MAINS 2025 GS-1 GEOGRAPHY - NOTES FOR PREDICTIONS

Weather Prediction: Traditional vs Modern/AI Methods & Mission Mausam

Mission Mausam

- Cabinet cleared a ₹2,000 crore programme to upgrade infrastructure used to make atmospheric observations.
- To enhance India's ability to predict and respond to extreme weather events and the impacts of climate change.
- **Focus:** To improve atmospheric observations; To enable better-quality monsoon forecasts; To improve alerts warning of deteriorating air quality; To warn of extreme weather events and cyclones.
- **Elements: Next-generation radars, satellite** systems with advanced sensors, high-performance **supercomputers, earth-system models, GIS-based automated Decision Support System** for real-time data dissemination.
- **Nodal agency MoES. Implementing by** IMD, IITM, Pune, National Centre for Medium-Range Weather Forecasting
- By 2026, it plans to install 60 weather radars, 15 wind profilers, and 15 radiosondes for updates on changing parameters of **wind speeds, atmospheric pressure, humidity, temperature** at various elevations of atmosphere.
- **Instruments to be Deployed:**
  - **Weather Radars** transmitting radio waves to detect rainfall, snowstorms, and other weather phenomena.
  - **Wind Profilers:** Radars that measure wind speed at various altitudes, aid weather predictions, used by pilots for flight safety. **Radiosondes:** 15 devices attached to balloons that measure temperature, pressure, humidity.
  - **Cloud-Simulation Chamber**: At IITM Pune. Will allow scientists to study artificial clouds, weather modification.
  - In India, experiments have been done on cloud seeding, which helps generate rain. Under **Cloud Aerosol Interaction and Precipitation Enhancement Experiment (CAIPEEX) programme**, trials were done by IITM along rain-shadow regions of Maharashtra's Solapur district from 2016-2018, studying Aerosol-cloud-precipitation interactions using Doppler weather radars.

Methods to Forecast Monsoons/Weather	
Statistical Methods	**Dynamical Models**
• IMD historically used statistical metho combining various weather parameters forecast monsoons. • Estimates were broad, missed key details, maki them less accurate for predicting droughts floods, which often coexist.	• These models are now the standard for forecasting. • They provide more accurate medium-range forecasts, which a useful for daily and seasonal predictions. • Monsoon Mission improved these models to allow predictio over various time scales, from daily forecasts to long-te seasonal outlooks.

Benefits of Mission Mausam:

- **Lightning Reduction:** In India, **lightning strikes cause more deaths** than other natural disasters like floods or landslides. Researchers are working on cloud modification techniques to reduce lightning strikes.
- **Other Benefits:** Benefits to Agriculture, Disaster Management, Applications in Defence, Aviation, and Shipping, Advanced Instruments for Weather Monitoring, Cloud Seeding for Rainfall Control.

Aspect	Traditional Methods	Modern / AI-Based Methods
Data Sources	Bio-indicators, Mathematics, Equations	Meteorological sensors, satellite, radar, IoT, Doppler datasets (IIIT-L, IMD)
Modelling	Empirical rules (e.g., Suri Jagek solar observations)	Numerical weather models (Bharat Forecast System, ECMWF)
Resolution	Local and general; variable accuracy	High spatial (6 km) and temporal resolution; sub-seasonal nowcasting
Speed & Cost	Real-time but limited forecasting horizon	AI models like Aardvark, FourCastNet: fast, laptop-run, cost-effective
Extreme Event Accuracy	Good for seasonal anomalies; poor for extremes	AI models sometimes struggle with rare extremes vs NWP

Examples:

- **World**: Google DeepMind's FourCastNet and Cambridge's Aardvark enable quick local forecasts.
- **India**: IIIT-L's sensor-fusion in UP and IMD's Bharat Forecast System improve regional forecasts.

Need to Shift from Traditional to Modern Methods

1. **Extreme socio-economic impacts** of floods/heatwaves necessitate precision forecasting.
2. **Data scarcity** and subjectivity in traditional methods limit systemic utility.
3. **Agricultural planning demands fine-grained forecasts**, not just seasonal indicators.
4. **GIS-enabled early warning** can save lives and infrastructure via hyper-local forecasting.
5. **Changing climate patterns** require data-driven adaptation, beyond indigenous rule-based systems.

Positives of Modern/AI Methods

1. Dramatically higher **accuracy and resolution**, reducing forecast errors.
2. **Speed**: AI models deliver long-range forecasts quickly, on low-cost hardware.
3. Strengthened disaster resilience—IMD's 6 km BFS helps manage floods/drought effectively.
4. Supports **climate adaptation apps** like IIIT–L's CRO for air quality and hydrology.
5. Scalable, portable solutions benefit developing regions lacking supercomputers.

Negatives & Limitations

1. AI models lack transparency—"black-box" nature impedes explainability.
2. Rare extreme events still challenge AI models—e.g., sudden-turn typhoons.
3. **Data biases** from low network density distort model accuracy.
4. High dependency on tech presents vulnerability—sensor failure/cybersecurity come into play.
5. Indigenous knowledge systems risk marginalization without integration alongside.

Government's & Global Recent Initiatives

1. **Mission Mausam** launched in 2024 – AI-ready weather-climate mission.
2. **Bharat Forecast System (May 2025)** – India's 6 km grid model.
3. **IIIT-L's Climate Observatory** in UP blends meteorological and pollution sensors.
4. **C–DAC/PCMC** deploy 72-hour flood forecasting in Pune for ward-level alerts.
5. Globally, **AI weather systems** being adopted by UK Met Office, ECMWF, NASA.

Way Forward

1. Develop **hybrid models** combining numerical weather prediction (NWP) with AI/ML systems.
2. Emphasize **explainable AI frameworks**, increasing transparency and societal trust.
3. Democratize infrastructure—invest in rural sensors and connectivity for equitable data capture.
4. **Co-produce forecasts** with indigenous knowledge custodians for hybrid accuracy.
5. Establish regulatory standards—**AI weather audits**, cross-border data sharing, open-source platforms.

Factors that Affect the Indian Monsoon

1. Differential Heating of Land and Sea

- **Explanation**: During summer, Indian landmass heats faster than the surrounding oceans, creating a low-pressure zone over the subcontinent. Moisture-laden southwest winds from the Indian Ocean rush in to fill this vacuum, bringing monsoon rains.
- **Keywords**: Thermal contrast, Inter-Tropical Convergence Zone (ITCZ), South Asian Monsoon.
- **Example**: Peninsular India heats up faster than the Bay of Bengal, drawing in moisture.
- **Thinker**: Sir Edmund Halley first proposed this thermal theory (1686).

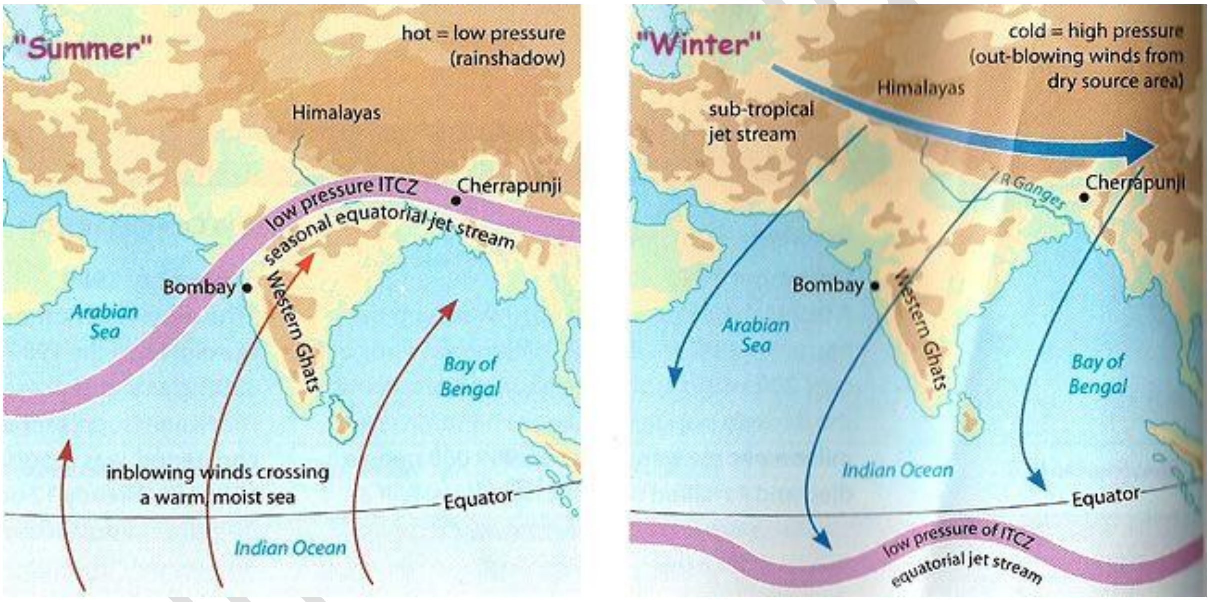
- **Report**: IMD Annual Climate Summary 2023.

2. El Niño–Southern Oscillation (ENSO)

- **Explanation**: El Niño weakens trade winds, warming central Pacific waters, which disrupts Indian monsoon by shifting the Walker Circulation. La Niña, conversely, enhances monsoon.
- **Keywords**: ENSO, Walker Cell, SST anomalies, Pacific Decadal Oscillation.
- **Example**: El Niño years like 2002, 2009 saw severe monsoon droughts.
- **Thinker**: Jacob Bjerknes, early ENSO studies.
- **Paper**: *IMD-ENSO Correlation Study 2021*.

3. Indian Ocean Dipole (IOD)

- **Explanation**: Positive IOD, when western Indian Ocean is warmer than eastern part near Sumatra, enhances monsoon rainfall over India.
- **Keywords**: SST gradient, East African rainfall, IOD index.
- **Example**: 2019 monsoon was above normal due to a strong positive IOD.
- **Thinker**: Saji et al., *Nature* (1999) introduced IOD.
- **Paper**: *Saji et al., A Dipole Mode in the Tropical Indian Ocean* (Nature, 1999).



4. Jet Streams (Subtropical Westerly Jet & Tropical Easterly Jet)

- **Explanation**: The withdrawal and northward shift of the Subtropical Westerly Jet (STWJ) allows the monsoon to penetrate. Tropical Easterly Jet (TEJ) promotes convection.
- **Keywords**: Upper air circulation, STWJ, TEJ, 200 hPa level.
- **Example**: Delay in STWJ shift delays onset in Kerala.
- **Thinker**: P. Koteswaram (1950s) discovered TEJ's link to monsoon.
- **Report**: *World Meteorological Organization (WMO) Jet Stream Bulletin 2023*.

5. Himalayas and Tibetan Plateau

- **Explanation**: Himalayas act as a physical barrier preventing cold Central Asian winds from interfering and deflecting monsoon currents toward the subcontinent.
- **Keywords**: Orographic barrier, plateau heating, monsoon trough.
- **Example**: Heating over the Tibetan Plateau creates upper-level divergence enhancing rainfall.
- **Thinker**: J.S.I. Lockwood (early Himalayan monsoon theories).

- **Paper**: *Boos & Kuang (2010)*, *Tibetan Plateau and Monsoon Genesis*.

