Zanskar Glaciers Are Slowing and Thinning, Raising Long-Term Water Security Risks Across the Upper Indus Basin:

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Recent Developments:

New Study on Zanskar Glaciers:

- A **2026 study published in *The Cryosphere*** analysed the long-term changes in **surface velocity and elevation** of **12 glaciers in the Zanskar Basin of Ladakh** during **1992–2023**.
- The study found a statistically significant **region-wide decline in glacier flow velocity**, with an average deceleration of **2.43 m per year per decade**, indicating sustained dynamical changes in the Zanskar glaciers.
- The mean central-flowline velocity of the studied glaciers declined from approximately **31.1 m/year in 1992 to 26.2 m/year in 2023**, representing an overall reduction of about **16%**.
- Glacier thinning accelerated substantially, increasing from approximately **0.22 m/year during 2000–2005 to 0.57 m/year during 2015–2020**, with the strongest thinning and velocity reductions occurring at lower elevations.
- The study links the slowdown primarily to **ice mass loss and thinning**, because thinner glaciers experience reduced **driving stress**, thereby weakening their ability to transport ice downslope from accumulation areas.

Significance for India:

- The findings are important because the **Zanskar Basin forms part of the Upper Indus system**, where changes in glacier mass and seasonal melt can influence downstream water availability.
- The study highlights that glacier change is not limited to visible **retreat of the terminus**; changes in **ice thickness and flow dynamics** can provide an important indicator of long-term glacier health.
- India's broader monitoring efforts have also identified **accelerated and heterogeneous mass loss** across Himalayan glaciers, with the mean retreat rate of HindKush Himalayan glaciers estimated at **14.9 ± 15.1 m/year** in government-reported assessments.

Understanding the Zanskar Glacier System:

Zanskar Basin:

- The **Zanskar Basin** lies in the **Western Himalaya of Ladakh** and has a **cold-arid to high-altitude desert climate**, with relatively weak penetration of the Indian Summer Monsoon and substantial winter precipitation associated with western disturbances.
- Its glaciers are therefore influenced by a combination of **temperature change, snowfall variability, winter precipitation, debris cover, topography, glacier geometry and terminus conditions**.
- Zanskar is hydrologically important because glacier and snowmelt contribute to river systems that ultimately connect with the **Indus drainage system**.

Important Geographical Features:

- **Pensi La Pass:** Located at roughly **4,400 m**, Pensi La is an important high-altitude pass connecting the **Zanskar region with the SurValley and Kargil**.
- **Drang-Drung Glacier:** It is one of the major glaciers of the Zanskar region and is associated with the headwaters of the **Stod/Doda River**; the 2026 study identifies Drang-Drung as the fastest-flowing glacier among its selected glaciers, with a mean flow velocity of about **57.9 m/year** over the study period.
- **Doda/Stod River:** The river originates in the **Drang-Drung glacier region** and flows through the Zanskar Valley before joining the broader Zanskar river system.
- **Zanskar River:** The **Doda/Stod and Lungnak rivers** converge near Padum to form the Zanskar River, which subsequently joins the **Indus River near Nimmu**.
- **Chadar Trek:** The winter freezing of portions of the **Zanskar River** historically enabled seasonal movement through the valley, demonstrating the close relationship between the region's cryosphere and human mobility.

Key Findings of the Zanskar Glacier Study:

Glacier Flow Is Decelerating:

- The 12 studied glaciers experienced a statistically significant average velocity decline of **2.43 m/year per decade** between **1992 and 2023**.
- The decline was stronger at lower elevations, where glaciers below **5,000 m** showed an estimated velocity reduction of **4.6 m/year per decade**, compared with **1.7 m/year per decade** above 5,000 m.
- The **5,000 m threshold used in the study is an analytical elevation division and should not be interpreted as the Equilibrium Line Altitude (ELA)**.

