GLACIAL LAKE OUTBURST FLOODS (GLOF)

SYLLABUS:

GS 3 > Disaster Management > Disaster mitigation > Floods

REFERENCE NEWS:

- Recently, Nepal experienced a catastrophic Glacial Lake Outburst Floods (GLOF) event which **caused a flash flood** along the Lende river flowing from Tibet to Nepal, and washed away a **China-built friendship bridge**. The bridge had serviced the 10-year old inland container port at Rasuwagadhi in Rasuwa (north of Kathmandu).
- The GLOF was caused by the breach of a **supra-glacial lake** (formed in **depressions on glaciers from meltwater**, highly prone to melting in the summer months), whose surface **area dropped from 63 ha to 43 ha in a day.**
- On the same day, **another GLOF occurred in Mustang district** in Nepal (north-west of Kathmandu).
- With **rising temperatures and subsequent glacial melt**, the increased risk of GLOFs is threatening life and property in the higher Himalayas.

WHAT IS GLOF?

- A Glacial Lake Outburst Floods (GLOF) is a type of flood occurring when **water dammed by a glacier or a moraine is released suddenly.**
- When glaciers melt, the water in these glacial lakes accumulates behind loose naturally formed **'glacial/moraine dams' made of ice, sand, pebbles and ice residue.**
- Unlike earthen dams, the **weak structure of the moraine dam leads to the abrupt failure** of moraine dam on top of the glacial lake, which holds large volume of water.
- A catastrophic failure of the moraine dam can release the water over periods of minutes to days causing extreme downstream flooding.
- **Glacial retreat due to climate change occurring in most parts of the Hindu Kush Himalaya** has given rise to the **formation of numerous new glacial lakes**, which are the major cause of Glacial Lake Outburst Floods (GLOFs).

STATS:

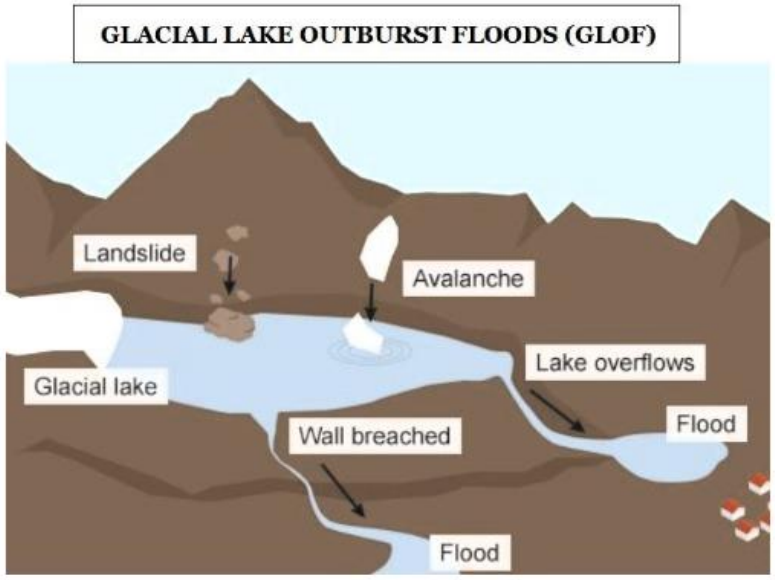
- As per **India's National Remote Sensing Centre**, the **Indian Himalayan Region (IHR)** is home to **11 river basins and 28,000 glacial lakes**.
- There are **two prominent types** of glacial lakes found in the IHR.
    1. The first are **supraglacial lakes**, formed in depressions on glaciers from meltwater, highly prone to melting in the summer months.
    2. The second are **moraine-dammed lakes**, formed by meltwater at the toe/snout of a glacier, dammed by loose debris or ice-cores, making them prone to sudden failure.
- Almost **two-thirds of GLOF events are triggered by ice avalanches or landslides**, and the remaining due to excessive meltwater pressure on weak moraine dams and earthquakes.
- The National Disaster Management Authority (NDMA) has identified **188 glacial lakes** in the Himalayan regions as potential **threats for breach due to heavy rainfall**, with **13 of these located in Uttarakhand.**
- **Rising surface temperatures** across the globe, including India, have increased the risk of GLOFs.
- The study published in *Nature Communications* reveals that approximately **15 million people worldwide** are at risk from Glacial Lake Outburst Floods (GLOFs), a threat that spans globally and not confined to India alone. Crucially, the research points out that **over half of this at-risk population** is concentrated in **just four nations: India, Pakistan, Peru, and China.**
- With **2023 and 2024 being the hottest years on Earth**, extreme temperatures in smaller geographies have been higher, thereby causing more glacial melt in certain pockets, making some glacial lakes highly risky.