6. Inter-Tropical Convergence Zone (ITCZ)

- **Explanation**: ITCZ is a low-pressure zone where trade winds converge. Its northward shift over India heralds the onset of monsoon.
- **Keywords**: Equatorial trough, convergence zone, low pressure belt.
- **Example**: Delay in ITCZ migration causes delayed onset.
- **Thinker**: Charles Ferrel on wind belts.
- **Report**: IMD's *Monsoon Onset Dates Report 2023*.

7. Snow Cover over Eurasia and Himalayas

- **Explanation**: Heavier winter snow over Eurasia leads to cooling, delaying monsoon onset. It affects thermal contrast.
- **Keywords**: Albedo effect, delayed heating, land-sea contrast.
- **Example**: Heavy snow in Western Tibet delayed 2023 monsoon by 5 days.
- **Paper**: *Blanford (1884)* – first proposed snow–monsoon inverse correlation.
- **Report**: NOAA Eurasian Snow Cover Index 2023.

8. Cyclonic Activity in Indian Ocean

- **Explanation**: Pre-monsoon cyclones (e.g., in Bay of Bengal) affect moisture availability and disrupt monsoon flow.
- **Keywords**: Tropical cyclones, vortex interaction, Madden–Julian Oscillation.
- **Example**: Cyclone Remal (May 2024) slightly delayed monsoon onset in Northeast India.
- **Report**: IMD Cyclone e-Atlas 2024.

9. Madden–Julian Oscillation (MJO)

- **Explanation**: MJO is a 30–60 day moving system of tropical convection. A strong MJO phase enhances rainfall.
- **Keywords**: Intraseasonal variability, convective phase, equatorial waves.
- **Example**: MJO in Phase 3–4 enhances Indian Ocean convection.
- **Thinker**: Roland Madden & Paul Julian.
- **Paper**: *Role of MJO in Indian Summer Monsoon* – IITM Pune 2022.

10. Local Factors: Land Use, Urbanization, Aerosols

- **Explanation**: Urban heat islands, aerosols, and land-use change alter local convection and cloud formation, affecting rainfall patterns.
- **Keywords**: Microclimate, UHI, land–atmosphere interaction.
- **Example**: Delhi and Mumbai show intense but short-lived urban convective rainfall events.
- **Thinker**: R. Kripalani (IITM Pune) – monsoon & aerosols.
- **Report**: *State of Indian Climate 2023 – MoES*.

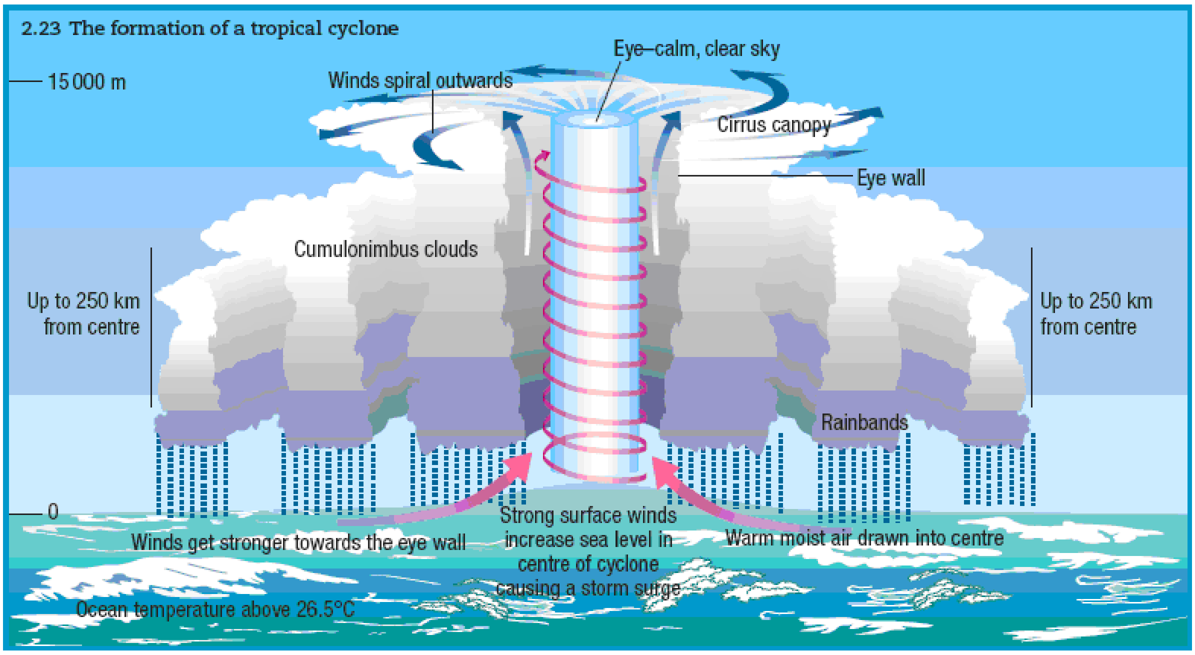
Reasons for Increasing Cyclonic Intensity

1. Warming Sea Surface Temperatures (SSTs)

- Rising SSTs (>28°C) provide latent heat energy, intensifying cyclones.
- Arabian Sea warming faster due to **anthropogenic climate change** (IPCC AR6, 2021).
- Example: **Cyclone Tauktae (2021)** intensified rapidly due to high SSTs.

2. Reduced Vertical Wind Shear

- Wind shear disruption is less frequent, allowing organized convection.
- **India Meteorological Department (IMD)** reports decreased shear during pre-monsoon.
- A factor in **Cyclone Biparjoy (2023)** sustaining intensity.



3. Indian Ocean Dipole (IOD) Influence

- Positive IOD enhances convection in western Indian Ocean, aiding Arabian Sea cyclones.
- **Ashok et al. (2004)** emphasized IOD's impact on Arabian cyclogenesis.

4. Urban Heat Islands (UHIs) & Heat Domes

- UHIs raise local temperatures, modifying land-sea thermal contrast.
- Heatwaves preceding monsoon alter low-pressure genesis.
- IMD flagged **Delhi heat dome** in May 2024 affecting monsoon onset.

5. Changing Monsoon Patterns & Onset Delay

- Delayed monsoon weakens jet streams, increasing cyclone formation window.
- **Rajeevan (2020)** highlights monsoon-cyclone inverse relation.

6. Increased Anthropogenic Aerosols in Bay, Shift to Arabian Sea

- Aerosols in Bay inhibit convection; Arabian Sea becomes favorable.
- **Nature Geoscience (2017)** study links aerosol impact to spatial shift in cyclogenesis.

7. Madden-Julian Oscillation (MJO) Phases

- MJO phases influence convection bursts, aiding rapid intensification.

- NASA research shows **MJO Phase 2 & 3** linked with Arabian Sea cyclones.

8. Northward Shift of ITCZ (Inter-Tropical Convergence Zone)
- ITCZ shift due to Arctic amplification alters low-pressure development zone.
- Shown in **NOAA data (2022)** aligning with northern Arabian Sea cyclogenesis.

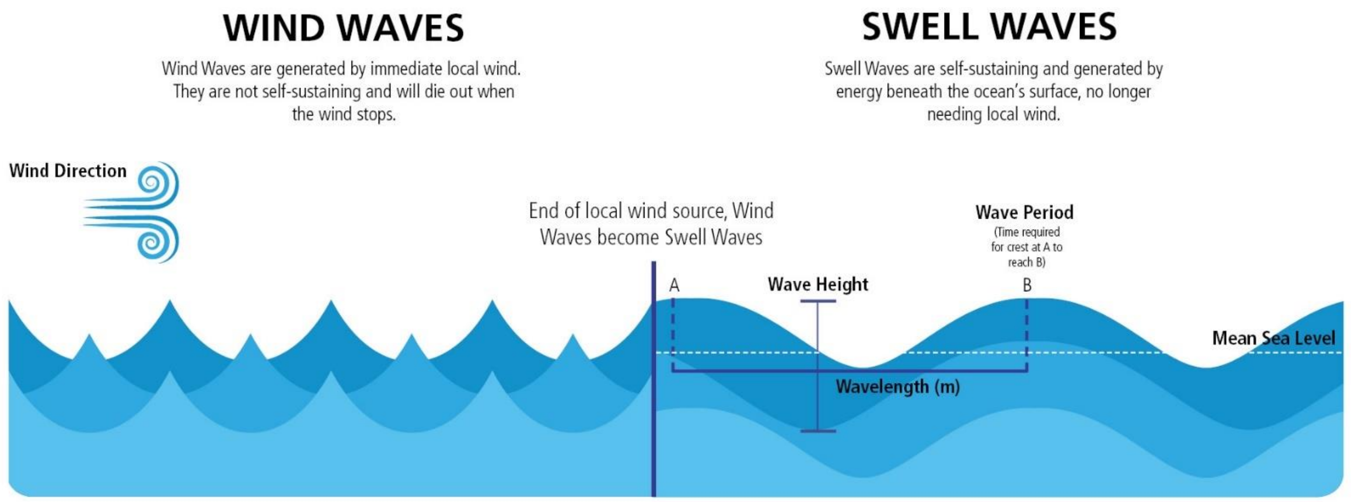
9. Absence of Rainfall Cooling
- Lack of pre-monsoon rainfall retains ocean heat, energizing cyclones.
- Reported by **Climate Dynamics journal (2023)**—"Dry spells fueling pre-monsoon intensification".

10. Global Climate Change-Induced Ocean-Atmosphere Feedbacks
- Warming oceans alter Walker circulation and Rossby waves.
- **WMO (2023)** links feedback loops to cyclone unpredictability and intensification.

Swell Waves

What
1. **Swell waves** are long, uniform, and regular surface gravity waves that are **generated by distant wind systems** (storms) and travel thousands of kilometers across oceans with little loss of energy.
2. Unlike local **wind waves** which are short and choppy, swell waves are **more organized** and have longer **wavelengths** and **periods**.
3. **Constructive interference**: when multiple swell waves overlap, they may lead to **rogue waves**.
4. **Remote origin**: generated in deep oceans, especially **Southern Ocean cyclones** or **tropical storms**.

Example from Current Affairs
1. **May 2024 Coastal Flooding (Kerala & Tamil Nadu)**: Swell waves originating from a **Southern Indian Ocean disturbance** led to **high tidal surges** along the Kerala coast.
2. The **India Meteorological Department (IMD)** issued a **'high swell alert'** based on wave models from **INCOIS**.



Waves with long wavelengths and periods arriving from a distant source are considered Swell.

Institutional Inputs:
1. **INCOIS (Indian National Centre for Ocean Information Services)**:
   - Regularly issues **"Swell Surge Forecasts"** via the **Swell Surge Alert System (SSAS)**.
   - Uses **WAVEWATCH III** model to simulate wave propagation from deep-sea events.

2. **IMD Marine Weather Bulletins**: Mention swell alerts for **fishermen warnings** and **coastal management**.

Relevant Research & Reports:

1. *Research Paper*: "Modeling of Swell Waves along Indian Coast Using WAVEWATCH III" – by Dr. M. Ravichandran (INCOIS, 2018)
2. *UNESCO-IOC Reports* on **tsunami early warnings** have emphasized how **swell waves can be mistaken for tsunamis**, causing panic.

