New Vision IAS Academy
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CLASS NOTES
DISASTER MANAGEMENT

TSUNAMI AND COASTAL EROSION

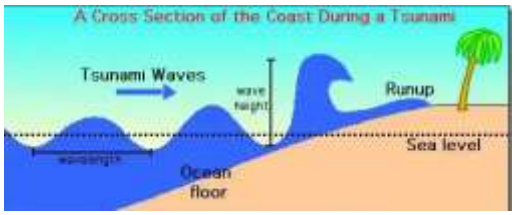
Tsunami:

- A Japanese term meaning "harbour wave
- Tsunamis are among the most destructive natural disasters on Earth
- They are series of multiple vertical waves caused by a large and sudden displacement of the ocean due to tectonic activity, earthquakes, volcanic eruptions or underwater landslides
- Earthquake generate tsunamis by vertical movement of the sea floor as in normal faulting or thrust faulting. If the sea floor movement is horizontal, tsunamis are not generated as in strike slip earthquake
- They are seismic sea waves.
- In India - The Ministry of Earth Sciences (MoES) as the Nodal Ministry, will prepare a detailed Action Plan for management of tsunami

CAUSES OF TSUNAMI

- The vertical movement of the seafloor generates Tsunami. Earthquakes are the main cause
- related with convergent plate- subduction zone and shallow earthquake
- The majority of tsunamis are caused by large, shallow earthquakes (magnitude larger than 7.0)
- The size of the Tsunami is related to the size of the earthquake.
- More than 80% of world's occurrences happen in the Pacific along its Ring of Fire subduction zones
- Eg. Chile (1960), Indian Ocean Tsunami (2004)
- Underwater explosion – A Nuclear Testing by the US generated Tsunami in 1940 and 1950s in Marshall Island.
- Volcanic eruption – Volcanoes that occur along the Coastal waters can cause several effects that can cause a tsunami.
- Landslides – Earthquake and volcanic eruptions generally generate landslides, these landslides when moving into the Oceans, bays and lakes can generate Tsunami.
- Anthropogenic Factors: Underwater nuclear explosions can generate tsunamis Eg. Nuclear Testing by the US generated Tsunami in 1940 and 1950s in Marshall Island

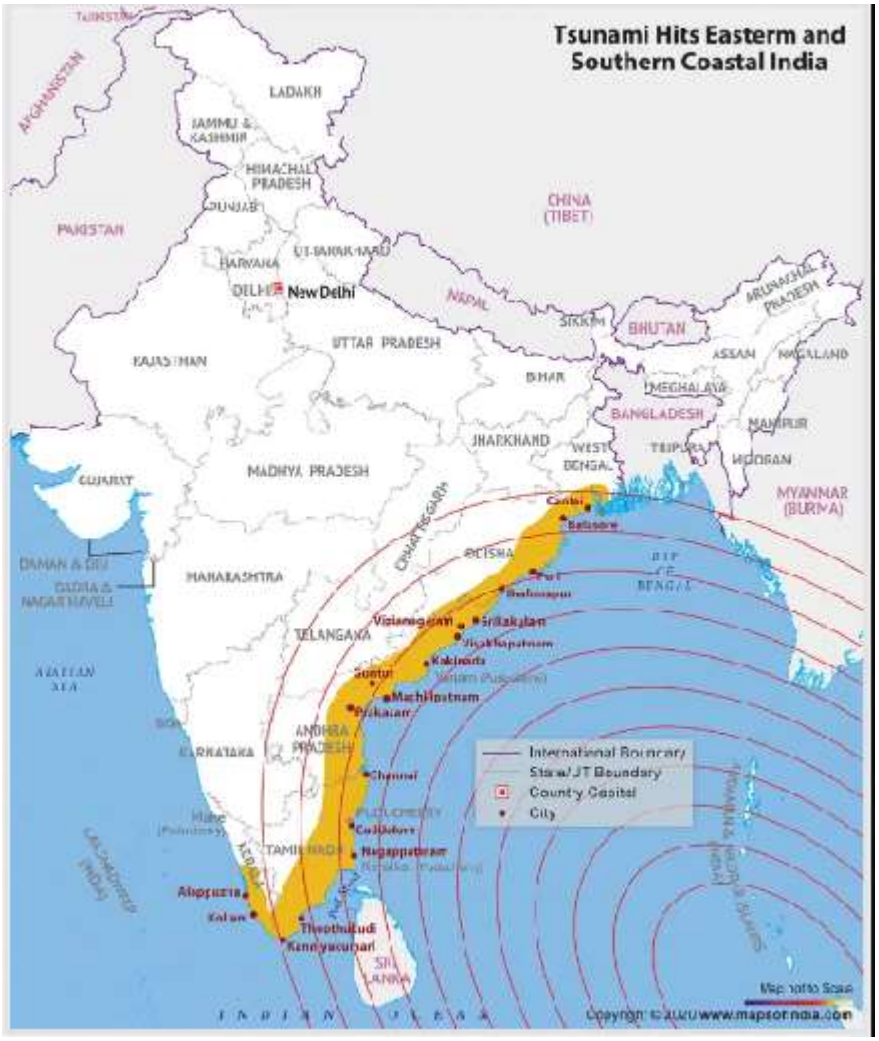
FEATURES :



- the Impact of tsunami is less over the ocean and more near the coast where they cause large scale destructions
- Long Wavelengths: They can span hundreds of kilometres from one wave crest to another
- As they approach shallow water near the coast, their height grows because of their long wavelengths.
- Their amplitude increases when events approach shallow water
- They cause more destruction near the coast
- Speed : 700 to 800 kmh
- Non-Periodic Nature: These waves are not periodic unlike regular ocean waves.
- Series of Waves: They occurs in multiple waves with periods ranging from minutes to hours
- Generally, the subsequent waves are more dangerous than the first wave

Tsunami-Prone Regions: Hotspots of Earth's Most Destructive Waves and Natural Disasters

- These are certain areas in the world which are particularly prone to tsunamis and the devastation they can bring.
- 78% Pacific Ocean (around the geologically active "Ring of Fire")
- 9% Atlantic Ocean and Caribbean Sea
- 6% Mediterranean Sea
- 5% Indian Ocean
- 1% Other Seas
- This is a map showing Tsunami prone areas in India



Two location : Near India

- The possible zones are Andaman – Sumatra or Makran (Pakistan).

Key Nodal Agency :

- Indian National Centre for Ocean Information Services (INCOIS)
- Established in 1999
- Under the Ministry of Earth Sciences.
- INCOIS through Indian Tsunami Early Warning Centre (ITEWC) is the nodal agency to provide tsunami advisories to India.
- The Indian Tsunami Early Warning Centre (ITEWC) established in 2007 at Indian National Centre for Ocean Information Services (INCOIS), Hyderabad under the Ministry of Earth Sciences
- It is the national authority to issue advisories for India
- Indian scientists are able to issue a warning 10 to 20 minutes after a big underwater earthquake happens in the Indian Ocean.
- Indian Early Warning Centre (ITEWC) has been accredited as Tsunami Service Provider for 28 Indian Ocean Rim (IOR) countries, along with Indonesia and Australia, for issuing regional warnings by the Intergovernmental Oceanographic Commission (IOC) of UNESCO.

Other Org :

It is an integrated effort of different organizations including the

- Department of Space (DOS),
- Department of Science and Technology (DST),
- The Council of Scientific and Industrial Research (CSIR),
- Survey of India (SOI) and
- National Institute of Ocean Technology (NIOT).

EFFECTS: ELEMENT AT RISK

- Loss of life and property: large displacement of water destroys housing and infrastructure in the areas affected by it. Also electrocution, gas leakage and explosions, damaging of tanks and floating of debris that further causes injury and death.
- Disease: Flooding and contamination caused due to the destruction of sewage systems cause outbreaks of diseases, infections and illness thus causing more death.

- Effect on environment and biodiversity – Tsunamis not only affect human beings but also cause harm to insects, animals, plants, and natural resources. Plants are uprooted due to violent waves of a tsunami, nesting sites are destroyed, land animals get killed by drowning and marine life is harmed by the flow of toxic chemicals into the water body. Solid waste and disaster debris are other critical environmental problems faced by a disaster-hit area.
- Economic cost – Tsunami causes contamination of soil and water. It increases the salinity of the soil. The mixing up of disaster debris with the soil and high salinity makes the soil infertile and unfit for cultivation thus adding to financial loss to the farmers and raising the chances of food insecurity.
- Post-tsunami reconstruction also requires a huge amount of financial investment. Thus, tsunami has a huge economic cost for an economy.

Impact on Coastal Areas

- After reaching the Coast, the tsunami waves release enormous energy stored in them and water flows turbulently onto the land destroying Port - cities and towns , structures, buildings and other settlements.
- Since the Coastal Areas are densly populated the world over , so the loss of life and property likely to be much higher by Tsunami as compared to other natural hazards in the coastal areas.
- The Extent of Devastation is much large, so it is beyond the capacity of Individual state or government to mitigate the damage.
- Hence Combined efforts at the International Levels are possible way of dealing with these disasters
  Ex: 26 Dec 2004 tsunami in which more than 3 lakh people lost their lives.

MEASURES : FOCUS ON

- The key factors to reduce potential losses due to tsunami are AWARENESS and PREPAREDNESS
- It is made up of two equally important components:- A network of sensors to detect tsunamis and A communications infrastructure to issue timely alarms to permit evacuation of the coastal areas.
- TSUNAMI RISK = TSUNAMI HAZARD x EXPOSURE x VULNERABILITY.

MITIGATION MEASURES

1. Effective Planning
2. The building of walls was done by Japan.
3. Planting trees as done in Tamil Nadu by a village
4. Proper relief and rehabilitation preparedness
5. Awareness among the masses

M.S. Swaminathan Committee Report has further recommended that:

- Mangrove wetlands should be regenerated.
- Coral reefs, grass beds, and coastal forests should be preserved and conserved for both short-term and long-term ecological and livelihood benefits.
- Raising coastal plantations like casuarinas, saliconia, palm, bamboo, etc. will act as an effective bio-shield and provide protection to the coastal communities.
- Geomorphologic features like sand dunes, beaches, coastal cliffs should be protected.
- Impact of natural hazards in the coastal and marine areas should be taken into account while formulating coastal area management schemes.

In both quantitative and qualitative terms, the practical applications of tsunami risk assessment for implementation of mitigation strategies of terrestrial and marine environments include:

STRUCTURAL AND NON STRUCTURAL MEASURES FOR REDUCING ELEMENT OF RISK

1. Building Codes (potential damage due to wave action and flooding)
2. GIS Mapping
3. Land-Use Planning (taking note of wave action & flooding)
4. Disaster Planning (in identified hazard zones)
5. Emergency Management
6. Emergency Personnel Training (necessary aspects relevant to marine situations)
7. Rescue and Response (cargo, tourist, inter-islands fishing community, (marine situations related recreational boating) to shipping)
8. Insurance Needs
9. Community Education
10. Simulated Tsunami Exercises

Global initiatives

- The Sendai Framework on Disaster Risk Reduction adopted in 2015 has put forward the following efforts to address tsunami-related hazards. These include
  - Hazard warning;
  - Mapping; and
  - Risk assessment.

News : India Coastline Recalculated for Risk Assessment

India's coastline has grown by 47.6%, from 7,516 km in 1970 to 11,098 km in 2023-24. The increase is due to the adoption of new methodologies for measuring coastal features.