Uttarakhand has witnessed **two major GLOF events** in the past few years. The first took place in **June 2013**, which affected large parts of the state, and **Kedarnath Valley** was the worst hit, where thousands of people died. The second occurred in **February 2021**, when **Chamoli district** was hit by flash floods due to the bursting of a glacier lake.

CAUSES OF GLOFs

- **Earthquake:**
    - An earthquake (Tectonic) or cryoseism (non-tectonic seismic event of the glacial cryosphere) can also cause GLOF.
    - During this, the boundary of the glacial lake will collapse suddenly and release the water in the glacial lake.
- **An avalanche of rock or heavy snow:**
    - During this, the water in the glacial lake might be displaced by the avalanche.
- **Volcanic eruptions**
    - Volcanic eruptions under the ice can also cause GLOF.
    - These volcanic eruptions might displace the boundary or increase the pressure on glacial lake or both.
- **Increase in flow of water:**
    - **A buildup of water pressure or structural weakness of boundary** due to an increase in the flow of water.

- **Heavy rainfall/melting of snow:**
  - This can lead to massive displacement of water in a glacial lake.
- **Long-term dam degradation can also induce GLOF.**



CONSEQUENCES OF GLACIAL LAKE OUTBURST FLOODS (GLOF):

- **Loss of Life and Property:**
  - The **Kedarnath disaster** in 2013, triggered by heavy rainfall leading to glacial melts, resulted in **over 5,000 deaths**.
  - This event underscores the devastating potential of GLOFs on human life and property. The sudden and overwhelming flow of water can wipe out entire communities, as seen in Uttarakhand.
- **Infrastructure Damage:**
  - The **2021 GLOF event in Rumbak, Ladakh**, caused extensive damage to infrastructure, including roads and bridges.
  - Such damage not only has immediate consequences but also long-term impacts on connectivity and economic activities in the region.
  - Also, **2023 South Lhonak GLOF (Sikkim)** destroyed the ₹2,000 crore **Chungthang Dam** and worsened downstream floods by silting and debris. **Teesta riverbed** has since **risen by several metres**, reducing its carrying capacity — a sign of cumulative risk to future infrastructure.
- **Agricultural Devastation:**
  - In 2014, the **Gya village in Ladakh** experienced a GLOF that **destroyed farmlands and crops**, illustrating how these events can also devastate agriculture, a critical source of livelihood for many.
  - The loss of agricultural land and productivity affects food security and economic stability in the region.
- **Environmental and Ecological Damage:**
  - GLOFs cause **habitat destruction and fragmentation**, affecting flora and fauna. The high-velocity flow of water and sediment can significantly alter landscapes, leading to long-term environmental degradation .

- For instance, **NDMA's 2025 surveys in Sikkim** found **shoreline instability and ice-core moraine weaknesses in glacial lakes**, increasing GLOF risk and Teesta river sedimentation.

