ABSTRACT COMPENDIUM

HIMALAYAN CONCLAVE

INDIAN HIMALAYAN REGION-2047: ENVIRONMENTAL CONSERVATION AND SUSTAINABLE SOCIO ECONOMIC GROWTH

NOVEMBER 13-15, 2025

Nature Protects if She is Protected

UNDP

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Conclave Abstract Compendium: Himalayan Conclave on Indian Himalayan Region-2047: Environmental Conservation and Sustainable Socio-Economic Growth (November 13-15, 2025)

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About the Conclave

The Himalaya can be portrayed in four hues — white, green, blue, and brown — representing its snow-clad peaks, forested and cultivated slopes, glistening rivers and streams, and fertile soils. These colours together mirror the region's ecological wholeness, and the Himalayan Conclave – 2025 seeks to attend to each of these dimensions through an integrated perspective of conservation and sustainable growth. Organized by the Govind Ballabh Pant National Institute of Himalayan Environment (GBPNIHE) under the aegis of the Ministry of Environment, Forest and Climate Change (MoEF&CC), Government of India, the Conclave is conceived as a flagship national event on "Indian Himalayan Region–2047: Environmental Conservation and Sustainable Socio-Economic Growth." It aligns with India's commitment to Viksit Bharat@2047, which envisions a developed, globally competitive, and sustainability-driven nation by its centenary of independence. Realizing this aspiration demands not only economic progress and technological advancement but also the safeguarding of natural ecosystems that ensure long-term national resilience.

At the heart of this vision lies the Indian Himalayan Region (IHR)—one of the planet's most significant ecological, hydrological, and cultural systems. Spanning 11 states and 2 union territories and covering about 16% of India's land area, the IHR sustains 4% of the nation's population, supports nearly 30% of its ethnic groups, and contributes 36 percent of forest cover and 44 percent of floral diversity. As the cradle of India's glaciers and alpine ecosystems, it provides freshwater lifelines for millions downstream and plays a decisive role in stabilizing the subcontinent's climate. Yet this crucial region is under growing stress. Anthropogenic pressures and Climate change impacts have accelerated glacier retreat, depletion in spring resurgence, flash floods, droughts, and landscape instability. At the same time, unplanned infrastructure, land-use degradation, and unsustainable tourism are eroding ecological integrity, while youth outmigration, limited livelihood options, and inadequate public services strain social stability.

Building upon the Action Plan for Himalaya (1992), the Himalayan Conclave 2025 aims to craft a strategic roadmap for safeguarding the Himalaya and fostering sustainable socio-economic development in the IHR by 2047. Over three days of deliberations, the Conclave will unite scientists, policymakers, practitioners, civil society representatives, and traditional knowledge holders to co-create actionable pathways that harmonize ecological protection with economic advancement, strengthen climate resilience, enhance green livelihoods, and reinforce inclusive governance and regional cooperation. By combining scientific insight with community wisdom, the Conclave aspires to generate outcomes that are scientifically credible, socially equitable, and economically viable. Ultimately, the Himalayan Conclave 2025 envisions a future where environmental conservation and socio-economic prosperity are not opposing pursuits but complementary pillars of national progress. In protecting the Himalaya—India's ecological backbone and strategic natural asset—the Conclave contributes directly to the nation's journey toward a sustainable, resilient, and developed India by 2047.

-Organizing Committee
Himalayan Conclave - 2025

HIMALAYAN BIODIVERSITY UNDER CHANGING CLIMATE: CHALLENGES CONSERVATION STRATEGIES

Assessing the State of Ecosystem Health in the Alpine Region of the Indian Himalaya: An Overview

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Abstract

The alpine ecosystem in the Indian Himalayan Region (IHR) represents a distinct biome, characterized by a heterogeneous landscape marked by geo-tectonic movements, a sharp elevational gradient, harsh climatic conditions, low primary productivity, a short growing season, and low vegetation cover. The region forms the upper catchments of Himalayan rivers, harbours unique assemblages of flora and fauna, and provides numerous ecosystem services to the millions of people living within and in the lower basins. Sustaining the alpine ecosystem to ensure the continued flow of services amid increasing anthropogenic pressures and a changing climate is of utmost importance. This requires assessing the ecosystem health and monitoring its state, as well as changes in land use and land cover (LULC) from time to time. Quantitative data on intensity of human use, population status of key floral and faunal species, flow of ecosystem services, and changes in biophysical features are the most reliable indicators of ecosystem health.

A few attempts have been made at assessing the health of ecosystems in other parts of the world before. Most of the authors agree that, analogous to the measures of human health, ecosystem health indicates the intactness and 'near natural' state of their structure and functioning. In other words, a healthy ecosystem has the ability to maintain the organizational structure of an ecosystem, resilience to stress over time, and its ability to meet human needs in a sustainable manner. Accordingly, ecosystem health can be judged through a combination of three inter-related elements, viz., (i) status of natural assets or components, i.e., how close or far they are from a 'good' state; (ii) the extent to which ecosystems retain their natural function and therefore have the capacity to deliver a range of benefits; and (c) extent to which ecosystems are resilient and their capacity to deliver benefits can be sustained under human and environmental pressures, including climate change. The complex nature of ecosystems and the paucity of information on them necessitate the use of scientific methods and the selection of reliable indicators to assess their health and provide a periodic "report card". Comprehensive monitoring of ecosystems and their functioning at various spatio-temporal scales also requires an interdisciplinary approach covering biological, physico-chemical, and socio-economic aspects and their influence on ecosystem functioning.

This presentation deals with possible tools and techniques for assessing the state of ecosystem health in the alpine region of IHR. Possible indicators (floral, faunal, and environmental) have been discussed, citing examples from the dry (trans-Himalaya) and moist alpine (Great Himalayan) regions. In an earlier assessment of alpine ecosystems under the National Mission on Sustaining Himalayan Ecosystems (NMSHE), using threatened mammals as indicator

species, it was found that the health of dry alpine ecosystems in most parts of Indian Trans-Himalaya is in a state of moderate to poor condition. Intensive study in one of the study sites, viz., Nelang Valley in Gangotri National Park (Uttarakhand), revealed that this ecosystem is severely impacted largely due to the heavy influx of migratory graziers during June to October and the presence of several packs of free-ranging dogs. Both habitats and populations of threatened mammals, especially the snow leopard (*Panthera uncia*), Tibetan wolf (*Canis lupus*), blue sheep (*Pseudois nayaur*), and Tibetan Argali (*Ovis ammon*) have suffered due to the above factors. High altitude sedge meadows and wetlands in the Trans-Himalaya exhibit the signs of degradation as indicated by loss of ground cover and soil erosion owing to sedentarization of the herders, excessive use by tourists, and diversion of water.

Unlike the Trans-Himalayan region, the moist alpine areas of the Greater Himalaya exhibit slightly different trends. For example, all alpine meadows outside Gangotri National Park (Bhagirathi catchment) are under heavy grazing pressure by domestic livestock, resulting in heavy erosion of soil and alpine vegetation. Another study based on four decades of LULC change in the alpine region of eastern Uttarakhand (part of Kailash Sacred Landscape) showed that in a span of 1976 to 1999, approximately 157 km^2 of agricultural land had been changed into alpine meadows and scrub due to abandonment of agriculture and outmigration of high-altitude farmers. While this change is taken as a positive sign for alpine ecosystems, a significant decrease in cryosphere and glaciers (25.5% during 1990 – 2020), coupled with a recent influx of tourists, has led to major changes in LULC in alpine areas, which await objective assessment. Assessment of ecosystem health across landscape stability gradients (e.g., pioneer environments in sub-nival zones, glaciated valleys, gently undulating pastures, etc) would require a comprehensive and in-depth analysis. Similarly, the state of ecosystem health and recovery patterns need to be compared across strictly and moderately protected sites (National Parks and Wildlife Sanctuaries).

The presentation discusses the limitations of the assessment made so far, flags scientific data gaps, and explores the use of more comprehensive frameworks based on Vigor-Organization-Resilience-Service (VORS) for evaluating ecosystem health for the alpine region of IHR under a changing climate and recent changes in LULC. An institutional mechanism for assessing the state of ecosystem health and monitoring is suggested.

Human-Wildlife Interactions in the Himalaya: Conflict Dynamics, Coexistence Strategies, and Community-Centred Approaches

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Abstract

The Indian Himalayan Region (IHR) spans about 12% of India's geographical area and covers six states, supporting nearly 6% of the country's population. However, increasing population and related human activities have placed significant pressure on its fragile ecosystems. Unsustainable land use, overexploitation of natural resources, and unplanned infrastructural development have led to habitat loss, fragmentation, and degradation, resulting in shifts in species distribution, reduced biodiversity, and even local extinctions. Climate change is further expected to intensify these issues by affecting the vital ecosystem goods and services provided by the Himalaya.

Human–Wildlife Conflict (HWC) has emerged as a major management challenge in the IHR, where human settlements and agricultural lands are often interspersed with or adjacent to fragmented wildlife habitats. This proximity leads to frequent encounters between people and animals such as rhesus macaques, wild pigs, porcupines, leopards (common and snow), Asiatic black bears, Himalayan brown bears, elephants, and wolves, species often responsible for crop damage, livestock predation, and occasional attacks on humans. Local communities bear significant economic losses from such conflicts and rely on traditional measures for protection. Although government departments provide compensation for human injury or death and for livestock or crop loss, the growing frequency and severity of conflicts have reduced public tolerance and led to resentment toward conservation efforts.

To ensure long-term ecological and social stability in the Himalayas, it is essential to systematically quantify and mitigate negative HWCs through participatory, research-based approaches. This includes identifying high-risk areas for continuous monitoring, assessing the ecological and behavioral factors driving conflicts, studying the movement patterns of conflict-prone species, and developing adaptive management strategies. Engaging local communities in the planning and implementation of these measures is crucial for reducing conflicts, improving coexistence, and sustaining both biodiversity and human well-being in the IHR.