Comparison: Old vs. New Measurement Methodology

Aspect	Old Methodology (1970)	New Methodology (2023-24)
Basis of Measurement	Straight-line distances	Included complex coastal formations
Coastal Features Measured	Limited to general shoreline length	Incorporated bays, estuaries, inlets, and other geomorphological features
Technology Used	Basic tools and manual calculations	Advanced geospatial technologies and mapping tools
Accuracy	Relatively less precise	More precise representation of dynamic coastline
Reported Coastline Length	7,516 km	11,098 km

- Revised Parameters: Updated methodology incorporates bays, estuaries, inlets, and other geomorphological features, replacing the older straight-line measurement approach. and marking a 47.6% increase in India's coastline
- Ministry: The recalculation was conducted under the Ministry of Home Affairs (MHA), guided by the National Maritime Security Coordinator.
- Based on data from the National Hydrographic Office and Survey of India

Coastline Increase Region :

- Gujarat -Increased from 1,214 km (1970) to 2,340 km (2023-24)
- West Bengal: Percentage increase of 357%, from 157 km to 721 km, marking the highest growth in percentage terms
- Tamil Nadu: Revised length increased to 1,068 km from 906 km, overtaking Andhra Pradesh.

States/UTs with Minimal or Negative Changes

- Kerala: Recorded the smallest increase, adding only 30 km (5%).
- Puducherry: The coastline shrank by 4.9 km (-10.4%), due to erosion and recalculation.
- Tamil Nadu vs. Andhra Pradesh: Tamil Nadu now ranks higher than Andhra Pradesh in coastline length after the new measurement.
- Puducherry's Contraction: Shrinkage attributed to erosion and refined calculations, contrasting the general trend of coastline growth elsewhere.

State wise Length-New(Old) In Km

1. Gujarat -2340.62 (1217.7)
2. Tamil Nadu-1068.69 (906.9)
3. Andhra Pradesh- 1053.07 (973.7)
4. Maharashtra- 877.97 (652.6)
5. West Bengal- 727.02 (157.5)
6. Kerala- 600.15 (569.7)
7. Odisha- 574.71 (464.4)
8. Karnataka- 343.3 (280)
9. Goa- 193.95 (101

In Union Territory

1. A & N -3083.5 (1962)
2. Lakshadweep- 144.8 (132)
3. Daman & Diu (DNDD)- 54.38 (42.5)
4. Puducherry UT(Incl all 4 parts)- 42.65 (47.6 km).

COASTAL EROSION

- Type of environmental disaster
- process of gradual loss of land along the coastline or landward retreat of coastline or shoreline
- Physical reduction of landmass at the coast that result from interfacing of marine, fluvial , and land-sliding (driven by interactions between groundwater and soil or rock) processes with the coast
- Extreme rainfall event contribute to soil saturation and associated shear strength reduction with land-sliding)
- Coastline are dynamic landforms and constantly subject to erosion and accretion (deposition of sediments)
- Coastal erosion is universal phenomenon due to increase of sea level due to climate change and global warming .
- Appr 40 % Population live near Coastal Region

CLIMATE CHANGE :

- Long term shift in temperature and weather pattern mainly due to man- made activities.
- GLOBAL WARMING :
- Long term increase in Earth average temperature due to increased human activities like burning of fossil fuels, and release of greenhouse gases like carbondioxide, nitrous oxide and methane.

Status of Coastal Erosion in India

- National Centre for Coastal Research, (NCCR), an attached office of the Ministry of Earth Sciences, Government of India has monitored the shoreline changes for entire Indian coastline

- Hazard Line: The Ministry of Environment, Forest & Climate Change (MoEFCC) has defined the hazard line to indicate shoreline changes and sea level rise.
- It is used for disaster management, adaptive planning, and mitigation measures in Coastal States/UTs
- Coastline of India - 33.6% of coast is eroding, 26.9% is accreting and 39.5% is in a stable state.
- State wise analysis suggests that more than 40% of erosion is noticed in four states/UT i.e. West Bengal (63%), Pondicherry (57%), Kerala (45%) and Tamil Nadu (41%) coast.

Causes of Coastal Erosion

- Natural Causes: Rising sea levels, Mangrove depletion, Cyclonic activity, Action of waves, winds, tides, currents, storms continuously shape the coastline, leading to erosion.
- Human Activities: Human interventions along the coast, including construction of harbors, ports, and coastal structures, deforestation , sand mining and dredging, disrupt natural sediment transport patterns

ELEMENT AT RISK DUE TO DISSATER :

- Tangible and intangible vulnerability loss
- physical , social, economic, environment loss
- impact weaker sections, old people and disabled people

FOCUS:

- Structural And Non Structural Measures

STRUCTURAL MEASURES :

- Groynes : Perpendicular to Shorelines.
- Breakwater - Offshore structure to break waves.
- Revetments - Like Seawall but made of concrete block or loose stone built in slope fashion.
- Sea wall - Vertical structure parallel to Shorelines.
- Offshore Artificial Coral Reefs
- Tetrapods- Concrete structure with four leg to prevent erosion
- Geotextile tube built in Andhra Pradesh and Odisha Coast

NONSTRUCTURAL MEASURES :

- Mangrove restoration
- Coastal Wetlands
- Integrated Coastal Zone Management
- Coastal Planting and Shelter Belts
- Restoring Sand Dunes
- Beach Nourishment - Adding Sand to erode beach
- Make Use of Indigenous Knowledge
- Focus more on Environmental Impact Assessments near Coastal Area

OTHER KEY MEASURES :

- focus on 4 R and 3 P
- Rescue, Relief , Rehabilitation, Restoration and Prevention, Preparedness, Proofing
- Awarness generation programm
- Use of local capacity and community involvement
- All development Plans should be integrated with DM Plans
- for real time monitoring and assessment - Use of remote sensing satellite for space based observation s
- Focus more on Risk Assessment (PMP) than Crisis Management (RRR)
- Increase - capacity building ; coping capacity, contingency planning Fund, Critical Facilities

Way Forward :

- From ‘Response and Relief’ to ‘Prevention and Mitigation’
- From ‘Reactive’ to ‘Proactive’ Measures
- From ‘Short-term Relief’ to ‘Long-term Resilience’
- From ‘Vulnerability’ to ‘Resilience’ - Building resilience reduces vulnerability and enhances disaster preparedness."
- From ‘Centralized Control’ to ‘Decentralized Empowerment’ - Promotes local autonomy in disaster management.
- From ‘Isolation’ to ‘Integrated Approach’ - Advocates for coordinated efforts across sectors and regions and ensures all stakeholders work together seamlessly."
- From ‘Ignorance’ to ‘Awareness and Education -: "Raising awareness and educating the public are crucial for effective disaster risk reduction."
- From ‘Temporary Solutions’ to ‘Sustainable Solutions’ - "Sustainable solutions ensure long-term safety and resilience."
- From ‘Individual Efforts’ to ‘Collective Action’ - Emphasizes the need for collective efforts in disaster management.
- From ‘Traditional Methods’ to ‘Innovative Approache- "Innovative approaches can enhance the efficiency and effectiveness of disaster management.
- From ‘Fragmented Policies’ to ‘Holistic Policies’- Advocates for comprehensive and cohesive disaster policies

- From ‘Short-term Gains’ to ‘Long-term Benefits-Prioritizing long-term benefits leads to sustainable resilience."
- From ‘Top-down Command’ to ‘Community Empowerment- Promotes empowering local communities in disaster management.
- From ‘Reactive Adaptation’ to ‘Proactive Adaptive Capacity’ -Proactive adaptive capacity prepares communities to handle evolving climate challenges."
- From ‘Socio-Economic Inequality’ to ‘Inclusive Risk Management’ - Uses: Focuses on addressing disparities and ensuring all groups are included in disaster management.
- From ‘Linear Economy’ to ‘Circular Economy’- Adopting a circular economy reduces waste and enhances resource use efficiency."
- From ‘Unilateral Actions’ to ‘Disaster Diplomacy’ -"Disaster diplomacy fosters international cooperation for effective disaster management."
- From ‘Risk Ignorance’ to ‘Risk-Informed Development’ -"Risk-informed development ensures that infrastructure projects are resilient to disasters."
- From ‘General Mapping’ to ‘Geo-Spatial Analysis’ -"Geo-spatial analysis provides precise flood risk maps and hazard assessments."

CYCLONE

Define :

- Cyclones are atmospheric and oceanic phenomena.
- A cyclone is a large-scale air mass rotating around a strong centre of low atmospheric pressure.
- Cyclones can be classified on the basis of their origin into tropical and extratropical cyclones.
- Wind circulation around a low pressure system is called cyclonic circulation and around a high pressure system is called anti cyclonic circulation
- The World Meteorological Organisation (WMO, 1976) uses the term 'Tropical Cyclone’ to cover weather systems in which winds exceed ‘Gale Force’ (minimum of 34 knots or 63 kph)

Background :

- The word Cyclone is derived from the Greek word Cyclos meaning the coils of a snake.
- It was coined by Henry Peddington because the tropical storms in the Bay of Bengal and the Arabian Sea appear like coiled serpents of the sea.

Movement Pattern:

- They are characterized by inward-spiraling winds that rotate counterclockwise in the Northern Hemisphere and clockwise in the Southern Hemisphere

Pressure system	Pressure Condition at the Centre	Pattern of wind direction	
		Northern Hemisphere	Southern Hemisphere
Cyclone	Low	Anticlockwise	Clockwise
Anticyclone	High	Clockwise	Anticlockwise

Nodal Agency :

- The India Meteorological Department (IMD) is the nodal government agency that provides weather services related to cyclones in India

2.2 Real time Observational Data for Cyclone EW

S. No.	Type of Observation	Nodal Ministry	Nodal Agency	Agencies to be Involved
1	Land-based Observations	Ministry of Earth Sciences	IMD	IAF, Indian Navy, DoS, CWC, State Irrigation Departments, Agricultural Universities, River Authorities, etc.
2	Ocean-based Observations	Ministry of Earth Sciences	INCOIS	National Institute of Ocean Technology (NIOT), Indian Navy, Coast Guard, Ships of opportunity, International Floating Platforms, etc.
3	Space-based Observations	Department of Space	ISRO	IMD, International satellite agencies from polar orbital and geostationary platforms
4	Special Observations	Ministry of Earth Sciences/ Department of Space	IMD/NRSA	IAF, CWC and other user agencies

Cyclones are known by many names the world over—

- typhoons in the North West Pacific including the South China Sea,

- hurricanes in the North Atlantic including the West Indies and in the Caribbean Sea and the North East Pacific
- Willy-Willies in North-Western Australia and
- TCs in the North and South Indian Ocean.

Medicanes	*Mediterranean hurricanes*, are rare tropical-like cyclones that occur in the Mediterranean Sea

Classifications

Cyclones are classified as extra tropical cyclones (also called temperate cyclones); and tropical cyclones.

