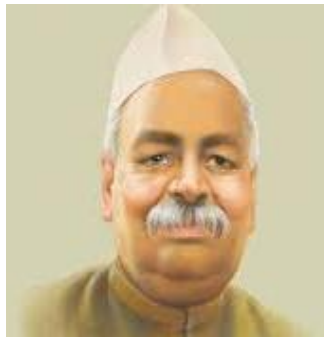




Himalayan Popular Lecture

7th Himalayan Popular Lecture: Ladakh Series



Indian Water Towers: Challenges and Imminent Threats

By

Prof. Ghulam Jeelani
Head, Department of Geology
University of Kashmir UT

10th September 2026

G.B. Pant National Institute of Himalayan Environment (NIHE)

Ladakh Regional Centre, Leh Ladakh (UT)

Prof. Ghulam Jeelani
Head, Department of Geology
University of Kashmir UT

1. Introduction

The G.B. Pant Memorial Lecture–2026 was centered on the theme “Indian Water Towers: Challenges and Imminent Threats”, with the scientific lecture delivered by Prof. Gh. Jeelani, Department of Geology, University of Kashmir, Hazratbal, Srinagar, Jammu & Kashmir. The lecture used the Himalayan cryosphere, particularly glaciers, snow and permafrost, as the central framework for understanding the changing water security of the Indian Himalayan region. The title slide of the lecture prominently presents the Drung-Drung Glacier snout and identifies Prof. Gh. Jeelani and the University of Kashmir as the speaker and institutional affiliation.

The lecture was particularly relevant to the mandate of the G.B. Pant National Institute of Himalayan Environment (NIHE), Ladakh Regional Centre, Leh, as it addressed climate-induced changes in water availability, cryospheric degradation, glacier and snowmelt contributions, groundwater recharge, runoff variability, water storage, glacial lake outburst flood (GLOF) hazards and the need for strengthened scientific monitoring.

The lecture also represents a logical progression of the Himalayan Popular Lecture/Ladakh Series, which has previously addressed climate change, water pollution, medicinal-plant biodiversity, environmental research and climate-change-related water issues in Ladakh. The preceding sixth Himalayan Popular Lecture, delivered by Prof. Saket Kushwaha on 10 September 2025, focused on *Climate, Agriculture, and Food Security Variability in Pathways* and emphasized the interdependence of climate, water, livelihoods and food security.

2. Theme and Context of the Lecture

The Himalayan region is widely recognized as a critical “**water tower**” because its glaciers, seasonal snowpack and frozen water resources regulate river flows and sustain downstream ecosystems, agriculture, hydropower, domestic water supplies and human settlements. The 2026 lecture examined this water-tower function through

a combination of regional maps, observed climatic trends, cryospheric observations, glacier mass-balance studies, hydrological modelling and field photographs.

The opening sections established the geographical and hydrological importance of the Indus River Basin (IRB) and its transboundary character. Maps presented in the lecture illustrated the basin's geographical extent, elevation gradients, population distribution, climatic zones and precipitation patterns. The lecture thereby demonstrated that the water resources of the Himalayan region cannot be understood solely at a local scale; rather, they must be assessed across interconnected mountain–river-basin systems.

The lecture further highlighted that climatic processes vary considerably with latitude and altitude, meaning that climate-change impacts on the atmosphere, cryosphere, hydrosphere and biosphere are spatially and vertically heterogeneous. This is particularly important in the Himalaya, where relatively small changes in temperature and precipitation can substantially modify snow accumulation, glacier melt, runoff generation and water availability.

3. Major Scientific Components of the Lecture

3.1 Himalayan Water Towers and the Cryosphere

A major component of the lecture was the conceptualization of the Himalayan cryosphere as a water-storage system, comprising:

- ✚ glaciers;
- ✚ seasonal snow;
- ✚ permafrost; and
- ✚ associated frozen-water reservoirs.

The lecture illustrated the distribution of these cryospheric resources across the Himalayan region and their relationship with major river systems. The maps demonstrated the close geographical association between high-elevation cryospheric zones and the headwaters of major transboundary rivers.

The presentation therefore emphasized that the loss or alteration of cryospheric storage is not simply a glaciological concern; it represents a broader water-security challenge with implications extending from high-altitude mountain environments to downstream populations.

3.2 Climatic Variability and Long-Term Trends

The lecture presented spatial patterns of annual precipitation and atmospheric circulation across the Himalaya, followed by long-term temperature and precipitation trends for Srinagar and Leh.