Human–Wildlife Interactions in the Himalaya: Predicted Developments by 2047

Forecasting the trajectory of human–wildlife conflict (HWC) toward 2047 involves examining how major drivers such as climate change, population growth, and habitat alteration will intensify and interact over time. Rising temperatures, prolonged droughts, extreme weather events, and shifting seasonal cycles are expected to disrupt resource availability for both humans and wildlife. As natural food and water sources become scarce, animals will increasingly move into human-dominated landscapes, heightening the likelihood of conflict. With the global population projected to approach 10 billion by 2050, growing demand for land and resources will further push human settlements into wildlife habitats. Consequently, more species are expected to become "synurbic", adapting to urban and peri-urban environments. While some wildlife will adjust to human presence, this coexistence often results in competition over resources such as food waste and pet feed, alongside elevated risks of disease transmission.

The Himalayan Action Plan for Vision 2047 places the management of human–wildlife coexistence at its core. Given the combined challenges of climate change, expanding human settlements, and intensifying competition for natural resources, the fragile Himalayan ecosystem faces mounting HWC pressures. Achieving a sustainable Himalayan vision by 2047 requires a strategic shift—from reactive conflict management to proactive coexistence-building. This approach must integrate ecological restoration, community engagement, sustainable livelihood development, and adaptive governance to balance human needs with biodiversity conservation.

Multiple interlinked factors are driving the rise in HWC across the Himalayas, creating an increasingly unstable socio-ecological balance. Unregulated infrastructure development, deforestation, and agricultural expansion have fragmented habitats, forcing wildlife into closer proximity with human populations. The Indian Himalayan Region (IHR) is warming faster than the global average, leading to profound effects on biodiversity and hydrological systems. Glacial retreat further impacts river systems, disrupting both ecosystems and local livelihoods. Traditional, ecologically balanced land-use practices such as mixed cropping and rotational grazing are being abandoned or replaced with monocultures, reducing food diversity for herbivores and predators alike. Abandoned farmlands often become hotspots for wildlife activity.

Additionally, unregulated mass tourism in ecologically sensitive mountain towns without adequate waste management or adherence to carrying capacity limits has aggravated habitat degradation and human disturbance. Poor waste disposal practices, particularly in tourist centers, combined with the cultivation of crops like maize and sugarcane near forest boundaries, create easy food opportunities for animals such as wild boars and leopards, drawing them into human settlements. Collectively, these developments underscore the urgent need for an integrated, forward-looking approach that promotes coexistence while safeguarding both human livelihoods and Himalayan biodiversity.

Towards Human–Wildlife Coexistence in the Himalaya by 2047: A Technology- and Community-Driven Vision

By 2047, advancements in artificial intelligence, machine learning, and spatial analytics are expected to revolutionize how human–wildlife conflicts (HWC) are understood and managed in the Himalayas. These technologies will enable highly detailed and accurate mapping of potential conflict hotspots by integrating diverse datasets—such as satellite imagery, wildlife movement patterns, climate trends, and human demographic information. Early-warning systems equipped with sensor networks, drones, and mobile applications will help alert communities about nearby wildlife presence, allowing for timely preventive action. Furthermore, AI-driven tools will support the tracking of conflict-prone species and the deployment of modern deterrence methods. Management strategies are anticipated to evolve from short-term, isolated interventions to comprehensive, multi-dimensional approaches. Key measures will include scientific land-use zoning, the creation of ecological corridors, and the restoration of landscape connectivity to facilitate the safe movement of wildlife while reducing pressure on fragmented habitats. Increasingly, the central role of local communities in conservation planning will be recognized, promoting inclusive governance models based on transparency, shared benefits, and participatory decision-making. Fair compensation mechanisms, revenue-sharing systems, and community-led conservation initiatives will enhance both social equity and conservation effectiveness. A forward-looking Himalayan Action Plan must prioritize proactive coexistence over reactive mitigation. Efforts should focus on restoring degraded forest landscapes and revitalizing natural habitats to ensure sufficient food and water resources for wildlife within their native ranges. This could involve planting native fruit-bearing species, reviving springs, and safeguarding wildlife corridors to link isolated protected areas. GIS-based land-use planning, particularly in buffer zones, can help regulate high-risk activities and enable data-driven management of conflict-prone regions. Empowering mountain communities to serve as key partners in conservation is essential. This can be achieved through community-based conservation programs, co-management systems such as Van Panchayats in Uttarakhand, and the integration of indigenous ecological knowledge with modern technology. Nature-based solutions like installing beehive fences to deter elephants or improving traditional livestock enclosures offer effective, low-cost ways to reduce conflicts. At the same time, promoting sustainable livelihood options such as community-managed ecotourism and organic agriculture will reduce dependency on fragile natural resources. Women, who often face the greatest challenges during resource conflicts, must be meaningfully included in the design and implementation of conservation and livelihood programs. To build trust and resilience, compensation mechanisms for wildlife-related losses need to be made faster, more transparent, and supported by national insurance schemes for farmers in conflict-prone regions. Adaptive management systems that evolve with changing climate and ecological conditions should be institutionalized, supported by real-time monitoring and dynamic data analysis. Strengthening the capacity of government agencies, NGOs, and local governance institutions through targeted training in conflict resolution, wildlife behavior, and technological applications will also be crucial.

Ultimately, achieving human–wildlife coexistence in the Himalayas by 2047 represents not only an environmental imperative but a cornerstone of sustainable mountain development. It calls for sustained investment in landscape-scale ecological restoration, underpinned by empowered local communities and adaptive, technology-enabled governance. True success will lie in transforming the perception of wildlife from being seen as adversaries to being recognized as an inseparable part of the Himalayan ecological and cultural legacy, to be protected and cherished for generations to come.

Bioprospection of microbial diversity in the Indian Himalayan region

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Abstract

Himalaya is recognized among the 36 globally recognized biodiversity hotspots. While extensive literature was available on the floral and faunal diversity of the Indian Himalaya, microbial diversity has also found its way in the last few decades to reveal its diversity, peculiarities, survival strategies, and applications. The research group working at GBP-NIHE prioritized the thrust areas as- the diversity of microorganisms (extremophiles) in extreme environments, both low and high temperature and their ecological and biotechnological relevance; rhizosphere microbial diversity associated with the diverse vegetation under low temperature environments and their importance in plant growth, biocontrol, and host competitiveness; assessment and monitoring of water resources for aquatic microflora; and the probiotic significance of fermented foods and beverages, traditionally prepared by the hill people.

Extremophiles: Extremophiles refer to the microorganisms that survive and multiply under harsh climatic conditions, from Geothermal areas to Polar regions, where they produce extremozymes for their survival. Thermophiles, the most primitive organisms, were isolated from the hot springs found in the Himalayan region, where the temperature was measured up to the boiling point. Dominance of the bacterial genera, namely Bacillus, *Paenibacillus*, and *Geobacillus*, was reported from these sites. Another extreme, the low temperature environments such as glaciers, cold deserts, and alpine regions, were studied for the colonization of psychrophilic/psychrotolerant microorganisms. These sites were found to be dominated by Bacillus, Pseudomonas, and *Serratia* (bacteria), *Penicillium*, Aspergillus, *Trichoderma*, and *Cladosporium* (fungi), and Streptomyces and *Nocardia* (actinobacteria). Microbial populations showed a decreasing order with increasing altitude and revealed selection of spore bearers and pigment producers in several studies. Microorganisms surviving the incidences of fire, prescribed as in the case of shifting cultivation and incidental as in the case of forest fire, were also investigated for their resilience to high temperatures. The potential of extremophiles to tolerate a wide temperature and pH range was observed in several studies and was considered as one of the survival strategies of these organisms and related to their usefulness in industrial processes. Further, the cold-adapted bacteria and fungi were studied for their biodegradation and bioremediation potential under a low-temperature environment by overproduction of the ligninolytic enzymes, such as laccases, produced in low quantity but for longer periods under low temperature stress. Besides, these organisms are a source of industrially important products such as antimicrobials, enzymes, pigments, etc. Cold-tolerant species of Pseudomonas, initially isolated from cold desert and glacial sites, exhibited potential to degrade the chemicals found in medicine and personal care products (PPCP).

Plant growth-promoting (PGP) microorganisms: Cold-adapted species of bacteria (*Bacillus* and *Pseudomonas*), actinobacteria (*Streptomyces* and *Nocardia*), and fungi (*Aspergillus*, *Penicillium*, and *Trichoderma*) were characterized for their PGP traits. Following the characterization of PGP microorganisms and the field-level demonstration trials at different altitudes across the IHR, the importance of native microorganisms was recognized for developing bioformulations. Besides agricultural and forest species, tea plantations that are cultivated across the Himalaya were extensively studied for the rhizosphere associates and their contribution to plant growth. The last decade was particularly dedicated to exploring the significance of endophytic microorganisms for their diversity and use in plant propagation. Dark septate endophytes, observed in high altitude vegetation, were considered as an indicator of varying climate with increasing altitude in mountain ecosystems.

Aquatic microflora and pollution assessment: Himalayan rivers are crucial as a source of water; therefore, the assessment of microflora and their activities is essential in aquatic freshwater habitats for the sustainable management of freshwater resources. Literature on microbial diversity of Himalayan water resources, such as fresh waters, lakes, glaciers, and hot springs, is now generating knowledge on the diversity of aquatic microflora, their applications, water contaminants under anthropogenic activities, etc. Bacteriological analysis of water samples collected from the river Jataganga, located at a pilgrimage town in the district Almora of Uttarakhand, showed the presence of bacterial species belonging to the families Enterobacteriaceae, Micrococcaceae, Pseudomonadaceae, and Bacillaceae, representing the indicators of water pollution and bacterial pathogens responsible for waterborne diseases.

