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Preventing Disaster and Managing Its Risk, Strengthening Resilience of Ecosystem for a Safer World-India Perspective on Himalaya

Dr. Anju Rathee Ahlawat

Assistant Professor, Department of Applied Science, Maharaja Surajmal Institute of Technology, C-4, Janak Puri, New Delhi, India

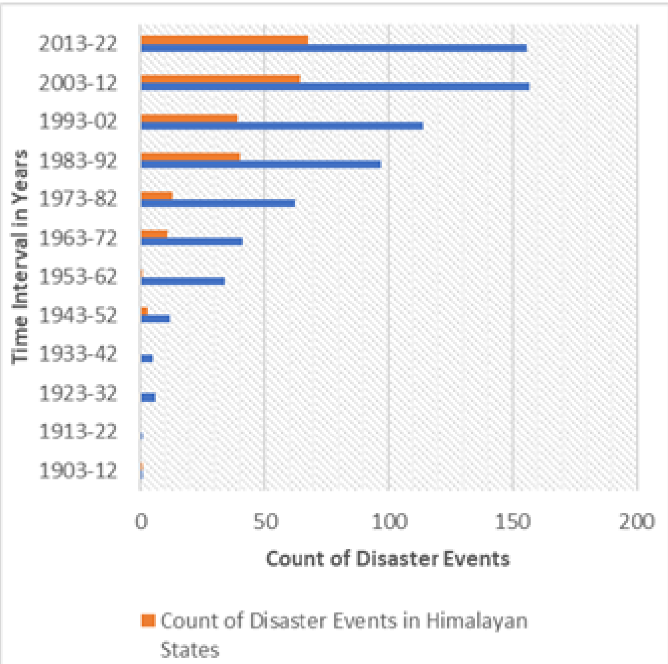
Abstract: ***The Indian Himalayan Region (IHR) is one of the most ecologically fragile yet strategically vital zones in the world. Intensifying climate change, accelerating glacial retreat, rising extreme weather events, and unscientific development have amplified disaster risks across the Himalayas. Cloudbursts, flash floods, landslides, and Glacial Lake Outburst Floods (GLOFs) pose escalating threats to human settlements, infrastructure, and ecosystems. The 2025 Uttarkashi disaster vividly demonstrated the region's vulnerability and the compounding impacts of meteorological anomalies and glacial dynamics. This paper examines the drivers of Himalayan disaster risks, scientific processes underlying extreme events, and the interplay of climate change with anthropogenic pressures. It explores the evolving role of Artificial Intelligence (AI), Machine Learning (ML), space-based monitoring, and policy interventions in strengthening disaster preparedness. It emphasizes ecosystem-based resilience, community-centered adaptation, and a future-ready governance framework integrating technology, scientific monitoring, and sustainable development. This study argues that only a synergistic balance between ecological safeguards, technological innovation, and participatory governance can ensure long-term resilience and sustainable development for Himalayan communities.***

Keywords: Disaster Risk Reduction, Himalayas, Climate Change, Cloudburst, GLOF, AI/ML, Ecosystem Resilience, Uttarkashi Floods, Sustainable Development, NDMA, IHR

1.Introduction

Climate-induced extremes-rising temperatures, erratic monsoons, glacier retreat, and hydrological imbalances-have made mountainous ecosystems highly vulnerable. The Himalayas, being a young fold mountain system, experience dynamic geomorphological processes including erosion, landslides, rockfalls, and seismic activity [1, 2]. India's Himalayan states are repeatedly exposed to hydro-meteorological disasters, as seen in the Kedarnath floods (2013), Chamoli disaster (2021), Sikkim GLOF (2023), Dehradun floods (2025), and Uttarkashi extreme event (2025).

Scientific evidence confirms that the Himalayas are warming at nearly **twice the global average**, leading to glacial thinning, unstable slopes, and increased frequency of extreme precipitation. Combined with unplanned development, deforestation, and infrastructure expansion, the region faces cascading disaster risks. Strengthening ecosystem resilience, improving early warning systems, and adopting sustainable development practices are crucial for preventing and mitigating disasters in the Himalayas. Below mentioned data [26] belongs to IHR (excluding Darjeeling District of West Bengal) and is highlighting that Himalayan States have observed nearing 40% of India's disasters over time.



Time Intervals in Years	Count of Disaster Events in India	Count of Disaster Events in Himalayan States
1903-12	1	1
1913-22	1	0
1923-32	6	0
1933-42	5	0
1943-52	12	3
1953-62	34	1
1963-72	41	11
1973-82	62	13
1983-92	97	40
1993-02	114	39
2003-12	157	64
2023-22	156	68

2.Climate Change and the Himalayan Fragility

The Indian Himalayan Region spans 13 states and union territories, covering approximately 2500 km. It functions as India's "water tower, " feeding major rivers including the Ganga, Yamuna, and Brahmaputra. However, the region's natural attributes-steep slopes, fragile geology, and tectonic instability-combined with human pressures heighten disaster exposure [7, 9, 11, 21].

