, blue economy, energy grid; 2022 Colombo Declaration (PM Modi attended; committed to BIMSTEC FTA by 2025).

KEY NOTE

Trade Policy Exam Framework: "India's trade policy can be described as SELECTIVELY OPEN -- liberal for services, IT and pharmaceuticals where India is globally competitive; protectionist for goods sectors (agriculture, dairy, automobiles) where domestic industry is vulnerable. Post-1991 average tariff has fallen from ~71% to ~15% but non-tariff barriers (NTBs) remain high. India has signed only 14 FTAs (vs Vietnam's 17, South Korea's 22, Australia's 18) -- reflecting defensive trade policy. However, 2022-23 saw a strategic shift with UAE CEPA and Australia ECTA -- India is now actively pursuing more FTAs. The RCEP withdrawal was controversial -- some economists argue India lost a strategic opportunity; others say it saved Indian farmers and manufacturers from cheap imports."

B.4 CURRENT AFFAIRS -- NEIGHBOURS AND TRADE (2022-2025)

G20 New Delhi Summit (September 9-10, 2023): India hosted the G20 Summit at Bharat Mandapam, New Delhi under the presidency theme "Vasudhaiva Kutumbakam" (the world is one family). Key outcomes: (a) IMEC (India-Middle East-Europe Corridor) announced -- India's answer to China's BRI; (b) African Union inducted as permanent G20 member (India pushed for this -- gave India more Global South support); (c) New Delhi Declaration adopted by consensus (India managed Russia-Ukraine language to get consensus, unlike failed 2022 Bali G20); (d) "One Future Alliance" for Digital Public Infrastructure (DPI) -- India's UPI/Aadhaar model for the world; (e) India-Middle East-Europe Economic Corridor signed.

Bangladesh Political Crisis -- Sheikh Hasina Exit (August 2024): Student protests over government job reservation quotas (August 2024) escalated into a mass movement demanding Sheikh Hasina's resignation. On August 5, 2024, Hasina fled Bangladesh to India. Nobel laureate Muhammad Yunus was sworn in as Chief Adviser of Bangladesh's interim government. India-Bangladesh relations are under strain: (a) Yunus government raised Teesta water issue; (b) Violence against Hindu minorities in Bangladesh (temples attacked); (c) Yunus government sought Hasina's extradition; India has not complied. BIMSTEC and bilateral connectivity projects are being reviewed.

India-Maldives Crisis and Muizzu ("India Out"): After Mohamed Muizzu's election as Maldivian President (November 2023) on an "India Out" platform, diplomatic tensions escalated. Muizzu demanded India withdraw its military personnel operating helicopters and a Dornier maritime patrol aircraft. India withdrew its military by May 2024. Muizzu visited China (his first state visit; January 2024) and signed several MoUs. India-Maldives tourism: Indian tourists briefly boycotted Maldives (after Maldivian minister made derogatory comments about PM Modi). The episode illustrated how India's small neighbours can pivot towards China as leverage.

India's Trade Deficit with China (FY 2022-23): India's trade deficit with China reached ~USD 83-100 billion in FY 2022-23 -- the largest bilateral trade deficit India has with any country. Despite the Galwan clash (June 2020), app bans, FDI restrictions on Chinese companies, and PLI schemes to reduce Chinese import dependence, the trade deficit has actually grown (not shrunk) because India's electronic import needs from China have increased. India's PLI for mobile phones has created an Apple-Samsung assembly ecosystem, but most components still come from China/Taiwan. Full supply chain decoupling from China will take 5-10+ years.

PYQ ANALYSIS -- CHAPTERS 39-40 (2010-2025)

Source	*Year*	*Marks*	*Question*
UPSC Civil	2024	15M	"Discuss the challenges in India-China relations. How has the Galwan Valley clash (2020) changed India's policy towards China?"

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UPSC Civil	2023	12M	"Examine India's trade policy challenges. Why did India withdraw from RCEP in 2019 and what are the implications of the India-UAE CEPA and India-Australia ECTA?"
UPSC Civil	2022	10M	"Discuss the significance of the India-Bangladesh Land Boundary Agreement (2015). What are the current challenges in India-Bangladesh relations?"
UPSC Civil	2021	12M	"Critically examine India's trade deficit. What are the major structural causes and what policy measures can reduce it?"
UPSC Civil	2020	10M	"Discuss the significance of the IMEC (India-Middle East-Europe Corridor) announced at the G20 New Delhi Summit for India's trade and connectivity."
UPSC Civil	2019	10M	"Discuss the significance of the Indus Waters Treaty (1960). What are the current challenges to the treaty?"
UPSC Civil	2018	12M	"Critically examine India's relations with its immediate neighbours under the 'Neighbourhood First' doctrine."
UPSC Civil	2017	10M	"Discuss the structure of India's external trade -- its composition of exports and imports and major trading partners."
IFoS GS	2024	10M	"Examine the environmental dimensions of India's trade -- the ecological footprint of India's major commodity imports (crude oil, coal, edible oil)."
IFoS GS	2023	10M	"Discuss the ecological risks of India's border infrastructure development (roads, tunnels, bridges) in the Himalayan regions with China, Nepal, and Bhutan."
IFoS GS	2022	10M	"Examine the ecological implications of the India-Middle East-Europe Corridor (IMEC) for India's coastal and marine environments."