- **Infrastructure Resilience:**
  - The damage to the **Teesta III dam during a GLOF event in 2023** reveals vulnerabilities in critical infrastructure. Dams and other structures in high-risk areas must be designed to withstand such events, incorporating considerations for spillway capacity and structural integrity to ensure safety.
- **Socio-economic Disruptions:**
  - Beyond the immediate impact, GLOFs can have lasting socio-economic consequences. For instance, the destruction of infrastructure such as hydroelectric power plants not only causes economic losses but also disrupts power supply, affecting industries and livelihoods far beyond the immediate area of the flood.
  - For example, **Sikkim GLOF's destruction of Chungthang Dam** significantly reduced power and water regulation capacity in northeast India.
  - Also, the recent 2025 GLOF in Tibet triggered flash floods in Nepal, destroying **four hydropower plants and cutting 8% of the country's power supply**, highlighting severe trans-boundary impacts.
- **Exposure and Vulnerability:**
  - Globally, approximately **15 million people worldwide** are potentially exposed to GLOF impacts, with significant numbers in India. The exposure and vulnerability to GLOFs highlight the importance of considering these factors in disaster risk management.
  - **India, Nepal, and Bhutan are among the top 5 countries globally in terms of GLOF vulnerability**, due to steep terrain, glacier density, and growing infrastructure in hazard-prone zones.

NDMA GUIDELINES ON MANAGEMENT OF GLOFS

- **Identifying potentially dangerous lakes:**
  - Potentially dangerous lakes can be identified based on field observations, records of past events, geomorphologic and geotechnical characteristics of the lake/dam and surroundings, and other physical conditions.
- **Use of technology:**
  - Promoting use of **Synthetic-Aperture Radar imagery** (a form of radar that is used to create two-dimensional images) to automatically detect changes in water bodies, including new lake formations, during the monsoon months.
  - Methods and protocols could also be developed to allow remote monitoring of lake bodies from space.
- **Channeling potential floods:**
  - To manage lakes structurally, the NDMA recommends **reducing the volume of water** with methods such as **controlled breaching, pumping or siphoning out water, and making a tunnel through** the moraine barrier or under an ice dam.
- **Uniform codes for construction activity:**

- Developing a broad framework for infrastructure development, construction and excavation in vulnerable zones.
- There is a need to accept procedures for land use planning in the GLOF prone areas.

- **Enhancing early warning systems (EWS):**
  - The number of implemented and operational GLOF EWS is very small, even at the global scale.
  - In the Himalayan region, there are at three reported instances (two in Nepal and one in China) of implementation of sensor- and monitoring-based technical systems for GLOF early warning.
- **Training local manpower:**
  - Apart from pressing specialised forces such as National Disaster Response Force (NDRF), ITBP and the Army, NDMA has emphasised the need for trained local manpower.
  - It has been observed that **over 80% of search and rescue is carried out by the local community** before the intervention of the state machinery and specialised search and rescue teams.
  - **The local teams could also assist in planning and setting up emergency shelters**, distributing relief packages, identifying missing people, and addressing the needs for food, healthcare, water supply etc.
- **Comprehensive alarm systems:**
  - Besides classical alarming infrastructure consisting of acoustic alarms by sirens, modern communication technology using cell and smartphones can complement or even replace traditional alarming infrastructure.
- **Awareness generation:**
  - NDMA emphasized the **need for psychological counselling of victims**. **Dissemination of accurate information** through press conferences and mass media.

INDIA'S PREPAREDNESS AND MITIGATION EFFORT:

- **Institutional Mechanisms**:
  - **The National Disaster Response Force (NDRF)/SDRF** mandated by the DM Act, 2005, will address, in close collaboration with all other field level agencies, all concerns regarding the response to the threat of GLOF disaster
  - The **National Disaster Management Authority (NDMA)** has moved from **post-disaster response** to **risk reduction** under its **Committee on Disaster Risk Reduction (CoDRR)**.
  - A **$20 million national programme** was launched:
    - Initially targeted **56 high-risk lakes**.
    - Now expanded to **195 lakes**, classified into **four risk categories**.
    - Program to be scaled up with **16th Finance Commission (FY2027–31)** support.
  - **Key Objectives of the National GLOF Mitigation Programme:**
    - **Hazard assessment** of each at-risk lake.
    - **Installation of AWWS (Automated Weather and Water Stations)**.