The displayed trend analysis indicated an overall temperature increase of approximately 0.85°C for Srinagar and 0.65°C for Leh, while the presentation also showed seasonal differences in warming. For precipitation, the displayed trends were comparatively small and seasonally contrasting, emphasizing that warming and precipitation changes do not occur uniformly across the region.

This aspect of the lecture was particularly significant because changes in Himalayan water resources are governed not only by mean temperature but also by the timing, magnitude and form of precipitation. A shift from snowfall toward rainfall, changes in the duration of snow cover, and altered seasonal melt patterns can all influence the timing and magnitude of river discharge.

Projected temperature and precipitation changes were also presented using future climate scenarios, demonstrating the potential for continued warming and substantial hydrological changes in the Himalayan region.

4. Changing Snow Cover Dynamics

Snow cover was identified as one of the important components controlling Himalayan water availability. The lecture presented projections of snow-depth dynamics under different future emissions scenarios, including SSP126, SSP245 and SSP585. The graphical presentation showed a declining tendency in snow depth toward the end of the century, particularly under the higher-emission pathway.

Historical observations were also used to demonstrate changes in snow-covered area. For the Upper Jhelum Basin, the lecture highlighted a reduction in snow-cover area from approximately 38% in 2000 to 28% in 2022.

These observations are important because snow acts as a seasonal water reservoir. Changes in snow accumulation and persistence can alter:

- ✚ the timing of snowmelt;
- ✚ seasonal streamflow;
- ✚ groundwater recharge;
- ✚ agricultural water availability;
- ✚ ecosystem water availability; and
- ✚ the reliability of downstream water resources.

Thus, declining snow storage may create a complex situation in which increased meltwater availability during certain periods is followed by reduced cryospheric contributions over longer time scales.

5. Glacier Distribution, Retreat and Mass Balance

The lecture provided an extensive assessment of glacier distribution across the Himalayan region and the Indus Basin. Glacier maps and mass-balance information were used to demonstrate the sensitivity of Himalayan glaciers to climatic changes.

Particular attention was given to representative glaciers including Parachik and Drung-Drung glaciers, supported by field photographs. The presentation also included time-series analyses of annual glacier mass balance across major sub-basins of the Indus River Basin.

A glacier-change assessment presented for the period 2011–2020 showed an increasing trend in glacier thickness loss, with the presentation reporting strong agreement between simulated and estimated losses. The figure indicated a statistically significant relationship, with $CC = 0.86$ and $P < 0.05$.

The field photographs of Drung-Drung, Parachik, Kolahoi, Machoi, Panzilla and Puchey glaciers complemented the quantitative evidence by providing direct visual documentation of glacier environments. These images underscored the importance of combining field observations with remote sensing and modelling approaches for understanding glacier change.

6. Runoff Variability and Hydrological Response

The lecture subsequently connected cryospheric changes with river discharge and runoff. Long-term runoff trends were presented for different Himalayan locations, followed by an assessment of the hydrometeorology of the Upper Jhelum Basin (UJB).

The hydrometeorological figure illustrated the seasonal relationship among precipitation, temperature, snow cover and river discharge. This provided an important demonstration of how climatic variables and cryospheric processes interact to regulate river flow.

Projected runoff simulations for the Upper Jhelum River Basin and other components of the Indus system were also presented under different climate scenarios. The historical and projected runoff figures demonstrated that future hydrological regimes may become increasingly variable and that the magnitude and timing of seasonal discharge could change considerably.

The lecture therefore emphasized that climate change should not be interpreted simply as a reduction in water resources. Instead, it may produce temporal redistribution and increasing variability of water availability, creating periods of enhanced runoff alongside periods of water scarcity.

7. Importance of Snowmelt and Glacier Melt for Water Resources

One of the most significant aspects of the lecture was the quantification of the contribution of different water sources to streamflow and groundwater.

For Ladakh, basin-wise estimates of snowmelt and glacier-melt contributions to streamflow were presented for the Dras, Suru, Indus, Nubra and Shyok basins. The presentation demonstrated considerable seasonal and basin-wise differences in cryospheric contributions.

The lecture also examined the contribution of snow and glacier melt to groundwater in Ladakh. The figure based on Lone et al. (2021) illustrated basin-wise contributions from snow, glacier and rainfall during different months, highlighting the role of cryospheric melt in sustaining groundwater systems.

For the Liddar catchment of Kashmir, the presentation provided quantitative estimates showing that snowmelt constituted a major component of groundwater-related contributions, while glacier melt also contributed seasonally. The displayed values for snowmelt, glacier melt and rainfall varied markedly among spring, summer, autumn and winter.

