

Reading the Himalayan Landscape: Glacial Processes, Climate and Flood Evidence in the Alaknanda Valley

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Figure 1: IIT ROORKEE ICED Field Trip to Satopanth Glacier

The third day of the Himalayan Field School focused on understanding the interactions between glacial processes, climatic conditions, river dynamics and hydropower development in the upper Alaknanda basin. The field journey from Joshimath towards Vasudhara Falls, followed by visits to the Jayprakash Vishnuprayag Hydropower Plant and Vishnuprayag, provided an opportunity to connect geomorphological concepts with observable landscape features and evidence of past disasters.

1. Glacial Geomorphology: Reading Erosion and Deposition in the Himalayan Landscape

Observations. Along the route towards Vasudhara Falls, changes in vegetation cover, exposed rock surfaces and valley morphology illustrated the variation in landscape characteristics with elevation. The discussion led by Professor Jürgen Mey focused on how glaciers modify mountain terrain through erosion, sediment transportation and deposition. Attention was given to lateral, terminal and medial moraines, which preserve evidence of former glacier extent and sediment movement.

Interpretation. Glacier behaviour is governed partly by its mass balance, defined as the difference between mass accumulation and mass loss over a specified period. Snow accumulation dominates the accumulation zone, whereas melting and other processes contribute to mass loss in the ablation zone. The Equilibrium Line Altitude (ELA) marks the approximate boundary where annual accumulation and ablation balance each other. A sustained negative mass balance can cause a glacier to thin and retreat.

The valley morphology also reflects the relative influence of fluvial and glacial erosion. Rivers typically produce V-shaped valleys through channel incision, whereas glaciers can widen and deepen valleys into U-shaped profiles with steep sides and broader floors. These forms provide a geomorphological basis for interpreting landscape evolution, although individual valley shapes can reflect multiple erosional processes.

Scientific implication. Identifying glacial landforms and understanding their formation helps reconstruct past glacier extent and landscape development. Combined with repeated glacier mapping, elevation data and mass-balance measurements, these observations can support assessments of long-term changes in Himalayan cryosphere systems.



Figure 2: Field Lecture 1



Figure 3: Field Lecture by Prof Jurgen (1) and Prof Axel Bronstert (2)

2. Glacier Retreat and Changing Meltwater Dynamics

Observations and discussion. At Vasudhara Falls, Professor Jürgen Mey discussed glacier retreat with reference to the Satopanth and Bhagirath Kharak glaciers, along with changes affecting other Himalayan glaciers, including Gangotri. The discussion connected changing glacier extent with climatic conditions and the role of meltwater in Himalayan river systems.

Interpretation. Glacier retreat occurs when cumulative mass loss exceeds accumulation over time, resulting in a reduction in glacier extent and, commonly, a shift of the glacier terminus towards higher elevations. Rising temperatures can increase melt rates, although precipitation, snowfall, glacier geometry and local climatic conditions also influence individual glacier responses.

Changes in glacier storage affect the timing and magnitude of meltwater contributions to downstream rivers. In the short term, enhanced melting can increase runoff during certain periods. Over longer timescales, continued loss of glacier ice can reduce the amount of stored ice available to sustain meltwater flows. Glacier change may also influence the formation and evolution of glacial lakes, although lake development and outburst risk depend on additional topographic, hydrological and geological factors.

Scientific implication. Assessing glacier retreat requires more than observing the position of a glacier terminus. Multi-year satellite imagery, field measurements, elevation change and mass-balance data are needed to quantify changes and understand their implications for downstream water availability and high-mountain hazards.



Figure 4: Way to Satopanth Glacier (1) and Vasundhara Falls (2)

3. Climate Change and the Indian Monsoon

Observations and discussion. At Vasudhara Falls, Professor Ankit Agrawal explained the relationship between global warming, climate change and the Indian monsoon. The discussion highlighted the importance of seasonal atmospheric circulation and the role of precipitation in shaping the hydrological behaviour of Himalayan catchments.