KEY NOTE	**High-Priority 2025-26 Topics:** India-China Depsang-Demchok disengagement announcement Oct 2024 + border patrol resumption; Bangladesh Hasina exit + Yunus government + Hindu minority violence; Maldives Muizzu India Out + military withdrawal; G20 IMEC announcement + Israel-Gaza disruption; India-Australia ECTA first year implementation; India-UAE CEPA performance (trade crossing USD 80B); RCEP 5-year post-withdrawal assessment; India-UK FTA stalling reasons; India's oil imports from Russia (discounted crude strategy); India's critical minerals import dependence (lithium, cobalt) -- all very high-priority for 2025-26 exams.

MODEL BOOK

Discuss the challenges in India-China relations since the Galwan Valley clash (2020). What strategic responses has India adopted?

UPSC CIVIL (Mains) | 15 Marks | 200 Words

The Galwan Valley clash of June 15-16, 2020 -- which killed 20 Indian soldiers in the first lethal India-China border confrontation since 1975 -- marked a definitive turning point in India-China relations. The relationship has since been characterized by simultaneous military standoff, economic interdependence, and strategic competition across the Indo-Pacific.

Background to Galwan: China had been steadily upgrading infrastructure in Tibet and Xinjiang since the early 2000s, creating a military access advantage India lacked. In April-May 2020, PLA forces intruded into multiple points in Eastern Ladakh (Galwan, Pangong Tso, Hot Springs, Gogra-Depsang). The June 15 fatal clash occurred during a de-escalation meeting.

TERRITORIAL DISPUTES:

1. **Aksai Chin:** 37,244 sq km India claims but China controls; building of Xinjiang-Tibet G219 highway through it revealed to India only in 1958.

2. **Arunachal Pradesh:** China calls it "South Tibet" -- India rejects this; PM Modi visited Arunachal (Hollong and Siyom bridge inaugurations 2024) asserting India's claim.
3. **Depsang:** Most complex unresolved friction; China occupies ~1,000 sq km blocking India's traditional patrol routes near the Y-Junction. Disengagement announced October 2024 but verification ongoing.

INDIA'S STRATEGIC RESPONSES:

1. **Military infrastructure surge:** BRO built 6,800+ km of roads in 2020-24; 40 key tunnels; advanced landing grounds; Sela Tunnel (Arunachal; India's longest bi-lane road tunnel) opened March 2024; India is achieving parity with China's military infrastructure in the border region.
2. **Diplomatic and economic measures:** 59 Chinese apps banned (TikTok, PUBG etc.); FDI from China restricted (Press Note 3, 2020 -- mandatory government approval for China-origin FDI); PLI schemes to reduce Chinese import dependence (electronics, APIs, chemicals); India did NOT cut trade (USD 100B bilateral trade continues -- economic reality).
3. **Minilateral engagement:** QUAD (India-USA-Japan-Australia) elevated to Leaders' Summit (2021); AUKUS (Australia-UK-USA; nuclear submarine deal) aligned with QUAD goals; India-France maritime partnership (Indian Ocean); India-Japan 2+2 format.
4. **Infrastructure in border villages:** Vibrant Villages Programme (VVP, 2023): 662 villages in UP, HP, Uttarakhand, Arunachal, Sikkim along LAC to be developed -- preventing population movement away from border, creating a "human shield" against Chinese forward patrol claims.
5. **Indo-Pacific strategy:** IPEF (Indo-Pacific Economic Framework) with USA; India-Pacific Islands Forum; expansion of SAGAR doctrine; Blue Economy; Andaman-Nicobar Command enhancement.

CHALLENGES REMAINING:

Trade dependence: Despite geopolitical tensions, India's USD 100B import dependence on China (electronics, APIs, machinery) cannot be decoupled quickly; PLI schemes will take 5+ years to build alternative supply chains.
Depsang resolution: Announced October 2024; details on patrol rights unclear; whether Chinese troops have actually vacated the Depsang plains is unverified.