Fermented foods /Probiotics: A variety of fermented foods and beverages have been popular among ethnic communities and tribes of the Himalayan region for their dietary significance and health benefits. These fermented foods and beverages are now receiving preference as an important source of natural 'probiotics'. These studies revealed strong associations between the microorganisms, mainly bacteria and yeasts, present in certain fermented foods and improved gut health and enhanced immunity. In the Himalayan scenario, a variety of fermented foods and beverages have been reported for their cultural and dietary significance initially from the Eastern Himalayan region and later from the Western Himalayan region.

Concluding remarks and prospects: The prioritized thrust areas for IHR microbial diversity are directly or indirectly related to the Sustainable Development Goals adopted by all United Nations Member States in 2015. Detailed studies on comparative assessment of microbial diversity in Himalayan, trans-Himalayan, and other extreme environments, such as Arctic, Antarctic, and Andean ecosystems, will lead to a better understanding of phylogeny and evolution of these unique microbial communities. In PGP research, the ecological and rhizosphere specificity aspects have emerged as important parameters in developing bioformulations for a specific set of climatic conditions, such as those prevailing in the mountain regions of IHR. Guidelines for the production and bioformulations are much required for the commercialization of this microbe-based based eco-friendly technology. Further, the importance of microorganisms in biodegradation and bioremediation is an emerging area in applied microbiology and biotechnology where extremophilic microorganisms are likely to contribute significantly. Monitoring of water resources is important in view of the microbial contamination leading to water pollution, specifically under the events involving mass gathering and anthropogenic activities. Fermented foods, a multi-disciplinary research area, are on their way to flourish with their multifaceted potential, mainly in relation to food and health security and income generation.

Finally, the success of all these research areas will depend on the safe preservation of microbial resources in culture collections and gene banks.

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Developing Proactive Biosecurity Frameworks for Himalayan Ecosystems: Prevention, Early Detection, and Rapid Response to Climate-Driven Invasive Alien Species

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Abstract

The Himalayan region, stretching across several countries and encompassing diverse climatic zones, harbors extraordinary biological and cultural diversity. Its ecosystems—ranging from subtropical forests to alpine meadows and cold deserts—provide vital services such as water regulation, carbon sequestration, and livelihood support for hundreds of millions of people downstream. Yet, this unique mountain system is increasingly threatened by climate change and biological invasions, two of the most pressing global change drivers. As temperature and precipitation patterns shift, both native and alien species are tracking suitable climatic conditions. The Himalaya, with its steep environmental gradients and rapidly warming high-elevation zones, is especially vulnerable to the upslope expansion of invasive alien species (IAS) that were previously restricted to lower elevations.

Historically, biosecurity and invasive species management in the Himalaya have been largely reactive, focusing on post-invasion control and eradication. Such approaches are costly, ecologically disruptive, and seldom successful in rugged and heterogeneous mountain landscapes. Moreover, the transboundary nature of Himalayan ecosystems complicates coordinated management, as invasions rarely respect political boundaries. To safeguard the ecological integrity of this region, there is an urgent need for proactive biosecurity frameworks that emphasize prevention, early detection, and rapid response (EDRR), integrating scientific tools with policy coordination and community engagement.

A recent comprehensive study documented 771 alien plant species (375 cultivated and 396 naturalized) across 12 Himalayan states and territories. The alien flora is dominated by Fabaceae and Asteraceae, with South America as the principal source region. Most aliens are perennial herbs, but annuals—especially those from the Americas—show a higher likelihood of naturalization. The greatest numbers and densities of alien and naturalized species occur in Uttarakhand, while Sikkim exhibits the highest species density per unit area.

Previous studies highlight the alarming potential for climate-driven range expansion of invasive alien plants in the Himalaya. Ensemble species distribution models integrating multiple algorithms and bias-correction approaches indicate that under future climate scenarios, species such as *Ageratum conyzoides*, *Anthemis cotula*, and *Hyptis suaveolens* are likely to expand their ranges, while *Conyza canadensis*, *Lantana camara*, and *Parthenium hysterophorus* may experience partial global contractions. Of particular concern is the predicted expansion of *H. suaveolens* and *A. conyzoides* into the northwestern Himalaya, and the emergence of *P. hysterophorus* and *L. camara* in new temperate habitats of the Kashmir Himalaya under high-emission scenarios.

Niche dynamic analyses further suggest that temperature-driven bioclimatic variables predominantly determine species distributions, with strong niche stability and conservatism across most taxa, although limited niche expansion and pioneering tendencies have been observed for *A. cotula* and *A. conyzoides* in certain regions. Collectively, these projections signal an imminent risk of invasion into fragile montane ecosystems, threatening biodiversity, ecosystem functioning, and local livelihoods.

Given the high ecological and economic stakes, systematic risk assessment is increasingly recognized as essential for prioritizing action and resource allocation. Applications of the Australian Weed Risk Management (AWRM) framework in Himalayan settings—including Dachigam National Park and the Hokera Ramsar site—demonstrate its effectiveness in distinguishing high-risk alien species and fast-spreading natives from low-impact taxa. For example, risk scoring and feasibility-of-control assessments at these sites identified *Anthemis cotula, Arctium lappa, Alternanthera philoxeroides, Phragmites australis*, and *Typha latifolia* as top-priority targets requiring immediate eradication or intensive containment. These frameworks also revealed that certain native species can pose comparable or even greater ecological risks than some introduced aliens, underscoring the need for holistic, trait-based screening.

A proactive biosecurity framework for the Himalaya should rest on three interconnected pillars: prevention, early detection, and rapid response. Prevention remains the most effective and cost-efficient defence against biological invasions. It involves risk screening of introduction pathways—horticulture, trade, tourism, and transportation—and implementing quarantine and inspection measures at points of entry. Given the porous borders and diverse governance systems across the Himalayan arc, prevention also requires regional harmonization of biosecurity policies. A shared regional database of high-risk species, coordinated through a Himalayan Biosecurity Network, could facilitate information exchange and joint risk assessments among India, Nepal, Bhutan, China, and other neighbouring countries.

Early detection demands a surveillance network capable of identifying new incursions before they become widespread. This can be achieved by combining remote sensing technologies, ecological niche models, and citizen science initiatives. The use of drones and high-resolution satellite imagery can detect vegetation changes indicative of invasion, while environmental DNA (eDNA) and metabarcoding tools enable rapid identification of alien taxa from soil and water samples. Equally important is the engagement of local communities, forest departments, and trekking groups in participatory monitoring, leveraging indigenous ecological knowledge that often perceives environmental shifts earlier than formal systems.

Rapid response ensures that once an invasive species is detected, immediate containment or eradication actions are initiated. This requires pre-approved response protocols, designated emergency funds, and trained rapid-action teams capable of on-ground intervention. Clear communication between researchers, agencies, and local authorities is vital to avoid delays that often render eradication infeasible. Restoration of native vegetation and habitat rehabilitation should be integral to response efforts to prevent reinvasion.

For proactive biosecurity to succeed, integration across scales and sectors is essential. Scientific research must inform policy, and policy must empower communities with tools and resources. Regional cooperation through platforms such as the International Centre for Integrated Mountain Development (ICIMOD) and a proposed Himalayan Council on Biodiversity and Biosecurity could foster coordinated surveillance and policy alignment. At the national level, biosecurity should be mainstreamed into existing forest, agriculture, and climate adaptation programs to ensure coherence and avoid duplication.

Capacity building remains central. Training forest guards, local NGOs, and citizen scientists in species identification, data reporting, and mobile applications can democratize surveillance. Developing Himalaya-specific field guides and digital identification tools will further strengthen early detection capacity. Integrating biosecurity into environmental impact assessments and climate adaptation plans will ensure that development projects in sensitive mountain areas do not inadvertently facilitate new invasions.

Realizing this vision requires sustained investment and a paradigm shift from reactive containment to anticipatory governance. Local communities must be recognized not as passive observers but as active partners in defending the Himalaya's ecological frontiers. As the region continues to warm and global connectivity intensifies, biosecurity must be viewed as a shared responsibility and a cornerstone of sustainable mountain development.

By integrating prevention, early detection, and rapid response within a proactive, collaborative, and adaptive framework, we can safeguard the Himalaya's biological heritage for generations to come.

Biodiversity conservation in the Indian Himalayan Region, a paramount pillar to achieve environmental sustainability under the Viksit Bharat @2047

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Abstract

Addressing the challenges of environmental sustainability is one of the important pillars to achieve the ambitious goals of Viksit Bharat @2047. The Indian Himalayan Region (IHR), forming a major portion of the two global biodiversity hotspots (i.e., the Himalaya and the Indo-Burma), is key to India's ecological and water security. In recent times, the imperatives of infrastructure development, along with the promotion of mass tourism, have led to unprecedented land-use transformations across the IHR. Being mostly mountainous, the IHR is experiencing rising risks from the global triple crises of climate change, biodiversity loss, and land degradation. The increasing frequency and intensity of extreme weather events and associated natural disasters in the region are causing a huge loss of precious human life and livelihood of the local communities. All these contemporary environmental concerns call for an integrated approach across the IHR, involving research and development institutions, policy and planning agencies, government line departments, ground-level grassroot organizations, and, above all, the active participation of indigenous communities.

To achieve the challenging goals of environmental sustainability, conservation of biodiversity, and its sustainable management in the IHR is crucial for building climate resilience and restoring degraded landscapes. In fact, safeguarding biodiversity from increasing threats emanating from unsustainable anthropogenic activities in the IHR will be a daunting task to accomplish during the ensuing two decades.

Given the surging sustainability challenges and lessons learnt from the ongoing environmental tragedies, it is imperative to revisit the developmental models implemented in the mountainous landscapes of the IHR over the recent past. It is time to mainstream in the process of policymaking and planning that the mountains, being ecologically fragile, deserve a different developmental path, as compared to the plains in the country.

Globally, and relevant for the IHR too, there is now a growing realization that the triple crises of climate, biodiversity, and land are interconnected. However, most of the prevailing efforts worldwide to tackle these planetary crises have been isolated in nature. Given the limitations of resources, particularly in developing countries, this calls for immediate integration in our policy-making and action plans to maximize the synergies, in order to achieve sustainable solutions.