Parameter	Definition	Role in Swell Waves
Wave Period	Time between wave crests	Longer in swells; allows long-distance propagation
Wave Height	Crest to trough distance	Moderate, consistent; increases hazard potential near coast
Group Velocity	Speed of wave energy	Determines how fast swell reaches coastlines
Fetch	Wind-blown distance over water	Larger fetch = more powerful swell generation
Wind Energy Transfer	Wind's energy imparted to ocean surface	Key to forming initial swell waves from remote storms

Coastline Recalculation

India's Coastline Recalculated

- Revised from 7,516 km (1970) to 11,098 km (2023–24) — a 48% increase due to a new method by the National Maritime Security Coordinator, accounting for bays, estuaries, inlets.
- **West Bengal**: Highest rise (357%), **Kerala**: Smallest (5%). **Puducherry**: Coastline shrank by 4.9 km.
- **Gujarat** still has the longest coastline, followed by **Tamil Nadu** (now ahead of Andhra Pradesh).

Method Used to Recalculate India's Coastline

1. **Use of Satellite Imagery**
   - High-resolution images from **Indian Remote Sensing (IRS)** satellites and **Cartosat series** were used to delineate the **High Tide Line (HTL)** and **Low Tide Line (LTL)**.
   - This improved the accuracy of identifying the coastal boundary features.
2. **Geographic Information System (GIS) Mapping**
   - **GIS tools** were employed to digitally trace the shoreline and create a detailed coastal vector dataset.
   - Enabled measurement of even **micro-level features** like small creeks, inlets, and estuaries.
3. **Fractal Geometry and Scale Correction**
   - Traditional methods underestimated the coastline due to using larger map scales (less detail).
   - Newer calculations considered the **'coastline paradox'**, where finer scale measurements lead to longer coastline values due to fractal-like curves.
4. **Integration of Tidal and Coastal Zone Parameters**
   - Data from **National Hydrographic Office** and **Survey of India** was integrated with **tidal benchmarks**, **erosion/deposition trends**, and **geomorphological data**.

What is the 11,098 km coastline?

1. This is the **most comprehensive measurement** of India's coastline using **high-resolution satellite data**, **fractal geometry**, and **modern geospatial techniques**.
2. It **includes**:
   - Mainland coast
   - Island territories (Andaman & Nicobar, Lakshadweep)
   - Tidal-influenced areas, creeks, estuaries, and minor coastal features which were previously excluded.

Aspect	Earlier Estimate (7,516 km)	New Estimate (11,098 km)
Technology used	Manual measurement, large-scale maps	Satellite imagery + GIS + LiDAR data
Detail level	Only major coastal curves	Micro-level features (creeks, inlets, mangroves)
Coastline paradox addressed	No	Yes, used **fractal geometry**
Tidal zones included?	Partially	Fully, including HTL and LTL

Implications of 11,098 km Coastline

1. **Policy Planning**: Accurate coastline helps in **disaster management**, **fisheries**, **port development**, and **coastal regulation** (CRZ rules).
2. **Climate Resilience**: Better estimation aids **vulnerability mapping** for sea-level rise and erosion.
3. **Legal/Maritime Claims**: Strengthens India's claim over **territorial waters**, **EEZ**, and **continental shelf** under **UNCLOS**.

AMOC (Atlantic Meridional Overturning Circulation)

What is AMOC?

1. AMOC is a **large system of ocean currents** in the Atlantic that carries **warm water from the tropics to the North Atlantic** and **cold water back southwards at deeper levels**.
2. It is a key component of **thermohaline circulation** ("global ocean conveyor belt").

3. Driven by **temperature (thermo)** and **salinity (haline)** differences – hence also called **Thermohaline Circulation**.

How Does AMOC Work?

1. **Warm, salty surface waters** flow northward via the **Gulf Stream** and **North Atlantic Drift**.
2. In the **Greenland-Iceland-Norway (GIN) Sea**, waters cool and sink (due to increased density).
3. These **deep cold waters return southward**, completing the overturning loop.

Positive Impacts of AMOC

1. **Global/Regional Benefits**

- **Moderates European climate**: Keeps Western Europe warmer than other regions at similar latitudes.
- Supports **nutrient cycling**, marine ecosystems, and **carbon sink functioning**.
- Helps maintain the **monsoon systems** by influencing heat distribution.

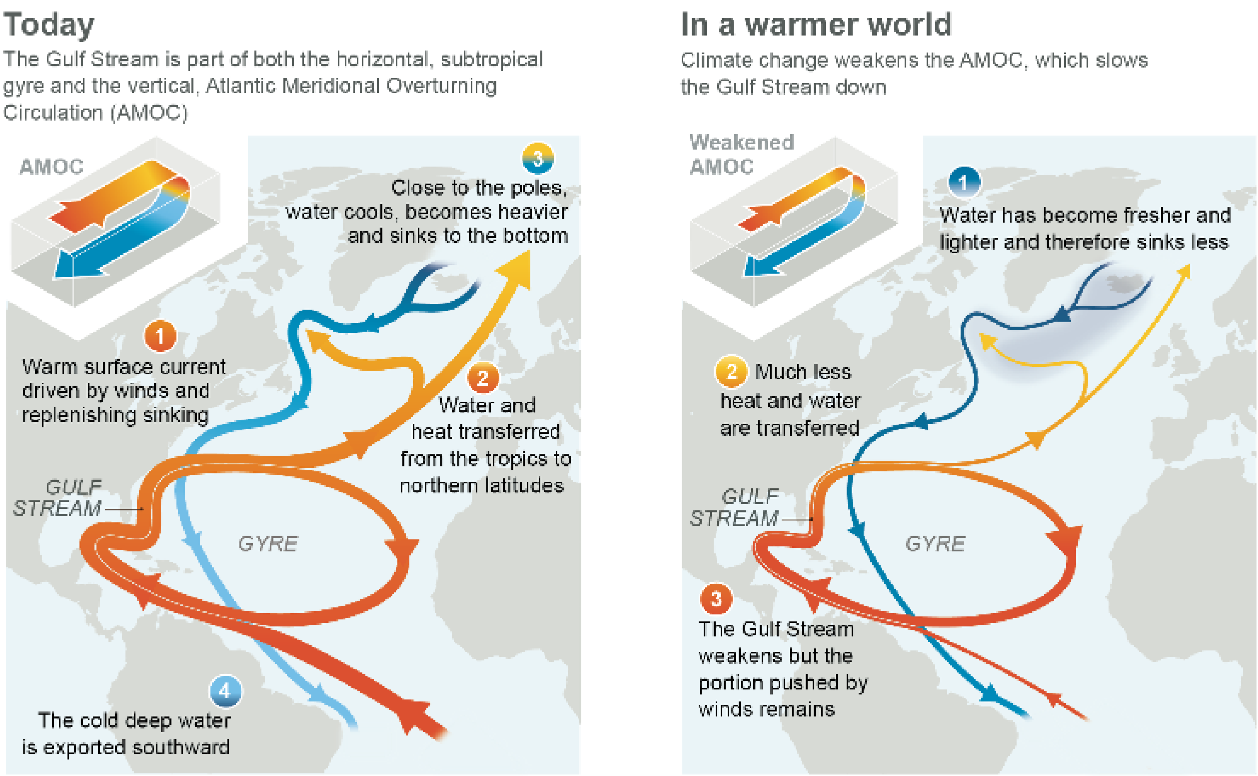
2. **Impact on India (Positive)**

- AMOC **strengthens the Indian monsoon** by aiding the **Indian Ocean-Walker Circulation**.
- Maintains **rainfall intensity and spatial distribution** critical for agriculture.
- Regulates **sea surface temperatures (SSTs)** over the Arabian Sea and Bay of Bengal.

Negative Impacts of AMOC Weakening/Collapse

1. **Global Impacts**

- **North Atlantic cooling** → harsh winters in Europe.
- **Sea-level rise on the U.S. East Coast**.
- **Amazon rainforest drying**.
- Collapse of **West African monsoon** → prolonged droughts.
- **Disruption of fisheries** in the North Atlantic.



2. **India-Specific Impacts (Negative)**

- **Weaker southwest monsoon** → Reduced rainfall in peninsular & central India.
- **Delayed onset** and **shortened rainy season**.
- Higher **sea surface temperatures** → more frequent **marine heatwaves**.
- **Bay of Bengal cyclones** may intensify due to warm stagnant water.
- Affects **ENSO-Indian Ocean Dipole** linkages, adding uncertainty to seasonal forecasting.

Current Affairs & Scientific Evidence

- **IMD Report (2024)**:
  - Increasing variability in monsoon linked to **Indian Ocean warming**, partially influenced by **changes in Atlantic SSTs**.
- **Indian Express & Down to Earth (2024)**:
  - Coverage on **"Marine Heatwave in Arabian Sea"** mentions AMOC's role in **global ocean heat redistribution**.

Way Forward

1. **Scientific Monitoring & Modelling**
   - Strengthen global observation networks: **ARGO floats, satellite altimetry, RAPID-MOCHA array**.
   - India should collaborate in **AMOC monitoring** via INCOIS & NIOT.
2. **Climate Mitigation**
   - Reduce **GHG emissions** under **Paris Agreement** to prevent AMOC destabilization.
   - Urge high emitters (e.g., US, EU) to adhere to **net-zero timelines**.
3. **Adaptation Strategies**
   - **Diversify water sources** (micro-irrigation, reservoirs) in monsoon-dependent regions.
   - Improve **seasonal monsoon forecasting** by integrating **Atlantic SST** data into IMD models.
   - Coastal regions should prepare for **sea-level anomalies** and **fisheries disruptions**.

Key Bodies & Reports

Institution/Report	Role/Contribution
IPCC AR6 (2021)	Warned of AMOC weakening; highlights monsoon & sea-level threats
WMO	Tracks ocean circulation & climate indicators
INCOIS (India)	Research on Indian Ocean's role in climate & potential AMOC impacts
NOAA & NASA	Provide real-time AMOC satellite data and long-term modelling
RAPID-MOCHA array	U.K.-U.S. project monitoring AMOC at 26.5°N in the Atlantic

Indian Ocean Structures Named

Indian Ocean Structures Named

- Ashok Seamount, Chandragupt Ridge, Kalpataru Ridge in Indian Ocean were approved by IHO and UNESCO's IOC.
- Situated along the Southwest Indian Ridge, discovered by the National Centre for Polar and Ocean Research.
- **Naming of Undersea Features**
- **Outside Territorial Sea:** Individuals/agencies can propose names per IHO's 2013 guidelines. Features must be identified before naming. Reviewed by IHO's SCUFN (Sub-Committee on Undersea Feature Names).
- **Within Territorial Sea:** National authorities must follow the same IHO guidelines.
- **IHO (International Hydrographic Organization):** Established in 1921; India is a member. Recognized as an international authority on hydrography.
- **IOC (Intergovernmental Oceanographic Commission):** Established in 1961; promotes marine science cooperation. **GEBCO:** Joint IHO-IOC project for ocean mapping, managed by SCUFN.