TEMPERATE CYCLONES

The low-pressure systems developing in the mid and high latitude, beyond the tropics are called the Temperate/ Extra-Tropical/ Mid-Latitude/ Frontal/ Wave Cyclones

- Most commonly formed at the polar fronts, where warm and moist air masses meet cold and dry air masses from poles.
- Occur mostly in winter, late autumn and spring.
- They stretch over large areas under the influence of westerlies.
- Approach of a temperate cyclone is marked by fall in temperature and pressure and a thin veil of cirrus clouds.
- These cyclones move from west to east under the influence of westerlies.
- The western disturbances arriving in North West India during winter are remnants of such cyclones

TROPICAL CYCLONES

- They are strong low pressure centres that originate over oceans in tropical areas and move over to the coastal areas bringing about large scale destruction due to violent winds, very heavy rainfall (torrential rainfall) and storm surge
- Violent storms; Originate over oceans in tropical areas
- A roughly circular calm area of comparatively light winds and fair weather at the centre is known as the Eye of the cyclone. It has lowest surface pressure and warmest temperatures and air descends at the centre
- The eye temperature may be 10°C warmer or more at an altitude of 12 km than the surrounding environment, but only 0-2°C warmer at the surface in the tropical cyclone
- Eye is surrounded by the eye wall with strong spiraling ascent of air where winds blow the fastest resulting in torrential rains.
- Latent heat of evaporation released by the condensation of moist rising air over oceans is the driving engine for tropical cyclones.
- They dissipate after they make landfall because the latent heat of evaporation is not available (moisture supply is cut off). They move in a parabolic path towards the west under the influence of trade winds.

Different names:

- Cyclones (Indian Ocean), Hurricanes (Atlantic), Typhoons (Western Pacific and South China Sea; Philippines islands, eastern China and Japan), and Willy-willies (North West Australia).

Type	Wind speed in km/h
Low pressure area (L)	Less than 31
Depression (D)	31-49
Deep depression (DD)	50-61
Cyclonic storm (CS)	62-88
Severe cyclonic storm (SCS)	89-118
Very severe cyclonic storm (VSCS)	119-165
Extremely severe cyclonic storm (ESCS)	166-220
Super cyclonic storm (SupCS)	221 or more

Basic Conditions for Cyclongenesis :

- Warm Ocean Waters:

Favourable Conditions for the formation

- Location over the ocean, at least 4–5o latitude away from the equator.
- Warm Ocean Waters - Large sea surface with temperature> 27° C and associated warming extending up to a depth of 60m with abundant water vapour in the overlying air (by evaporation)
- Atmospheric instability that encourages the formation of massive vertical cumulus clouds due to condensation of rising moist air
- Presence of the Coriolis force- helps to organize the winds into a spiral pattern, crucial for cyclone formation
- The presence of cyclonic vorticity (rate of rotation of air) that initiates and favours rotation of the air cyclonically

- High humidity in the lower to middle levels of the troposphere provides ample moisture for the formation of clouds and thunderstorms
- High relative humidity in the atmosphere up to a height of about 5,000 metres,
- Small variations in the vertical wind speed; •
- A pre-existing Disturbance (weak low-pressure area)- can provide a focal point for cyclone development.
- Upper divergence above the sea level system
- Low vertical wind shear between the lower and higher levels of the atmosphere
- Define: (vertical wind shear is the rate of change of wind between the higher and lower levels of the atmosphere)
- Strong vertical wind shear can disrupt the storm's structure and prevent it from developing.

Characteristic	Tropical Cyclone	Temperate Cyclone
Origin	Thermal Origin	Dynamic Origin - Coriolis Force, Movement of Air Masses
Latitude	10-30° N and S of the equator	35-65° N and S of the equator. More pronounced in Northern hemisphere due to greater temperature contrast
Frontal System	Absent	Formation due to frontogenesis
Formation	Forms at sea (>26-27°C); dissipates on land	Can form on land and seas
Season	Seasonal: Late summers (Aug-Oct)	Irregular, fewer in summers, more in winters
Size	Limited to smaller area: 100-500 km diameter	Larger area: 300-2000 km diameter
Shape	Elliptical, Anvil Shaped	Inverted 'V' (middle latitude cyclones)
Rainfall	Heavy but short-lasting	Slow, continuous rainfall for days or weeks
Wind Velocity	Much greater (100-250 kmph)	Comparatively low (30-150 kmph)
Isobars	Complete circles, steep pressure gradient	'V' shaped, low pressure gradient
Lifetime	Lasts <1 week	Lasts 2-3 weeks
Path	East to West (Trade Winds)	West to East (Weterlies)
Calm Region	Eye at the center, calm region with no rainfall	No single region with inactive winds or rains
Driving Force	Energy from latent heat of condensation	Energy depends on air mass densities
Influence of Jet Streams	Relationship with upper-level airflow less clear	Distinct relationship with upper-level airflow (Jet streams, Rossby waves)
Clouds	Few varieties (cumulonimbus, nimbostr-atus)	Variety of cloud development at various elevations; occluded front clouds
Influence on India	Affects both coasts; East coast more impacted	Brings rains to North-West India; associated with 'Western Disturbances'

Polar Cyclones

- Are small-scale weather systems that occur in polar regions, formed with rapid development and shorter lifespans
- Typically have a smaller scale compared to temperate cyclones
- Primarily over oceanic areas in the arctic or antarctic regions
- Influenced by the extreme local temperature contrasts between the cold polar air and relatively warmer ocean waters
- Formed due to polar front - it serves as the boundary between cold polar air and warmer subtropical air.
- Polar jet stream also helps in formation of this cyclones
- Upper-level winds:- the polar jet stream plays a vital role in enhancing cyclogenesis by providing additional lift above the surface low-pressure system
- Polar cyclones are characterized by cold air at their core, unlike tropical cyclones that have warm cores.
- While polar cyclones can bring strong winds and heavy precipitation, they are generally not as intense as tropical cyclones.
- Polar cyclones can bring extremely cold temperatures and blizzard conditions to the polar regions
- The strong winds associated with polar cyclones can cause blowing snow, reduced visibility, and damage to infrastructure
- Navigation Hazards: Polar cyclones can create hazardous conditions for ships and aircraft operating in the polar regions.

SPECIAL CYCLONES

Fujiwhara Effect = Definition: Interaction between simultaneous tropical storms within 1,400 km.

Bomb Cyclone =

- Characteristics: Midlatitude storm, rapid intensification (≥24 mb in 24 hours). •

- Genesis: Clash of warm and cold air masses. •
- Areas: Common on the US coast, colder months

Key words

- Tropical cyclone are characterised by large pressure gradients .
- Eye of the cyclone- Low-pressure center of the cyclone
- Eye of the Cyclone A term used for the centre of a cyclone. It is the point where the wind rotates in a counter-clockwise direction.
- The eye is a region of calm with subsiding air.
- The lower the pressure in the eye, the more intense is the cyclone.

Around the eye is the eye wall, where there is strong ascent of air to greater height reaching the tropopause

Eye-wall- Surrounds the eye with the strongest winds and heaviest rain and is the most destructive part of the cyclone

- cyclones - They have closed isobars which leads to greater velocity
- Landfall A point on the land where a cyclone just crosses the coast.
- Storm Surge It is an abnormal rise in the level of water along a shore, primarily as a result of the high winds and low pressures generated with tropical cyclones; generally affects only coastal areas but may intrude some distance inland.

BRING OUT RELATIONSHIP BETWEEN CLIMATE CHANGE AND CYCLONES ?

The Key points which explain how Climate Change affect Cyclones are :

- Increased Sea Surface Temperatures: Warmer ocean waters are the primary fuel for cyclones. As climate change drives up ocean temperatures, it provides more energy for cyclones to develop and intensify
- Higher Sea Levels: Rising sea levels exacerbate the impacts of storm surges, the coastal flooding caused by cyclones. Even if a cyclone's intensity remains the same, higher sea levels mean storm surges will reach further inland, causing more damage
- Changes in Rainfall: Climate change is expected to increase the amount of rainfall associated with cyclones. Warmer air can hold more moisture, leading to heavier precipitation and increased risk of flooding
- Increased Intensity: There's growing evidence that the average intensity of cyclones has increased in recent decades. This means more storms are reaching higher categories (like Category 4 or 5 hurricanes) with stronger winds and greater potential for damage
- Potential Changes in Cyclone Tracks and Uncertainty about Frequency: Some research suggests that climate change may be altering the tracks of cyclones, potentially exposing new areas to these destructive storms

Way forward :

- In summary, the relationship between cyclones and climate change is characterized by warmer ocean temperatures leading to stronger storms with increased intensity and rainfall, along with rising sea levels exacerbating storm surges and coastal flooding risks
- Climate change is increasing the risks associated with cyclones. Need for Action: Reducing greenhouse gas emissions is crucial to mitigate the impacts of climate change on cyclones and other extreme weather events.

Vulnerability Profile of Cyclone in India :

- India has a coastline of 7,516 km, of which 5,700 km are prone to cyclones of various degrees.
- About 8% of the area in the country is prone to cyclone-related disasters
- About one-third of it's population live in 13 coastal states and UTs who are, thus vulnerable to cyclone related disasters
- More cyclones occur in the Bay of Bengal than the Arabian Sea and the ratio is approximately 4:1.

The southwest monsoon plays a crucial role in altering cyclone paths:

During monsoon season (June to September), strong westerly winds develop over the Arabian Sea due to intense heating over land areas like India. These westerlies can steer cyclonic systems northward or northwestward towards Gujarat and Maharashtra instead of allowing them to continue westward into open waters.

Conversely, during non-monsoon periods or when monsoonal influences are weaker, cyclones may still follow more traditional paths influenced primarily by trade winds.

Location :

- Cyclones occur in the Bay of Bengal than the Arabian Sea and the ratio is approximately 4:1.
- Four states (Tamil Nadu, Andhra Pradesh, Orissa and West Bengal) and one UT (Puducherry) on the east coast and one state (Gujarat) on the west coast are more vulnerable to hazards associated with cyclones.
- Category I: Higher vulnerability States i.e. Andhra Pradesh, Gujarat, Odisha, Tamil Nadu and West Bengal.
- Category II: Lower vulnerability States i.e. Maharashtra, Karnataka, Kerala, Goa, Pondicherry, Lakshadweep, Daman and Diu, Andaman and Nicobar Islands.

Time Period :

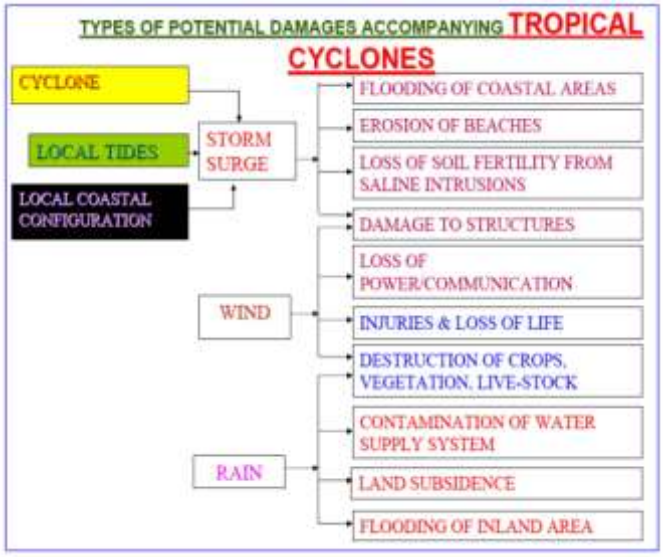
- Cyclones occur in the months of May–June and October–November, with their primary peak in November and secondary peak in May.

- Cyclones generally do not form during the active monsoon season due to several atmospheric and oceanic conditions that are not conducive to their development.
- High Vertical Wind Shear: During the monsoon season, strong vertical wind shear, ack of sea surface temperature gradient, and the presence of the monsoon trough makes it difficult for cyclones to form and intensify during the active monsoon season.

India Coastal Region Impacted by Cyclone More , Why ?

- Flat coastal terrain, shallow continental shelf, high population density, geographical location and physiological features of its coastal areas makes India extremely vulnerable to cyclones and its associated hazards like storm tide (the combined effects of storm surge and astronomical tide), high velocity wind and heavy rains
- Climate change and its resultant sea-level rise can significantly increase the vulnerability of the coastal population.