In the IHR, the bountiful biodiversity and associated traditional knowledge systems form the scientific basis to guide nature-based solutions. There is a need to revive, reward, and upscale the local-level best practices and solutions of biodiversity conservation, sustainable utilization, and ecosystem management. Conservation of biodiversity in the IHR will contribute significantly to achieving climate adaptation, enhancing resilience in natural ecosystems, sustaining the flow of ecosystem goods and services, and uplifting the socio-economic status of the mountain communities and life-supporting services to the downstream population.

In comparison to other mountain regions of the world, the availability of scientific data on the biodiversity of the IHR is scarce. Even if available, the data are scattered across the scientific literature and are short-term. It is time to employ the emerging data analytical tools and AI revolution to synthesize the precious biodiversity data with unprecedented speed and scale using interoperable platforms under the FAIR data-sharing framework. Notwithstanding a few isolated efforts in recent decades, the long-term biodiversity monitoring sites in the IHR with sustained funding deserve priority. The documentation of biodiversity, including lower groups of organisms, calls for urgent capacity building in our taxonomic workforce. Although molecular tools, remote sensing, and digital technologies have revolutionized the monitoring, mapping, and modelling of populations, species, ecosystems, and landscapes, they can never substitute the field-based biodiversity studies. It is the actual natural wild areas where the ecological 'theatre' plays out by involving multiple trophic levels and interacting biotic and abiotic factors that maintain the biodiversity and ecosystems to sustain our economies.

Looking ahead, the path to progress towards Viksit Bharat @2047, and even beyond during the second half of the 21st century, will be largely determined by how much we are able to achieve environmental sustainability in our economic developmental trajectory. And towards this aspirational national mission, biodiversity conservation and sustainable management in the Indian Himalayan Region will be one of the paramount pillars.

Himalayan Biodiversity: Policies and Opportunities

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Abstract

The Himalayan ranges are the youngest mountain systems of the world and represent diversified attributes in all the systems. The Indian Himalayan region (IHR) covers a geographical area of approximately 591 thousand sq km. The river systems and geo-climatic conditions support establishing civilization in this region. It is recognized as one of the 34 global biodiversity hotspots, which is a treasure for the Himalaya. It has nearly 1000 tree species, 675 wild edibles, and 1,740 species of medicinal value. The region is a center of knowledge for heritage, religion, and spiritualism, and also a source of innumerable ecosystem goods and services. Tourism is playing an important role in its economy. Resource depletion, ecological imbalance, and economic unsustainability as long-term impacts have been observed due to changing population dynamics and threats of climate change. The region is largely inhabited by indigenous societies, and their livelihood is dependent upon the biodiversity. Hence, sustainable biodiversity is important to protect the interests of the people. In this direction, several steps have been taken in the country to address the challenges of climate change and its impact on the Himalayan region. The National Action Plan on Climate Change (NAPCC) was launched in 2008. Eight missions are under this NAPCC (www.dst.gov.in):

1. National Solar Mission
2. National Mission for Enhanced Energy Efficiency
3. National Mission on Sustainable Habitat
4. National Water Mission
5. National Mission for Sustaining the Himalayan Eco-system
6. National Mission for a Green India
7. National Mission for Sustainable Agriculture
8. National Mission on Strategic Knowledge for Climate Change

The missions, namely **National Mission for Sustaining Himalayan Ecosystem** (NMSHE) and **National Mission on Strategic Knowledge for Climate Change** (NMSKCC), were entrusted to DST, GOI for implementation. The National Mission for Sustaining the Himalayan Ecosystem - NMSHE was established to promote research, capacity building, and sustainable development practices in the Indian Himalayan region. The important issues addressed under this mission are (www.dst.gov.in):

a) Himalayan Glaciers and the associated hydrological consequences

b) Biodiversity conservation and protection

c) Wildlife conservation and protection

d) Traditional knowledge and livelihood

e) Planning for the sustainability of the Himalayan Ecosystem

Along with these verticals, other ongoing initiatives to address the challenges of the Himalayas, such as studies on glaciological monitoring to monitor the glacier mass balance and risk assessment of Glacial Lake Outburst Floods (GLOFs), are also underway. The monitoring stations, automatic weather stations, are being established to monitor the glacial melt and its status. Disaster Management Authorities (DMA) and State Disaster Response Fund (SDRF) have also been established to mitigate disasters in different Indian Himalayan states. Technologies like Remote Sensing (RS) and Geographical Information System (GIS) have been used to document the status of glaciers and glacial lakes in the Himalaya. To mitigate climate change and its effects in the Himalayas, the major policies are interventions (Table 1), have been formulated and implemented in the country (One Himalaya and One Policy, 2023).

Table 1: The major policies are interventions are:

Year	Initiatives
2005	National Health Mission
2006	Pradhan Mantri Krishi Sinchayee Yojana (PMKSY)
2008	National Action Plan for Climate Change (NAPCC)
2009	National Disaster management Policy, Intensification of forest Management Scheme (IFMS)
2011	National Rural Livelihood Mission, Deen Dayal Antyodaya Yojana, National Innovations in Climate Resilient Agriculture (NICRA)
2012	Mid-Himalayan Watershed Development Project, National Aquifer Mapping and Management Program, and Dam Rehabilitation and Improvement Projects
2013	National Plan for Conservation of Aquatic Ecosystem
2014	National Mission on Agriculture Extension and Technology (NMAET), Namami Ganga/ National mission for clean Ganga, Green India Mission (GIM), Mission for Integrated Development of Horticulture (MIDH), National Livestock Mission (NLM)
2015	National Mission for Sustainable Agriculture, National Mission on Himalayan Studies
2016	Compensatory Afforestation Act (CAMPA), Aapda Mitra, Pradhan Mantri Fasal Bima Yojana
2017	Securing Livelihoods in the Himalayas, Green Skill Development Program
2018	Pradhan Mantri van Dhan Yojana
2019	The Jal Jeevan Mission, PM Kisan
2020	Nagar Van Udyan Yojana

2022	Pradhan Mantri Poshan Shakti Nirman

The objectives and recommendations of these policies are mainly to support Climate Resilient Infrastructure, Green Technology Innovation and Research, ecosystem-based adaptation, Early warning system, Renewable Energy Transition, and sustainable bioresource management etc. The sustainable bioresources management in IHR should be strategies with the following:

- Agricultural diversification and integrated farming
- Promotion of Millets and other indigenous nutrient-rich crops of the Himalayas
- Innovation in the agricultural industry
- Adoption of methods for all types of Biodiversity for conservation and management

Along with the above, the other areas that require attention are: energy security, solid waste management, land use and land cover, cultural heritage of the Himalaya, preparedness of disaster management, etc. Some recommendations that may be useful and associated with Himalayan biodiversity are:

1. Establishment of Ecosystem Integrity Index (EII) for Carbon footprinting in IHR
2. Establishment of a Himalayan Biobank
3. Use of Climate Smart Index methodology
4. Strengthen research institutions in the IHR
5. Promotion of biodegradable packaging materials
6. Promote of integrate culture, protect intellectual property rights, and utilize indigenous knowledge for sustainable biodiversity conservation
7. Water management
8. Waste management, etc.

In the Himalayan biodiversity, the relationship among the species, genus, and their high level of genetic diversity indicates resilience and suggests addressing the gaps and challenging issues through R&D, existing data analysis, and collaboration among the potential stakeholders.

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Himalayan Biodiversity under Climate Change: Challenges and Opportunities

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Abstract

The world over the years has made remarkable progress towards prosperity in multiple perspectives. For instance, the proportion of people living in extreme poverty has fallen from 63% of the global population in 1950 to <10% today, despite growth of the global population from 2.5 billion to 7.3 billion; life expectancy has increased from 40–50 years in 1900, to more than 80 years today, especially in the high income countries; and child mortality in almost all nations has dramatically fallen. However, this progress has come at a huge cost, manifested through what is called the 'triple planetary crisis' characterized by climate change, biodiversity loss, and ecosystem degradation/pollution. Since human health is inextricably linked to the health of the planet, actions taken to mitigate climate change, prevent pollution, and conserve biological diversity would surely and substantially benefit human health and wellbeing. India is home to an incredibly rich biodiversity, linked inextricably to its unique geographical, cultural, and linguistic diversity. It supports nearly 8% of global biodiversity on just 2.3% of global land area, cross-cutting major parts of four of the 36 global biodiversity hotspots. This biodiversity is not only the bedrock for invaluable ecosystem functions and services, but also of immense economic value worth trillions of rupees annually. It cushions against diseases and disasters with a myriad of other ecological, socio-cultural, and spiritual uses. Yet the country's biodiversity in the Anthropocene is severely threatened by climate change, exacerbated by land-use land-cover changes and biological invasions. India is no exception to the rapid global loss of species and populations, with 15-37% of species predictably facing extinction risk by 2050 (IPBES, 2023). Even the hotspots may experience an average loss of 31% of their area and are suitable for 17% of the considered invasive species under an analogue climate, with significant implications for India. It is pertinent to mention that the biodiversity loss reduces the ecosystem stability and efficiency in a nonlinear and saturating way. Diverse communities are more productive because they contain key species that largely influence productivity, and differences in functional traits among organisms increase total resource capture and ecosystem functions. In view of India's Viksit Bharat agenda and commitment to the Sustainable Development Goals (SDGs) and Post-2020 Biodiversity Framework, there is an urgent need to conserve biodiversity under a changing climate for people and the planet to ensure real peace and prosperity. Mountain systems are oversensitive to global change. Home to 915 million people, more than 50% of the world's population depends on goods and services from the mountains. Covering >12% of the world's land surface, mountains support 25% of the world's terrestrial biodiversity, hosting almost half of the world's biodiversity hotspots. Of the 20 plant species that supply 80% of the food, six originated in mountains, which include maize, barley, sorghum, potatoes, tomatoes, and apples. Himalaya, considered as third pole of the world and

the water tower of Asia, is incredibly rich in biodiversity. Yet, in view of the huge information gaps and data deficits, the Himalayan Biodiversity Hotspot, especially Western & Eastern Himalaya, is considered a diversity dark spot. The Indian Himalayan Region (IHR) comprises about 16% of India's area with a population of around 86 million, hosting 36% of India's forests, 60% of endemic plant species,100% glaciers, and alpine areas. Yet, many decisions about the Himalayas are made from outside the Himalayas, thereby asking for a revisit to the governance models existing in the region and its institutions. In this backdrop, a pan-Himalayan programme on Himalayan Biodiversity under Climate Change needs to be in place to achieve the following objectives:

- Bridging the gaps that make the Himalayan Biodiversity Hotspot a Diversity Darkspot.
- Advancing biodiversity science to better understand the climate change-driven shifting baseline syndrome.
- Characterization, value addition, sustainable utilization, and climate-smart conservation of biodiversity through innovations and technological interventions, especially using AI.
- Having effective governance models for strengthening infrastructure and building capacity to nurture young innovators, researchers, and professionals to drive the national agenda on biodiversity and ecosystem resilience.