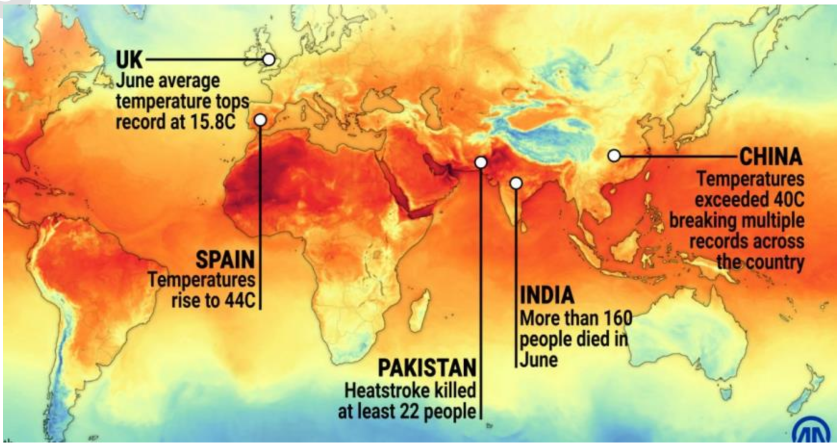
Heatwaves

What is a Heatwave?

1. As per the **India Meteorological Department (IMD)**, a **heatwave** is a period of abnormally high temperatures, more than the normal maximum temperature that occurs during the **summer season (March–June)**.
2. It predominantly affects **North, Central, and Eastern India**, and increasingly **Southern Peninsular and Coastal regions** due to **urban heat island** and **climate change**.

IMD Norms for Declaring a Heatwave

Condition	Criteria
Plains	Max temp ≥ 40°C and deviation from normal is +4.5°C to +6.4°C (Heatwave)
	Deviation ≥ +6.5°C (Severe Heatwave)
Coastal areas	Max temp ≥ 37°C and deviation ≥ +4.5°C (Heatwave)
Hilly regions	Max temp ≥ 30°C and deviation ≥ +4.5°C (Heatwave)
Absolute criteria (any region)	Max temp ≥ 45°C (Heatwave), ≥ 47°C (Severe Heatwave)



Guidelines & Frameworks

1. NDMA Guidelines (2016, Updated 2023)

- Mandates states to develop **Heat Action Plans (HAPs)**.
- Recommends:
  - Early warning systems (via IMD)
  - Public awareness and media outreach
  - Inter-agency coordination
  - Cooling centers, water stations, shaded public spaces
  - Special care for vulnerable groups: elderly, outdoor workers, slum dwellers

2. State Examples

- **Ahmedabad Heat Action Plan (2013)** – India's **first HAP**. Includes **heat alerts, community outreach, and water booths**.
- **Odisha** – Mandates school closures, adjusted working hours during alerts.
- **Telangana** – Real-time **WBGT-based labour advisories** for construction workers.
- **Delhi** – Urban HAP includes **green cover, reflective roofs, and portable water provision**.

Key Concepts and Indicators

Term	Explanation
Wet Bulb Globe Temperature (WBGT)	Combines **temperature, humidity, wind, and radiation** to assess **heat stress** risk
Urban Heat Island	Cities become significantly warmer than surroundings due to concrete, poor ventilation
Heat Index	Perceived temperature based on actual temperature + relative humidity

Top 5 Solutions to Mitigate Heatwave Impacts

1. **Early Warning & Forecasting Systems**
   - Use of **WBGT-based alert systems** and city-level **heat forecasts** from IMD and NDMA.
   - Dissemination through mobile alerts, public hoardings, radio.
2. **Heat Action Plans (HAPs) & Governance**
   - Mandatory for all cities >1 million population (as per 2024 NDMA advisory).
   - Institutionalize coordination between **health, urban, labour, and education departments**.
3. **Urban Resilience Measures**
   - **Cool roofs**, reflective materials, increased **green cover**, **urban water bodies**.
   - Enforce **building codes** and **heat-resilient infrastructure**.
4. **Protecting Vulnerable Populations**

- Set **labour codes** on work-rest cycles (WBGT < 32.5°C for outdoor work).
- Community shelters, water booths, shaded rest zones, and **hydration protocols**.

5. **Awareness, Education & Behavioral Change**
    - School-level **heat education programs**, workplace advisories.
    - Awareness on **symptoms of heatstroke, first-aid, hydration norms**.

Coffee

Why in News: Climate Change Impact on Coffee Plantations

1. Rising temperatures, erratic monsoons, and unseasonal rains have affected flowering and yield, particularly in Karnataka and Kerala.
2. Coffee Board of India warned that Arabica production is especially vulnerable.
3. Farmers reported increased pest attacks like white stem borer and coffee rust due to warmer winters.

Ideal Growing Conditions for Coffee

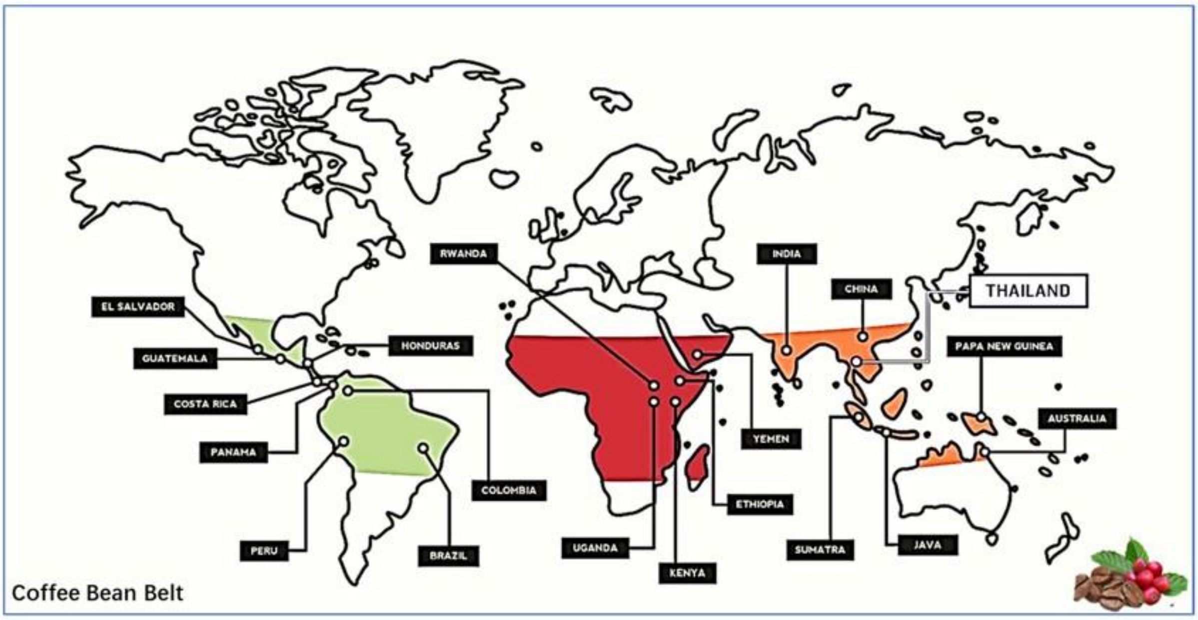
Factor	Requirement
Temperature	15°C – 28°C (Ideal: ~23°C); sensitive to frost
Altitude	600–2,000 m above sea level; high-altitude improves flavor quality
Rainfall	1,200 – 2,000 mm annually; well-distributed over the year
Soil	Well-drained, fertile, slightly acidic soils (pH 5.5–6.5), volcanic or loamy
Shade	Grows better under partial shade or agroforestry systems
Sunlight	Indirect sunlight or diffused light is preferable

Two main species: **Arabica** (milder, high altitude, 60% of global production) and **Robusta** (stronger, lower altitude, disease resistant)

Global Distribution of Coffee

Region	Major Producers	Characteristics
South America	**Brazil** (largest producer), Colombia, Peru	Brazil – mechanized, large estates; Colombia – Arabica focus
Central America	Honduras, Guatemala, Costa Rica	High-altitude Arabica; shade-grown, quality-driven
Africa	Ethiopia (origin of Arabica), Uganda, Kenya, Ivory Coast	Smallholder farms, rich flavor profiles, traditional practices
Asia	**Vietnam** (2nd largest), Indonesia, India	Vietnam – Robusta powerhouse; India – diversified agroforestry
Oceania	Papua New Guinea, Australia (minor)	Specialty coffee, smaller output

Coffee Belt: Lies between the **Tropics of Cancer and Capricorn (23.5°N to 23.5°S)** – warm, moist equatorial zones.



India: Coffee Cultivation and Features

Climatic & Geographical Conditions

1. **States**: Karnataka (≈70%), Kerala, Tamil Nadu, Andhra Pradesh, Odisha, and NE states (Assam, Meghalaya).
2. Grown on **slopes of Western and Eastern Ghats** at altitudes of 800–1,800 m.
3. **Rainfall**: ~1,000–2,500 mm/year via **SW monsoon** and **NE monsoon**.
4. India's coffee is typically **shade-grown** under forest canopies.

Types Grown

1. **Arabica**: 35–40% (higher altitudes; more prone to pests)
2. **Robusta**: 60–65% (lower elevation; higher yield, disease resistant)

Special Features

1. **Monsooned Malabar Coffee**: Unique Indian specialty where beans are exposed to moist monsoon winds—swells the beans, alters flavor.
2. **Agroforestry-based**: Coffee is grown with **pepper, cardamom, arecanut, banana**, preserving biodiversity.
3. **Export-oriented**: ~70–75% of India's coffee is exported (Italy, Germany, Russia main buyers).

India ranks 6th globally in coffee production (after Brazil, Vietnam, Colombia, Indonesia, Ethiopia).

Challenges Faced in India

1. **Climate variability**: Erratic rainfall, rising temperatures affecting flowering.
2. **White stem borer, leaf rust**: Major pests and fungal diseases.
3. **Price volatility**: Linked to international market fluctuations.
4. **Smallholder fragmentation**: Affects mechanization and quality consistency.

Way Forward

1. Promote **climate-resilient coffee varieties**.
2. Expand **specialty coffee branding** (GI-tagged beans like Baba budan giri).
3. Enhance **agroforestry incentives** and **carbon credit mechanisms**.
4. Improve **value addition and domestic consumption**.
5. Strengthen support from **Coffee Board of India** for small growers.

Critical Minerals

What Are Critical Minerals?

1. **Critical minerals** are mineral resources **essential for economic and national security**, and have **high supply risk** due to geographic concentration or lack of substitutes.
2. Vital for **clean energy (solar panels, EVs, wind turbines)**, **semiconductors**, **defense**, **aerospace**, and **telecom** sectors.

Key Global Critical Minerals and Their Distribution

Mineral	Key Producers	Uses
Lithium	Australia, Chile, Argentina (Lithium Triangle), China	EV batteries, grid storage
Cobalt	DR Congo (~70%), Russia, Australia, Canada	Lithium-ion batteries, superalloys
Graphite	China (~80%), Mozambique, Madagascar	Anodes in batteries, lubricants
Nickel	Indonesia, Philippines, Russia, Canada	EVs, stainless steel
Rare Earth Elements (REEs)	China (~60%), USA, Australia, Myanmar	Magnets, wind turbines, electronics
Bauxite (Aluminium)	Australia, China, Guinea, Brazil	Aircraft, packaging, EVs
Copper	Chile, Peru, China, DR Congo	Power transmission, electronics
Tin	China, Indonesia, Myanmar	Solder in electronics
Platinum Group Metals (PGMs)	South Africa, Russia, Zimbabwe	Catalytic converters, hydrogen fuel cells

China dominates the processing and refining of most critical minerals, particularly REEs, lithium, and graphite—creating geopolitical dependencies.

India's Critical Minerals Landscape

Identified Critical Minerals in India (2023-24)

1. The Ministry of Mines, in coordination with the Indian Bureau of Mines (IBM), identified **30 critical minerals**.
2. Key among them: **Lithium, Cobalt, REEs, Nickel, Graphite, Titanium, Beryllium, Tungsten, Vanadium**.