These findings have major implications for Himalayan water management because they demonstrate that water resources cannot be assessed by considering precipitation alone. Snow, glacier ice, rainfall and groundwater are interconnected components of a coupled mountain hydrological system.

8. Permafrost as an Emerging Water-Resource Component

The lecture extended the discussion beyond glaciers and snow to permafrost, highlighting its potential contribution to meltwater. The presentation included research by Jeelani et al. (2024) examining permafrost-related meltwater contributions.

This is particularly important for high-altitude landscapes because permafrost degradation can have multiple consequences. Apart from altering water release, thawing frozen ground can influence slope stability, groundwater processes, geomorphic hazards and high-altitude infrastructure.

Consequently, the Himalayan water tower needs to be conceptualized as a multi-component cryospheric system, rather than one based exclusively on glacier storage.

9. Water Storage and Groundwater Changes

The presentation also incorporated satellite-derived GRACE observations to illustrate anomalies in total water storage, groundwater storage and surface-water storage.

The inclusion of large-scale satellite observations was important because direct measurement of water storage in remote Himalayan terrain is challenging. Such

observations can provide valuable regional-scale information when combined with ground-based measurements and hydrological models.

The lecture consequently advocated a multi-source approach involving:

1. ground observations;
2. satellite remote sensing;
3. atmospheric and balloon-based observations;
4. remotely sensed datasets; and
5. reanalysis and model-based information.

This integrated monitoring framework was presented as essential for understanding complex climate–cryosphere–hydrology interactions.

10. Glacier Lake Outburst Floods and Other Cryospheric Hazards

Another important component was the discussion of moraine-dammed lakes and projected GLOF events. The distribution of moraine-dammed lakes across the Himalaya was presented along with historical GLOF information.

The lecture also presented projected GLOF events under future climate scenarios, demonstrating that changing cryospheric conditions may increase the importance of high-altitude glacial-lake hazards.

In addition to GLOFs, the concluding section drew attention to drying springs and catastrophic avalanches in high-altitude regions, noting their direct implications for strategic establishments and tribal communities.

This highlighted an important shift from considering climate change merely as an environmental issue to understanding it as a water-security, livelihood, infrastructure and disaster-risk issue.

11. Water–Energy–Food Nexus

The lecture also connected changing Himalayan water resources with the broader water–energy–food nexus. A comparative figure for 2015 and 2080 illustrated

projected changes in water availability, energy and food requirements, with substantial increases shown for the future period.

This perspective is particularly important for the Himalaya because mountain water resources simultaneously support:

- ✚ drinking-water supplies;
- ✚ agriculture and horticulture;
- ✚ livestock systems;
- ✚ hydropower;
- ✚ ecosystems and biodiversity;
- ✚ downstream industries; and
- ✚ human settlements.

Consequently, alterations in cryospheric storage can propagate through multiple sectors, creating cascading impacts across mountain and downstream societies.

12. Major Challenges Identified

The lecture identified several interconnected challenges confronting the Upper Indus Basin and the Himalayan water-tower system.

12.1 Climate change

The presentation emphasized that climate change is expected to exert profound effects on the Upper Indus Basin through changing temperature, precipitation, snow cover, glacier mass balance and runoff.

12.2 Anthropogenic pressure

The lecture specifically recognized the interaction between climate change, topographic complexity and growing anthropogenic pressure as a major source of vulnerability.

12.3 Inadequate in-situ observations

A major knowledge gap identified in the lecture was the non-availability of adequate in-situ data. This limits the ability to validate satellite observations and model projections and to understand localized hydrological processes.

12.4 Lack of water-storage estimates

The lecture highlighted the lack of adequate volumetric estimation of stored water resources as a major research gap requiring immediate attention.

12.5 Uncertainty in source-wise contributions

Reliable estimates of the relative contribution of snow, glacier ice, precipitation and groundwater to stream discharge in individual catchments remain insufficient, despite their importance for effective water-resource management.

12.6 Emerging cryospheric hazards

The drying of springs, avalanches, glacier-related hazards and GLOFs represent important risks to mountain communities, infrastructure and strategic establishments.

13. Need for an Integrated Himalayan Monitoring Network

One of the strongest recommendations emerging from the lecture was the establishment of a large, dense and robust monitoring network.

The presentation explicitly emphasized the need to monitor multi-proxy parameters through ground-based, satellite-based, balloon-based, remotely sensed and reanalysis/model-based approaches. It further stressed that monitoring should encompass atmospheric, surface and subsurface components, including physical, chemical and biological processes.