For accomplishing these objectives, strengthening the existing centres of biodiversity and converting them into centres of excellence is very important. This is anticipated to generate an invaluable dataset for better informing policy planning and timely interventions across multiple sectors to deal with the challenges of rapid biodiversity erosion under climate change in the Himalayas. It eventually promises to promote sustainable livelihoods and bioresource-based businesses in a new environmental scenario. It would also enable transformative actions needed to put in place tools and solutions for mainstreaming biodiversity in the region and reducing threats to biodiversity in order to ensure that biodiversity is used sustainably to meet people's needs. It will also bridge key knowledge gaps to better allow a national and eventually a global synthesis. Key areas that merit attention are:

- Monitoring biodiversity and vegetation dynamics across representative ecosystems and existing long-term ecological observatories (LTEOs), combined with flux towers,
- Linking functional traits to species responses and community outcomes in observational and experimental settings
- Improved understanding of the below-ground ecological dynamics of the Spread of invasive species into new regions - impacts on biodiversity
- Changing phenology and decoupling of plant-animal interactions (pollination, dispersal) and Ecological restoration of degraded ecosystems
- Novel ecosystems and ecosystem vulnerability assessment for better management
- Preventing increasing incidences of wildfires for biodiversity conservation
- Species redistribution and range shift (latitudinal and elevational) under a changing climate. And Climate-smart and AI-assisted biodiversity conservation.

Bioremediation of Waste in the Himalaya: Integrating Microbial Solutions for Human and Organic Waste Management

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Abstract

The Himalaya, with its fragile ecosystems and extreme climatic conditions, faces an escalating challenge of waste management. Remote terrain, limited accessibility, and prolonged snow cover often render conventional systems ineffective. Waste generation across these regions is diverse, encompassing human waste from high-altitude settlements, kitchen waste from tourist destinations, and agro-residual biomass from small-scale farming. The combination of these waste types, if unmanaged, leads to soil and water contamination, air pollution from open burning, and black carbon emissions that contribute to glacial darkening and faster melting. The urgency of these challenges requires adaptive, locally viable, and environmentally responsible solutions that can operate efficiently even at sub-zero temperatures. Traditional Himalayan sanitation systems, especially the dry toilets of Lahaul, Spiti, and Ladakh, once represented a sustainable mechanism for nutrient recycling and water conservation. These waterless systems, which transformed human waste into nutrient-rich night soil compost, provided an ecologically balanced model of circular waste management. However, with modernization, the dependence on chemical fertilizers increased and also weakened the closed nutrient cycle that had supported soil fertility in these cold mountain ecosystems. Reviving and enhancing this system through microbial innovations provides a scientifically validated approach to restoring ecological integrity while ensuring public health and awareness. Comprehensive studies on night soil compost from Lahaul Valley revealed that it is rich in organic carbon, nitrogen, phosphorus, and potassium, and largely free from harmful pathogens, thereby meeting safety standards for agricultural use. The compost improved the germination rate in crops, indicating its non-toxicity and potential as a soil amendment. Microbiome profiling revealed a diverse community of psychrotrophic and hydrolytic bacteria capable of producing enzymes such as cellulase, protease, and amylase, as well as plant growth-promoting compounds like indole-3-acetic acid and siderophores. Cold-tolerant microbial communities play a crucial role in the rapid degradation of organic matter at low temperatures, making them ideal candidates for sustainable composting systems. Based on the potential of cold-tolerant bacterial communities, bamboo biochar-based microbial amendment, termed the Compost Booster, was developed using indigenous bacterial strains. The biochar matrix provided a porous structure that improved aeration and microbial colonization while enhancing moisture retention in composting piles. When applied to human waste in high-altitude settlements, the amendment reduced composting time from several months to less than ninety days. The resulting compost was stable, odour-free, and enriched with plant nutrients. User feedback from multiple Himalayan villages confirmed improved compost quality, reduced biomass volume,

and enhanced ease of operation. The intervention also demonstrated that biochar serves as both a microbial carrier and a carbon-sequestering material, contributing to climate change mitigation. Parallel advancements in organic waste management addressed the increasing problem of unprocessed kitchen and agro-residual waste in Himalayan settlements.

Indigenous cold-adapted bacterial consortia were developed from composting environments to decompose mixed organic waste effectively at low temperatures. Consortia, composed of multiple hydrolytic and plant growth-promoting bacterial strains, stabilized compost within thirty days while enhancing nutrient availability and microbial diversity. Cold-active hydrolytic enzymes collectively produced by these bacterial assemblages proved highly effective in degrading lignocellulosic residues such as wheat bran, sugarcane bagasse, corn stover, and lemongrass. Field trials in cold hilly regions demonstrated that these microbial formulations could successfully decompose diverse organic substrates, including cow dung, leaf litter, and horse dung, producing phosphate-rich compost that restored soil fertility and reduced reliance on chemical inputs. The microbial solutions present an integrated model of bioremediation for the Himalaya. The microbial innovations restore the natural nutrient cycle, mitigate pollution, and reduce black carbon emissions, aligning with national missions for sustainable mountain development and climate resilience. Building upon these successful microbial interventions across the cold and arid landscapes of the western Himalaya, it becomes increasingly evident that similar science-driven innovations hold immense promise for the North Eastern Himalaya. While foundational research has demonstrated the feasibility of microbial bioremediation under extreme mountain conditions, the North Eastern Region presents a distinct set of environmental and socio-economic challenges that demand region-specific adaptations. The following section outlines these emerging challenges and prospective microbial pathways for a sustainable future.

The North Eastern Region of India faces additional pressures from rapid urbanization and the generation of waste driven by tourism. Growing tourist inflows support local livelihoods yet contribute to rising volumes of unregulated solid waste in sensitive ecosystems. The region's distinct climatic character, marked by high rainfall and humidity, further complicates waste management. Prolonged wet seasons and elevated moisture levels often result in excessive leachate generation, reduced aeration, and slower decomposition of organic waste, making conventional composting systems difficult to sustain. Municipal systems across the region remain overstressed due to limited handling capacity, lack of source segregation, and inadequate composting or landfill infrastructure. Consequently, open dumping and burning of biodegradable and non-biodegradable waste are widespread, causing leachate pollution, soil and water degradation, and loss of landscape aesthetics. In this context, microbial bioremediation offers a scientific and environmentally friendly solution for managing organic waste. Indigenous microbial consortia developed from local waste environments, ranging from cold alpine to humid subtropical zones, can be optimized through metagenomic and culture-based screening. High-performance bacterial strains with efficient enzymatic activities can be combined into synergistic formulations that accelerate the degradation of organic matter, stabilize composting temperatures, and produce nutrient-rich, pathogen-free compost.

Decentralized waste management systems at the household level can promote segregation of wet and dry waste through education and incentive-based initiatives. Panchayat or ward-level composting units utilizing local microbial formulations can efficiently treat biodegradable waste, while non-recyclable materials can be directed toward recycling or upcycling. This structure minimizes transportation costs, reduces landfill dependency, and fosters local ownership of waste solutions. Beyond environmental gains, the model carries strong socio-economic potential. Linking compost with organic farming systems can create a circular local economy where waste becomes a resource for soil enrichment and income generation. By integrating microbial innovation, community participation, and regional adaptability, the North Eastern Himalaya can evolve into a model for sustainable, zero-waste mountain ecosystems.

A Multi-Stakeholder Approach to Mitigating Human Wildlife Conflict in the Indian Himalayan Region

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Abstract

The Indian Himalayan Region (IHR), one of the most biodiverse and ecologically fragile mountain systems on Earth, is witnessing a rapid escalation in Human Wildlife Conflict (HWC). This region harbours nearly one-third of India's mammalian fauna and sustains a dense human population that depends heavily on forest-based agriculture, pastoralism, and ecosystem services. The dense human populations are interspersed with habitats of large mammals such as leopards (*Panthera pardus fusca*), Asiatic black bears (*Ursus thibetanus*), and various mountain ungulates, including goral, *serow*, and ibex. Expanding agriculture, linear infrastructure, hydropower projects, and tourism have fragmented forest corridors, reducing ecological connectivity and intensifying the overlap between human and wildlife resource use. The manifestations of the HWC are multifaceted it ranging from livestock predation and crop raiding to human injury and fatalities, leading to substantial livelihood losses and eroding public tolerance toward wildlife. In many mid-altitude valleys of Jammu and Kashmir, Himachal Pradesh, and Uttarakhand, for instance, repeated leopard attacks on livestock and bear raids on orchards have become routine occurrences, prompting cycles of resentment, retaliatory poisoning, and illegal trapping. These conflicts are not isolated incidents but indicators of structural ecological stress, a product of shrinking habitats, declining wild prey, and increasing human encroachment along forest edges. Governance gaps such as inadequate compensation systems, poor coordination among departments, and the absence of predictive monitoring further exacerbate the situation. Furthermore, these conflicts are not isolated events but indicators of deeper structural imbalances between development pressures, habitat degradation, and governance gaps. Since the IHR region is climate change vulnerable, the changing climate is further compounding the issues by altering vegetation phenology, shifting species distributions, and modifying the temporal patterns of animal movement, thereby increasing the frequency and unpredictability of encounters (Zimmermann et al. 2023; Linnell et al. 2021, Sharief et al. 2023, Mukherjee et al. 2023, Kumar et al. 2022). The climate-mediated shifts in vegetation phenology and fruiting cycles, warmer winters, and erratic snowfall patterns are changing the temporal patterns of animal movement and elevational migration. Further the bears now remain active in winter months because of the changing hibernation behavior, winter activity is leads to increase in conflicts because non hibernating bears move out towards the human settlements for food as phenologically nothing is left to eat in wilderness areas, similarly the common leopards which is one of the most frequently involved wildlife species in also now exploiting newly available prey in modified habitats.