Important Deposits & Prospects in India

Mineral	States/Regions
Lithium	*Jammu & Kashmir (Reasi)* – India's first major reserves (~5.9 million tonnes, 2023)
Graphite	Odisha, Jharkhand, Chhattisgarh
REEs	Andhra Pradesh (Visakhapatnam), Kerala (Chavara), Tamil Nadu, Jharkhand

Mineral	States/Regions
Titanium & Ilmenite	Odisha (Chhatrapur), Kerala (beach sands), Tamil Nadu
Cobalt, Nickel	Odisha (Sukinda), Nagaland (small occurrences)
Bauxite	Odisha (Panchpatmali), Gujarat, Maharashtra

Deep Ocean Resources (Polymetallic Nodules)

1. Located in the **Central Indian Ocean Basin**, rich in **cobalt, nickel, manganese, copper**.
2. Explored under the **Deep Ocean Mission** and **ISA (International Seabed Authority)** agreement.

Critical Minerals - Challenges

- Africa is moving away from the **'pit-to-port' model**, focusing on value addition. China has a major presence in **cobalt mining** in Congo. India has signed **MoU with Zambia and Zimbabwe**.
- **China announced decision to restrict export** of antimony, critical mineral used in strategic sectors such as defence, for military equipments. China dominates every supply chain segment covering mining, extraction, refining and processing, controlling 60% of rare earth production, 60% of critical minerals production and 80% of the processing worldwide. India has strategic dependence on China for critical minerals like lithium, nickel, cobalt, and copper led to imports.
- India has 100% import dependence for lithium, cobalt, and nickel. 95% of India's copper is imported. **Unavailability of quality reserves of niobium, germanium, and rhenium**.
- Many critical minerals are **deep-seated**, requiring **high-risk investments** in **exploration** & **mining tech**.
- **J&K lithium reserves** are **inferior** in quality and quantity compared to global standards. **Limited processing capabilities** (Ex, inability to extract **lithium** from **5.9 million tonnes** of resources).
- **Centre cancelled auction of three critical mineral blocks** due to fewer-than-expected bidders. The cancelled blocks include Salal-Haimna lithium, titanium, and bauxite block (Jammu & Kashmir), Muskaniya-Gareriatola-Barwari potash block (Jharkhand), and Kurunjakulam graphite block (Tamil Nadu).
- Nayakkarpatti **tungsten** block auction annulled by Government. Tungsten (Wolfram) is crucial for defence and high-tech industries, with no effective substitutes. India has limited tungsten resources, only 5% in Tamil Nadu, Haryana, Uttarakhand, and West Bengal, rest in Karnataka, Rajasthan, Andhra Pradesh, Maharashtra.

Policy Framework & Strategic Steps

1. **Critical Minerals List (2023)**: Released by **Ministry of Mines** in collaboration with **CEA** and **NITI Aayog**.

2. **KABIL (Khanij Bidesh India Ltd)**: A joint venture of **NALCO, HCL, MECL** to secure overseas critical mineral assets (e.g., in Australia, Argentina).
3. **Faster Auctioning** of 100+ mineral blocks under **Mineral (Auction) Amendment Rules, 2023**.
4. **India-Australia Critical Minerals Partnership** (2022): Collaboration on lithium and cobalt.
5. **India-USA IPEF & QUAD Critical Minerals Dialogue**.

Initiative	Purpose
Minerals Security Partnership (MSP)	Led by USA, includes India, Australia, Japan, EU – secure supply chains
European Critical Raw Materials Act (2023)	Reduce dependency on China
US Inflation Reduction Act	Incentivizes domestic mineral processing

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Rare Earth Elements

What Are Rare Earth Elements (REEs)?

- REEs are a group of **17 chemically similar elements** in the periodic table:
  - **15 lanthanides** (La to Lu) + **Scandium (Sc)** + **Yttrium (Y)**
- Despite the name, they are **not rare**, but are **rarely found in concentrated, extractable forms**.
- Crucial for **high-tech, green, and defense sectors**: wind turbines, EVs, solar panels, smartphones, precision-guided missiles.

Global Distribution of REEs

Country	Key Facts
China	Controls ~**60–65%** of global REE production, dominates **processing/refining (~90%)**
USA	**Mountain Pass, California** – major mine, dependent on China for refining
Australia	Rich deposits at **Mount Weld**, 2nd largest REE producer
Russia	REE reserves in Siberia, limited production
Myanmar	Emerging producer, major supplier of **heavy rare earths** to China
Brazil	Substantial reserves, underdeveloped extraction
Vietnam & Malaysia	Potential-rich, part of global diversification efforts

Geopolitical Risk: China has used REE export restrictions as a tool (e.g., 2010 dispute with Japan), prompting diversification initiatives globally.

India's Rare Earth Elements: Deposits and Potential

Major Deposits

Location/State	Type & Characteristics
Andhra Pradesh (Visakhapatnam, Srikakulam)	Monazite-bearing beach sands (Light REEs)
Tamil Nadu (Manavalakurichi)	Coastal placers – Ilmenite, monazite, zircon
Kerala (Chavara, Kollam)	Heavy mineral sands, significant monazite content
Odisha (Gopalpur, Chatrapur)	Coastal deposits with monazite
Jharkhand (East Singhbhum)	Inland REE-bearing pegmatites
Rajasthan, Gujarat	Alkali rock complexes, underexplored

Key Agencies Involved

- **IREL (India) Ltd.**: Public sector unit under DoAE, extracts REEs from monazite.
- **AMD (Atomic Minerals Directorate)**: Explores inland REE reserves.
- **Bhabha Atomic Research Centre (BARC)**: Research on extraction & separation technologies.

India's Strategic Challenges and Gaps

- **Heavy REEs (HREEs)** are limited in Indian reserves; most Indian REEs are **light REEs (LREEs)** like **Cerium, Lanthanum**.
- **Lack of separation & refining infrastructure** → India exports raw monazite and imports processed REEs.
- **Dependence on China** for high-purity REE oxides used in high-tech industries.

Policy Measures and Way Forward

Initiative/Policy	Purpose/Progress
Critical Minerals List (2023)	REEs identified as strategic; prioritizing exploration & processing
India-Australia REE Collaboration	Joint exploration and tech transfer for rare earth processing
National Geoscience Data Repository (NGDR)	Mapping REE potential sites for private and public miners
FDI in mineral exploration liberalized	Allows 100% FDI in mining/processing to attract global tech & capital
REE refinery planning	Plans to build **India's first commercial REE separation plant** (under DAE/IREL)

Mining Methods & Rathole Mining

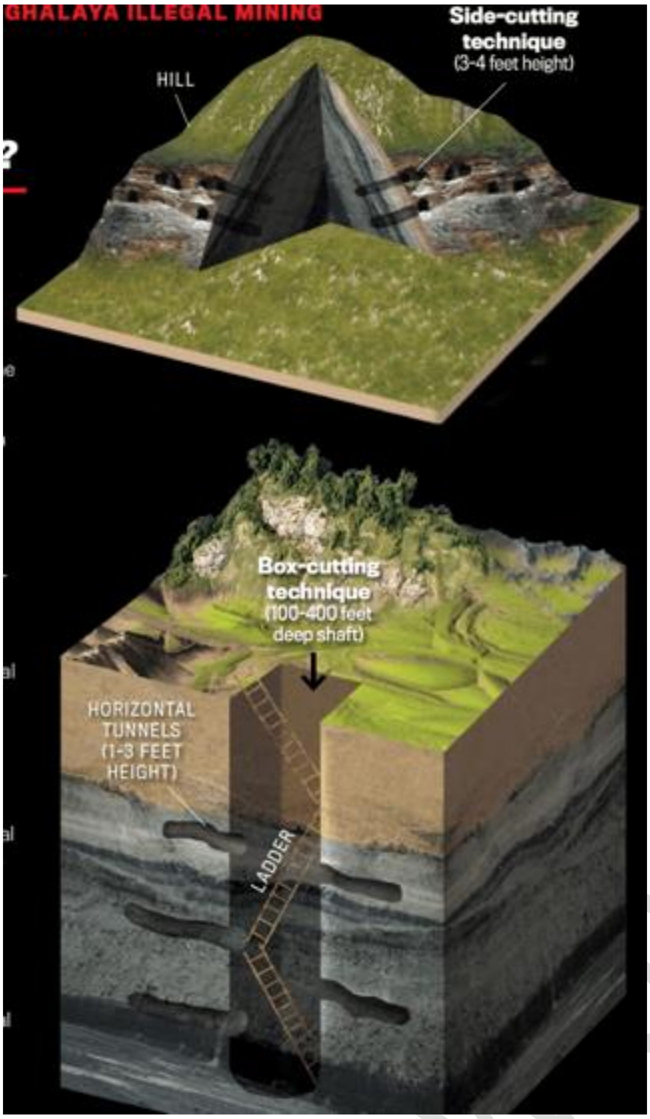
Major Mining Methods Used Worldwide

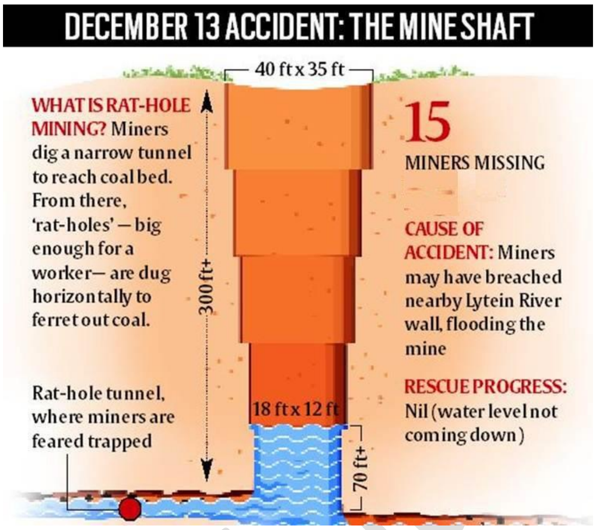
Method	Description	Examples
Open-pit mining	Extraction from surface pits; used for low-grade ores near the surface	Copper (Chile), Iron (Australia, Odisha)
Underground mining	Tunnels created to access deep ore bodies	Gold (South Africa), Zinc (Hindustan Zinc, India)
Placer mining	Extraction from riverbeds or alluvial deposits (often manual)	Gold in Alaska, Diamonds in Congo
Mountaintop removal	Top of a mountain blasted to extract coal underneath	Coal mining in Appalachia (USA)
Solution mining (in-situ leaching)	Use of chemicals to dissolve minerals underground	Uranium (Kazakhstan), Potash (Canada)
Dredging	Mining of minerals from underwater sediments, seas, or rivers	Tin from Indonesia's sea beds
Strip mining	Large-scale removal of surface layers to reach coal seams	Lignite in Germany and Tamil Nadu
Rathole mining *(illegal)*	Small, narrow tunnels dug manually, often without safety or ventilation	**Coal in Meghalaya, India**

Rathole Mining in India: A Closer Look

What is Rathole Mining?