India's post-Galwan China policy can be summarised as "competitive coexistence with guardrails" -- engaging economically while building military and strategic deterrence. The Vibrant Villages Programme, BRO infrastructure surge, and QUAD engagement form a coherent response. However, the fundamental asymmetry in border infrastructure (China's comprehensive transport advantage in Tibet) will take another decade to bridge fully.

Critically examine India's trade deficit. Discuss the commodity and partner composition and suggest structural reforms needed.

UPSC CIVIL (Mains) | 15 Marks | 200 Words

India's merchandise trade deficit -- USD 241 billion in FY 2023-24 -- is among the world's largest bilateral trade imbalances for a country at India's income level. It is a structural challenge rooted in energy import dependence, limited domestic manufacturing of high-tech goods, and gold import demand. Understanding its composition is essential for designing effective policy.

COMPOSITION OF THE TRADE DEFICIT:

Crude Oil (40% of deficit): India imports ~USD 160 billion of crude annually (3rd largest importer; domestic production only 30 MT vs consumption 250 MT); a 10% rise in oil prices adds ~USD 15-16 billion to India's import bill; Strategic Petroleum Reserve (9-10 days cover at Vizag, Mangaluru, Padur); post-Ukraine war, Russia's discounted crude has mitigated some cost increase.

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Electronics from China (~USD 75B): Phones, components, displays -- India assembles many phones but imports 80%+ of components from China/Taiwan; PLI schemes are building assembly (Apple iPhone; Samsung) but full supply chain shift takes 5-10 years.

Gold (~USD 35B): India imports 700-800 tonnes annually; world's 2nd largest gold consumer; structural demand from jewelry industry and investment; import duty raised to 15% (2022); Gold Monetisation Scheme, Sovereign Gold Bonds (SGB) tried to channel demand to paper gold -- limited success.

China trade deficit (~USD 83-100B specifically with China): India's single largest bilateral deficit; machinery, chemicals, APIs, synthetic fabrics -- all dominated by China; not reducible without PLI manufacturing buildup.

STRUCTURAL CAUSES:

1. **Energy import dependence:** India produces only 12% of its oil and 54% of its gas needs domestically; renewable energy transition reduces future oil imports (PM Surya Ghar, EVs, green hydrogen).
2. **Manufacturing underdevelopment:** India imports what it cannot make -- high-end electronics, precision machinery, specialty steel; manufacturing share of GDP has stagnated at 14-16% vs China's 28%; PLI schemes target this.
3. **Trade policy inconsistency:** India has raised import duties since 2017 ("Make in India" protectionism) while also trying to attract export-oriented FDI -- mixed signals deter investors.

STRUCTURAL REFORMS NEEDED:

1. **Energy security:** Accelerate renewable energy (500 GW by 2030 target); ethanol blending (E20 by 2025 to reduce petrol imports); green hydrogen exports as future offset.
2. **Export diversification:** FTAs (UAE CEPA, Australia ECTA, UK FTA under negotiation, EU FTA) to open markets; India needs more market access, not just production incentives.
3. **Reduce gold demand:** Scale up Sovereign Gold Bonds (SGBs) as zero-import alternatives; financial literacy for rural gold savers; regulated gold ETFs.
4. **Critical mineral supply chains:** Domestic lithium, REE production (Critical Minerals Mission); KABIL overseas acquisitions; reduce chemical import dependence with domestic API, specialty chemical production.

India's trade deficit is manageable given the offsetting services surplus (+USD 133B) and remittances (USD 125B) -- India's current account deficit of ~USD 91 billion (~2% of GDP) is within sustainable limits. The structural challenge is converting India's domestic demand into domestic manufacturing capacity. The PLI ecosystem, FTA strategy, and energy transition together form the three-pillar response.

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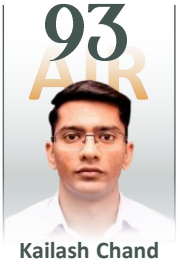
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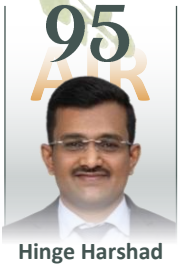
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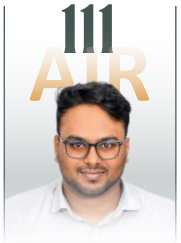
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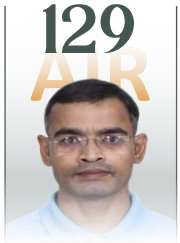
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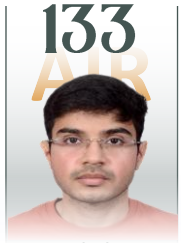
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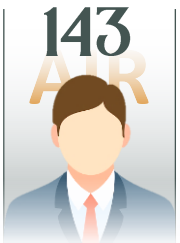
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