A. Accelerated Warming

The Himalayas exhibit temperature rise sharper than the global mean. This accelerates glacial melt, expands glacial lakes, and increases likelihood of GLOFs. Events such as the 2023 Sikkim GLOF and the expansion of lakes near the Gangotri glacier highlight the risk.

B. Erratic Precipitation and Monsoon Extremes

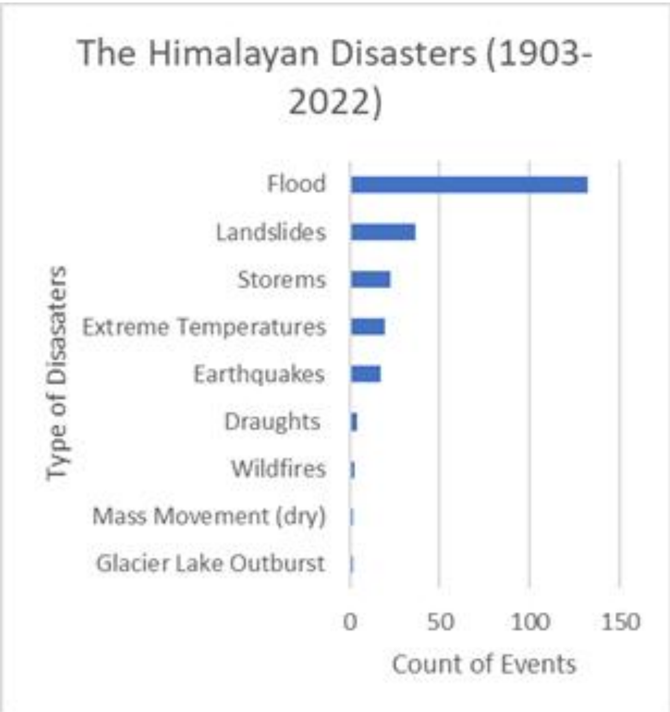
Climate change is altering monsoon behaviour. Frequent cloudburst-like events, unusually high 24-hour rainfall, and rapid snowmelt episodes generate flash floods and debris flows.

C. Geological and Seismic Vulnerability

Being a young orogenic belt formed by the collision of the Indian and Eurasian plates, the region continues to experience tectonic stress. Historic events like the 2005 Kashmir earthquake demonstrate the potential for cascading disasters.

D. Ecological Degradation

Deforestation, hill-cutting, riverbed encroachment, and hydropower tunnelling destabilize slopes and weaken natural resilience.



This Himalayan Disasters since 1903 up to 2022	
Type	**Count**
Glacier Lake Outburst	2
Mass Movement (dry)	2
Wildfires	3
Draughts	4
Earthquakes	17
Extreme Temperatures	20
Storms	23
Landslides	37
Flood	132
Total	240

3.Science of Cloudbursts and Glacial Lake Outburst Floods (GLOFs)

A, Cloudburst Formation

Cloudbursts occur when warm, moisture-laden air is forced upward due to orographic lifting [5, 8]. As it rises, the air cools adiabatically, leading to condensation and the formation of dense cumulonimbus clouds. Powerful updrafts suspend large water droplets and ice particles, which eventually fall as intense localized rainfall once saturation exceeds thresholds. Rainfall intensity >100 mm/hr is typically classified as cloudburst.

B. Langmuir Precipitation Process

Falling large raindrops collide with smaller ones, growing rapidly and intensifying rainfall.

C. GLOF Mechanism

GLOFs occur when glacial lakes-dammed by loose moraines-burst due to ice/rock avalanches, dam failure, or glacier collapse [3]. The release creates high-energy floods capable of destroying settlements and hydropower structures downstream [6, 10]. Similar events include the 2021 Chamoli disaster and the 2023 Sikkim Teesta GLOF.

4.Case Study: The 2025 Uttarkashi Disaster

A. Green Event Overview

On 5 August 2025, flash floods devastated Dharali and Sukhi Top in Uttarkashi. The Kheer Ganga River overflowed, carrying massive sediment and debris. Although reported as cloudbursts, India Meteorological Department (IMD) recorded only 6.5 mm rainfall in Harsil and 11 mm in Bhatwari in 24 hours, far below cloudburst criteria.

B. Scientific Interpretation

The discrepancy suggests the possibility of a GLOF or glacier collapse. Climate-induced glacier thinning creates unstable lake systems that can breach unexpectedly. High-velocity floods and debris-rich flow in Dharali indicated a non-rainfall trigger [3].