Glacier Thinning Is Accelerating:

- Surface thinning increased from approximately **0.22 m/year during 2000–2005 to 0.57 m/year during 2015–2020**, indicating a substantial acceleration in ice loss.
- The spatial correspondence between **thinning and velocity decline** supports the conclusion that glacier mass loss is a major control on the observed reduction in ice flow.
- Thinning reduces the **gravitational driving stress** that enables glacier ice to flow downslope, thereby weakening the glacier's capacity to replenish lower-elevation ice through internal movement.

Glacier Response Is Spatially Heterogeneous:

- Individual glaciers do not respond identically to climate forcing because their behaviour depends on **geometry, topography, debris cover and terminus type**.
- **Lake-terminating glaciers** can display locally different velocity behaviour near their termini because interaction with proglacial lakes can modify ice dynamics.
- Therefore, regional glacier assessments should avoid treating all Himalayan glaciers as a single uniform system.

Why Glacier Velocity Matters:

Glacier Flow as an Indicator:

- Glacier velocity represents the movement of ice from **accumulation zones towards ablation zones** and therefore provides information about the internal dynamics of a glacier.
- A reduction in velocity can indicate changes in **ice thickness, mass balance, surface slope or basal conditions**, although velocity alone cannot establish the exact cause.
- The Zanskar study is significant because it combines long-term **satellite-derived velocity observations** with glacier elevation-change data to identify the relationship between thinning and deceleration.

Climate Change–Glacier Feedback:

- **Global warming** increases glacier mass loss when melting and other forms of ablation exceed accumulation.
- Persistent mass loss reduces **ice thickness**, which can reduce gravitational driving stress and subsequently slow glacier flow.
- Reduced flow can alter the redistribution of ice within the glacier, potentially accelerating the long-term depletion of stored ice in vulnerable lower-elevation sections.

Implications for the Upper Indus Basin:

Glacier Melt and Water Availability:

- Himalayan glaciers function as **natural water-storage systems**, releasing water seasonally and contributing to river discharge during periods when precipitation is relatively limited.
- The Department of Science and Technology notes that Himalayan glacier changes can affect **long-term lean-season river flows, water availability and hydropower generation**.
- Persistent glacier mass loss therefore represents not merely a cryospheric issue but a **water-security, agricultural, energy and ecological concern**.

The Peak Water Concept:

- **Peak water** refers to the stage at which glacier meltwater contribution to river runoff reaches a maximum before declining as the glacier loses a substantial portion of its stored ice.
- Initially, accelerated melting can increase runoff from a shrinking glacier, but continued ice loss eventually reduces the amount of ice available for future meltwater generation.
- The concept is particularly relevant to glacier-dependent basins because the short-term increase in runoff can mask a developing **long-term decline in natural water storage**.
- The exact timing of peak water varies by **glacier, basin, climate scenario and hydrological conditions**; therefore, a specific year such as 2028 should not be treated as a universal prediction for the entire Upper Indus Basin.

Impacts on Key Sectors:

- **Agriculture:** Reduced long-term meltwater availability can increase irrigation stress in downstream regions, particularly during dry periods.
- **Hydropower:** Changes in the timing and magnitude of glacier and snowmelt can affect seasonal inflows and hydropower planning.
- **Ecosystems:** Altered river regimes can affect aquatic ecosystems, wetlands and downstream biodiversity.
- **Communities:** Mountain communities face simultaneous risks from **water scarcity, changing seasonality and cryosphere-related hazards**.
- **Transboundary water management:** Because the Indus system crosses national boundaries, cryospheric changes can acquire wider **geopolitical and water-governance significance**.

Emerging Hazard of Glacial Lake Outburst Floods:

GLOF Risk:

- Glacier retreat and thinning can contribute to the expansion or formation of **glacial lakes**, particularly where meltwater accumulates behind unstable moraine or ice dams.
- Failure of such natural dams can produce a **Glacial Lake Outburst Flood (GLOF)**, generating sudden and potentially destructive downstream flooding.
- GLOF risk is therefore different from long-term water scarcity: **glacier loss can simultaneously increase short-term flood hazards and reduce long-term water-storage capacity**.