1. A **primitive, unscientific mining technique** involving narrow, vertical shafts (≈3–4 feet wide) dug into the ground.
2. Workers (often children) manually dig coal and pass it up in baskets.
3. **Mostly prevalent in the Jaintia Hills of Meghalaya** for coal extraction.
4. **Vertical Shaft Type**
    - Narrow vertical pits (3–4 feet in diameter) are dug straight down into the ground.
    - Coal is extracted from **horizontal tunnels** that branch out at the bottom.
    - Commonly used when coal seams lie deep below the surface.
    - **High risk of collapse**, flooding, and suffocation due to lack of structural support and ventilation.
5. **Side-Cutting Type**
    - Horizontal tunnels are directly cut into the hill slopes or exposed coal seams.
    - Coal is manually dug and transported out using baskets or small carts.
    - Typically used in **hilly areas** where coal is near the surface.
    - Poses risk of **landslides** and **exposure to toxic gases**.





Why in News? (2024–2025 Updates)

1. **April 2024**: 4 workers died in a **coal mine collapse in East Jaintia Hills**, renewing focus on illegal rathole mining.
2. Despite the **2014 NGT ban**, rathole mining continues under the guise of **"transportation of extracted coal"**.
3. Supreme Court recently asked Meghalaya government to ensure **strict implementation of environmental & safety norms**.

Issues with Rathole Mining

Category	Issues
Human Rights & Safety	Frequent accidents; child labor; suffocation, collapse, flooding
Environmental	Acid mine drainage; groundwater pollution; deforestation
Legal	Banned by NGT (2014) but persists due to lack of enforcement & political nexus

Category	Issues
Social	Exploitation of tribal workers; weak compensation mechanisms
Economic	Unaccounted coal; loss of state revenue; informal economy growth

Important Reports and Judicial Interventions

- **NGT Ban (2014)**: Declared rathole mining illegal in Meghalaya citing environmental and human rights concerns.
- **Supreme Court (2019)**: Allowed limited coal transportation; stressed on scientific mining & safety.
- **Justice BP Katakey Committee (2022)**:
    - Appointed by Meghalaya HC to assess compliance.
    - Found ongoing illegal mining despite multiple directives.
- **Comptroller and Auditor General (CAG) Report (2023)**:
    - Criticized the Meghalaya government for poor enforcement and lack of regulatory oversight.

Solutions and Way Forward

1. Shift to Scientific Mining

- Encourage **mechanized underground mining** or **open-cast mining** with safety measures.
- Incentivize use of **safety gear, ventilation systems, and proper waste disposal**.

2. Legal & Regulatory Reform

- Enforce strict **monitoring by DGMS (Directorate General of Mines Safety)**.
- Include tribal miners in **formal licensing frameworks** with training and insurance.

3. Economic Alternatives for Local Communities

- Promote **sustainable livelihoods** (e.g., agroforestry, eco-tourism) to reduce coal dependency.
- Establish **skill development programs** in mining districts.

4. Environmental Restoration

- **Rehabilitate abandoned mines** through afforestation and mine water treatment (AMD management).
- Strict adherence to **Environmental Clearance (EC)** and **Forest Clearance (FC)** norms.

5. Technology-Based Monitoring

- Use of **remote sensing, drone surveillance, GIS mapping** for illegal mine detection.

River Linking

What is River Linking?

1. River linking refers to **interconnecting rivers through canals, tunnels, and reservoirs** to transfer water from **surplus (flood-prone)** basins to **deficit (drought-prone)** regions.
2. It is aimed at **redistribution of water resources** across regions for **irrigation, drinking water, flood control, and hydroelectric power generation**.

Why River Linking? (Purpose)

Need	Explanation
Spatio-temporal water imbalance	80% of rainfall in 4 months; some rivers flood while others run dry
Agricultural productivity	Supports rainfed regions; mitigates drought impact

Need	Explanation
Urban and rural water supply	Ensures year-round drinking water availability
Hydropower generation	Linkages may allow for run-of-the-river or storage-based energy potential
Flood mitigation	Channeling excess water reduces flood damage
Climate resilience	Helps adapt to erratic monsoons and dry spells caused by climate change

How River Linking Works

1. Implemented through the **Interlinking of Rivers (ILR) Programme** by **National Water Development Agency (NWDA)** under the **Ministry of Jal Shakti**.
2. Two major components:
    - **Himalayan Component**: Transfer of water from Himalayan rivers (e.g., Brahmaputra, Ganga) to northern & western India.
    - **Peninsular Component**: Linking of rivers like Godavari, Krishna, Cauvery, and Mahanadi in southern India.
3. Requires:
    - **Canals**, **pumping stations**, **tunnels**, **storage reservoirs**, and **barrage structures**.

Positive Impacts (Human Geography Lens)

Aspect	Impact
Agriculture	Enhances irrigation in drought-prone areas (e.g., Marathwada, Bundelkhand)
Drinking water	Ensures supply in arid urban centers and tribal districts
Livelihoods	Creates rural employment, boosts agro-based industries
Health & Nutrition	Improved crop diversity, reduced malnutrition with assured irrigation
Migration	May reduce **distress migration** from rural areas due to crop failures
Disaster risk	Mitigates floods in states like Bihar and Assam; controls droughts in Tamil Nadu & Rajasthan

Negative Impacts

Issue	Explanation
Environmental degradation	Large-scale deforestation, habitat loss, and altered river ecology
Displacement	Submergence of land → tribal and rural displacement, loss of livelihoods
Water disputes	Intensifies interstate and international disputes (e.g., with Bangladesh)
Cost and delays	Huge capital expenditure, long gestation periods

Issue	Explanation
Inefficiency risk	Climate change may alter "surplus vs deficit" assumptions

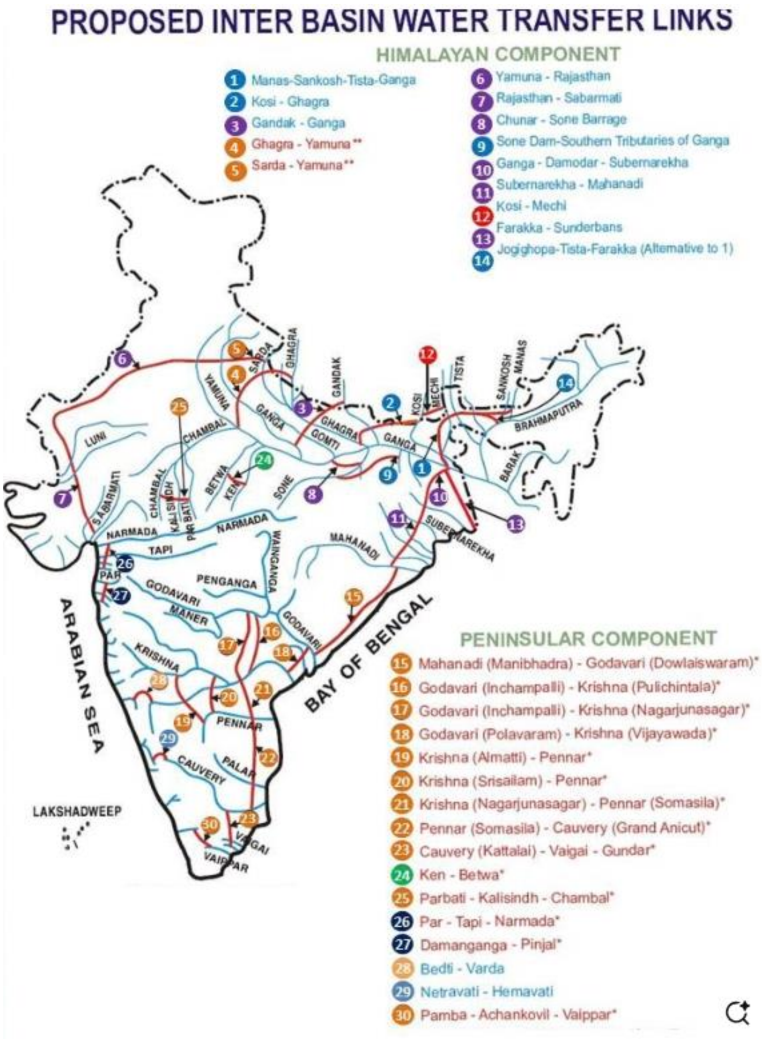
Examples

Global

Country	Project	Outcome/Issues
China	South-North Water Transfer Project	World's largest; huge cost & ecological concerns
USA	California Aqueduct	Supplies water from north to arid south
Australia	Snowy Mountains Scheme	Diversion for irrigation and hydropower

India

Project	Status	Notes
Ken–Betwa Link (MP-UP)	Work initiated (2022–23)	First ILR project; will benefit Bundelkhand but submerge tiger habitat
Godavari–Krishna–Cauvery Link	Under planning	Southern India drought mitigation
Par–Tapi–Narmada Link	Facing opposition (Gujarat)	Tribal displacement concerns
Mahanadi–Godavari Link	Proposed	Water surplus in east to deficit regions in south



Way Forward

1. **Intra-basin Prioritization**

o Promote **local water harvesting**, **revival of traditional systems** before large ILRs.

2. **Scientific Water Budgeting**

o Use **dynamic hydrological modelling** to assess surplus-deficit correctly under climate variability.

3. **People-Centric Planning**

o Ensure **free, prior, informed consent** of affected communities (esp. ST areas under PESA Act).

4. **Environmental Safeguards**

o Strict **EIA**, wildlife corridor conservation, and biodiversity offset mechanisms.

5. **Regional Cooperation**

o Strengthen **transboundary dialogues** (e.g., with Bangladesh on Brahmaputra) under **Ganga-Brahmaputra-Meghna basin cooperation**.

Effects of Major Dams

What is the Medog County Dam?

1. China has proposed a **super dam** in **Medog County, Tibet Autonomous Region**, on the **Yarlung Tsangpo** River, just **before it enters India as the Brahmaputra**.
2. Part of China's **14th Five-Year Plan**, it is expected to be **larger than the Three Gorges Dam**.
3. Strategically located near the **Great Bend of the Tsangpo**, which is ecologically and tectonically sensitive.

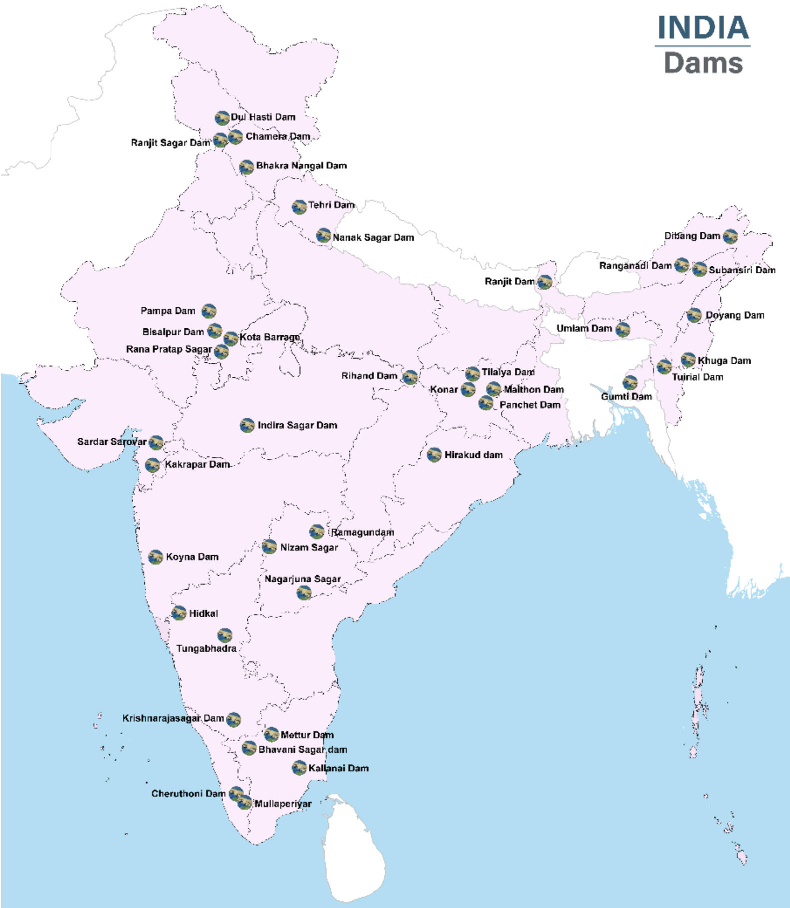
Environmental and Geopolitical Effects

1. Hydrological Disruption

- **Flow manipulation** could reduce **water availability downstream**, especially in **Arunachal Pradesh and Assam**.
- May alter the **seasonal flow regime**, affecting **monsoon synchrony and sediment load**.

