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EDITORIAL

Towards the Stewardship of the Third Pole: The Himalaya

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The Himalaya plays a vital role in global weather and climate, influencing the Asian Monsoon. Large rivers, viz. the Indus, Ganga, Brahmaputra, Irrawaddy, Salween, Mekong, Yangtze and Yellow rivers originate from the Himalaya. These rivers provide the much needed freshwater to 1.4 billion people in Asia. Their river plains provide food to almost 40% of the world's population. It has the largest concentration of snow and ice outside polar regions. It holds large reserves of trapped carbon in permafrost and wetlands. The grasslands and forests have a unique biodiversity and are under threat. The Himalaya is warming faster than the rest of the globe and this is affecting snow and glaciers as well as the biodiversity of the region (Navalgund et al., 2019). Being a young mountain chain, it is highly prone to natural hazards, especially earthquakes, landslides, floods and extreme rainfall events. The Indus and Ganga drain into the Arabian Sea and Bay of Bengal, respectively, and deposit huge quantity of sediments and form the Indus and the Bengal fans. Himalaya has a profound impact on social, economic, cultural aspects and demography of India, Bhutan, Tibet, China, Nepal, Pakistan and has a significant hydrological impact on Myanmar, Afghanistan, Bangladesh, Laos, Thailand and Vietnam.

The evolution of Himalaya is linked to the fragmentation of the Gondwana supercontinent and the northward movement of the Indian plate about 130 million years ago. The Indian plate continued to move northward and its underthrusting beneath the Eurasian plate resulted in the accumulation of strain energy in this region, as evidenced by GPS measurements (Bilham, 2004). The central seismic gap (falling in Himachal Pradesh, Uttarakhand) is considered a potential area of future earthquakes in a recent study. No great earthquakes (>Magnitude 8) have occurred in this region in the last 200 years. Vertical uplift in the central seismic gap has been reported using radar interferometric data, suggesting enough strain build-up for triggering a mega earthquake (Sreejith et al., 2025). Council of Scientific and Industrial Research – National Geophysical Research Institute (CSIR-NGRI) has recently published a strain map of the Himalaya and provides insight into the nature of strain building across the Himalaya.

The threat of earthquakes in the Himalaya is real and there is a need to understand hazard generating processes for earthquakes and resulting landslides. Such studies can be facilitated by the measurement and modelling of stress at plate boundaries through GNSS, a continuously operating ground-based dense network of GPS/GNSS to measure the rate of change and building up of strain at plate boundaries, use of SAR interferometry to measure deformation and long-term strain accumulation using NASA-ISRO Mission (NISAR) data, and availability of high-resolution satellite-based terrain data along with air-borne, in situ and ground-based geophysical measurements. The outcome of such a study will provide an insight into crustal deformation and active faults for earthquake/landslide hazard assessment. It will be immensely useful if such a study is coordinated with the neighbouring countries.

The Himalaya has the largest cryospheric surface outside the poles, covering about 33,000 sq. km in the Indian Himalaya and plays a crucial role in influencing earth system processes. Satellite data has provided vital inputs on characterising of glaciers and inventories of glaciers were carried out to record changes at the Space Applications Centre – Indian Space Research Organisation (SAC-ISRO). Most glaciers have been retreating, 1–60 m per year. Overall loss in area of glaciers was about 16–17% due to faster retreat of smaller glaciers and fragmentation (Kulkarni et al., 2011). The temperature in the Himalaya is projected to rise substantially during this century, and snowfall is likely to decline. However, there is no regular glacier monitoring programme currently operational in the Indian Himalaya. While India sustains satellite-based efforts (e.g., ISRO's glacier inventory atlases) and initiatives under the National Mission for Sustaining the Himalayan Ecosystem

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(NMSHE), field-based mass balance studies remain confined to just a few glaciers. The data from the geodetic network of the Survey of India should be effectively utilised to study the fragmentation of glaciers. There is a need to monitor glaciers every two years to understand changes and their likely impacts on the availability of water in the mountains as well as in plains and on ecosystems using high-resolution remote sensing observations.

Mass balance studies are available for a few glaciers only. One of the challenges is to estimate the thickness of glaciers. Digital elevation models, along with GPR data, can provide a reasonable estimate of the thickness of glaciers. It is proposed that an annual monitoring of the mass balance of representative glaciers, about 30 glaciers, should be launched. The measurement of geological, hydrological and atmospheric parameters at 'Himansh' in the Chandra basin, by Earth System Science Organisation – National Centre for Polar and Ocean Research (ESSO-NCPOR), needs to be replicated in other basins as well. The large mass of ice being removed from the Himalaya including Tibet is ultimately transferred to the sea. Considering the quantum of ice that is being removed annually from the Himalaya, the solid earth response to deformation associated with glacio-isostatic adjustment is required for understanding this process.

Many moraine-dammed lakes have already created and are being formed due to the retreat of glaciers. According to a survey conducted by International Centre for Integrated Mountain Development (ICIMOD), there are 20,200 such lakes in the Himalaya. The National Remote Sensing Centre (NRSC) of ISRO has brought out most recent inventory of Himalayan glacial lakes in three major river basins and 28,043 glacial lakes (≥0.25 ha) have been mapped, using Resourcesat-2 LISS-IV satellite images, for the entire Indian Himalayan River Basins, with a total lake water spread area of 1,31,070.90 ha (Rao et al., 2023). The increase in volume of such lakes is about 14% and there is an increasing threat of Glacial Lake Outburst Flood (GLOF) (Nie et al., 2017). Many of these lakes have already doubled or tripled in size over the last 3 to 4 decades and pose a significant risk for future GLOF events. Models for the formation of such lakes and their likely discharge have been developed; however, there is a need for the development of an early warning system and risk assessment for downstream habitations. Satellite-based observations are vital as all such lakes are located in very remote areas. An international network is required to monitor such lakes and develop an early warning system.

