

Cryospheric Decline and Cultural Erosion: Climate Change Impacts on Winter Sports and Livelihoods in the Indian Himalayas

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Abstract:

The experience of climate change has produced significant instability in the cryosphere of the Indian Himalayas, not merely in temperature increases, but also in heterogeneous and regionally extensive snow processes. Scientific evidence on the effects of seasonal persistence of snow has led to a quantifiable reduction in seasonal snow cover (23.6% below normal) and significantly reduced winter durations (only half of the ice-skating rink within the city of Shimla remaining operational). This instability has badly disrupted the scheduled sports events, and key infrastructure investments have been deterred. More importantly, its impacts are socio-cultural: denudation increases the rate of forced migration, exacerbates economic inequity, and poses psychosocial risks, demonstrating that ultimately, the crisis hinges on cultural trauma and the loss of identity by mountain communities. Moreover, the conventional high-tech approach toward the issue, which is artificial snowmaking, has a serious conflict with the IHR. Its extensive water use collides with severe threats of water insecurity affecting billions of people downstream, and its water use contributes significantly to the emissions behind the crisis itself. This type of technology is dangerously susceptible to a kind of major maladaptation unless it is subject to critical examination with local resource limitations. Any effective policy

should resist the illusion of local homogeneity, recognizing the dissimilarity between the dynamic Western Himalayas (Karakoram Anomaly) on the one hand and the struggling Central Himalayas on the other. The shift of policymaking and policy towards a more reactive management of crises (e.g., postponing events) should be shifted towards more integrated, science-driven approaches that involve evaluations of vulnerable areas. The retrospective of eight years over which approved means of adapting to change, like the Shimla rink conversion, have happened, points to the fact that policy underperformance and governance inertia are enhancing sporting heritage loss even in the example where such mechanisms remain technically integrated. Necessary efforts are needed to short-circuit implementation and make the adaptation funds useable on time. Cultural heritage and protection of the Himalayan cryosphere urgently need a coordinated policy addressing science, cultural knowledge and equitable adaptation.

Keywords: *Cryospheric decline, Hindu Kush Himalaya (HKH), Elevation-dependent warming, Snow cover variability, Winter sports tourism, Cultural erosion, Livelihood vulnerability, Artificial snowmaking, Ice stupas adaptation.*

Introduction:

Hindu Kush Himalaya (HKH) is considered the third pole in the world by scientists because this territory has the largest deposits of snow and ice not in the poles (Morris, 2017). It is also intrinsically linked to the water security and livelihoods of close to a quarter of 2 billion individuals in Asia since it nourishes 12 significant waterway systems, including the Indus, Ganges and Brahmaputra tracks (Global Climate Risk, 2025). Climate change is also particularly impactful on this sensitive high-altitude setting where accelerated rates of warming are frequently seen- what is referred to as elevation-dependent warming (Almagioni et al., 2025). The visual impacts of this warming are predominantly found in irregularity in precipitation patterns as well as a substantial causal drop in the seasonal sustainability of snow. According to the due examination, seasonal snow endurance in the HKH has been reaching a 23-year low, standing at 23.6 per cent lower than the typical mean (Global Climate Risks, 2025). This crisis is no isolated event, but five years out of the past six years have experienced below-average snowfalls, indicating a fundamental change of the regional climatic regime (Global Climate Risks, 2025). Not just undermined in the first place through their effects on

snow-based priorities, like mountain touring and related leisure pursuits, these cryosphere transformations disrupt hydrological patterns and enhance extreme weather occurrences, as well as posing a direct challenge to the cultural and economic grounds concerning lives in the mountains (Matta et al., 2025; Azmat, 2025).