- **Establishing Early Warning Systems (EWS)** downstream.
- **Risk mitigation**: lake drawdowns, retention structures.
- **Community engagement**: crucial for trust and access in sacred/geographically sensitive areas.

- **Centre for Glacial Research, Studies & Management (CGRSM)**
  - This initiative will help in ensuring a wider view of glacial studies as a component of the environment/climate change
- **Scientific and Technological Initiatives:**
  - **SAR Interferometry**: Remote sensing method to detect slope instability changes of 1 cm — **underutilised**, flagged as a critical gap.
  - **Electrical Resistivity Tomography (ERT)**: Used to detect **ice cores** inside moraine dams.
  - **Bathymetric surveys**: Estimate lake water volume.
  - **UAV & slope surveys**: Assess terrain vulnerability.
  - **Remote sensing** (surface area change) remains the only viable method in many regions, but it is **post-facto**, not predictive.
- **Monitoring and Field Deployments:**
  - In **Sikkim**, **real-time monitoring stations** now relay data every 10 minutes, including images of lake ends and shorelines.
  - **ITBP units** reoriented for **manual early warning roles** in inaccessible high-altitude areas.
  - After monsoon 2025, **another round of expeditions** planned across States.

NDMA GUIDELINES ON MANAGEMENT OF GLOFs:

- **Identifying Potentially Dangerous Lakes:** Based on field surveys, past events, geomorphology, and physical conditions.
- **Use of Technology:** Promote Synthetic Aperture Radar (SAR) for detecting lake changes.Develop remote monitoring systems for glacial lakes.
- **Channeling Potential Floods:** Use controlled breaching, siphoning, pumping, or tunnels to reduce water volume.
- **Uniform Codes for Construction:** Framework for land use, infrastructure, and construction norms in vulnerable zones.
- **Enhancing Early Warning Systems (EWS):** Few global examples; urge more sensor-based EWS in the Himalayas.
- **Training Local Manpower:** Emphasize community training; locals conduct ~80% of early rescue operations.
- **Comprehensive Alarm Systems:** Combine sirens with smartphone alerts and modern communication tools.
- **Awareness Generation:** Encourage victim counselling, accurate press releases, and media outreach.

STRATEGY PLAN FOR IMPLEMENTATION:

Short Term:

- Specialized Committee under Ministry of Jal Shakti.

- Identify risk zones via Remote Sensing & GIS.
- Ground-based EWS with water level sensors.
- Regular monitoring using satellites and GIS.

Long Term:

- App-based geoportals and public hazard maps.
- Awareness campaigns through NGOs and local art/traditions.
- Establish National GLOF Data Centre and geo-portal for integrated data access.

WAY FORWARD:

- **Dynamic Risk Mapping and Prioritisation:**
  - Periodic re-evaluation of risk-prone glacial lakes using satellite-based SAR, ERT, and bathymetric data to prioritise mitigation.
- **Strengthen Early Warning Systems (EWS):**
  - Expand AWWS and downstream alerting systems in all 195 high-risk glacial lakes.
  - Integrate real-time telemetry with IMD and CWC platforms.
- **Transboundary Cooperation:**
  - Establish GLOF information-sharing mechanisms with China and Nepal for upstream monitoring and early alerts.
- **Climate-Resilient Infrastructure:**
  - Redesign dams, hydropower stations, and bridges in GLOF zones with spillway buffers, sediment bypass systems, and shock-resistant structures.
- **Institutional and Community Preparedness:**
  - Equip ITBP, NDRF, SDRF, and local responders with high-altitude rescue kits and GLOF-specific SOPs.
  - Engage communities in sacred/high-altitude lake regions through confidence-building measures and participation in monitoring.
- **Policy and Governance Reforms:**
  - Mandate GLOF risk evaluation in EIA for all infrastructure in Himalayan states.
  - Establish a unified *Glacial Risk Management Authority* for IHR coordination.
- **Expand Data Infrastructure:**
  - Operationalise National GLOF Data Centre by 2026 to centralise cryosphere and hazard data.
- **Capacity Building and Awareness:**
  - Train State Disaster Management Authorities (SDMAs), panchayats, and schools in GLOF drills.
  - Leverage traditional knowledge and art for community outreach in hill districts.