Element at Risk :



- The population, properties, economic activities, including public services, etc. at risk in a given area.
- Loss of lives, livelihood opportunities, damage to public and private property and severe damage to infrastructure
- Climate change and the resultant sea-level rise is also likely to exacerbate the seriousness of this problem in the coming decades
- Exceptionally heavy rainfall causes flooding. Storm surge inundates low-lying areas in the coastal areas resulting in loss of life and destruction of property, besides eroding beaches and embankments, destroying vegetation and reducing soil fertility

Impact : Devastating potential

- Result in inundation of human settlements.
- Agricultural fields , damaging crops and
- Destruction of structures viz. Houses; lifeline infrastructure-power and communication towers; hospitals; food storage facilities; roads, bridges and culverts; crops etc.
- The most fatalities come from storm surges and the torrential rain flooding the lowland areas of coastal territories.
- Sea water inundates low lying areas of coastal regions and causes heavy floods, erodes beaches and embankments, destroys vegetation and reduces soil fertility.

INDIAN METEOROLOGICAL DEPARTMENT

The Indian classification of these intense low pressure systems (cyclonic disturbances) is shown in Table

Type of Disturbances	Wind Speed in Km/h	Wind Speed in Knots
Low Pressure	Less than 31	Less than 17
Depression	31-49	17-27
Deep Depression	49-61	27-33
Cyclonic Storm	61-88	33-47
Severe Cyclonic Storm	88-117	47-63
Super Cyclone	More than 221	More than 120

1 knot - 1.85 km per hour

Cyclones are classified into five different levels on the basis of wind speed. They are further divided into the following categories according to their capacity to cause damage:-

Cyclone Category	Wind Speed in Km/h	Damage Capacity
01	120-150	Minimal
02	150-180	Moderate
03	180-210	Extensive
04	210-250	Extreme
05	250 and above	Catastrophic

CLASSIFICATION OF CYLONES IN INDIA

- Indian Meteorological Department(IMD) is the nodal agency for early warning of cyclones and floods.
- Natural Disaster Management Authority is mandated to deal with the disaster management in India. It has prepared National Guidelines on Management of Cyclone.

- National Cyclone Risk Mitigation Project (NCRMP)was launched by Home ministry to upgrade the forecasting, tracking and warning about cyclones in states.
- National Disaster Response Force(NDRF) has done a commendable performance in rescuing and managing relief work.

THE NATIONAL CYCLONE RISK MITIGATION PROJECT (NCRMP)

- to be implemented with financial assistance from the World Bank,
- Include - four major components:
- Component A: Improvement of early warning dissemination system by strengthening the Last Mile Connectivity (LMC) of cyclone warnings and advisories.
- Component B: Cyclone risk mitigation investments.
- Component C: Technical assistance for hazard risk management and capacity building.
- Component D: Project management and institutional support.

These components are highly interdependent and have to be implemented in a coherent manner.

MANAGEMENT OF TROPICAL CYCLONES: RISK REDUCTION MEASURES: STRATEGIES FOR RESILIENT COMMUNITIES

Key Lines : NDMA Guidelines

- Assessment of Damage of tangible vulnerability
- Create Monitoring cells
- Create . Emergency Operations Centres and Search and Rescue Operations
- Community-Based Preparedness -Encourage NGO, PRI, ULB to generate awareness
- Increase coping capacity by providing training and capacity building measures
- Focus more on risk assessment (PMP) than crisis management (RRR)
- Preparation of Hazard and vulnerability maps
- Integration of disaster management plans with Developmental Plans
- Early Warning Systems: Establish and maintain robust early warning systems to provide timely and accurate information about cyclone formation and movement.
- Public Awareness and Education: Conduct public awareness campaigns and educational programs to inform communities about cyclone risks and safety measures
- Infrastructure Resilience: Improve the resilience of infrastructure to withstand cyclone impacts, including strengthening buildings, roads, and coastal defenses
- Relief and Rehabilitation: Provide immediate relief supplies, including food, water, medical aid, and other essentials to affected populations
- Improve Coordination and Collaboration among various government agencies, NGOs, and community organizations involved in disaster management and Engage in international cooperation and exchange of best practices for cyclone management.

To Address Challenges we need Comprehensive Approach :

Focus on Risk Assessment :

- Preventive Measures
- Mitigation Strategies
- Preparedness Measures
- Sustainable Practices
- Community Participation

LONG TERM PREVENTION AND MITIGATION MEASURES can be broadly be divided under three heads -

i. Structural Measures
ii. Non-structural measures.

The mitigation strategies of tropical cyclonic disasters focus on integrated use of structural and non-structural measures.

Measures to Manage

- Structural measures include the construction of cyclone shelters, cyclone-resistant buildings, road links, culverts, bridges, canals, drains, saline embankments, and surface water tanks, and the establishment of communication and power transmission networks.

Non-structural measures:

- Coastal belt Plantation: Act as a wide buffer zone against strong winds and flash floods.
- Hazard maping and hazard vulnerability risk analysis
- focus on early w arning dissemination systems,
- coastal zone management,
- raising awareness, etc.disaster risk management, and
- capacity building of all stakeholders involved
- Doppler weather radar, aircraft reconnaissance and latest and the most advanced is meteorological satellites to generate information to develop forecasts and to issue warnings.

- There is a need of harmonizing the national and local level disaster resilient bylaws, land use zoning, resource planning
- The building material technology promotion council (bmtpc) of ministry of urban development, based on hazard vulnerability of India identified cyclone prone districts of India taking into consideration cyclone hazards of the coastal districts.

PM Ten Point Agenda for DRR

The PM Ten Point Agenda for Disaster Risk Reduction provides a comprehensive framework aimed at strengthening resilience through institutional frameworks, community engagement, risk assessment, early warning systems, capacity building, financial mechanisms, resilient infrastructure development, climate adaptation strategies, research innovation, and international cooperation.

IMD's Colour Coding of Cyclones

- It is a weather warning that is issued by the IMD to aware people ahead of natural hazards.
- The four colours used by IMD are Green, Yellow, Orange, and Red.

NAMING OF TROPICAL CYCLONES

- to enable easy identification and to eliminate confusion when there are multiple systems in any individual basin at the same time
- to assist people to identify the system from which danger is most imminent.
- These names are taken from lists which vary from region to region and are selected a few years earlier
- The list is decided upon, depending on the region, either by committees of the World Meteorological Organisation (WMO) or by national weather offices (IMD in India) involved in the forecasting of cyclones. Each year, the names of highly destructive cyclones are 'retired', to be replaced by new ones

Guidelines to adopt names of cyclones:

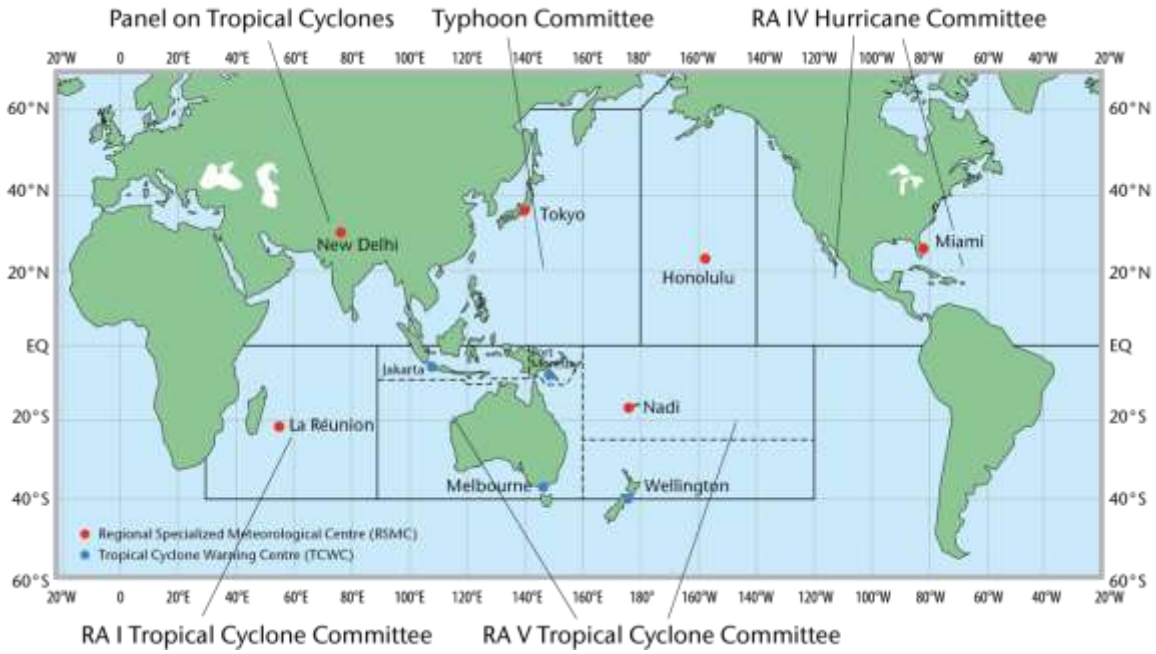
- The proposed name should be neutral to (a) politics and political figures (b) religious believes, (c) cultures and (d) gender
- Name should be chosen in such a way that it does not hurt the sentiments of any group of population over the globe
- It should not be very rude and cruel in nature
- It should be short, easy to pronounce and should not be offensive to any member
- The maximum length of the name will be 8 letters
- The proposed name should be provided with its pronunciation and voice over
- The names of tropical cyclones over the north Indian Ocean will not be repeated. Once used, it will cease to be used again.

How are Tropical Cyclones Named?

Six Regional Specialised Meteorological Centres (RSMCs)

Ocean Region	RSMCs Name
South-West Pacific Ocean	RSMC Nadi-Tropical Cyclone Centre, Fiji Meteorological Service
South-West Indian Ocean	RSMC La Reunion-Tropical Cyclone Centre/Meteo-France
The Bay of Bengal and the Arabian Sea	Tropical Cyclones New Delhi/India Meteorological Department
Western North Pacific Ocean and the South China Sea	Tokyo-Typhoon Center/Japan Meteorological Agency
Central North Pacific Ocean	Honolulu Hurricane Center
The Caribbean Sea, Gulf of Mexico, North Atlantic, and eastern North Pacific Oceans	Miami-Hurricane Center/National Hurricane Center

- Here are five tropical cyclone regional bodies in the world:
  - ESCAP/WMO Typhoon Committee,
  - WMO/ESCAP Panel on Tropical Cyclones,
  - RA I Tropical Cyclone Committee,
  - RA IV Hurricane Committee,
  - RA V Tropical Cyclone Committee.



- WMO/ESCAP Panel on Tropical Cyclones is responsible for naming of cyclones in the Indian Ocean.
- It comprises of thirteen countries in the region –
- [1] Bangladesh, [2] India, [3] Iran, [4] Maldives, [5] Myanmar, [6] Oman, [7] Pakistan, [8] Qatar, [9] Saudi Arabia, [10] Sri Lanka, [11] Thailand, [12]United Arab Emirates and [13] Yemen.
- Here are the 169 (13 countries × 13 columns) new names of tropical cyclones suggested by the 13 member countries of the WMO/ESCAP Panel.
- These names applied to the cyclones over the North Indian Ocean, including the Bay of Bengal and the Arabian Sea.