The challenges in managing HWC in the Himalayas lie in its multidimensional nature, i.e., ecological, social, and institutional. Ecologically, steep gradients, limited prey base, and patchy

habitats constrain animal movement, while increased livestock density and open-grazing practices create high-risk zones. Socio-economically, the mountain communities depend heavily on forests for subsistence, making them particularly vulnerable to wildlife damage. Inadequate compensation, bureaucratic delays, and low trust in institutional mechanisms further fuel animosity. From an institutional perspective, fragmented responsibilities across the forest, agriculture, and revenue departments hinder coordinated action. Moreover, conventional mitigation measures such as fencing, capture, or translocation often address symptoms rather than causes, neglecting the broader ecological context or the social fabric of affected communities. The IUCN's Guidelines on Human Wildlife Conflict and Coexistence (IUCN SSC, 2023) emphasize that viable coexistence depends not only on technical interventions but also on understanding the values, perceptions, and power dynamics among stakeholders. Mitigation in the Himalayan context must therefore move from reactive crisis management to proactive coexistence planning. A holistic approach involves three complementary dimensions: ecological restoration, community participation, and institutional coordination. Ecologically, maintaining habitat connectivity through forest restoration, corridor identification, and regulation of land-use change is central to reducing conflict hotspots. Science-based early-warning systems combining remote sensing, camera traps, and citizen reporting can help predict seasonal movement and high-risk periods. Socially, the community engagement is indispensable: awareness programmes, participatory monitoring, and alternative livelihood models such as eco-tourism, beekeeping, and non-timber forest product (NTFP) value chains can reduce dependence on high-risk resources. Financially, the introduction of payment for ecosystem services (PES), micro-insurance, and community-managed compensation schemes can enhance resilience. Institutionally, interdepartmental coordination mechanisms and district-level conflict management committees with representation from local governance bodies, NGOs, and scientists can improve response time and transparency. Incorporating behavioral science insights, such as risk perception and tolerance thresholds, into the communication strategies can further enhance coexistence outcomes (Dickman et al. 2020; Marchini & Glikman 2022).

Therefore, a multi-stakeholder framework for the IHR must align conservation science with socio-political realities, which are landscape-specific. This can be operationalized through four interconnected pillars. Firstly the (1) Mapping and preparedness: Develop high-resolution conflict-risk maps integrating land-use, climate, and socio-economic data to guide proactive interventions; secondly, the (2) Prevention and rapid response mechanism: Establish decentralized, well-trained response teams equipped with mitigation tools and transparent protocols for verification and compensation; thirdly, the (3) Participation and co-management: Institutionalize community-based monitoring networks, fostering local stewardship and ownership of mitigation strategies and finally the (4) Policy integration and sustainability: Mainstream HWC mitigation into State Wildlife Action Plans, District Climate Adaptation Strategies, and Himalayan ecosystem missions such as NMSHE. The long-term vision should promote adaptive coexistence landscapes where ecological integrity, human safety, and livelihood security reinforce each other. Achieving this requires sustained investment, cross-sectoral collaboration, and a shared commitment to the principle that coexistence is not the absence of conflict but the management of it through trust, transparency, and inclusion.

Policy integration and long-term outlook in a multi-stakeholder context

Long-term mitigation of HWC in the Indian Himalayan Region requires the institutionalization of a multi-stakeholder governance framework that bridges science, policy, and community action. The Himalayas are not only ecologically fragile but also administratively complex, shared among multiple jurisdictions, each with different priorities and governance capacities. Therefore, no single agency can effectively address the socio-ecological dimensions of conflict in isolation. Sustainable solutions demand the convergence of scientific institutions, government departments, local governance bodies, civil society organizations, and international frameworks under a shared vision of coexistence and resilience.

At the policy interface, the framework should align with the National Mission for Sustaining the Himalayan Ecosystem (NMSHE), which advocates ecosystem-based adaptation and knowledge-driven decision-making, and the Kunming Montreal Global Biodiversity Framework (GBF, 2022), which calls for participatory governance, inclusive benefit-sharing, and reduction of human–wildlife conflict as part of biodiversity targets. Translating these commitments to action requires coordination across scales. At the national level, the Ministry of Environment, Forest and Climate Change (MoEF&CC), the Zoological Survey of India (ZSI), the Wildlife Institute of India (WII), and the State Forest Departments must collaborate on creating a centralized conflict knowledge platform by integrating ecological, demographic, and spatial data to enable evidence-based decision-making. Whereas, at a finer scale of district level, the district administrations, through their forest, agriculture, revenue, and disaster management departments, play a critical role in operationalizing this framework by forming District Conflict Management Cells (DCMCs) that coordinate rapid response, compensation, and long-term preventive planning. At the community level, Panchayati Raj institutions, Biodiversity Management Committees (BMCs), and the local cooperatives act as the social anchor points for coexistence. Their role extends beyond awareness and vigilance to co-designing mitigation interventions such as livestock protection, waste management, and habitat restoration. Non-governmental organizations and academic institutions contribute by providing training, technology transfer, and capacity-building in conflict-risk assessment, ecological monitoring, and participatory planning. For instance, conflict-risk modeling by scientific agencies can help state and district authorities overlay spatial risk layers with administrative and financial data to prioritize high-risk areas, optimize resource allocation, and track policy effectiveness.

The integration of climate projections (SSP2.6 and SSP8.5) into HWC models will enable all stakeholders to anticipate future shifts in species distribution, cropping patterns, and vulnerability hotspots. These scientific foresights will be crucial for adaptive planning, allowing district administrations to invest in climate-resilient infrastructure, promote alternative livelihoods, and restore ecological corridors that buffer human settlements. Simultaneously, aligning these strategies with decentralized financial mechanisms such as the

Compensatory Afforestation Fund Management and Planning Authority (CAMPA) and Payment for Ecosystem Services (PES) ensures that communities benefit directly from conservation outcomes.

Ultimately, the multi-stakeholder approach transforms HWC mitigation from a reactive, event-based exercise into a dynamic system of co-production of knowledge and shared responsibility. It creates a continuum where scientists provide foresight, policymakers enable action, administrators ensure coordination, and communities sustain coexistence on the ground. Such an integrated framework exemplifies the new Himalayan development paradigm: one that harmonizes biodiversity conservation with human well-being, guided by transparency, equity, and adaptive governance. In this context, coexistence becomes not merely the absence of conflict but the presence of collaboration between institutions, disciplines, and people toward a resilient and nature-positive Himalayan future.

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Strengthening Human–Wildlife Coexistence in the Indian Himalaya: An Evidence-Based Perspective

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Abstract

Human–wildlife interactions across the Indian Himalayan Region have intensified as ecological transitions and human activities increasingly overlap. Expanding settlements, shifting land-use patterns, climate-driven changes in vegetation and water availability, and new roads and powerlines have brought people and wildlife into closer proximity than before. In Uttarakhand, the Nandhaur Landscape illustrates this challenge clearly, functioning simultaneously as a critical wildlife habitat and a livelihood zone for forest-dependent communities. The Nandhaur area—encompassing the Nandhaur Wildlife Sanctuary, the Kilpura–Khatima–Surai corridor, and adjoining forest divisions—connects major conservation regions across India and Nepal, supporting elephants, tigers, leopards, bears, and ungulates. At the same time, numerous villages rely on forests for fodder, fuelwood, grazing, and agriculture. This dual use of shared spaces naturally increases the likelihood of encounters, especially for households with limited alternatives to forest-based resources. Conflict data from 2007–2020 provide a detailed picture of this interaction: 759 recorded incidents include livestock losses, crop damage, human injuries, property destruction, and occasional fatalities. Carnivores—mainly leopards and tigers—account for most of the 388 livestock depredation cases, while elephants dominate crop and property-related incidents. Snakebite cases and rare attacks by other wildlife add to the pressure on communities. Different parts of the landscape experience different species-specific risks: villages along the Kilpura–Bramdeo–Boom corridor repeatedly face elephant-related damage, while settlements closer to the sanctuary or higher slopes see more carnivore activity. Seasonal and spatial patterns are also pronounced. Monsoon months show the highest number of incidents, likely due to dense vegetation, increased agricultural activity, and greater wildlife movement. Hotspot mapping confirms that conflict clusters strongly in the eastern part of the Haldwani Forest Division, particularly near the Indo–Nepal border, where human settlements overlap with wildlife travel routes. Although conflict frequency declined from its 2017 peak, the persistence of hotspots indicates chronic, not incidental, patterns of interaction. The economic burden on affected communities is significant. Compensation payments over the fourteen years exceed one crore rupees, covering losses to crops, livestock, property, and human livelihoods. More than 400 livestock animals were killed during this time, causing major financial setbacks for households reliant on dairy or draft power. Compensation helps but is sometimes slowed by verification processes, adding stress for already vulnerable families. Beyond financial loss, the psychological impact—felt strongly by women, elders, and daily forest users—remains largely unmeasured.

