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CLIMATE CHANGE & HIMALAYAN CRYOSPHERE: RIVER NEXUS IN NORTHEAST INDIA (WITH SPECIAL REFERENCE TO ASSAM)

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Abstract

The Himalayan cryosphere plays a pivotal role in sustaining the hydrological dynamics of the Brahmaputra and Barak river basins, which are critical for the community prosperity of Northeast India. In recent decades, there has been accelerated glacier retreat, declining snow cover, and changes in melt patterns in the eastern Himalaya. These are largely due to rising temperatures and shifts in the monsoon pattern. Concurrently, shifts in the onset, intensity, and frequency of extreme rainfall during the Indian Summer Monsoon have affected flood risks and sediment levels in the region. Human activities and land-use changes have exacerbated these hydrological challenges, increasing the risk of both river and flash floods.

This review synthesizes current information on the interactions between cryosphere degradation, monsoon variability, and downstream hydrology in Northeast India, focusing on the Brahmaputra and Barak systems. This paper critically evaluates observational data, remote sensing studies, and hydrological models to assess trends in glacier mass balance, snowmelt contributions, river flow, and sediment flux. Furthermore, examining the potential of nature-based solutions (NbS), such as wetland restoration, floodplain reconnection, and catchment reforestation, in mitigating flood risks while delivering co-benefits for biodiversity and livelihoods.

Keywords: Eastern Himalaya, Brahmaputra basin, glacier retreat, monsoon variability, flood risk, Nature-based Solutions

`1. Introduction

The eastern Himalayan region, which feeds into the Brahmaputra and Barak rivers, is a critical headwater zone sustaining agricultural production, ecology, and culture in Northeast India, stretching from Arunachal Pradesh to parts of Sikkim and Bhutan. These river systems are predominantly sourced by glaciers, snowmelt, and monsoon rains and are highly sensitive to climate variability. Evidence from satellite imagery, in-situ monitoring, and regional climate modeling indicates an overall acceleration of cryospheric changes, shifts in the timing of monsoons, and changes in flooding frequency over recent decades (Dimri et al., 2021)

The Himalayan cryosphere of Asia, often referred to as the “Third Pole” due to its vast reserves of ice, is witnessing temperature rises higher than the global average. This has led to significant glacier retreat, particularly in the eastern region, which is distinct from the western Himalaya in terms of precipitation, glacier morphology, and climatic processes. Snow cover duration has shortened, and the timing of peak meltwater contribution to rivers is shifting (Bolch et al., 2012).

Simultaneously, the Indian Summer Monsoon, the dominant hydrological force for the region, is undergoing significant changes. Recent studies suggest a trend towards increasingly erratic onset and withdrawal dates, and more frequent extreme rainfall events, which have implications for river discharge patterns and flood risk (CEEW analysis, based on IMD data, 2012–2022) (CEEW, 2025). In the Brahmaputra basin, peak discharges are likely to increase under high-emission scenarios, which will enhance erosion, sedimentation, and bank-line instability (Gain et al., 2011).

These changes, along with land-use transformation, including deforestation, agricultural expansion, and infrastructure development, magnify the flood hazards. Traditional engineering measures, such as embankments, have provided partial protection but may fail during extreme events and often tend to interfere with natural flows of water and sediment.

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Nature-based solutions (NbS) provide an integrative alternative, utilizing ecosystem processes to mitigate flood hazard while promoting biodiversity and local livelihoods. In Northeast India, efforts such as wetland restoration, riparian buffer zone development, and community-led catchment management have been promising but remain under-documented and under-leveraged (India Water Portal, 2025).

2. Climate Change and the Himalayan Cryosphere

According to the IPCC Sixth Assessment Report, Eastern Himalayan glaciers have been retreating at high rates, with smaller glaciers more vulnerable to complete disappearance. Rising mean annual temperatures, coupled with decreasing snowfall and increasing rainfall, have shifted the precipitation regime from snow-dominated to rain-dominated systems (Bolch et al., 2019). This transition reduces the natural water storage capacity of the cryosphere and alters river hydrology.

Permafrost melting, although less studied within the Eastern Himalayas, is also of further concern. Melting permafrost degrades mountain slopes, increasing the likelihood of landslides and glacial lake outburst flood (GLOF) occurrence. Recent satellite-based research emphasizes that several glacial lakes in Arunachal Pradesh and Sikkim are growing, thereby increasing the risk of devastating downstream flooding events (Nie et al., 2013).