New List of Names for Tropical Cyclone over North Indian Ocean

The Weather Channel

Place	List 1	List 2	List 3	List 4	List 5	List 6	List 7	List 8	List 9	List 10	List 11	List 12	List 13
Bangladesh	Nisarga	Biparjoy	Arnab	Upakul	Barshon	Rajani	Nishith	Urmi	Meghala	Samiron	Pratikul	Sarobor	Mahanisha
India	Gati	Tej	Murasu	Aag	Vyom	Jhar	Probaho	Neer	Prabhanjan	Ghurni	Ambud	Jaladhi	Vega
Iran	Nivar	Hamoon	Akvan	Sepand	Booran	Anahita	Azar	Pooyan	Arsham	Hengame	Savas	Tahamtan	Toofan
Maldives	Burevi	Midhili	Kaani	Odi	Kenau	Endheri	Riyau	Guruva	Kurangi	Kuredhi	Horangu	Thundi	Faana
Myanmar	Tauktae	Michaung	Ngamann	Kyarthit	Sapakyee	Wetwun	Mwaihout	Kywe	Pinku	Yinkaung	Linyone	Kyeekan	Bautphat
Oman	Yaas	Remal	Sail	Naseem	Muzn	Sadeem	Dima	Manjour	Rukam	Watad	Al-jarz	Rabab	Raad
Pakistan	Gulab	Asna	Sahab	Afshan	Manahil	Shujana	Parwaz	Zannata	Sarsar	Badban	Sarrab	Gulnar	Waseq
Qatar	Shaheen	Dana	Lulu	Mouj	Suhail	Sadaf	Reem	Rayhan	Anbar	Oud	Bahar	Seef	Fanar
Saudi Arabia	Jawad	Fengal	Ghazeer	Asif	Sidrah	Hareed	Faid	Kaseer	Nakheel	Haboob	Bareq	Alreem	Wabil
Sri Lanka	Asani	Shakhti	Gigum	Gagana	Verambha	Garjana	Neeba	Ninnada	Viduli	Ogha	Salitha	Rivi	Rudu
Thailand	Sitrang	Montha	Thianyot	Bulan	Phutala	Aiyara	Saming	Kraison	Matcha	Mahingsa	Phraewa	Asuri	Thara
United Arab Emirates	Mandous	Senyar	Afoor	Nahhaam	Quffal	Daaman	Deem	Gargoor	Khubb	Degl	Athmad	Boom	Saffar
Yemen	Mocha	Ditwah	Diksam	Sira	Bakhur	Ghwyzi	Hawf	Balhaf	Brom	Shuqra	Fartak	Darsah	Samhah

2023:

Bay of Bengal Region

- Cyclone Mocha
- Cyclone Biparjoy (June): Arabian Sea- Gujarat Impact
- Cyclone Michaung
- Cyclone Remal
- Cyclone Asna

2024: Bay of Bengal

- Cyclone Dana (October)
- Cyclone Fengal (November)

Next name till unused but in list

- Shakhti *(unused)*

- Montha *(unused)*
- Senyar *(unused)*
- Ditwah *(unused)*

List of Cyclones that hit India from 2019 to 2024

Cyclone Name	Dates	Peak Intensity	Affected Areas	Damage (USD)	Fatalities
Cyclone Pabuk	Jan 4 - Jan 8, 2019	Tropical Storm	Andaman Sea	Minimal	None
Cyclone Fani	Apr 26 - May 4, 2019	Extremely Severe (175 km/h)	Odisha, West Bengal	$8.1 billion	89
Cyclone Vayu	Jun 10 - Jun 17, 2019	Very Severe (135 km/h)	Gujarat	Moderate	None
Cyclone Hikka	Aug 6 - Aug 9, 2019	Very Severe (120 km/h)	Oman (minimal impact in India)	Minimal	None
Cyclone Kyarr	Oct 24 - Nov 2, 2019	Super Cyclonic (220 km/h)	Arabian Sea (no direct impact on India)	Minimal	None
Cyclone Maha	Oct 30 - Nov 7, 2019	Extremely Severe (150 km/h)	Arabian Sea (no direct impact on India)	Minimal	None
Cyclone Bulbul	Nov 5 - Nov 11, 2019	Very Severe (110 km/h)	Odisha	Moderate	None
Cyclone Pawan	Dec 2 - Dec 7, 2019	Tropical Storm	Arabian Sea	Minimal	None
Cyclone Amphan	May 16 - May 21, 2020	Extremely Severe (260 km/h)	West Bengal	$13 billion	128
Cyclone Tauktae	May 17 - May 26, 2021	Extremely Severe (210 km/h)	Gujarat	$8.1 billion	170
Cyclone Yaas	May 23 - May 26, 2021	Very Severe (130 km/h)	Odisha	$610 million	None
Cyclone Jawad	Dec 2 - Dec 6, 2021	Very Severe (120 km/h)	Andhra Pradesh, Odisha	Minimal	None
Cyclone Asani	May 8 - May 12, 2022	Very Severe (130 km/h)	Andhra Pradesh	Minimal	None
Cyclone Mandous	Dec 9 - Dec 12, 2022	Very Severe (120 km/h)	Tamil Nadu	Moderate	None
Cyclone Sitrang	Oct 22 - Oct 25, 2022	Tropical Storm	Assam, Odisha, West Bengal	Minimal	None
Cyclone Biparjoy	Jun 6 - Jun 15, 2023	Extremely Severe (195 km/h)	Gujarat	$700 million	None
Cyclone Remal	May 24 - May 28, 2024	Severe (110 km/h)	Odisha	$600 million	None
Cyclone Asna	Aug 25 - Sep 3, 2024	Tropical Storm	Madhya Pradesh	$30 million	None
Cyclone Dana	Oct 24 - Oct 25, 2024	Expected to be Severe	Odisha, West Bengal	$72 million (Rs. 600 crore)	Affected 14 districts in Odisha, impacting over 41 lakh people across 166 blocks.
Cyclone Fengal	Nov 25-Nov 27, 2024	Expected to be Deep Depression	Tamil Nadu and Puducherry		

Thunderstorms and Tornadoes

Thunderstorms and tornadoes are brief but highly destructive, typically limited to a small area

Thunderstorms:

- A well grown cumulonimbus cloud producing thunder and lightning. •
- Caused by intense convection during hot, humid conditions.
- Short duration occurring over a small area; Violent in nature.

- • When these clouds reach altitudes with subzero temperatures, hailstones form and fall as hailstorms. In cases of limited moisture, dust storms are created.

Tornadoes:

- Sometimes severe thunderstorms generate a spiralling wind with very low pressure at the center that descends like the trunk of an elephant, causing massive destruction on its way; generally occur in middle latitudes; tornadoes over the sea are called waterspouts.

CLOUDBURST

- Cloudburst is a sudden heavy rainstorm event over localised area within short time frame.
- Cloudbursts are short-duration, intense rainfall events over a small area.
- This phenomenon is characterized by the rapid release of moisture from cumulonimbus clouds, often during thunderstorms.

FEATURES

- Cloudbursts are highly localized
- small geographical area and less time frame
- Extreme Rainfall Rates
- Accompanied by Thunderstorms and may also involve hail.
- Rapid Onset: The onset of rain during a cloudburst is very sudden, leading to immediate impacts such as flooding
- Formation of Cumulonimbus Clouds

Details Facts :

- Rain over 100mm per hour is categorised as a cloudburst.
- Rainfall of 10 cm or more in an hour over a roughly 10 km x 10-km area is classified as a cloudburst event.
- By this definition, 5 cm of rainfall in a half-hour period over the same area would also be categorized as a cloudburst.
- Several studies have shown that climate change will increase the frequency and intensity of cloudbursts in many cities across the globe

CONSEQUENCES OF CLOUDBURSTS:

- resulting in heavy downpours
- Flash floods.
- Landslides
- Mudflows
- Loss of Life and Property
- Impact on Infrastructure and Development

RECOMMENDED PRACTICES FOR IMPROVING CYCLONIC RESISTANCE OF DWELLINGS/LOW-RISE BUILDINGS

Geomorphic Characteristic of Coastal Ecosystems

1. Beaches
2. Sand dunes and bars
3. Rock cliff and rocky foreshores
4. Estuaries , lakes and lagoons
5. Mud and tidal flats
6. Delta, Salt Marshes and Tidal inlets
7. Low land coast spit and barrier islands

1. Beaches

- Buffer against coastal erosion
- Habitat for many plants and animals
- Spawning ground for turtles
- Energy base to support the diverse population of deposit and filter feeding organisms
- Energy sources for coastal birds and fish
- Aesthetics

2. Sand Dunes and bars

- Sand reserve for protection and stability of the coast
- Shelter for supply and recharge of fresh water aquifer
- Habitat for Several p and Animals
- Important tourism and recreational measure

Threat to Beaches and Sand Dunes and Bars :

- Industrial citing
- Sand mining
- Development and unplanned Urbanization
- Engg structures that affect coastal erosion
    - Mining for mineral and construction
    - Road Rail and other infrastructure dev

Need :

- Demarcate setback line for dev. Control
- Allow beach cycle to return and after cyclone passage
- Conservation of dunes
- Develop artificial dunes and stimulate dune growth
- Restriction of sand mining by promoting usage of alternative material for construction.

Flood

- Indian Agriculture has been heavily dependent on the monsoon rainfall. Droughts and Floods are the two accompanying features of Indian Climate.
- Different regions of the country have different weather and rainfall patterns and, therefore, while some parts face devastating floods, other parts may, at the same time, experience drought conditions

Table 1.1: *Seasonal Distribution of Rainfall in India*

Season	Period	Percentage of Distribution
Pre-monsoon	March-May	10.4
South-west monsoon	June-September	73.4
Post-monsoon (Northeast Monsoon)	October-December	13.3
Winter rains	January-February	2.9

FLOOD

- The temporary overflow of a large amount of water in an area, massivelyaffecting human life, is called a flood.
- Higher water level along rivers/coasts leading to land inundation.
- The National Disaster Management Authority (NDMA) of India defines floods as an overflow of water that submerges land that is usually dry.
- 12 to 15 % India is flood Prone
- About 40 million hectares of land in the country are liable to floods according to the National Flood Commission
- The Nodal Agency for flood Forecasting is: Central Water Commission

CWC:

- Technical organisation that functions as part of the Ministry of Jal Shakti
- Help state governments in devising and analysing flood control measures
- They undertake flash flood forecast as well
- Focus Flood Control, Irrigation, Navigation, Drinking Water Supply and Water Power Development
- HQ Delhi , founded 1945
- 'Water Quality Monitoring Network' consisting of monitoring stations at 552 key locations covering all the major river basins of India

National Water Academy located at Pune is responsible for training of Central and State in-service engineers

Floods in India – Different Agencies for Flood Control in India

1. India Meteorological Department (IMD) – provides rainfall or cyclonic event forecast which is used by all the agencies for preparedness to deal with the floods.
2. National Disaster Management Authority (NDMA) – The job of relief and rescue is carried out by the National Disaster Response Force (NDRF) with state counterparts. NDMA works under Prime Minister Office (PMO) – and National Institute of Disaster Management (NIDM) – works under the Union Ministry of Home Affairs (MHA).
3. Central Water Commission (CWC) – The main job of CWC is to procure the data of hydrology at the national level – like river discharge measurement and water level in dams etc – to alert the states about any imminent or potential flood.