Ecological factors further complicate the situation. Habitat fragmentation, shrinking corridors, and linear infrastructure push wildlife into altered movement patterns. Elephants reroute when confronted with barriers and may enter croplands if traditional paths are blocked. Leopards and bears may be drawn toward villages by food waste or unattended livestock. Tigers, though generally more elusive, may venture close to human-use zones when dispersing or following prey. These behavioural adjustments reflect how wildlife navigates increasingly human-modified landscapes.

Evidence from mitigation efforts in nearby regions underscores the limitations of approaches that rely only on structural barriers. Evaluations of elephant-proof walls in the Terai Arc Landscape have shown hundreds of breaches, demonstrating that without ecological insight and long-term maintenance, such barriers serve only as partial solutions. This reinforces the need for strategies grounded in species biology, community engagement, and landscape ecology.

A comprehensive approach to coexistence must integrate prevention, protection, response, and recovery. Preventive measures—such as early-warning systems, risk-sensitive cropping, better waste management, and community communication networks—help reduce the likelihood of dangerous encounters. Protective steps, including improved livestock enclosures, insulated powerlines, and safer pathways near forests, reduce vulnerability. Effective response mechanisms depend on trained teams, coordination between departments, and clear procedures for handling emergencies. Recovery requires timely compensation, community insurance models, and mental health support for affected families.

Strong governance is essential for ensuring that these interventions endure. Implementing national guidelines at the state level, creating dedicated conflict management units, involving communities in monitoring, and securing maintenance budgets are all crucial. Women's participation, in particular, strengthens early detection and local decision-making. Regular assessment of corridor functionality and mitigation structures ensures that interventions remain relevant as landscapes change.

The experience of the Nandhaur Landscape demonstrates that coexistence is not only feasible but necessary for ecological and social stability. The region's biodiversity significance and cultural reliance on natural resources make it central to India's conservation agenda. By enhancing habitat connectivity, adopting wildlife-sensitive infrastructure, incorporating new technologies, and building community resilience, the Himalayan region can move from reactive conflict management to a proactive coexistence model.

As India moves toward Vision 2047, this integrated approach will be essential for ensuring that mountain communities remain secure and wildlife populations continue to thrive. The lessons from Nandhaur show that long-term coexistence requires adaptable planning, strong community partnerships, and an understanding of both ecological dynamics and human needs, enabling a future where both people and wildlife can sustain their place in the Himalayan landscape.

Himalayan Biodiversity under Changing Climate: Challenges and Conservation Strategies

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Abstract

The Himalayan region is very well known for the unique topographical gradients, which support diverse and unique biodiversity. The region is one of the recognized megabiodiversity hotspots. The Indian Himalayan Region (IHR), which forms the major part of the Himalayan region, supports three biogeographic zones, i.e., Trans Himalaya, The Himalaya, and North East India, and 8 biogeographic provinces, namely, Ladakh mountains, Tibetan Plateau, North west, West, Central & East Himalaya, Brahmaputra valley, and North East Hills. The unique topographical gradients, i.e., diverse habitats, aspects, slopes, and altitudes, support unique vegetation and biodiversity. It has a large altitudinal range (i.e., 250 – 8,586m). The vegetation along an altitudinal gradient comprises tropical, sub-tropical, temperate, sub-alpine, and alpine types and varies from east to west, from low to high altitudes, habitat to habitat, and aspect to aspect. The IHR supports 18,440 species of plants, of these, 8,000 species (40 % endemics) are represented by Angiosperms; 44 species (15.91% endemics) by Gymnosperms, 600 species (25%) by Pteridophytes; 1737 species (32.5%) by Bryophytes; 1159 species (11.21%) by Lichens; and 6,900 species (27.4%) by Fungi. Of the total species, one thousand forty-eight (1,748) species have been known for their medicinal properties, 675 as wild edible; 960 species of orchids; and 155 species of sacred plants are reported from the IHR. Of the total orchid species, 900 species are reported from North East India alone. More than 60% species of orchids are epiphytic, and the remaining are terrestrial, including lithophytes and saprophytes. The majority of species are moisture-loving. From the Trans, North Western and Western Himalaya, a total of 6,745 species of Angiosperms (604 trees, 1049 shrubs & 5092 herbs) belonging to 225 families, 1768 genera are recorded. Out of these, 4,035 species belonging to 1461 genera and 207 families of economically important plants are reported from the Trans, North Western, and Western Himalaya. Of these, amongst the reported economically important species, 3174 species of medicinal plants, 925 species of wild edibles, 683 species of fodder, 262 species of fuel, 159 species of timber/house building, 148 species of religious, etc., are reported. The floristic diversity of IHR is facing tremendous pressure due to various anthropogenic activities. The over exploitation and habitat degradation of the species due urbanization, forest degradation, construction of roads, industrialization, construction of Hydro- electric projects, forest fire and biomass burning, tourism beyond carrying capacity, overgrazing, unmanaged solid waste dumping, biological invasion, conversion of forest land into agriculture land, etc. have caused the rapid population depletion of many ecologically and ecologically important species, deduction in ecosystem services, ecosystem imbalance and environmental changes. These factors are largely contributing to climate change. The

population explosion is also a major problem, leading to increased demand for ecologically and economically important floristic components, ultimately leading to their rapid population depletion. If these factors continue to operate, the species that are placed under Critically Endangered, Endangered, and Vulnerable categories of the International Union for Conservation of Nature (IUCN) may become extinct, and even other species falling under Near Threatened, Least Concern, and Indeterminate categories may shift under Critically Endangered, Endangered, and Vulnerable categories. The meteorological data of the region indicate that there is an increase in the maximum and minimum temperatures and a decrease in precipitation, i.e., rainfall and snowfall. Such changes in the environmental conditions have caused a shift in the flowering period and an altitudinal shift of the species. Early flowering in *Rhododendron arboreum*, *R. campanulatum*, *Myrica esculenta*, *Reinwardia indica*, *Bombax ceiba*, *Jasminum* spp., Rosaceous species, i.e., *Malus pumila* (Apple), *Pyrus* spp., *Prunus* spp., *Rosa* spp., *Rubus* spp., *Prinsepia utilis*, etc., has been observed. Such a shift in the phenology of species is leading to changes in the biological cycles of the species, which is affecting the pollination of many cross-pollinated species. Increase in the maximum and minimum temperatures and decrease in rainfall and snowfall are also promoting the altitudinal shift of the pests and pathogens. In the Kullu Valley of Himachal Pradesh, a shift in the Apple belt from Nagwai to Dove, Katrain (Approximately 35 – 40 km), introduction of Mango (*Mangifera indica*), Guajava (*Psidium guajava*), Papaya (*Carica papaya*), and Citrus fruits (*Citrus spp.*) have been observed. Similarly, the occurrence of wild species such as *Withania somnifera* (Ashvagandha), *Sapium sebiferum*, *Dalbergia sissoo, Woodfordia fruticosa*, and *Justicia adhatoda* (All tropical plants), etc., and apple plantation and production in Lahaul and Spiti Valleys, Pooh Block of Kinnaur district, and also plantation and production of apple in Ladakh Union Territory clearly show the impact of climate change. The upward (up to 2600m) and downward (300m) shift of the *Pinus roxburghii*, an opportunistic species, also shows the changes in environmental conditions. Compositional changes, particularly in seedlings and saplings of the sub–alpine forests, namely, *Abies pindrow, Quercus semecarpifolia, Betula utilis*, etc., and altitudinal shift of *Juniperus polycarpos* (in Lahaul Valley), *Pinus gerardiana* (in Pooh Block of Kinnaur district and Pangi Valley), *Pinus wallichiana, Abies pindrow, Betula utilis, Populus ciliata, Rhododendron campanulatum*, etc., have been reported. This could be a consequence of climate change. Similarly, the occurrence of *Taxus wallichiana* in the Lahaul valley in the form of saplings and seedlings revealed the recent arrival of this species in the Lahaul valley. This clearly shows that changing environmental conditions, particularly climate change, are leading to an altitudinal shift of the species. In the Lahaul valley, the occurrence of seedlings and saplings of *Juniperus polycarpos* in avalanche-prone areas and beyond the altitudinal distribution of the species in the higher elevations is clear-cut evidence of the impact of climate change. Also, the occurrence of *Pinus wallichiana* in the altitudinal range of Betula utilis and *Rhododendron campanulatum* in Himachal Pradesh (Sangla Valley) and Nanda Devi Biosphere Reserve is evidence of an altitudinal shift, possibly as a consequence of climate change. Therefore, There is a need to; (i) assess and monitor the floristic diversity in relation to climate change; (ii) assess and monitor the agro-ecosystems; (iii) assess and monitor the populations of endemic and threatened species and develop Ecological Niche Models for predicting the suitable areas of these species for in-situ conservation; (iv) assess and monitor the urban biodiversity; (v) monitor the biological cycle (phenology) of the ecologically and economically important species; (vi) assess and monitoring the forest hydrology; (vii) assess and monitor the ecosystem services; (viii) eradicate the invasive species; (ix) develop packages of practices of ecologically and economically important species for mass multiplication; (x) restore degraded forest landscapes through plantations of native broad leaved species with the participation of Forest Department and local inhabitants; (xi) promote green infrastructure in the urban areas and along the roadsides; and (xii) create awareness among the inhabitants for the conservation of biodiversity.

Keywords: Indian Himalayan Region, Floristic diversity, Orchids, Medicinal, Wild edible, Native, Endemic, Anthropogenic, Climate change, Threatened, Conservation

LAND, WATER, AND ATMOSPHERE INTERACTIONS IN A CHANGING CLIMATE

Combating Land Degradation in the Indian Himalayan Region: Challenges and Solutions

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Abstract

The Indian Himalayan Region (IHR), spanning 13 states and union territories including Uttarakhand, Himachal Pradesh, Jammu & Kashmir, Ladakh, and the northeastern states, is an ecologically fragile landscape spread over 53.7 million ha, inhabited by over 51 million people who practice hill agriculture for sustenance on 13.6 % of the total IHR area. Major components of Himalayan agriculture include crops, livestock, horticulture, fisheries, and agro-forestry, and it shows excellent diversity within different geographic regions of this mountain system. Himalayan agriculture is also susceptible to various natural and anthropogenic factors. It faces constraints such as small and fragmented holdings, undulating terrains, limited scope for irrigation and farm mechanization, poor soil quality, limited resource availability, inadequate processing, storage, and marketing facilities for produce, and man-animal conflicts (crop damage by wild animals). The land holding in the hill area is smaller (700-900m2) than the national average (1370 m2). Transmigration and environmental degradation due to soil erosion are other cardinal issues confronting the Himalayan region and its agriculture.