3. Hydrological Implications for the Brahmaputra–Barak Basin

The Brahmaputra and Barak rivers are crucial for Northeast India, supporting agriculture, fisheries, hydropower, and the region's drinking water needs. The Brahmaputra, in particular, relies on both glacial melt and monsoon rainfall. The glacial and snowmelt constitute approximately 20-25% of its annual runoff, and the rainfall-runoff of about 66% and 59% (Patel *et al.*, 2021).

However, climate change is transforming these hydrological dynamics. A 2019 assessment of the broader Hindu Kush Himalaya region projects that one-third of all glaciers will vanish by 2100 even under a 1.5 °C warming scenario, with losses reaching 50% under moderate emissions (RCP 4.5) and over 67% under high emissions (RCP 8.5). This melting is expected to initially boost flows, but beyond around 2050, glacial meltwater input will decline irreversibly (Wikipedia).

4. Ecological and Socio-Economic Consequences

Ecologically, climate change accelerates biodiversity loss, disrupts natural habitats which ultimately causes ecosystem instability. Whereas, the socio-economic consequences lead to an increase in the frequency of floods, droughts, and cyclones, causing severe damage to agriculture, infrastructure, and livelihoods.

4.1 Biodiversity Impacts

The Northeast Indian Himalayas harbor rich biodiversity, including endemic species such as the red panda and clouded leopard. The altered river regimes are endangering aquatic ecosystems, where native fish species like *Tor putitora* (golden mahseer) are at risk of extinction due to habitat fragmentation and fluctuating water levels. During dry periods and inundation during extended floods, riverine wetlands face shrinkage, which is critical for migratory birds.

4.2 Agricultural Livelihoods

Over 80% of the population in Northeast India relies on agriculture. Shifting hydrological regimes disrupt paddy cycles and jhum (shifting cultivation) systems, leading to food insecurity. A 2016 study in the *Journal of Agrometeorology* focused on Jorhat, Assam. It used climate projections under different RCP scenarios and estimated rice yield reductions ranging from -12.7% (under RCP 2.6) to as high as -43.4% (under RCP 8.5), for the year 2050, depending on transplanting dates.

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4.3 Human Settlements and Disaster

Cryosphere-driven processes, including glacial melt and changing snow regimes, exacerbate floods and landslides in downstream regions. Assam, one of India's most flood-prone states, experienced over 30 major flood events between 2000 and 2020, with cumulative displacement running into millions of people (ASDMA, 2019; CSE, 2022; IPCC, 2021). GLOFs from upstream Bhutan and Arunachal Pradesh contribute to transboundary flood risks. Annual flood-related damages in Assam are typically reported in the range of ₹200–300 crore (≈ approximately USD 25–40 million), although international assessments suggest that the long-term economic costs could be much higher (World Bank, 2020).

5. Nature-Based Solutions (NbS)

Nature-Based Solutions uses natural processes and ecosystems to mitigate environmental and societal challenges like climate change, focusing on protecting, restoring, and sustainably managing ecosystems.

5.1 Wetland Restoration

Deepor Beel, a Ramsar wetland near Guwahati, covers about 10 km² in the dry season and expands to over 40 km² during floods. It helps manage excess water. However, its ability to hold floodwater has decreased. The storage capacity fell from 20.95 million m³ in 2001 to 15.35 million m³ in 2019 because of encroachment and pollution (Ahmed *et al.*, 2021). Restoration efforts like desilting, weed control, and reforestation are in progress but face challenges due to ongoing waste dumping.

5.2 Floodplain Reconnection

Embankments limit natural floodplain storage in Assam. However, there are few large-scale reconnection projects. The state has approved detailed project reports for 16 wetlands under the National Mitigation Fund, totaling ₹634.83 crore, to improve water retention. Despite this, initiatives to remove embankments are still rare (Sentinel Assam, 2023).

5.3 Catchment Reforestation

Planting trees in degraded catchments reduces runoff and stabilizes soils. The Gethsemane Forest in Udalguri, which spans 7.36 km² and contains 1.4 million trees, shows how community-led reforestation improves water regulation and biodiversity. This method can be applied to Arunachal's agroforestry systems (Wikipedia, 2023).

6. Conclusion

The rapid degradation of the cryosphere, increased volatility of the monsoon, and changing water patterns are worsening flood risks in Northeast India. Although traditional structural protections are still important, nature-based solutions such as restored wetlands, reconnecting floodplains, and managing catchments provide multiple ways to reduce risks and build resilience. It is crucial to address significant data gaps and incorporate nature-based solutions into climate-smart water management. This approach will help protect ecosystems and vulnerable communities in this fast-changing area.

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