Four Flood Categories According to Central Water Commission flood forecasting network:

- Normal Flood - when the water level of the river is below the warning level.
- Above Normal FLOOD- If the water level of the river at flood forecasting site touches or crosses its Warning level (Yellow Colour)
- SEVERE FLOOD: water level the river at site touches or crosses Danger Level (Orange colour)
- EXTREME FLOOD: the water level of the river touches or crosses the "HIGHEST FLOOD LEVEL" recorded at any forecasting site so far. (Red colour)

Note : Red and Orange Bulletin are disseminated upto the Prime Minister's Office and Cabinet Secretariat and Yellow Bulletins are sent upto Secretaries of various Ministries concerned with flood loss mitigation

Reason :

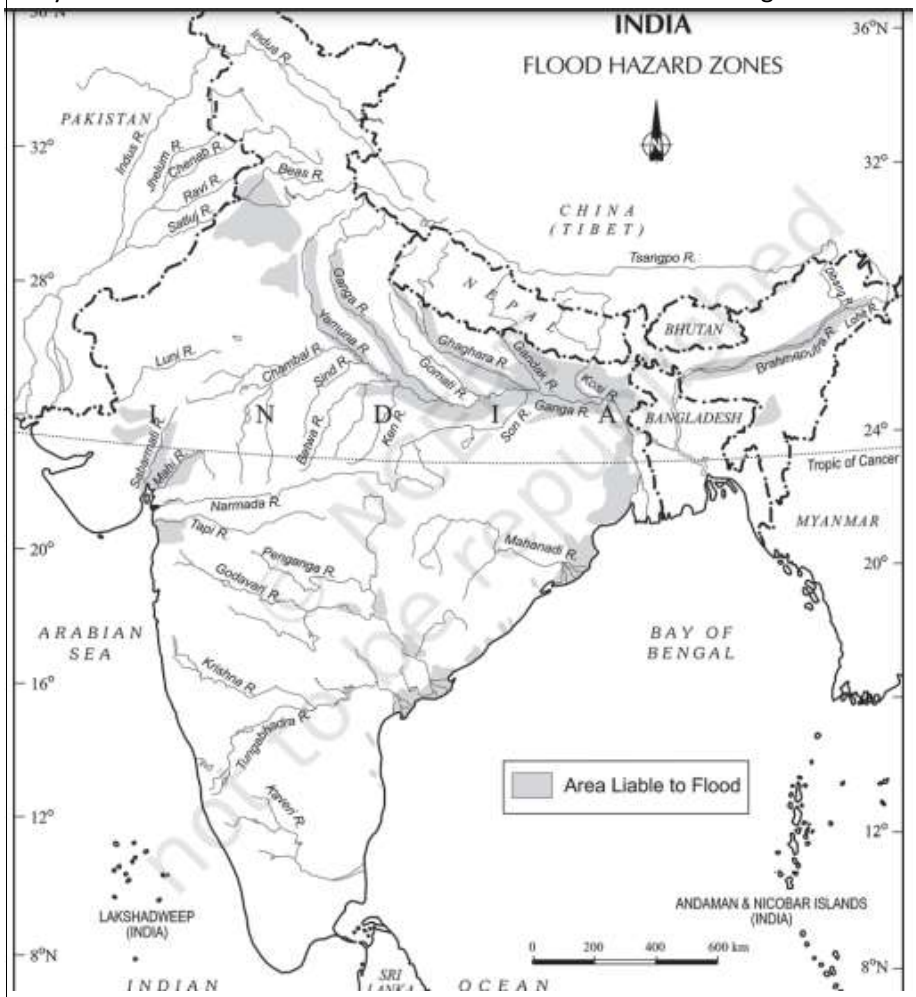
- Low lying regions more prone to floods
- High intensity rainfall or excessive rainfall, Cloud Burst (excessive rain within short period)
- inadequate carrying capacity of rivers, due to siltation. and blockage in the drains
- change in river course
- blocking of river by landslides

- narrowess of river
- Due to storm surge in coastal areas
- breaking of a dam or
- increased flow of water in an area
- strong tides, storms at sea , cyclones and tsunami
- Melting of ice and snow
- Global Warming: Due to the increased rise in global temperature, glaciers of the Himalayan range start to melt. As a result, the seawater level also rises, causing floods in surrounding years

Human Factors: Intensified, Magnitude and gravity of floods

- Human beings play an important role in the genesis as well as spread of floods
- Indiscriminate deforestation
- unscientific agricultural practices
- disturbance along natural drainage channels
- Colonisation of flood plains and river- bedsIncreasing Urbanisation, dumping of Garbage, and Construction of Embankments, roads etc reduce infiltration capacity and increases the surface runoff.

Dam and embankment failure: Dam collapse and river embankment failures due to poor infrastructure can also cause floods
Encroachment on floodplains: Construction and settlement in floodplain areas disrupt the natural flow of water during floods.
Encroachment of water bodies: Encroachment of lakes, ponds and other water bodies aggravates the risk of floods because they cannot contain the extra water when the situation of flooding arrives.



- High Flood Prone Affected Areas shown in Map: Assam, West Bengal and Bihar
- The flood prone regions of India are the
- Himalayan Rivers Basin (Kosi and Damodar Rivers in particular),
- North Western River Basin (Jhelum, Ravi, Sutlej and Beas Rivers) and the central
- Peninsular River Basin (Narmada, Chambal, Godavari, Krishna and Cauvery River).

States	Reason of floods
Punjab, Uttar Pradesh	Vulnerable to Occasional floods

Rajasthan, Gujarat, Haryana ,Punjab	inundated due to flash floods
Tamil Nadu	retreating monsoon during Nov to January
Flood in Orissa and Andhra Pradesh is due to monsoon depression and cyclonic storms	

Examples :

1. Uttarakhand Flood, 2013: Devastating floods with high casualties.
2. Kerala Flood, 2018: Record rainfall led to severe flooding.
3. Brahmaputra Flood, 2019: Significant impact on Assam and surrounding areas.
4. Maharashtra Flood, 2020: Affected Solapur and Pune.
5. Hyderabad Floods: Heavy rains caused flash floods.
6. Kerla flood floods July 2024 – causes 90+ death
7. Delhi flood July 2024

Types of Flood :

- River Floods: These occur when rivers overflow their banks due to excessive rainfall or snowmelt.
- Coastal Floods: These are caused by storm surges during cyclones or high tides, affecting coastal regions.
- Urban Floods: Urban Flood: When the drainage system of urban areas fails to absorb rainwater, it creates urban floods. problem of urban flooding has become serious as evidenced by the floods in Mumbai, Bangalore, Chennai, Vadodara, Ahmedabad, Surat, Kolkata, Hyderabad,

Flash Floods:

- Sudden and intense flooding-- are caused when rainfall creates flooding in less than 6 hours . FF are usually associated with cloud burst, storms and cyclones. Flash floods occur due to high rate of water flow as also due to poor permeability of the soil.
- They can occur in urban areas located near small rivers, since hard surfaces such as roads and concrete do not allow the water to absorb into the ground.

Glacial Lake Outbursts Flood (GLOF):

- Is a type of flood where sudden release of water from a glacial lake that can lead to catastrophic flooding downstream
- Shrinking glaciers have led to the formation of a large number of glacial lakes all across the himalayas.
- Many of these high-altitude lakes are potentially dangerous, because of their potential to cause flash floods
- Many of the big glaciers which have melted rapidly and gave birth to the origin of a large number of glacier lakes.
- These include regions like Himachal Pradesh, Sikkim, Ladakh, Arunachal Pradesh, Jammu & Kashmir, and Uttarakhand.

Consequences:

- Floods have serious consequences on the national economy and society
- Destruction of settlements
- Damage to infrastructure
- Displacement: Floods result in a humanitarian crisis and displacement of the people
- Loss of lives and property
- Spread of disease - cholera, Hepatitis
- Contamination of water supplies
- Crop Loss and Livestock Loss
- Environmental impacts: Floods cause soil erosion, sedimentation, and degradation of ecosystems
- The impact on those affected may cause psychological damage to those affected, in particular where deaths, serious injuries and loss of property occur

Positive Side:

- Fertile Silt deposition
- Recharging water sources: Inundation of the flood plains helps recharge the groundwater, which is an important source of drinking water and is essential for agriculture.
- Rejuvenation of the river ecosystem: The river ecosystem is crucial for the biodiversity of fish, wildlife, and waterfowl, and its seasonal variability and varied sediment and flow regimes help maintain this balance.
- Agriculture: Floodwaters carry nutrients and sediments, which are deposited on flood plains, enriching the soil. Rice paddies are flooded deliberately to take advantage of this natural fertilisation process

Institutional Mechanism for Flood :

- Central Water Commission (CWC): It was set up in 1945 and focuses on flood control, water resource conservation, irrigation, hydropower generation, flood management, and river conservation in the country..
- National Disaster Management Authority (NDMA): NDMA has prepared these Guidelines for Flood Management, to assist the ministries and departments of the GOI, the state governments, and other agencies in preparing Flood Management plans (FMPs).

- The National Water Policy (2012): It emphasises flood control through structural measures, integrated reservoir operation, natural drainage system rehabilitation, farming systems, and non-agricultural development, aiming for long-term solutions to devastating floods.
- Flood Forecasting Network: The CWC has implemented a flood forecasting system with 175 stations across major interstate rivers, enabling real-time data collection, automatic transmission, flood forecast formulation, and efficient information dissemination.
- Flood Management and Border Areas Programme (FMBAP): It is being implemented throughout the country for effective flood management, erosion control, and anti-sea erosion and to help maintain peace along the border.
- Structural Measures: Since 1954, the government has constructed 33,928 km of new embankments and 38,809 km of drainage channels, completed 2,450 town protection works, and raised 4,721 villages above flood levels.
- Post-disaster response and recovery: India has set mechanisms for the post-disaster response, such as search and rescue operations, relief and rehabilitation camps, NDRF forces, and the use of earth observation satellites.
- Cooperation with the neighbouring countries: India has cooperation with neighbours like Nepal, China, and Bhutan for the exchange of hydro-meteorological data for early preparedness of flood management.

M4 Strategy: Mitigation Strategy

- Mapping: E.g., Hazard maps, Identify flood-prone areas
- Manpower: E.g., Trained personnel.
- Money: E.g., Funding and resources.
- Media: E.g., Awareness campaigns and disseminate information.

Flood Management :

1. Redistribution of Excess Water Reduces flood severity in high-risk zones and Reduced Flood Risks by Integrating river link projects
2. Interlinked river systems can enhance drainage capacities in flood-prone areas.
3. Floodplain Utilization-Utilizes floodplains for water storage and management
4. Efficient Water Management: The Indira Gandhi Canal Project can manage floodwater for irrigation and storage. o Benefit: Balances water distribution and reduces flood risks

Flood :

1. Flood Mapping: E.g., Hazard maps.
2. Land Use Control: E.g., Zoning regulations.
3. Optimized Engineering Structures: E.g., Raised platforms.
4. Ongoing Flood Forecasting: E.g., IMD updates.
5. Development of Early Warning Systems: E.g., Real-time alerts

NDMA Guidelines :

Structural Measures:

- Storage Reservoirs/Dams: E.g., Kosi Barrage.
- Embankments/Levees: E.g., Brahmaputra Embankments.
- Drainage Improvement: E.g., Urban drainage projects.
- Channel Improvement: E.g., River dredging.
- Catchment Area Treatment: E.g., Afforestation.
- Construction of Floodwater Storage Structures
- Diversion of Flood Water: E.g., Flood diversion projects.
- Linkages of Rivers: E.g., River linking projects. Implementing River Linking Projects:
- Building Check Dams-Example: Rajasthan's Johads are traditional check dams that capture and store floodwaters for irrigation and groundwater recharge.
- Creating Floodwater Harvesting Pits-Example: Maharashtra's Zai Pits capture and store rainwater from floods to recharge groundwater and support agriculture
- Creating Flood-Proof Infrastructure-Example: Kerala's Kuttanad Region utilizes flood-resistant infrastructure to manage floodwaters and support agriculture.
- Revitalizing Traditional Water Management Systems-Example: The Andhra Pradesh's Tank System uses traditional tanks to store and manage floodwaters for irrigation

Non-Structural Measures:

- Implementation of Flood Plain Zoning: E.g., Zoning regulations (Ministry of Jal Shakti.)
- Flood Proofing: E.g., Raised platforms.
- Flood Management Plans: E.g., Integrated water resources.
- Flood Forecasting: E.g., IMD’s forecasting system.
- Flood Mapping: E.g., Hazard maps.
- Integrating Flood Forecasting and Early Warning Systems: o Example: The Central Water Commission (CWC) provides flood forecasts to help manage and utilize floodwaters effectively.
- Legislations: E.g., Flood risk management laws.