Definition and Significance of Traditional Winter Sports in the IHR

In India, winter sporting is a relatively geographically localized activity, with most activities being concentrated on the northern side of the country, mainly Jammu and Kashmir, Himachal Pradesh, and Uttarakhand, as well as Sikkim and Arunachal Pradesh (Winter sports in India, 2025). Although there are modern commercial activities, including skiing, snow rugby, snow cycling, and snow football among them, it is said that the real value of winter sport is in the fact that it remains an element of the regional culture and a component of local identity (Winter sports in India, 2025; Mountain Mysteries, 2025). The winter activities utilized by and through the years tend to be Shrove activities, much like the cultural celebrations. Like the Manali Winter Carnival, the Halda Festival in Lahaul or the historic Ice-Skating Carnival in Shimla, ritualized activities change natural lands into collective spaces of play (Mountain Mysteries, 2025; Himachal Pradesh Tourism Development Corporation, n.d.). These carnivals combine participatory sports featuring folk music, basic meals, artisanship bazaar and dances (Mountain Mysteries, 2025). This integration of leisure, ritual and commercial activity implies that this viability of winter sports is not always a recreational pursuit but it constitutes an essential, though auxiliary, element of economic dependency of most communities (Azmat, 2025). Climate change is not just a threat to tourism industry in economic terms, but a cultural menace to the identity and social unity of mountain communities. And this study argues that unprecedentedly non-uniform patterns of snow covers and drastic impairments of snow reliability are causing drastic, multi-faceted harm to the traditional winter sports in Himalayan areas due to climate change. This is causing climate risk to develop into more than an economic emergency but rather a root cause of cultural loss and progressive socio-political unrest in the Indian Himalayas. The further break down of analysis is formulated in such way that the physical manifestations of the cryospheric instability must be identified first and the particular effects on the educated and community sports are thereafter analyzed in a uninterrupted manner. Following that, the paper will discuss the cascading socio-economic and cultural vulnerabilities among mountain communities and conclude with a critical analysis of

existing adaptation measures and development of long lasting, sustainable, and integrated solutions.

Physical Evidence of Cryospheric Instability in the IHR

Spatiotemporal Variability of Snow Cover and Persistence (2001–2025): The most direct physical effect of the climate change on the winter sports would be the shorter days of the snow cover, decrease in its depth and timing all over the IHR (Azmat, 2025). Those transformations significantly change the water cycle in the area and jeopardize essential ecosystem services (Matta et al., 2025). Recent observations are showing a tendency of warmer, drier winters, which severely reduces the time span on which snow-dependent activities can be carried out (Nair, 2025; Azmat, 2025). This development of a new normal comes along with environmental impacts like a rising number of wild fires the way that the kind of wild fire that afflicted Ganderbal, about 60 kilometers North of Gulmarg, experienced this decade just previous showcases the perilous process of desicating the winter scene (Nair, 2025).

The severity of the decrease of the seasonal snow persistence all through the Hindu Kush Himalaya (HKH) is the overall macro-level indicator of the crisis. The fact that it fell to its lowest point in 23 years with 23.6% lower than what is normal points to the vulnerability in the region (Global Climate Risks, 2025). Therefore, in the case the total precipitation remains the same, the snow storage period is reduced drastically. The miniaturization of the standard winter season and decreased snowpack causes the water stress in the season to be poor in the beginning of the year (Global Climate Risks, 2025; Azmat, 2025). The impacts of ski recreation affect so much more than just recreational skiing, the basic consequences of less snow coverage are crucial effects to availability of melt water to agricultural needs during the spring and summer which can be up to a billion significantly raising the key coverage of hydropic security to involve two billion personally (Global Climate Risk 2025).

Contrasting Regional Dynamics: The Karakoram Anomaly vs. Central Himalayan Decline: A crucial finding in cryospheric research is that snow dynamics are not uniformly negative across the IHR, which has profound implications for localized policy and tourism investment (Tauqir et al., 2025). Treating the "Himalayas" as a single climatic entity risk misallocating resources and underestimating regional vulnerabilities.

Scientific Heterogeneity in Snow Dynamics

Scientific data confirms a fundamental spatial conflict in snow cover trends:

Western Himalayas (WH) and Karakoram: Unlike on the global ice loss trends, the region has a positive snow cover than expected and negative net mass balance (0.0389) over the period 2004 to 2024 (Tauqir et al., 2025). This mechanism is commonly known as the Karakoram anomaly driven mainly by the increased levels of winter precipitation caused by the intensified Western Disturbances (WDs) and a consistent temperature of the regions (Tauqir et al., 2025; Almagioni et al., 2025). This is a case of local stability, which offers temporary stability and is similar to the Karakoram precipitation patterns in the south (Tauqir et al., 2025).

Central Himalayas (CH): Very contrastingly, the CH shows a negative net mass balance. This is a monsoon dominated region, whose snow-covered areas (SCA) reduce significantly at the high altitudes, highly contributed to by warming that is pronounced by the elevation (Tauqir et al., 2025). This heterogeneity of such trends creates a level of high political and financial risk to national adaptation strategies (Tauqir et al., 2025). As an example, whilst investment policy is informed by the localized positive dynamics of the WD-dominated Western Himalayas, vulnerable Central Himalayan zones (such as in Uttarakhand) would receive insufficient support, accelerating their vulnerability to climate change. Most importantly, numerous of the more popular, and lower-grade Indian ski resorts and winter hubs, many of which make their commercial viability, depend upon how well they strip accumulate perfuse snow, are not within the range of the Karakoram Anomaly (Nair, 2025; Azmat, 2025).