Such a network would facilitate:

- ✚ long-term glacier mass-balance monitoring;
- ✚ snow-depth and snow-cover assessment;
- ✚ permafrost monitoring;
- ✚ streamflow measurement;

- ✚ groundwater monitoring;
- ✚ spring-discharge assessment;
- ✚ precipitation and temperature observations;
- ✚ glacier-lake surveillance;
- ✚ GLOF early-warning systems;
- ✚ avalanche-risk assessment; and
- ✚ integrated climate–hydrological modelling.

For a region as heterogeneous as the Himalaya, the combination of high-resolution local observations and large-scale remote-sensing/model products would be particularly valuable.

14. Relevance to G.B. Pant NIHE, Ladakh Regional Centre

The subject of the lecture closely aligns with the mandate and objectives of the G.B. Pant National Institute of Himalayan Environment, Ladakh Regional Centre. The Centre's stated objectives include addressing water scarcity, conserving critical cold-desert habitats and

biodiversity, promoting alternative livelihoods for climate-vulnerable communities and fostering climate-smart communities in the Trans-Himalayan landscape.

The lecture therefore provides a strong scientific basis for strengthening the Centre's activities in:

i. Cryosphere monitoring

Long-term monitoring of glaciers, snow cover, permafrost and associated hydrological processes.

ii. Water Security assessment

Quantification of water storage and source-wise contributions of snowmelt, glacier melt, rainfall and groundwater.

iii. Climate-change impact assessment

Development of location-specific assessments for Leh-Ladakh and other Trans-Himalayan landscapes.

iv. Disaster-risk reduction

Monitoring and assessment of GLOFs, avalanches, glacier instability and other high-altitude hazards.

v. Community-oriented research

Understanding implications of changing water availability for agriculture, livestock, pastoralism, livelihoods and settlements.

vi. Science–policy interface

Generation of robust scientific datasets that can support climate adaptation, water-resource planning and disaster-risk management.

The lecture's emphasis on “Science for society,” networks and collaborations, promotion of successful models, engagement of local youth and sustainable technology is also consistent with the stated mission of the Ladakh Regional Centre.

15. Key Takeaways from the Lecture

The major messages of the G.B. Pant Memorial Lecture–2026 can be summarized as follows:

- ❖ The Himalayan cryosphere is a critical component of regional water security.
- ❖ Climate change is altering temperature, precipitation, snow cover, glacier mass balance and runoff regimes.
- ❖ Water availability is becoming increasingly variable in both space and time, making conventional assumptions about seasonal water supply less reliable.
- ❖ Glaciers, snow and permafrost need to be studied as interconnected components of a single mountain hydrological system.
- ❖ Snowmelt and glacier melt make important contributions to streamflow and groundwater, but their relative contributions vary substantially among basins and seasons.
- ❖ The Upper Indus Basin is exposed to multiple interacting pressures, including climate change, complex topography and increasing anthropogenic activities.

- ❖ GLOFs, avalanches and drying springs represent emerging risks for mountain communities and strategic infrastructure.
- ❖ There is an urgent need for improved in-situ observations, particularly in remote high-altitude regions.
- ❖ Satellite observations, field measurements and modelling must be integrated rather than used independently.
- ❖ A dense, robust and long-term Himalayan monitoring network is essential for evidence-based water-resource management.

16. Suggested Way Forward

Based on the issues highlighted during the lecture, the following actions emerge as important priorities for Himalayan environmental research and management:

A. Establish long-term cryosphere observatories

Strategically located monitoring sites should be developed across representative glaciers, snowfields and permafrost zones of Ladakh and the Western Himalaya.

B. Strengthen hydrological monitoring

Stream gauges, automatic weather stations, snow-depth sensors, spring-discharge monitoring and groundwater observation networks should be expanded, particularly in data-scarce catchments.

C. Develop integrated water-budget assessments

Future research should quantify the relative contribution of precipitation, snowmelt, glacier melt, permafrost melt and groundwater to individual Himalayan catchments.

D. Establish cryosphere-based early-warning systems

Remote sensing, field observations and modelling should be integrated for monitoring GLOFs, avalanches, glacier instability and other climate-related hazards.

E. Develop high-resolution climate–hydrological models

Models should incorporate the strong altitude-dependent variability of Himalayan climate and cryospheric processes.

F. Strengthen interdisciplinary collaboration

Geologists, glaciologists, hydrologists, climatologists, ecologists, remote-sensing specialists, disaster-management experts and social scientists should work together to address Himalayan water security.