Indian Preparedness:

- The **National Glacial Lake Outburst Flood Risk Mitigation Programme (NGRMP)** was initiated under the National Disaster Management Authority for selected Himalayan States and Union Territories, including **Ladakh**, to strengthen GLOF-risk reduction.
- The **Central Water Commission (CWC)** is the nodal agency for monitoring glacial lakes and water bodies in India and monitors **902 glacial lakes and water bodies larger than 10 hectares** in the Himalayan region using remote-sensing techniques during the relevant monitoring season.

Drivers of Himalayan Glacier Change:

Climatic Drivers:

- **Rising temperatures** increase surface melting and can lengthen the ablation season.
- Changes in **winter snowfall** can reduce the accumulation required to replenish glacier mass.
- Alterations in **western disturbances and precipitation patterns** can affect the snow accumulation regime of the Western Himalaya.
- Changes in the balance between **snow accumulation and ice ablation** determine whether a glacier gains or loses mass over the long term.

Non-Climatic and Local Controls:

- **Debris cover** can have contrasting effects: thick debris can insulate underlying ice, while thin debris can enhance absorption of solar radiation and promote melting.
- **Glacier geometry and topography** influence ice thickness, slope and gravitational driving stress.
- **Terminus characteristics**, including contact with proglacial lakes, can modify local glacier dynamics.
- Consequently, regional climate change produces **heterogeneous glacier responses** rather than identical behaviour across all glaciers.

Black Carbon and Cryosphere:

Role of Black Carbon:

- **Black carbon** is a light-absorbing aerosol produced primarily by incomplete combustion of fossil fuels and biomass.
- When deposited on **snow and ice**, black carbon reduces surface albedo and increases absorption of solar radiation, potentially accelerating melting.
- Reducing emissions from **diesel transport, inefficient combustion, biomass burning and other high-emission sources** can therefore provide a regional climate-adaptation co-benefit for the Himalayan cryosphere.
- Recent research also highlights the importance of **absorbing aerosols and their transport towards Himalayan glacier systems**, strengthening the case for improved aerosol monitoring.

India's Institutional Response:

National Mission for Sustaining the Himalayan Ecosystem:

- The **National Mission for Sustaining the Himalayan Ecosystem (NMSHE)** is one of the eight missions under the **National Action Plan on Climate Change (NAPCC)**.
- The mission focuses on developing scientific and institutional capacity to continuously assess the **health of the Himalayan ecosystem**, including glaciers, and to support climate adaptation and policy formulation.
- Its thematic work includes **glacier and snow monitoring, water resources, climate trends, ecosystem vulnerability, biodiversity and adaptation planning**.

Scientific Monitoring Network:

- Government-supported institutions including the **National Centre for Polar and Ocean Research (NCPOR), Geological Survey of India, National Institute of Hydrology, Wadia Institute of Himalayan Geology and other research organisations** contribute to Himalayan cryosphere research.
- NCPOR monitors representative Himalayan glaciers under the **Cryosphere and Climate programme** to understand differential glacier responses and their implications for downstream hydrology.
- DST-supported programmes have also strengthened **glaciology capacity-building**, including field-based training in Ladakh and the establishment of institutional networks for Himalayan ecosystem research.

Integrated Glacier-to-Basin Approach:

- Glacier monitoring should be integrated with **snow cover, precipitation, groundwater, river discharge, agriculture, hydropower and downstream water demand**.
- A basin-level approach is more useful than monitoring individual glaciers in isolation because changes in glacier melt interact with **seasonal snowmelt, rainfall and other components of the hydrological cycle**.
- Long-term datasets are essential because glacier dynamics involve substantial **interannual variability** and cannot be reliably assessed through short-duration observations.

Measures to Strengthen Himalayan Cryosphere Resilience:

Improve Cryosphere Monitoring:

- Expand **high-altitude automatic weather stations, glacier mass-balance measurements, ice-thickness surveys and river-discharge monitoring**.
- Combine **satellite remote sensing, digital elevation models, field observations and geospatial modelling** to improve glacier-scale and basin-scale assessments.
- Maintain long-term datasets capable of distinguishing **climate-driven trends from short-term natural variability**.