Table 1: Observed Snow Cover Trends and Mass Balance in Key Himalayan Regions (2001–2024)

Himalayan Region	Observed Snow Cover Trend	Mass Balance Trend ()	Primary Climatic Driver	Relevance to Sports Vulnerability
Western Himalayas (WH)	Positive SCA trend (Almagioni et al., 2025)	(Positive) (Tauqir et al., 2025)	Enhanced winter precipitation (Western Disturbances) (Tauqir et al., 2025)	Localized stability offers temporary resilience, but overall region remains vulnerable to lower-altitude warming.
Central Himalayas (CH)	Declining SCA (Higher Altitudes) (Tauqir et al., 2025)	(Negative) (Tauqir et al., 2025)	Elevation-dependent warming; Monsoonal influence (Tauqir et al., 2025)	High vulnerability; accelerated snow retreat threatening high-altitude tourism.

Hindu Kush Himalaya (HKH) Overall	Declining seasonal persistence (Global Climate Risks, 2025)	N/A	Rising global temperatures, erratic patterns (Global Climate Risks, 2025)	23.6% below normal snow persistence (23- year low); severe macro-level water stress.(Global Climate Risks, 2025)

Direct Impacts on Organized and Community-Based Winter Sports

Impact on Established Sporting Events and Investment:

This growing uncertainty and diminishing snow cover have a direct translation into organized winter sports disruption. The most obvious implication is the delay and cancelation of large events. Indicatively, there is the cancellation of the 2025 Khelo India Winter Games to be held in Gulmarg that has never been called upon since the second consecutive year contesting a considerable shortage of natural snow, enforcing many features on around 300 competing athletes (Nair, 2025). Such unpredictability has major economic deterrents on the long term development. Unpredictable snow will deter the much-needed investment in tourism infrastructure, which will eventually lower employment options as many jobs, and massively destroy Kashmir as a traditional snow sports destination (Azmat, 2025). The change of behavior also adds to the future economic losses since local and international tourists and athletes are shifting to new destinations that they expect to have more reliable snow cover in, like Himachal Pradesh or other foreign destinations like Kazakhstan (Azmat, 2025). This tourism displacement manifestation is an ongoing feedback loop thus further undermining the Himalayan traditional winter spots financial sustainability (Azmat, 2025).

Case Study: The Fate of Natural Ice-Skating in Shimla (Himachal Pradesh)

The deterioration of an old open natural ice-skating rink in Shimla summarizes the cultural and structural dangers that have an impact on the old winter sports. It does not only serve as a recreational destination, but also the cradle of ice skating in India, and a major center of community events as the only open-air ice skating rink in Asia, dating back to more than 100 years (ANI, 2025; Himachal Pradesh Tourism Development Corporation, n.d.; Sharma, 2020). Climate change in this case can be measured: ten years ago, there were usually 100-110 then skating sessions on the rink every winter there; now, however, with the rise in temperatures and weather variations, it has shaved it down to only 50-55 (ANI, 2025). More

so, the pressures are compounded through localized urban factors, such as tree-cutting, uncontrollable building appears in the area, destruction of the Rivoli Theatre (which used to provide a layer of protection to the rink against direct sunlight), and pollution (Economic Times, 2023). Such human-related processes are added with an increasing maximum temperature to postpone the start of the skating season, reducing the period of service (Economic Times, 2023). The way to modern adaptation has been marked by systemic failure, in spite of its apparent vulnerability. One of the projects that has been approved to transform the natural rink to an indoor artificial rink using plans such as Swadesh Darshan, has remained stagnant in almost eight years (Economic Times, 2023; Vyas and Nagal, 2023). Such a long-term delay caused by governance inertia and bureaucratism has led to the loss of time-related money (Vyas and Nagal, 2023). This illustrates that governance failure, along with the high rate of urbanization and infrastructure disregard, can hasten sporting heritage destruction, in itself a kind of cultural erosion by inaction, despite the availability of potential solutions being available in the technical literature.