2. Ecosystem Imbalance

- Disrupts **aquatic biodiversity**, such as **Mahseer** and **Gangetic dolphin**, due to changed flow and temperature.
- **Obstructs fish migration** and reduces **wetland recharge** in Assam (e.g., Majuli Island, Dibru-Saikhowa biosphere).



3. GLOF and Seismic Risk

- Region is prone to **Glacial Lake Outburst Floods (GLOF)** and **earthquakes**.
- Dam-induced **reservoir-triggered seismicity (RTS)** increases disaster vulnerability.
- Example: **Assam Floods (2020, 2022)** linked to upstream hydrological surges and glacial melt.

4. Flash Floods and Sudden Release

- Large dam storage allows **China to control sudden release of water**, raising fears of **flooding as a geopolitical weapon**.
- Past example: **Sutlej flood (2000)** linked to unannounced Chinese dam burst.

5. Transboundary Conflict Risk

- Lack of a **water-sharing treaty between India and China** over Brahmaputra fuels mistrust.
- India's downstream projects (e.g., **Lower Siang, Subansiri**) face delays due to fear of upstream control.

Solutions and Way Forward

1. Bilateral & Multilateral Agreements

- Formalize a **transboundary river treaty** with China like India has with Pakistan (Indus Waters Treaty).
- Use platforms like **BIMSTEC**, **UN Watercourses Convention**, or **Ganga-Brahmaputra-Meghna Basin Framework** for regional cooperation.

2. Joint Hydrological Data Sharing

- Establish real-time **flood and flow monitoring stations** at key border points.
- Strengthen MoUs like the existing one between **India-China (2002, renewed 2018)** for Yarlung Tsangpo water flow during monsoon.

3. Ecological Impact Assessment

- Push for **transboundary EIA norms**, as per **Espoo Convention**, before mega-dam approval.
- India should advocate for a **river basin-level Strategic Environmental Assessment (SEA)**.

4. Regional Preparedness

- Enhance **early warning systems** in Arunachal and Assam (via IMD, CWC, ISRO).
- Promote **resilient infrastructure and floodplain zoning** to manage flood risk.

5. Strengthen Domestic Dams Strategically

- Expedite construction of **Arunachal multipurpose dams** (e.g., Subansiri, Dibang) for **run-of-the-river storage** to counter Chinese control.
- Integrate **sediment flushing and fish ladders** to maintain ecological health.

Relevant Terms & Concepts

Term	Definition/Context
GLOF	Sudden flood from glacial lake breach, often worsened by climate change and dam stress
Reservoir-induced Seismicity (RIS)	Earthquakes triggered due to weight of dam water on fault lines
Environmental Flow (E-Flow)	Minimum river flow needed to sustain ecosystems downstream
Ecohydrology	Study of interactions between water and ecosystems
Hydropolitics	Political conflict or cooperation arising from shared water resources

Examples of Dam-Induced Flood Concerns

1. **Sutlej Flash Flood (2000)**: Sudden water surge from Tibet, killed 20+ in Himachal.
2. **Chamoli Disaster (2021)**: Linked to glacial break, possibly exacerbated by dam activity.
3. **Assam Floods (Recurring)**: Seasonal intensification, possibly aggravated by upstream water release patterns.

Earthquake and Tsunami

2004 Indian Ocean Earthquake & Tsunami

- **Magnitude 9.1 earthquake** occurred off **Sumatran coast** and was **third largest** earthquake in world since 1900. The earthquake's source was **30 km below the ocean floor**, in the **Sunda Trench**, where the **Indo-Australian plate** subducts beneath the **Burma microplate**. The earthquake tore through **1,300 km of plate boundary**, from **Sumatra** to the **Coco Islands**. Quake was felt in **Indonesia, Bangladesh, India, Malaysia, Maldives, Myanmar, Singapore, Sri Lanka & Thailand**.
- Mangroves act as **vital buffers** against waves but were destroyed for **shrimp farming, wood, fuel, and tourism**. Construction of **artificial barriers** (brick and mortar walls) can increase vulnerability to waves.
- The **2011 Japan earthquake** (magnitude 9.1) caused a tsunami reaching up to **39 meters**.
- **Indian Tsunami Early Warning Centre (ITEWC)** was established in **2007** under MoES. It operates **seismological stations, bottom pressure recorders, and tidal stations** across the Indian Ocean & provides **real-time tsunami alerts** within **10 minutes** of detecting a potential tsunami-producing earthquake. **India** is **5th country** to have such an advanced tsunami warning system, after U.S., Japan, Chile, and Australia.
- **About Tsunami**: Tsunamis are **large ocean waves** primarily caused by the **sudden displacement** of water, typically due to several geological events. **The most common causes include**:
  - The majority of tsunamis (72%) are triggered by **underwater earthquakes**.
  - **Volcanic activity** can also generate tsunamis, especially when eruptions occur near or under the ocean.
  - **Both underwater and above-water landslides** can displace water and generate tsunamis.
  - Although rare, **impacts from meteorites** can create tsunamis by displacing large volumes of water.
  - Underwater **nuclear tests** have historically generated tsunamis as well.
  - The breaking off of **chunks of ice from glaciers** can also lead to localized tsunami events.

Earthquake Swarm

- **Occurs when multiple seismic events of comparable intensity strike** a small area in relatively quick succession.
- A state of emergency was declared on **Greece's Santorini and the nearby islands of Ios, Amorgos, and Anafi**.
- Swarms have been **reported in peninsular India. After heavy rain,** water seeps into small fractures in underground rocks. A 2008 study estimated that for every 10 metre's **rise in the water table, the pressure inside the rocks increased** by almost 1 atm, and which is released in earthquake swarms.

Shallow Earthquake

- The 4-magnitude earthquake that originated in Delhi was the strongest since a 4.6- magnitude temblor in 2007. It was 'shallow,' or a mere five kilometres from the surface. **Shallow Earthquakes:**
  - **Depth Classification: Shallow**: Occur at depths of 0 to 70 km. **Intermediate**: Occur at depths of 70 to 300 km. **Deep**: Occur at depths of 300 to 700 km.
  - **Destructive Potential: Shallow earthquakes are generally more destructive** than deeper ones because **seismic waves from shallow earthquakes travel shorter distances** to the surface, resulting in more intense shaking. The **energy released from shallow earthquakes is closer to the surface**.
  - **Common Occurrence:** Shallow earthquakes are the **most frequent type** of earthquakes, with about **75% of the total energy released from earthquakes** originating from shallow-focus events.
  - **Aftershocks:** Shallow-focus earthquakes **often generate numerous aftershocks**.

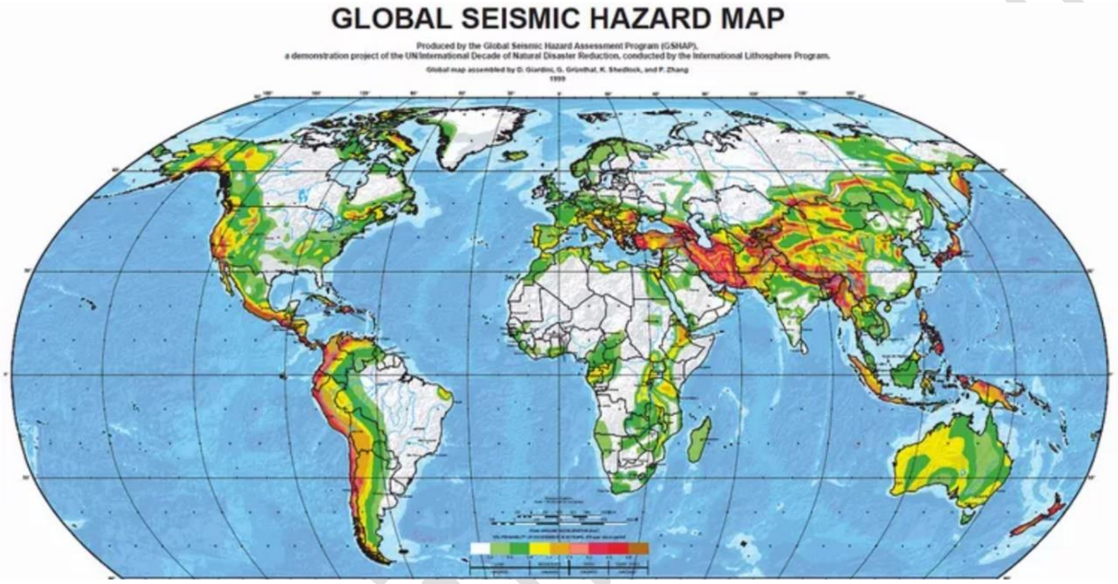
Myanmar Earthquake

- **Myanmar lies in a seismically active region** at the convergence of **four tectonic plates — the Eurasian, Indian, Sunda, and Burma microplate.**
- Had its source in central Myanmar, about 20 km from **Mandalay**, the country's second-largest city. Mandalay, located on the east bank of the **Irrawaddy river**, is close to the seismically active **Sagaing fault**. The damage zone extended to **Bangkok**, the capital of neighbouring Thailand, which is about 1,000 km from the earthquake's epicentre.
- The outpouring of water from the rooftop pool was due to **seismic seiches** — oscillations in the water triggered by the passage of seismic waves. Slower, long-period seismic waves can cause top floors to sway more and amplify seiches.
- Devastation was concentrated in the southern areas of the Sagaing fault because this region is sitting on a **thicker pile of alluvium which amplifies the seismic energy**, as compared to the northern parts of the fault. This also explains why **China's southwest Yunnan Province**, which is north of the fault, escaped earthquake-induced damage.
- Neighbouring eastern parts of India also escaped damage because the **energy released by the earthquake dispersed in a north-south direction**, following the trend of the fault.