C. Impact and Losses

i. Entire Dharali market submerged
ii. Destruction of homes, hotels, and homestays
iii. Roads, bridges, and the ancient Kalp Kedar temple damaged
iv. Army personnel among casualties
v. Severe disruption to tourism and Char Dham Yatra economy

D. Gaps in Early Warning and Response

Despite IMD alerts, local preparedness remained inadequate. The event highlighted the need for better dissemination, community-level coordination, and scientific monitoring of glacial systems.

5.Human-Induced Vulnerabilities in the Himalayas [16, 17, 19]

A. Unregulated Development

Expansion of roads (e.g., Char Dham), hydropower tunnelling, and construction on unstable slopes amplify disaster risks [21].

B. Deforestation and Slope Destabilization

Forest loss reduces soil retention, increasing landslide frequency.

C. Encroachment and Riverbed Modification

Channel narrowing and poor drainage exacerbate flood intensity.

D. Tourism Pressure

Influx of millions of pilgrims creates infrastructure stress in geologically weak areas.

E. Land Subsidence Events

The 2023 Joshimath crisis revealed the consequences of unchecked construction in fragile terrain [22].

6. Technological Interventions: AI, ML, and Remote Monitoring

A. Energy Predictive Analytics

AI/ML models process satellite data, hydrological conditions, and meteorological inputs to forecast extreme events [14, 25].

B. Early Warning Systems

Doppler radars, automated weather stations, and glacial sensors help detect cloudburst possibilities and lake movements.

C. Real-Time Disaster Response

AI-guided drones map damaged regions, support rescue planning, and monitor landslides.

D. Social Media Mining

ML algorithms analyze public distress signals and geotagged posts to identify affected zones during emergencies.

E. Long-Term Planning

Scenario modeling aids policymakers in designing resilient infrastructure and land-use plans.

7. Ecosystem-Based Disaster Resilience

A. Nature-Based Solutions

i. Reforestation and slope stabilization
ii. Wetland restoration as natural buffers
iii. Sustainable water drainage systems

B. Community-Centered Approaches

Indigenous knowledge of Himalayan communities helps identify safe zones, water flow patterns, and unstable slopes [20].

C. Sustainable Livelihoods

Promoting organic farming, eco-tourism, and decentralized energy systems reduces pressure on fragile ecosystems.

8. Policy Landscape and Institutional Framework

A. National Disaster Management Authority (NDMA) India Initiatives

The National Disaster Management Plan (2019) emphasizes Himalayan hazards like landslides, cloudbursts, and GLOFs.

B. NMSHE and IHCAP

National Mission for Sustaining the Himalayan Ecosystem (NMSHE) and Indian Himalayas Climate Adaptation Programme (IHCAP) enhance climate adaptation, glacier monitoring, and capacity building [12, 13].

C. SECURE Himalaya Project

Securing livelihoods, conservation, sustainable use and restoration of high range Himalayan ecosystems (SECURE) project focus on biodiversity conservation and community-based resilience.

D. IHDP and NAPCC

The Integrated Himalayan Development Program (IHDP) and The National Action Plan on Climate Change (NAPCC) support integrated Himalayan planning and climate mitigation.

E. State Disaster Response Fund (SDRF) Increased Allocation

Himalayan states receive 90% central funding for disaster relief.

F. Regional Cooperation

The Hindu Kush Himalayan (Disaster Risk Reduction) DRR Hub facilitates transboundary early warning systems [4, 15].

9. Building a Future-Ready Disaster Management Framework

A. Sustainable Land-Use Planning

Strict enforcement to prevent construction on floodplains and unstable slopes; adoption of Himalayan-specific Environmental Impact Assessment (EIA) [17].

B. Technology-Driven Hazard Monitoring

AI-enabled modeling, high-resolution satellite mapping, and glacial surveillance systems [25].

C. Community-Based Disaster Management

Participatory hazard mapping, first responder programs, and school-level capacity building.

D. Strengthened Governance

Improved coordination among NDMA, IMD, geological institutions, and state agencies.

E. Build Back Better

Post-disaster reconstruction should adopt resilient designs, slope stabilization, and ecological restoration.

10. Conclusion

The Himalayan region stands at a critical juncture where climate change, fragile geology, and unregulated development intersect to create a complex disaster landscape. The 2025 Uttarkashi disaster serves as a powerful reminder that reactive measures are insufficient. A holistic, future-ready framework-integrating scientific monitoring, technology adoption, ecological protection, and empowered communities-is essential for building resilience. Guided by longstanding recommendations [23] such as the Mishra Committee (1976) and J.C. Pant Committee (1999), India must shift from "disaster response" to "disaster prevention and risk reduction." Only a synergy of environmental stewardship, scientific innovation, and sustainable development can safeguard Himalayan ecosystems and ensure a safer world for future generations.

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