Threats to Traditional Localized Winter Games and Festivals

Displacement of dependable winter snow per se is a direct threat on the social and cultural material factored by traditional winter festivals. Folk dances, craft bazaars, and where the tribespeople eat together are all parts of events such as the Halda Festival at Lahaul and the numerous carnivals in Manali and Shimla which surround their sporting focus (Mountain Mysteries, 2025; Himachal Pradesh Tourism Development Corporation, n.d.). Once the athletic aspect i.e. skating ice on the ice or local snow merry-go-rounds become less reliable, the occurrences would lose its charm as a pure entertainment and ritualized enterprises, losing its cultural value and popularity altogether (Mountain Mysteries, 2025). Also, the regularity of cancellation of events as demonstrated in the situation with Shimla and shortening of the training windows, as in the case of Khelo India (Nair, 2025; ANI, 2025), has a great effect on the pipeline of development of athletes. Such a significant decrease in the number of practice sessions minimizes the capacity of the local children and adult youth to advance in winter sports, which diminishes the overall possibility of India to play on the international level, and which may reduce employment prospects in the industry (ANI, 2025). The quantifiable loss in the amount of snow is, consequently, an equivalent loss in human capital and sport legitimacy on a national scale.

Socio-Economic and Cultural Vulnerability of Mountain Communities

Livelihood Disruption and Economic Ripple Effects

The effects of climate change have extreme ripple effects because of the interrelationship of the economies of the Himalayas. Decreased winter-based tourism harms supplementary earnings collected through snow based tourism which is essential in funding the communities engaged in year round farming and local crafts related to agriculture and crafts (Azmat, 2025). Other than the area of tourism, agro-based livelihoods are also devastated (Matta et al., 2025). Timber and non-timber forest products (NTFPs) including medicinal herbs, which are essential income and livelihood sources of many communities, will be affected by climatic changes because vegetation cycles change, species become more limited, and forest fires are more common (Matta et al., 2025). At the same time, a higher level of glacial release by changes in climate, such as Glacial Lake Outburst Floods (GLOFs) and landslides, causes often a severe damage to key infrastructure, in particular roads and hydropower facilities. Such kind of infrastructure damages is not only costly economically, but also a significant burden in terms of access to services, as well as delaying the process of recovery in case of disasters (Matta et al., 2025).

Economic Equity and Climate-Induced Migration

The described challenges further increase the already present economic disparity, to the detriment of the most disadvantaged participants who depend on natural resources, specifically women and indigenous communities, as their means of livelihood (Matta et al., 2025). This has resulted in the population displacement and forced migration of working-age populations towards urban settlements in pursuit of security and economic certainty due to livelihood failure and climate threatened disasters (Matta et al., 2025).

Such an exodus triggered by climate has two negative outputs: first, it generates the risk of labor shortages in rural settlements, which limit the agricultural production and economic growth of the area (Matta et al., 2025), and second, it generates en-masse flooding of cosmopolitan centers, where uncontrolled urbanization, the growth of shanty towns, and multiple burdens on basic services such as sanitation, drinking water, and healthcare (Matta et al., 2025).

Erosion of Cultural Heritage and Aesthetic Value

Climate change has more than just economic hardship on its psychosocial implications. The pervasive deterioration of the local livelihoods and interference of the traditional life cycles cause major psychosocial dangers among migrant populations (Matta et al., 2025). These challenges involve loss of identity, loss of social bonds and being subject to xenophobia and cultural alienation in their new cities (Matta et al., 2025). Critical shared history and social ritual are lost when the traditional anchors of the area, e.g. local winter sports and festivals, fail, adding to this shared climate-induced cultural trauma.

Moreover, the aesthetic, spiritual and cultural value of the mountain landscapes themselves is reduced due to the physical deterioration of the glaciers and snow (Azmat, 2025; Xie et al., 2025). Glacier melting alters the original natural landscape causing a decline in its scenic and cultural beauty thus decreasing the total visitor experience and tourism demand (Xie et al., 2025). This unfriendly pollution damages the internal landscapes of the disadvantaged people whose identity is principally utmost to the natural snow-white landscape (Azmat, 2025).

5. Critical Analysis of Adaptation Strategies and Maladaptation Risks

The Economic and Environmental Calculus of Artificial Snowmaking

Artificial snow, a method of ski resort coping up with decreases and fluctuations in natural snow, has become a common tactic used by ski resorts worldwide (Hanley, 2024; Gonseth, 2012). But in the Hoandsaw, naturally poor location context of the Indian Himalayas, such a band-aid solution is becoming more and more hard to maintain because of the record warm winters that curtail its usefulness and start breaking the bank (Nair, 2025).