The Indus, Ganga and Brahmaputra are major rivers and the lifeline of the Indian subcontinent. The changing water cycle due to global warming is likely to affect the water flow in these rivers. The Indus river water flow is primarily due to the melting of snow, while the contribution of snow and ice melt in the Ganga and the Brahmaputra is relatively low. It has been reported that snow cover has been decreasing with an increase in atmospheric temperature. However, reliable estimates of snow cover and its volume are not generated for all these basins. Developing models to estimate snow cover depth using passive microwave radiometers is essential. The frequency of floods has increased in the Himalaya due to increased events of extremely heavy rainfall which is consistent with warming and the observed increase in water vapour. Improved satellite-based observations and modelling are required for accurate forecasts of water flow. An early warning system for forecasting floods in the Himalaya must be developed, which should also include floods due to GLOF.

The forest and grasslands of the Himalaya, one of the global biodiversity hotspots, are unique and host diverse flora and fauna. The forest cover is under stress in India and Nepal, while it is stable in Bhutan. The loss of forest cover has increased the incidences of landslides and soil erosion in Nepal. An optimum forest cover is vital for preserving biodiversity. In the Indian Eastern Himalaya, large-scale deforestation has caused substantial forest loss, underscoring the region's critical role in biodiversity conservation and the regulation of global carbon, energy, and water cycles (Bhuyan et al., 2025). Forest fires are a major hazard and about half of the forest is susceptible to fire. A database on the distribution of forests and Biodiversity Characterization at Landscape Level has been developed for the Indian Himalaya at the Indian Institute of Remote Sensing (IIRS) - ISRO. However, there are gaps in the information on the estimation of biodiversity and climate change–induced shifts in vegetation and species loss, and identification of hotspots. Land Use Land Cover (LULC) changes for three decades in the river basins of the Himalaya and the human dimensions of the impact of climate change have been addressed (Saha & Senthil Kumar, 2018). The integration of long-term LULC and habitat change maps, species data and socioeconomic data is required to understand habitat change scenario.

In the mountainous terrain of Himalaya, about 1500 people depend on each sq. km of agriculture land compared to about 500 persons on plains and hence pressure on land and forest areas has increased. Apart from population pressure, the changing climate has also been impacting the agriculture significantly. The accelerated warming and glacial melt in the Hindukush Himalaya along with declining monsoon rainfall, an increase in warm days and nights and hot and dry extremes in the Northeastern Himalaya have impacted the agriculture (Dhara et al., 2025). Evidence of shift in fruit tree belt, increased incidences of pests and diseases, and a decline in productivity of food and tree crops have been observed (Saha & Senthil Kumar, 2018). In the Eastern

Himalayan region of India, shifting cultivation has driven complex spatio-temporal patterns of forest disturbance and regrowth, reflecting a transition from traditional jhum cycles to more permanent and commercially oriented land-use practices with significant ecological implications (Bhat et al., 2024). An understanding of soil erosion, nutrient loss and crop productivity through satellite and ground-based observations are required to understand land degradation processes and their impact on the ecosystem.

The high growth of population in the Himalaya, increased tourism and development of infrastructure, hydropower projects, along with natural hazards in the Northwestern Himalaya, require planning for sustainable urban centers. Predictive models based on terrain characteristics, LULC and availability of water and energy are to be developed for sustainable spatial growth.

The Himalayan region is increasingly under stress due to urbanisation, tourism and large-scale infrastructure projects, such as the construction of roads, railways, tunnels, airfields, which have been undertaken to support defence as well as developmental needs including hydropower generation and dam building. However the environmental issues are placed as secondary to state security and development needs. The Himalaya must be viewed from the perspective of how political decisions and anthropogenic activities interplay with the Himalayan environment, climate change, and natural hazards. It requires an interdisciplinary approach and a mechanism to understand the Himalayan environment, its role in the earth system processes vis-à-vis international politics. The UN General Assembly declared 2025–2034 as the Decade of Action for Cryospheric Sciences. It will advance climate science, build stronger international partnerships, and increase worldwide awareness of Earth's frozen regions. Satellite data can provide information on the interaction of cryospheric surface and atmosphere, land surface processes including land use, vegetation and ecosystem changes and their interaction with the anthropogenic environment. The insights provided by satellite observations are crucial to the understanding of the Himalayan environment.

It is therefore imperative that the following aspects to be implemented.

(i) Strengthen systematic, continuous, automated, long-term satellite and ground-based observations of atmospheric, hydrological, geological and geophysical parameters to understand patterns and trends of earth system processes and model the same.
(ii) Future research to focus on snow & ice dynamics, mass balance and evolution of cryosphere to understand the fate of glaciers and their driving forces and on modelling of Glacial Lake Outburst Flooding.
(iii) Reliable estimates of snowmelt contributions in Himalayan river basins for forecasting regional water availability.
(iv) Improve our understanding of earthquake processes, landslides and avalanches and risk assessment to human habitation and infrastructure for disaster risk reduction.

Collaborations with research institutes in understanding the Himalayan system is crucial to develop strategies to provide resilience to large populations. The Himalaya should be treated as a unique ecological system. Hence the stewardship of the Himalaya is crucial for the well-being of people living in the mountains and plains.

As we embark on 2026, we are committed to improve the Journal's reach and readership. Springer Nature has conferred the 'Society Impact Award ' recognising our sustained contribution to the United Nations Sustainable Development Goals through high quality research focused on societal issues.

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Wish You a Very Happy and Prosperous New Year.

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