G. Promote community-based water monitoring

Local communities and young people can play an important role in monitoring springs, streams, snow conditions and other environmental indicators, thereby strengthening the science–society interface.

17. Overall Outcome of the Lecture

The G.B. Pant Memorial Lecture–2026 successfully brought together evidence from climatology, glaciology, hydrology, groundwater science, remote sensing and field-based investigations to present an integrated understanding of the Himalayan water-tower system. The presentation moved systematically from the regional geography of the Indus Basin to climatic trends, snow dynamics, glacier change, runoff, meltwater contribution, groundwater storage, permafrost, moraine-dammed lakes and future GLOF risks.

Particularly noteworthy was the lecture's emphasis that the major challenge is not simply the loss of individual glaciers, but the transformation of the entire mountain water-storage and water-release system. The conclusion strongly advocated comprehensive monitoring because the impacts of climate change across the Upper Indus Basin are spatially and altitudinally variable and because substantial gaps remain in in-situ observations and water-storage quantification.

18. Conclusion

The **G.B. Pant Memorial Lecture–2026 on “Indian Water Towers: Challenges and Imminent Threats”** provided a comprehensive scientific perspective on the changing cryosphere and hydrology of the Himalaya, with particular emphasis on the Indus River Basin and the Western Himalayan region. The lecture demonstrated that

glaciers, snow, permafrost, groundwater and surface water are interconnected components of a highly sensitive mountain water system.

The evidence presented on declining snow cover, glacier mass loss, changing runoff, cryospheric melt contributions, groundwater storage and potential GLOF hazards highlights the need for urgent, sustained and scientifically coordinated monitoring. The presentation's conclusion identified inadequate in-situ observations and insufficient quantification of stored water and source-wise contributions as critical knowledge gaps.

For the Ladakh Regional Centre of G.B. Pant NIHE, the lecture carries particular significance because its findings directly intersect with the Centre's objectives concerning water scarcity, cold-desert ecosystems, climate-vulnerable communities and climate-smart Trans-Himalayan development.

Overall, the lecture reinforced the message that safeguarding the Himalayan water towers requires a transition from fragmented observations to an integrated, multi-proxy, basin-scale and long-term monitoring framework, supported by scientific collaboration, advanced technologies, field observations and community participation. Such an approach will be essential for strengthening climate resilience, securing water resources and protecting Himalayan ecosystems and communities in the decades ahead.



G.B. PANT NATIONAL INSTITUTE OF HIMALAYAN ENVIRONMENT
(An Autonomous Institute of Ministry of Environment, Forest & Climate Change, Govt. of India)
Ladakh Regional Centre, Leh, Ladakh

Himalayan Popular Lecture: Ladakh Series

1st Lecture: Impact of Climate Change on India's Trans Himalayan Region (2020) by Shri C. Phunsog, IAS-Retd. (Vice Chancellor, University of Ladakh)

2nd Lecture: Water: Pollution and Remediation (2021) by Prof. S.K. Mehta (Vice Chancellor, University of Ladakh)

3rd Lecture: Medicinal Plants Biodiversity of Cold Arid Ladakh Himalaya (2022) by Dr. O.P. Chaurasia (Director DRDO-DIHAR, Leh)

4th Lecture: Exploring the Marvels of Himalaya and Shaping the Future Environmental Research (2023) by Shri Jigmet Takpa, IFS (Principal Chief Conservator of Forest (Retd.), Ladakh)

5th Lecture: Climate Change and Water Issues in Ladakh (2024) by Sri Sonam Lotus (Scientist E & Head, Met Centre Leh (IMD), Leh, Ladakh)

6th Lecture: Climate, Agriculture, and Food Security Variability in Pathway (2025) by Prof. Saket Kushwaha (Vice Chancellor, University of Ladakh)

G.B. PANT NATIONAL INSTITUTE OF HIMALAYAN ENVIRONMENT

(An Autonomous Institute of Ministry of Environment, Forest & Climate Change, Govt. of India)

Ladakh Regional Centre, Leh, Ladakh



Objectives

- ❖ To promote alternative livelihoods for climate change vulnerable cold desert communities.
- ❖ To facilitate conservation of critical/ important cold desert habitats and biodiversity
- ❖ To strengthen and establish approaches for addressing issues of water scarcity.
- ❖ To foster climate smart communities in the trans-Himalayan landscape.

Our Mission

- ❖ Science for society,
- ❖ Networks and collaborations
- ❖ Promotion of successful models,
- ❖ Private sector engagement,
- ❖ Harness energies of local young
- ❖ Promoting use of sustainable technology