- Earthquake of 1792 was a **'megathrust' earthquake** & generated a tsunami in the northern Bay of Bengal and **caused widespread soil liquefaction** in Chittagong. The large thrust fault extends further north onto the **Chittagong-Tripura fold belt**, where several moderate earthquakes continue to occur.
- **Deeper earthquakes** occur in the southern regions closer to Indonesia or the Indo-Burmese regions in the north, bordering the subduction front along the Indo-Eurasian plates.
- The Mandalay earthquake was **sourced from within the continental part** of the mountain range.
- Tectonic block between Indian plate and Sagaing fault is called the **Burma plate or the Burma sliver.**
- Unlike the **vertical motions of fault blocks** along the frontal part of the convergence zone, where one tectonic block is pushed up on the other, the **movement is horizontal** on the Sagaing fault, with the blocks sliding past each other. **San Andreas fault** in the western U.S. is another such example.
- Unlike **thrust faults**, where earthquakes originate at either shallow or deeper sources, earthquakes on **strike-slip faults are almost always shallower** (10-15 km). Classified as a **ridge-trench transform fault**.
- **Bagan** in Central Myanmar has also been subjected to several damaging earthquakes.

Seismic Zones

1. Seismic zones in Indian subcontinent is divided into four seismic zones (II, III, IV, and V) based on scientific inputs relating to seismicity, earthquakes occurred in the past and tectonic setup of the region.
2. Previously, earthquake zones divided into five zones with respect to the severity of the earthquakes, but Bureau of Indian Standards [IS 1893 (Part I):2002], has grouped the country into four seismic zones.; the first and second seismic zones were unified.
3. The bureau of Indian standards is the official agency for publishing the seismic hazard maps and codes. It has brought out versions of seismic zoning map: a six zone map in 1962, a seven zone map in 1966, and a five zone map 1970/1984.



Seismic Active Zone

1. **Seismic Zone II**

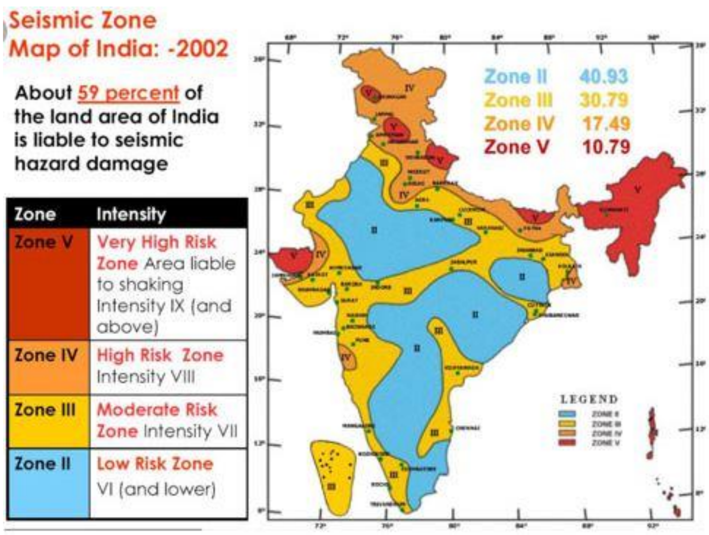
- Area with minor damage (i.e., causing damages to structures with fundamentally periods greater than 1.0 second) earthquakes corresponding to intensities V to VI of **MM** scale (MM - Modified Mercalli Intensity scale). It covers the areas which are not covered by other three seismic zones discussed below.

2. **Seismic Zone III**

- Moderate damage corresponding to intensity VII of **MM** scale. It comprises Kerala, Goa, Lakshadweep islands, remaining parts of Uttar Pradesh, Gujarat and West Bengal, Parts of Punjab, Rajasthan, Madhya Pradesh, Bihar, Jharkhand, Chhattisgarh, Maharashtra, Orissa, Andhra Pradesh, Tamil Nadu and Karnataka.

3. **Seismic Zone IV**

- Major damage corresponding to intensity VII and higher of **MM** scale. It covers remaining parts of Jammu and Kashmir and Himachal Pradesh, National Capital Territory (NCT) of Delhi, Sikkim, Northern Parts of Uttar Pradesh, Bihar and West Bengal, parts of Gujarat and small portions of Maharashtra near the west coast and Rajasthan.



4. **Seismic Zone V**

- Area determines by pro seismically of certain major fault systems. It is seismically the most active region, and comprises entire northeastern India, parts of Jammu and Kashmir, Himachal Pradesh, Uttaranchal, Rann of Kutch in Gujarat, part of North Bihar and Andaman & Nicobar Islands.
- Earthquake zone V is the most vulnerable to earthquakes, where historically some of the country's most powerful shock have occurred. Earthquakes with magnitudes in excess of 7.0 have occured in these areas, and have had intensities higher than IX.

Here is a comprehensive, UPSC-relevant breakdown of **Landslides** – their types, causes, regional differences (Himalayas vs Western Ghats), recent examples, NDMA guidelines, and solutions.

Landslides

What Are Landslides? ***(Also Known As: Slips, Slope Failures, Mass Movements)***

1. A **landslide** is the **downward movement of soil, rock, and organic materials** under the influence of gravity, often triggered by rainfall, earthquakes, or human activity.
2. Includes various types such as:
   - **Debris flow** (fast-moving with water)
   - **Rockfall** (free fall of rock)
   - **Mudflow**
   - **Creep** (slow, continuous downslope movement)
   - **Translational/rotational slides**

Why/How Do Landslides Occur?

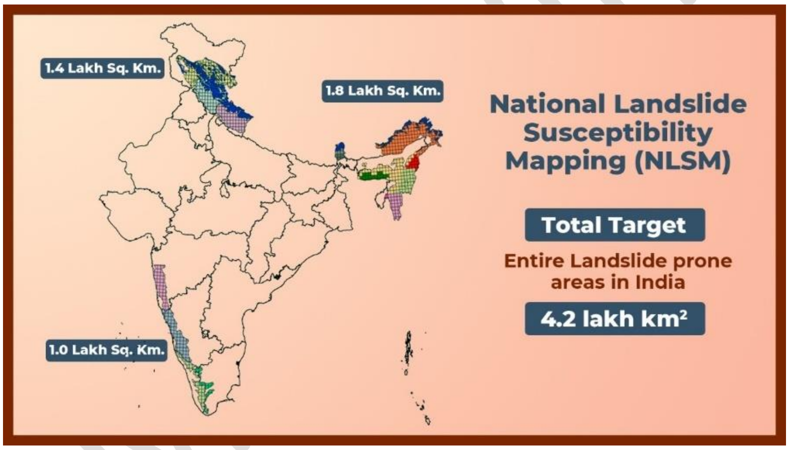
Causes	Explanation
Natural Causes	Heavy rainfall, earthquakes, volcanic activity, weathering, slope steepness
Anthropogenic Causes	Deforestation, unplanned construction, road-cutting, mining
Climate Change	Increases intensity of rainfall → saturation of slopes → slope failure

Himalayas vs Western Ghats: Nature of Landslides

Feature	Himalayas	Western Ghats
Geology	Young fold mountains, tectonically active	Old, weathered block mountains
Slope	Steeper, highly dissected	Moderate slopes
Triggering Factors	Earthquakes, glacial melt, monsoon	Intense monsoon bursts, deforestation
Frequency	More frequent, widespread	Localized, mainly along escarpments
Examples	Kedarnath (2013), Joshimath (2023), Sikkim (2024)	Wayanad (2023), Idukki (2020), Nilgiris

Recent Examples (India & World)

Region	Incident	Year	Cause
Sikkim, India	Landslide due to glacier lake burst	2024	GLOF + cloudburst
Joshimath, UK	Land subsidence in high-altitude town	2023	Tectonics + human construction
Wayanad, Kerala	Flash landslides during monsoon	2024	Extreme rainfall, slope saturation
Papua New Guinea	Massive landslide killed 2,000+	2024	Heavy rain, deforestation
Nepal	Monsoon-induced landslides in hilly terrain	2023	Intense rainfall

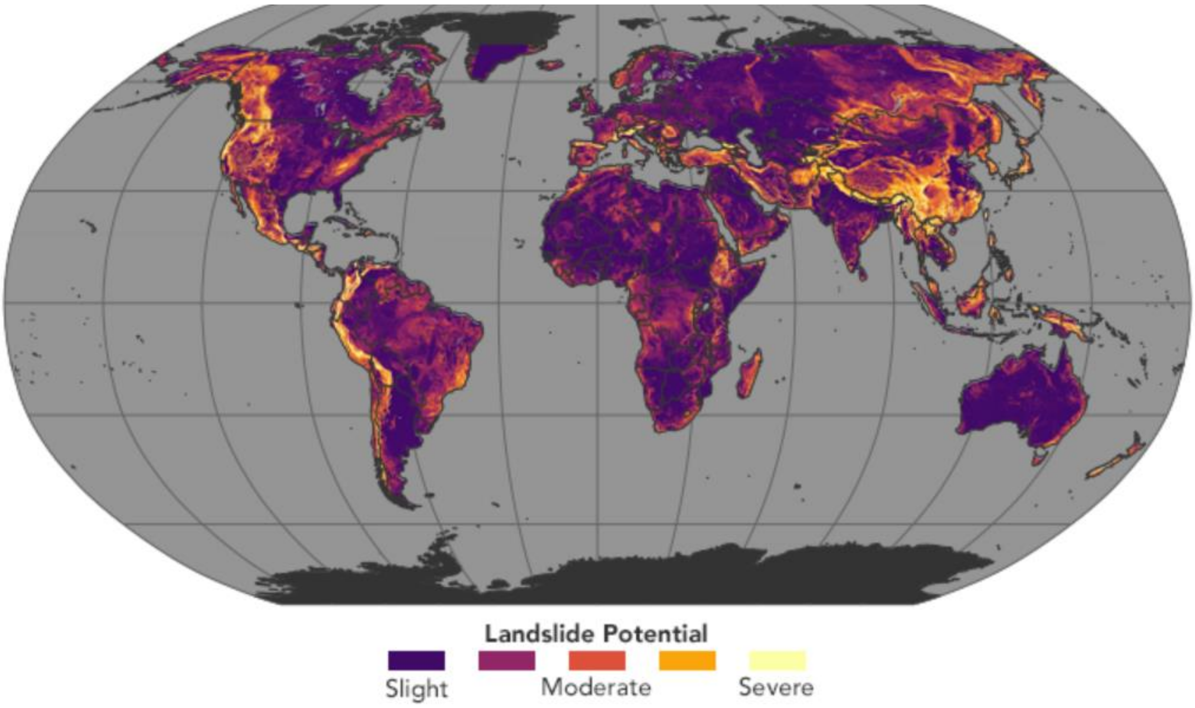


NDMA Guidelines on Landslide Management (2009 & 2019)

Key Recommendations:

1. **Hazard Zonation Mapping** using GIS & remote sensing
2. Promote **bio-engineering techniques** (vegetation for slope stabilization)
3. **Early Warning Systems (EWS)**: Rainfall thresholds, automated sensors
4. Training of **Landslide Response Teams (LRTs)**
5. Guidelines for **eco-safe road construction**, tunneling, and slope drainage
6. Strict **land-use zoning laws** in vulnerable zones
7. Community awareness & mock drills

NDMA has developed **Landslide Risk Management Framework (LRMF 2020–30)** under Sendai Framework compliance.



2000 - 2013

Best Solutions and Mitigation Strategies

Category	Solutions
Structural	Retaining walls, slope terracing, gabion walls, rock bolting, debris flow barriers
Bio-Engineering	Vetiver grass planting, afforestation, check dams
Policy-Based	Strict EIA enforcement, zoning laws, land-use planning
Technological	Satellite monitoring (ISRO CARTOSAT), LIDAR surveys, rainfall threshold alarms
Disaster Preparedness	Community-based disaster management, school safety programs