Interpretation. Global warming refers specifically to the long-term increase in Earth's average surface temperature, whereas climate change encompasses broader changes in temperature, precipitation patterns and the frequency or intensity of certain extreme events. The Indian summer monsoon is driven by seasonal atmospheric circulation, including land–sea thermal contrasts and large-scale pressure and wind patterns. Its spatial and temporal variability strongly influences rainfall across the Himalayas.

In high-relief catchments, precipitation interacts with steep slopes, complex drainage networks and snow- and ice-covered terrain. Intense rainfall can generate rapid runoff, increase river discharge and trigger slope instability where geological and hydrological conditions are favourable. However, the relationship between climate change and individual extreme events must be assessed using appropriate meteorological records and event-specific analysis rather than inferred from a single field observation.

Scientific implication. Understanding changing precipitation patterns is essential for hydrological modelling and hazard assessment in Himalayan basins. Combining rainfall records, temperature observations, snow and glacier data, and river discharge measurements can help improve flood forecasting and evaluate potential changes in future hydrological extremes.



Figure 5: Field Lecture 2

4. Hydropower Development in a Sediment-Rich Himalayan River

Observations. During the return journey, the group visited the Jayprakash Vishnuprayag Hydropower Plant on the Alaknanda River. Project representatives explained the operation of this run-of-the-river hydropower scheme, which has an installed capacity of 400 MW. Water is diverted through a conveyance tunnel to the powerhouse, where turbines drive generators before the water is discharged back into the river system.

Interpretation. Run-of-the-river hydropower projects utilise river flow and available hydraulic head to generate electricity. Their performance depends on water availability, hydraulic design and operational conditions. In the Himalayas, these projects operate within steep, geologically complex catchments where sediment transport and extreme hydrological events can pose significant engineering challenges.

Sediment-laden flows can cause abrasion of turbines and other hydraulic components, while excessive sediment deposition can affect intakes and reduce operational efficiency. Floods and debris-rich flows may also damage infrastructure and disrupt power generation. These risks make sediment management,

suitable intake design, monitoring and emergency planning important components of hydropower operation.

Scientific implication. Hydropower development in Himalayan valleys requires an integrated assessment of energy generation, river processes and environmental conditions. Engineering design and operational planning should account for sediment transport, flood hazards and the need to maintain the ecological functioning of river systems.

5. Vishnuprayag: Physical Evidence of the 2021 Chamoli Disaster

Observations. At Vishnuprayag, near the confluence of the Dhauliganga and Alaknanda rivers, the group examined physical features associated with the February 2021 Chamoli disaster. These included a damaged rope bridge, large boulders, accumulated debris, siltation marks on temple walls, and damaged pavement with exposed and eroded reinforced cement concrete (RCC).

Interpretation. These features provide evidence of the destructive effects of a high-energy, sediment-laden flow. Large boulders and deposited debris indicate the capacity of the flow to transport coarse material, while siltation marks provide clues to the maximum level reached by sediment-bearing water. Damage to bridges and pavement illustrates the effects of hydraulic forces, impact from transported debris and erosion around infrastructure.

The 2021 Chamoli disaster involved a destructive flood and debris flow in the Rishiganga–Dhauliganga system. The event is widely associated with a high-mountain rock–ice avalanche that generated a rapidly moving, sediment-rich flow downstream. As the flow travelled through the confined valleys, entrainment of additional sediment and rock material contributed to its destructive potential.

The field observations at Vishnuprayag demonstrate how the effects of a major flood can remain visible in the landscape after the event. However, individual deposits and damage features should be interpreted alongside event records, terrain information and other evidence to establish their precise origin and extent.

Scientific implication. Post-disaster field investigations provide valuable evidence for understanding flood propagation, sediment transport and infrastructure vulnerability. Mapping high-water marks, documenting deposited material and recording damaged structures can help validate hydraulic models, identify exposed locations and improve future hazard assessments and emergency action plans.



Figure 6: Investigating the Flood Evidences at Vishnuprayag Confluence.