- Awareness: E.g., Public education campaigns.
- Flood Insurance: E.g., Risk coverage policies.
- International Cooperation: E.g., China-Kosi collaboration., India Nepal Cooperation
- Use of space technology
- The capacity development covers the aspects of flood education, target groups for capacity development, capacity development of professionals, training, research and development and documentation with respect to flood management

FLOOD AND DROUGHTS AND INTERLINKING OF RIVERS

Interlinking of Rivers Question:

1. Interlinking of rivers may serve as a major source of assured irrigation and all weather inland navigation in India. Comment on its feasibility taking into account physical, economic, and ecological implication. 20 marks UPSC mains optional 2017
2. Interlinking of rivers may address the issue of paucity of water but poses a serious threat to the indigenous ecological diversity of the said rivers. Comment.
3. The concept of scarcity and surpluses of water must look beyond State Boundaries

INTERLINKING OF RIVERS

Aim : transfer water from surplus to water deficit areas in the country through Inter- Basin water transfer links.

BACKGROUND : Evolution of the Idea

- Father of Inter Linking of River : Sir Arthur Cotton, 1858, British Irrigation Engineer, draws up plan to Interlink major Indian rivers for export and Import; address water shortages and droughts in South Eastern India ; Boost Inland Navigation.
- In 1970s- Dr K. L. Rao , Former Irrigation Minister - Proposed ' National Water Grid'.
- Suggested Ganga and Brahmaputra river surplus areas and central and south India water deficit linking .
- In 1977 - Captain Dastur Proposal : Construction of Canals - Himalaya and Garland Canal
- In 1980, National Prespective Plan- NPP (then Ministry of Irrigation- Now Ministry of Jal Shakti)
- In 1982, National Water Development Agency Set up for NPP; identified 30 links.
- In 2002. Task Force Set Up for Inter Linking Rivers.
- Hashim Commission Report - 2004 -2005
- In 2012, Supreme Court directed Centre to constitute expert committee
- In 2015, B. N. Navalawala Committee : Task Force For Interlinking of Rivers.
- In 2016, Pattiseema Lift Irrigation Project and Ken Betwa Link (First Interlinking of India)
- Now NPP - Called as " National River Linking Project "

BENEFITS :

- Management of Drought Prone and Flood Prone Regions by River Interlinking .
- Mitigate water deficiency and decrease the chances of recurring floods.
- Enhancing the availability of water in drought prone and rain- fed area.
- Ensure Ecological Security - To Address Water Crisis and water redistribution.
- Ensuring Food Security; Hunger ; (Benefits 35 Million hectare of irrigation) from 140 to 175 million hectare Irrigation Potential Increase .
- Contain Migration(Rural to Urban)
- Ensure Health Security - Boost Drinking water availability .
- Distribution Pattern of Rainfall in India is Uneven (Large scale Spatial-Temporal Variation)
- Decrease Crop Failure and Farmers Suicides
- Optimum Use of Water Resources and Promises Water Conservation efforts.
- Solve the water crisis by providing alternative, perennial water resources;
- Need Not to have wait for good monsoon and build storage reservoirs .
- Regional Imbalance of river water can be reduce -Benefits to Farmers
- Energy Security - Increase in Hydropower Potential (Increase 34000 MW electricity)
- Water Security - Increase Ground water recharge
- About 85% of groundwater is used for irrigation every year in our country
- Increase water consumption demand due to rise in population (in India)
- Irregular distribution of Water can be overcome.
- Improve Irrigation Pattern , Inland Navigation and Agricultural Food Production.

- Inland Waterways - boost River tourism
- Boost Rural Economy and Annual Income for farmers and Reduce Poverty
- Employment Opportunities will also Increases. (agriculture, power, transport & construction sector)
- Increase overall economic activities of the country and increase GDP
- Helps to Promote Sustainable Development and Ensure greater equity.
- Ensure National Integration; Boosting Communal Harmony ; Foster Cooperative Federalism .

CHALLENGES IN NATIONAL RIVER LINKING PROJECT :

- Loss in Forest Cover and threat to biodiversity .
- Ken - Betwa Interlink Impact Panna Tiger Reserve.
- Change in Physiography may Increase Environmental Issues
- May allow free transport of invasive alien species may affect biodiversity.
- Conflicts of States ex Karnataka and Tamilnadu Cauvery River Issue
- Increase of Economic Cost (expenditure and maintenance cost) and Social Cost (displacement of people)

DISADVANTAGES :

- Political Challenges; Economic and Environmental Challenges; International Challenges
- Socio -Economic- Political and Environmental Implications:
- Economic Implications: Need Huge Capital Investment for dams and reservoir
- Social Implications : Displacement of People and Tribal communities; Rehabilitation Issue
- Social Unrest and Psychological Damage due to forced resettlement of the people;
- Environmental Costs: Deforestation; Soil Erosion and Sedimentation; River Pollution ;
- River may change their course
- Water Logging, More Evaporation loss, Salinity ; Land Submergence ;
- Ecological Implications : Disturb ecological imbalance; Impact Habitat, Ecological Niche and Home range of animals ; Threat to Biodiversity and Impact Protected Areas.
- Political Effects: strained relationships with neighbours (Pakistan , Bangladesh); Challenges in Coordination with these countries .
- Water being State Subject - difficult to resolve issues of water sharing between States.

Government Measures :

- Detailed planning of this mega-Civil Engineering project - National Perspective Plan - is being undertaken by the National Water Development Agency (NWDA) under Ministry of Jal Shakti .
- Under this project, 30 links and some 3000 storages will connect 37 Intra State -Himalayan and Peninsular rivers.
- Two Components : Himalayan (14 canal links)and Peninsular Component (16 canal links).
- The Ken Betwa Link Project is the first river interlinking project in India.
- The National Water Development Agency (NWDA) is the authority for the interlinking of rivers
- Central government thinks for NIRA- National Interlinking of Rivers Authority as independent autonomous body and replace NDWA.

PROJECTS IN HIMALAYAS :

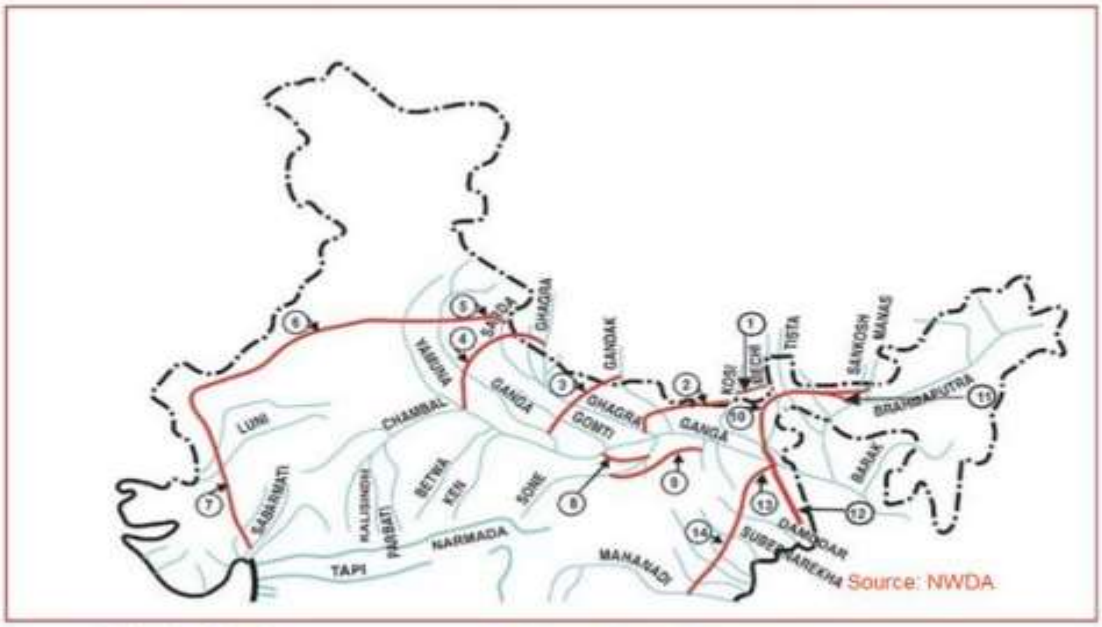
- Under this component, 14 Links have been identified.
- And Construct Storage Reservoir on Ganga and Brahmaputra Basin in India and Nepal.
- Conserve Monsoon Flow for Irrigation and Hydropower generation, along flood control.
- The linkage will transfer surplus flows of the Kosi, Gandak and Ghagra to the west.
- A link between the Ganga and Yamuna is also proposed to transfer the surplus water to drought-prone areas of Haryana, Rajasthan and Gujarat.

PROJECTS IN THE PENINSULAR COMPONENT:

- Include 16 Links Part of Southern Water Grid.
- Connect Rivers of South India
- It envisages linking the Mahanadi and Godavari to feed the Krishna, Pennar, Cauvery, and Vaigai rivers.
- This linkage will require several large dams and major canals to be constructed.
- Besides this, the Ken River will also be linked to the Betwa, Parbati, Kalisindh, and Chambal rivers.