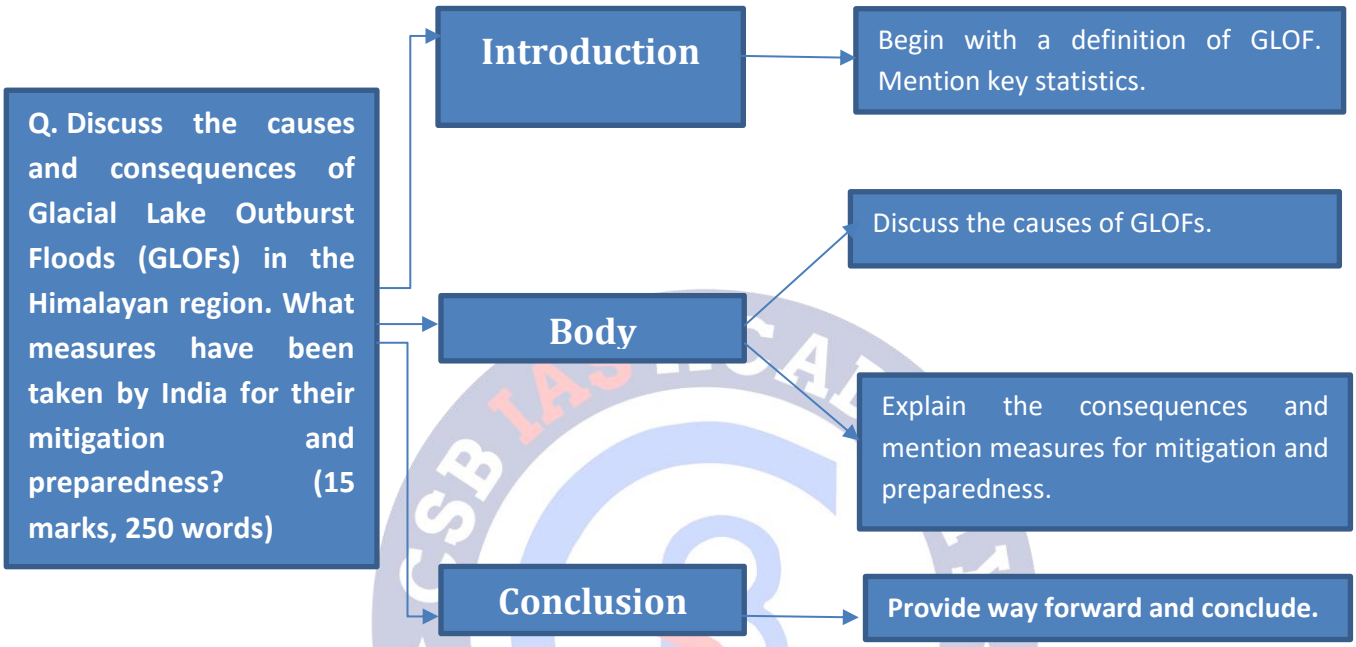
CONCLUSION:

- Glacial Lake Outburst Floods (GLOFs) represent a growing threat in a warming Himalaya. Proactive risk mapping, infrastructure resilience, and regional cooperation are essential to safeguard lives and ecosystems.