Water Scarcity and ETA

The process of artificial snow creation is very resource-intensive and entails large quantities of water and energy consumed (Gonseth, 2012; Steiger, 2023). This requirement is an extreme ethical trade-off in the IHR in which snow shortages endanger the water security to almost two billion humans (Global Climate Risks, 2025). The very basis of the unsustainable nature of diversion of large volumes of water to recreational slopes in water-depleted areas is that, unless advanced optimization and recycling systems are provided, the unsustainable nature of the exercise will prevail (Xie et al., 2025). High consumption artificial snowmaking as a commercial sports activity competes with basic necessities of local agricultural societies to further increase economic inequity and opportunities to conflict over resources in the future (Nair, 2025; Global Climate risks, 2025).

Energy Consumption and Emissions

Artificial snow making depolarizes an adapted and mitigated state also. It is also an energy-consuming process, and the amount of energy it needs is equal to the amount consumed by thousands of households using machine-made snow (Steiger, 2023). In Canada, the production of this process is estimated at an annual 130 000 metric tons (Steiger, 2023). As the global needs in snowmaking are estimated to go up by 55 to 105 in terms of consumption during scope of global warming, the present primary adaptation strategy becomes a cause, not only of its own developing climate change scenario character by locking the resorts into the tiring cycle of growing operating expenses and other wayward environmental demands (Gonseth, 2012; Steiger, 2023). To reduce the environmental footprint, therefore, sustainable resorts need to invest in using renewable sources of energy such as wind or solar power (Xie et al., 2025).

Indigenous and Low-Impact Resilience Models

After the high-cost, high-impact model of commercial snowmaking processes, a clear opposition is the emergence of divergent tendencies to the concept of native resilience exemplified by the indigenous Ladakh region of Trans-Himalayan. In this case, local inventors have come up with ice stupas, which are man-made glaciers formed through spraying the absent glacial stream waters in the freezing air using a set of pipes (Morris, 2017).

These conical ice formations are effective, affordable water storage options, melting gradually all year round in the dry springs and summer to supply an important quantity of meltwater to the farmers (Morris, 2017). The model of the ice stupa shows that local and ecosystem adaptability that involves the local knowledge in cooperation with the scientific ideas can help preserve resilience due to the absence of excessive artificial snowmaking in regions with lack of water during the season that would lead to a significant environmental burden and resource conflict (Morris, 2017; Matta et al., 2025).

Policy Failures and Gaps in Implementation

The latent ineffective capability to implement endorsed projects of adaptation like the eight-year lag in transforming the Shimla ice-skating ring (Economic Times, 2023; Vyas and Nagal, 2023) reinforces a significant divide in governance. Successful adaptation, it is highlighted in the research literature, needs to be integrated using better climate monitoring and the synergy between indigenous knowledge and scientific improvement as a way to protect ecologically and socio-economically with a strong resilience (Matta et al., 2025). Not success in dealing

with bureaucratic inertia and making sure funds are well utilized right when they are needed is an equally deadly obstacle as the actual warming.

Conclusion and Future Directions

The experience of climate change has produced very sharp instability in the cryosphere of the Indian Himalayas, not merely in the increase in temperature, but heterogeneous and regionally extensive snow processes. Scientific evidence on the effects on seasonal persistence of snow has led to a quantifiable reduction in seasonal snow cover (23.6% below normal) and greatly reduced winter durations (only half of ice-skating rink within the city of Shimla remaining operational). This unstability has badly thrown off the scheduled sports events, and the key infrastructure investments have been deterred. More importantly, its impacts are socio-cultural: denudation increases the rate of forced migration, increases economic inequity, and impacts with psychosocial risks, demonstrating that ultimately, the crisis hinges on cultural trauma and loss of identity by the mountain communities. Moreover, the conventional high-tech approach toward the issue, which is artificial snowmaking, has a serious conflict of the IHR. Its extensive water use collides with severe threats of water insecurity affecting billions of people down the river and its water use amounts to significant emissions behind the crisis themselves. This type of technology is dangerously susceptible to a type of major maladaptation unless it is subject to critical examination with local resource limitations. Any effective policy should resist the illusion of local homogeneity, seeing the dissimilarity between the dynamic Western Himalayas (Karakoram Anomaly) on the one hand and the failing Central Himalayas, on the other. The shift of policymaking and policy towards a more reactive management of crises (e.g., postponing events) should be shifted towards more integrated, science-driven approaches that involve vulnerable areas evaluations. The retrospective of eight years over which approved means of adapting to change, like the Shimla rink conversion, has happened, points to the fact that policy underperformance and governance inertia are enhancing sporting heritage loss even in the example where such mechanisms remain technically integrated. Necessary efforts are needed to short-circuit implementation and make the adaptation funds useable on time. Cultural heritage and protection of the Himalayan cryosphere urgently needs coordinated policy addressing science, cultural knowledge and equitable adaptation

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