PROPOSED INTER BASIN WATER TRANSFER LINKS

HIMALAYAN COMPONENT

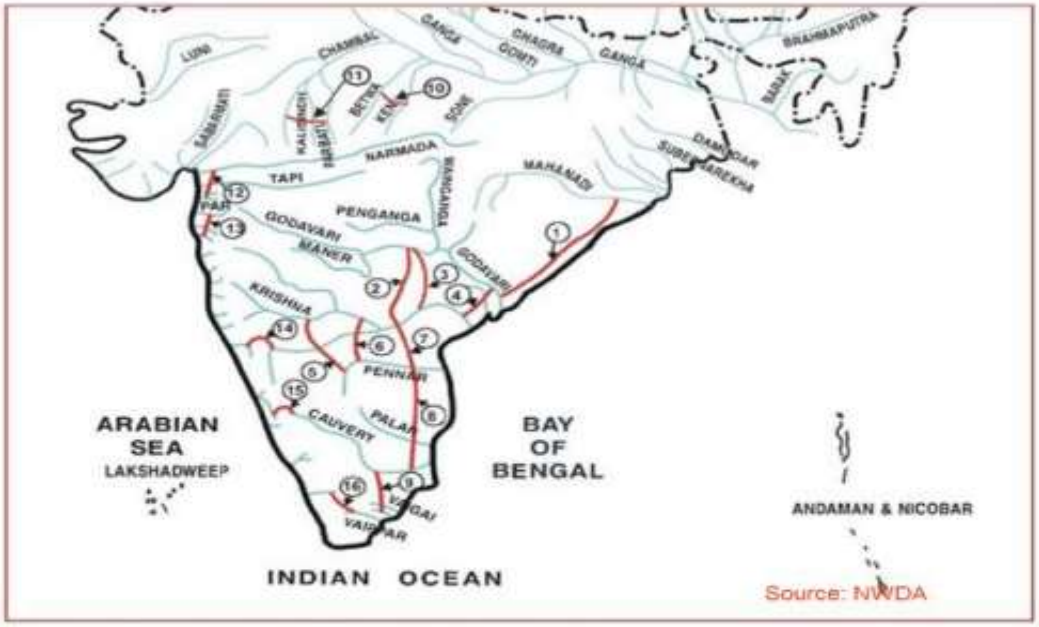


1. Kosi – Mechi
2. Kosi – Ghagra
3. Gandak – Ganga
4. Ghagra – Yamuna *
5. Sarda – Yamuna *
6. Yamuna – Rajasthan
7. Rajasthan – Sabarmati
8. Chunar- Sone Barrage
9. Sone Dam – Southern Tributaries of Ganga
10. Manas –Sankosh - Tista - Ganga
11. Jogighopa – Tista – Farakka (Alternate)
12. Farakka – Sunderbans
13. Ganga (Farakka) – Damodar – Subernarekha
14. Subernarekha – Mahanadi

* FR Completed

PROPOSED INTER BASIN WATER TRANSFER LINKS

PENINSULAR COMPONENT



1. Mahanadi (Manibhadra) – Godavari (Dowlaiswaram) *
2. Godavari (Inchampalli) – Krishna (Nagarjunasagar) *
3. Godavari (Inchampalli) – Krishna (Pulichintala) *
4. Godavari (Polavaram) – Krishna (Vijayawada) *
5. Krishna (Almatti) – Pennar *
6. Krishna (Srisailam) – Pennar *
7. Krishna (Nagarjunasagar) – Pennar (Somasila) *
8. Pennar (Somasila)–Palar- Cauvery (Grand Anicut) *
9. Cauvery (Kattalai) – Vaigai – Gundar
10. Ken – Betwa *
11. Parbati – Kalisindh – Chambal *
12. Par – Tapi – Narmada *
13. Damanganga – Pinjal *
14. Bedti – Varda
15. Netravati – Hemavati
16. Pamba – Achankovil – Vaippar *

* FR Completed

ALTERNATIVE APPROACHES :

- Increase watershed development and Rain water Harvesting
- Change in Appropriate Cropping Pattern

- Nature Based Solution- Indigenous Knowledge
- Focus more on Water Conservation Practices and Community Participation.
- Water use Efficiency and Micro Irrigation Methods- Drip and Sprinkler
- Intensive Afforestation Measures

Way Forward :

- Interlinking is Contentious Issue requires Balance between Potential Benefits and Risk.
- Urgent Need to Examine the feasibility of Inter Linking of Rivers
- Detailed Hydrological, Geological, Meteorological, and Environmental Analysis of the Project Should be done .
- Detailed Analysis Should be done for Other Possible Alternatives than Concerned Project .
- Rehabilitation and Relief Package to resolve development displacement issue .
- Including Local Communities, Farmers, Environmentalist in Planning and Implementation Projects .
- interlinking of rivers may be pursued in a decentralized manner
- In 2011 Ashok Chawla Committee -underscored the need for a comprehensive national legislation on water either by bringing water in the Concurrent List or through a legal framework for treating water as a unified common resource. Some Recommdations of Mihir Shah Committee.
- Central Water Commission (CWC) and the Central Ground Water Board (CGWB) should be restructured and unified to form a new National Water Commission (NWC)- will help ensuring sustainable management of water resources
- to develop a cost-effective and suitable technology to recycle and reuse urban and industrial wastewater.
- to formulate and implement programs to control pollution of water bodies and aquifers.

EXAMPLES

- Polavaram irrigation Project (National Project Status) - On Godavari River in Andhra Pradesh transfering river water to Krishna River Basin; Boost to Reservoir based tourism in Papikonda National Park.
- Pattiseema Lift Irrigation Scheme: Connecting Godavari - Krishna River ; Owner Andhra Pradesh
- Ken Betwa Link Project : Ken Surplus water diverted to Deficit Betwa Basin and provide water security in Backward Bundelkhand region of Madhya Pradesh and UP but impact Panna Tiger Reserve (Daudhan Dam- Ken River inside Panna Reserve)

DAMANGANGA - PINJAL LINK PROJECT :

- Damanganga Emerges From Western Ghats Nashik (MS) And Travels To Arabian Sea.
- Flows Through - Maharashtra, Gujarat, DNH And Daman & Diu.
- The Industrial Towns Of Vapi, Dadra And Silvassa Lie On The North Bank Of The River, And The Town Of Daman Occupies Both Banks Of The River's Mouth
- Damanganga Surplus Water Diverted To Deficit Pinjal River
- Pinjal River -Emerges From Palghar, MS. (Benefits To Mumbai Region)

Par - Tapi - Narmada Link Project :

- Transfer water from Western Ghats Region to Saurashtra and Kutuch (water deficit areas)
- Linking Seven Reservoirs in North Maharastra and South Gujarat
- The seven dams proposed in the scheme are Jheri, Mohankavchali, Paikhed,Chasmandva, Chikkar, Dabdar and Kelwan

Parambikulam Aliyar river project

- Between Kerala -Tamilnadu
- Linking Bharatapuzha and Kaveri Basins
- Benefits Drought Prone Region Coimbatore, TN and Chittur Area of Kerala

Telugu Ganga river Project:

- Krishna River to Penner River
- Andhra Pradesh to Tamilnadu
- Help to Chennai metropolitan area for drinking and irrigation purpose
- Help to Drought Prone Region - RayelSeema , Andhra Pradesh
- Srisailam Reservoir of Krishna - canal linking to - Somasila Reservoir in Pennar Valley .

Manas-Sankosh-Teesta-Ganga (M-S-T-G) link project

- Key Part of Himalaya Component under NRLP.
- Diversion of Surplus water from Manas and Sankosh to Ganga Region,

Kosi-Mechi Interlinking project of Bihar

- Second interlinking project after Ken -Betwa in MP
- Helps to mitigate flood in Kosi River
- Mechi, a tributary of river Mahananda.
- Eastern Kosi Main Canal (EKMC) system provide irrigation benefits to the water scarceMahananda basin command
- Mahananda rises from Darjelling Hills, Basin Includes West Bengal and Bihar
- It is spread over districts of Purnea, Kishanganj, Araria and Katihar in Bihar and Malda, West Dinajpur and Darjeeling in West Bengal.

DAMS

- India ranks third after China and USA
- Total Dams : 5334 (Including 400 Key dams)
- These Artificial barrier resulting reservoir used for :

Benefits :

- Key role in Sustainable Development and Resource Management
- Irrigation
- Hydropower generation
- Flood control
- Groundwater Recharge
- Facilitating Navigation, Aquaculture,
- Supplying water for human consumption
- Supporting diverse sectors and contributing socio-economic development of the Region.
- Tourism Potential

Concerns

- Displacement and Rehabilitation Issues of community
- Threat to Ecological Habitat and Niche- Negative Impact on Ecosystems and Biodiversity
- Sedimentation and Siltation- accumulation of silt in reservoirs reduce storage capacity; Impact dam efficiency
- Maintenance and cost
- Safety concerns of the dams resulted in loss of life and damage to property

Key Facts :

- Highest Dam : 260 M Height - Tehri Dam, Bhagirathi river, Uttarakhand
- Largest Dam: Bhakra Nangal Dam ,Sutlej River in Himachal Pradesh - Punjab Border
- Longest Dam : Hirakud Dam. Mahanadi river
- Largest Masonry Dam : Nagarjuna Sagar , Krishna river, Telegana (World Largest Artifical lake)
- Oldest Dam : Kallanai Dam , Kaveri River, Tamilnadu

TOP 10 LARGEST DAMS IN INDIA ARE AS FOLLOWS:		
Tehri Dam Bhagirathi	Uttarakhand	260.5 m Highest Dam in India
Bhakra Nangal Dam Sutlej	Himachal Pradesh	226 meters
Lakhwar Dam Yamuna	Uttarkhand	204 meters
Idukki Dam Periyar	Kerala	168.91 meters
Nagarjuna Sagar Dam Krishna	Telangana/Andhra Pradesh	124 meters
Sardar Sarovar Dam Narmada	Gujarat	163 meters
Hirakud Dam Mahanadi	Odhisha	60.96 m Longest Dam in India
Indira Sagar Dam Narmada	Madhya Pradesh	92 meters
Mettur Dam Kaveri	Tamil Nadu	37 meters
Almatti Dam Krishna	Karnataka	160 meters

DAM FAILURE ?

- A “collapse or movement of part of a dam or its foundation, so that the dam cannot retain water.
- In general, a failure results in a release of large quantities of water imposing risks on the people or property downstream

Reasons for Dam Failure ?

- Geological Instability - Tectonic induced calamities like landslides , earthquakes
- seismic damage by earthquakes
- Design Limitations - Imporper materials ; underestimated water flow calculations, can result in structural weaknesses ; foundational defects
- extreme weather events
- Glacial lake outburst flood ex Sikkim Floods
- Unprecedented Rains ex Kerala Floods 2018
- Structural flaws due to engineering and structural deficiencies
- Human factors -Lack of Maintainence ; Poor operational decisions

- Age of Dam -like the Mullaperiyar dam, are over a century old and have witnessed disputes owing to concerns regarding their structural integrity with age, stressing the requirement for continuous assessment and reinforcement of aging dams.

Catastrophic Consequences of Dam Failures on the Downstream Side

- Loss of Lives: The Machchhu dam failure in 1979 is a heart-wrenching testament to the human toll of dam failures, with thousands of lives lost in a tragic event that shook the nation.
- Massive Property Damage
- Ecological Destruction: The Ratnagiri dam failure in 2019 in Maharashtra brought to the fore the severe environmental repercussions of dam failures, causing an ecological imbalance with the loss of flora and fauna, thereby underscoring the need for eco-friendly preventative measures.
- Displacement: The concerns surrounding the Idukki Dam in Kerala, emphasize the enormous social issue of displacement, where communities risk losing their homes and livelihoods, creating a cycle of poverty and homelessness that is difficult to break.
- Long-term Psychological Impact: The survivors of the Francis Dam failure in 1928 in the USA endured long-term psychological trauma, a testimony to the mental health toll dam failures can inflict on individuals, ranging from PTSD to anxiety disorders

Two examples of large dam failures:

1. Kakhovka Dam failure: In June 2023, the dam in Ukraine was breached, leading to extensive flooding along the lower Dnieper River. Many experts believe that Russian forces likely deliberately damaged a segment of the dam to hinder the Ukrainian counter-offensive.
2. Polavaram Dam Failure – In August 2022, the Polavaram dam in Andhra Pradesh failed to contain the floodwaters of the Godavari river, leading to massive floods in the surrounding areas.

Efforts by Government:

- Proactive measures, such as robust maintenance, monitoring, and community preparedness, are imperative to prevent catastrophic dam failures and safeguard lives and property
- Dam safety act 2021: The Act provides for the surveillance, inspection, operation, and maintenance of all specified dams across the country.
- DRIP project: World Bank assisted Dam Rehabilitation and Improvement Project (DRIP), to improve the safety and operational performance of selected dams, coupled with institutional strengthening through a system wide management approach

Conclusion

While dams remain indispensable to India's developmental goals, safety cannot be compromised. By crafting policies inspired by global success stories and grounded in community participation and technological advancements, India can ensure the safe and sustainable operation of its dams, safeguarding countless lives and precious resources

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