PRACTICE QUESTION:

Q. Discuss the causes and consequences of Glacial Lake Outburst Floods (GLOFs) in the Himalayan region. What measures have been taken by India for their mitigation and preparedness? (15 marks, 250 words)

APPROACH:



MODEL ANSWER:

Glacial Lake Outburst Floods (GLOFs) are sudden releases of water from glacial lakes, usually formed by meltwater dammed by fragile moraine barriers. These events can cause catastrophic flooding downstream. According to the National Remote Sensing Centre, the Indian Himalayan Region (IHR) has over **28,000 glacial lakes**. A 2023 *Nature Communications* study noted that around **15 million people globally** are at risk, with **India, Pakistan, China, and Peru** accounting for over half of this exposure.

Causes of GLOFs:

1. **Seismic Events:** Earthquakes or cryoseisms (non-tectonic glacial tremors) can destabilise moraine dams, leading to sudden breach.
2. **Avalanches and Rockfalls:** Sudden mass displacement of snow, ice, or rock into a lake can create surges that overtop or burst the dam.
3. **Volcanic Eruptions:** Though rare, sub-glacial volcanic activity can cause rapid melting and structural failure.
4. **Increased Inflow:** Rapid snowmelt, excessive rainfall, or glacial retreat increases hydrostatic pressure within the lake.
5. **Dam Degradation:** Long-term erosion, melting of buried ice cores, and sediment displacement reduce moraine integrity.

Consequences of GLOFs:

1. **Loss of Human Life:** The **2013 Kedarnath disaster** led to over 5,000 deaths. Sudden nature of GLOFs offers little time for evacuation.
2. **Infrastructure Destruction:** The **2023 South Lhonak GLOF** destroyed the ₹2,000 crore **Chungthang Dam**, caused extensive siltation, and raised the Teesta riverbed by several metres.
3. **Agricultural Damage:** In **2014**, the Gya village GLOF in Ladakh destroyed farmlands, impacting food security and livelihoods.
4. **Ecological Damage:** GLOFs disrupt alpine habitats, increase sedimentation, and reshape river morphologies.
5. **Transboundary Risks:** The **2025 Tibet-origin GLOF** destroyed four hydropower plants in Nepal, reducing its power output by 8%, illustrating geopolitical implications.
6. **Socio-Economic Impacts:** Loss of hydro projects affects energy and water supply in high-altitude areas, stalling regional development.

India's Measures for GLOF Mitigation and Preparedness:

- **Institutional Response:** NDRF/SDRF are mandated under the DM Act, 2005 for coordinated GLOF disaster response; NDMA now focuses on risk reduction via CoDRR.
- **National Programme:** A $20 million mitigation programme launched—targeting 195 high-risk lakes, with support expected under the 16th Finance Commission.
- **Research and Data Centres:** CGRSM established for focused glacial studies linked to climate change and environment.
- **Technological Tools:** Use of SAR Interferometry, Electrical Resistivity Tomography (ERT), UAVs, bathymetric and slope surveys for risk detection; remote sensing used for post-facto surface change monitoring.
- **Field Monitoring:** Real-time stations in Sikkim relay 10-minute data updates; ITBP repurposed for early warnings in remote regions; new multi-state expeditions planned post-2025 monsoon.
- **NDMA Guidelines:** Identification of dangerous lakes, SAR-based monitoring, early warning systems, structural mitigation (siphoning, breaching), trained local response teams.

Way Forward:

- Expand predictive monitoring and risk mapping.
- Build climate-resilient infrastructure in GLOF zones.
- Formalise transboundary early-warning cooperation with Nepal and China.
- Institutionalise GLOF risk assessment in EIAs.
- Operationalise a National GLOF Data Centre for integrated glacial hazard data.

As GLOFs become more frequent in a warming Himalayan ecosystem, India's shift from reactive response to risk-based mitigation offers a sound pathway. Strengthening surveillance, infrastructure, and regional cooperation remains vital to minimise future disasters.