Reduce Black Carbon:

- Target major sources of **black carbon emissions**, including inefficient combustion, diesel transport and biomass burning.
- Strengthen regional monitoring because atmospheric pollutants can cross administrative and national boundaries before reaching high-altitude cryospheric environments.

Strengthen GLOF Preparedness:

- Develop comprehensive inventories of **potentially hazardous glacial lakes** and regularly update them using satellite imagery.
- Install **early warning systems** at high-risk locations and combine remote sensing with ground-based observations.
- Integrate structural interventions, controlled drainage where scientifically feasible, hazard mapping and community preparedness into GLOF management.

Promote Climate-Resilient Mountain Development:

- Promote **water-efficient agriculture, improved irrigation management, rainwater harvesting and local water-storage systems** in vulnerable mountain communities.
- Encourage locally appropriate adaptation measures such as **Ice Stupas**, which artificially store winter water as ice for gradual use during the spring agricultural season.

- Ensure that roads, hydropower projects and tourism infrastructure incorporate **glacier, landslide, avalanche and GLOF risk assessments** before construction.

Strengthen Regional Cooperation:

- Cryosphere changes in the **HindKush Himalaya** have implications beyond national borders because major river systems are transboundary.
- Greater **data sharing, scientific collaboration, disaster-warning cooperation and basin-level hydrological assessment** can improve climate resilience across the wider Indus system.

UPSC Relevance:

GS Paper I – Geography:

- **Himalayan geomorphology, glaciers, snowmelt, drainage systems, Western Disturbances, rain-shadow effect and climate-induced changes in physical geography.**
- Relationship between **glacier dynamics and river systems** in the Upper Indus Basin.

GS Paper II – Governance and International Relations:

- **Transboundary river-basin management**, regional cooperation and water security in the HindKush Himalayan region.
- Institutional mechanisms such as **NMSHE, NGRMP and CWC-led glacial-lake monitoring**.

GS Paper III – Environment and Disaster Management:

- **Climate change, cryosphere degradation, GLOFs, black carbon, water security, hydropower and climate-resilient infrastructure.**
- Use of **remote sensing, satellite imagery, geospatial technology and early warning systems** for environmental monitoring and disaster-risk reduction.

Essay and Ethics:

- The Zanskar case illustrates the principle that **climate change converts ecological degradation into economic, social and intergenerational risks**.
- It also demonstrates the need to balance **development, ecological security, scientific evidence and the interests of vulnerable mountain communities**.

Value Addition for UPSC:

Key Conceptual Linkages:

- **Climate warming ? glacier mass loss ? ice thinning ? reduced driving stress ? glacier deceleration ? declining long-term ice storage ? altered future water availability.**
- **Glacier retreat/thinning ? glacial-lake expansion ? GLOF risk ? downstream disaster vulnerability.**
- **Accelerated melt ? temporary increase in runoff ? peak water ? long-term decline in glacier-derived runoff after substantial ice depletion.**
- **Black carbon deposition ? lower snow/ice albedo ? greater solar absorption ? enhanced melting.**

Important Data Points:

- **12 glaciers:** Number of Zanskar glaciers analysed.
- **1992–2023:** Study period.
- **2.43 m/year per decade:** Average glacier-flow deceleration.

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- **31.1 to 26.2 m/year:** Approximate decline in mean central-flowline velocity between 1992 and 2023.
- **0.22 to 0.57 m/year:** Increase in the observed thinning rate between the early and later study periods.
- **902:** Glacial lakes and water bodies currently monitored by CWC in the Himalayan region under the cited government monitoring framework.
- **NMSHE:** India's principal national mission specifically focused on sustaining the Himalayan ecosystem under the NAPCC.

Mains-Ready Conclusion:

- The Zanskar glacier study demonstrates that **cryosphere change is not merely a consequence of climate change but a direct determinant of future water, disaster and development security**. India's response therefore needs to move from isolated glacier monitoring towards **integrated glacier-to-basin management**, combining scientific observation, climate mitigation, GLOF preparedness, community adaptation and transboundary cooperation.