Due to steep slopes, fragile geology, and intense storms, the Himalayas are intrinsically prone to soil erosion, which is further aggravated by the numerous road construction, mining, and hydropower projects. Recent estimates indicate that in the North-west Himalayas, on average, 17% of the area falls in a very severe category with erosion rates > 40 t ha-1 yr-1, while about 25% area has an erosion rate of more than 10 t ha-1 yr-1. Within the North-western Himalayan region, Uttarakhand has the highest area (21.19%) under water erosion, followed by Himachal Pradesh (17.76 %) and Jammu and Kashmir (9.14%). Overall, about 23% of the Himalayan states have potential erosion rates of> 40 t ha-1 yr-1. It calls for serious efforts to employ appropriate soil and water conservation measures to check land degradation problems.

In the recent past, an increasing frequency of cloudburst events has been observed in the Indian Himalayas, particularly in Uttarakhand, Himachal Pradesh, Jammu & Kashmir, and Ladakh, with Uttarakhand emerging as the most affected region. A significant rise in cloudbursts has been observed since the early 2000s, especially in the Bhagirathi and Alaknanda basins, making Uttarkashi highly vulnerable to flash floods. Cloudbursts are sudden, intense rainfall events—typically exceeding 100 mm per hour over a small area of 20-30 square kilometres—that are increasingly common in the Indian Himalayas. These phenomena, often occurring during the monsoon season (June-September), are amplified by the region's steep topography, where orographic lift forces moist air upward, leading to rapid condensation and deluge. While cloudbursts are natural, their frequency and severity have risen due to climate change, which increases atmospheric moisture capacity (by about 7% per 1°C of warming), and human

activities that exacerbate vulnerability. In the fragile Himalayan ecosystem, they trigger flash floods, debris flows, and landslides, directly contributing to land degradation through soil erosion, vegetation loss, and sedimentation.

In view of the expected impact of climate change on land and water and subsequently on agriculture and ecology, the United Nations (UN) has set specific goals for land and water management as part of its Sustainable Development Goals (SDGs), particularly under Goal 6 (Clean Water and Sanitation), Goal 13 (Climate Action), and Goal 15 (Life on Land). These goals form part of a comprehensive global framework aimed at achieving sustainable land and water use, preserving ecosystems, and combating the impacts of climate change. Land Degradation Neutrality (LDN) is a global goal aimed at preventing, reducing, and reversing land degradation, ensuring that the amount and quality of land resources remain stable or improve over time. It was established as part of the United Nations Convention to Combat Desertification (UNCCD) and is also a key component of the United Nations' Sustainable Development Goals (SDGs), specifically under SDG 15: Life on Land. The Himalayas' vast geography, cultural diversity, and varied microagroclimatic zones offer a unique opportunity to develop multiple agricultural growth dimensions (or "horizons"). This article is confined to one of the diverse horizons, i.e., Land and Water, and it reflects a brief account of various aspects of land degradation and approaches for preventing, reducing, and reversing land degradation in the Indian Himalayan region.

Summary – Solutions for Controlling Land Degradation in the Indian Himalayas

Land degradation in the Indian Himalayan Region (IHR) can be reversed through integrated, multi-scale interventions combining engineering, biological, socio-economic, and policy measures. Innovative approaches and strategies focused on nature-based solutions regarding land and water management could be a sustainable way forward. The research efforts made in rainfed areas for resource conservation and productivity enhancement following the approach of the watershed in the past 4-5 decades have identified several resource conservation techniques for the hills and valleys, which reduce the risk of soil degradation, preserve the productive potential, decrease the level of inputs required, and sustain agricultural productivity in the long run. These measures include land shaping or mechanical measures, agronomic manipulations, vegetative barriers, alternate land use systems, and run-off harvesting and recycling techniques. The agronomical measures are generally recommended on mildly sloping lands with the objective of maximizing in-situ rainwater conservation to ensure protection against erosion and higher productivity. They include contour farming, intercropping, strip cropping, mixed cropping, cover management, mulching, crop geometry, tillage practices, and diversified cropping systems. Mechanical measures are adopted to support the agronomical measures on steeper slopes or where the run-off is high by reducing the length and/or degree of slope to dissipate the energy of flowing water. They include land levelling, bunding, terracing, conservation bench terracing, and contour trenching. Drone-based LiDAR mapping provides a cutting-edge solution for detailed, accurate, and efficient land surveying, helping in fields from natural resource management to landscape planning. As LiDAR technology and drone capabilities continue to advance, the applications and accessibility of this powerful tool are likely to expand. IoT devices and tools need to be integrated with watershed programs, which results in fast, accurate, and cost-effective planning, implementation, and evaluation of natural resources-related plans. These innovations in land and water management, whether modern technologies or traditional practices adapted for today's needs, are helping to create more resilient, water-efficient, and sustainable agricultural and land-use systems in particular and watersheds as a whole. Land degradation in the IHR is reversible if solutions shift from reactive disaster response to proactive landscape restoration.

Role of Groundwater in Water–Energy–Food Nexus in the Himalayas

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Abstract

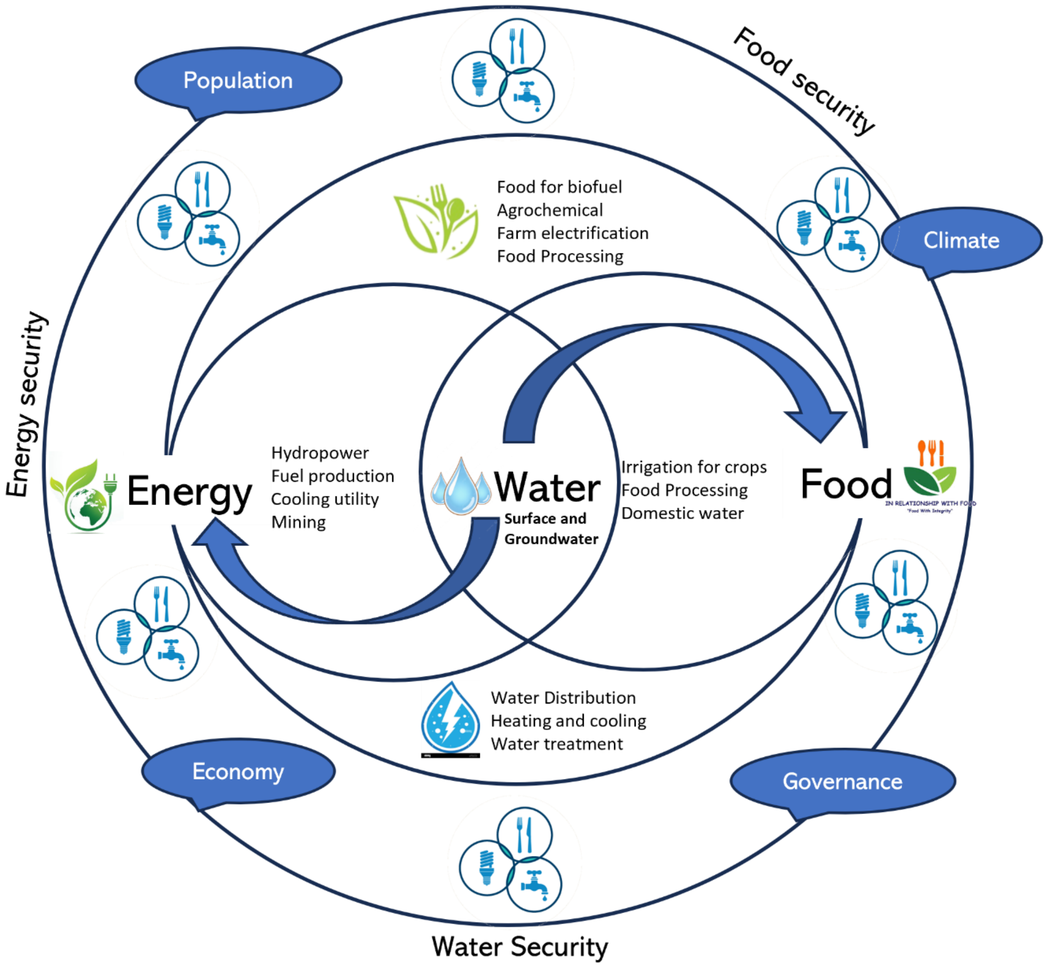
The Himalayan system, the largest global store of frozen water after the polar regions, provides a reliable water supply to almost 2 billion people. Marked atmospheric warming has changed the balance of this so-called Asian water tower and altered surface water resources in the downstream region. Hence, the reliability of groundwater seems to be increased in the Himalayas under such circumstances. As India moves towards Vision 2047, focusing on sustainable development and resource security, the management of Himalayan Groundwater proves to be the strategic priority. It balances the water, energy, and food security by providing water to these sectors, like sustaining agricultural production, hydropower, and irrigation-based energy demands. However, this essential source of water is facing the challenge of increasing stress due to population growth, unregulated abstraction, land use change, and the impact of climate change. Thus, understanding the role of groundwater in the framework of the water-energy-food nexus (WEF) is essential to develop an integrated management in the fragile Himalayan environment. Groundwater is increasingly critical for sustaining the livelihoods across the Himalayan region, yet its management remains the least understood component of the hydrological cycle. The characteristic features, like steep topography, complex geology, and highly variable climatic conditions, host a series of shallow, discontinuous, and fractured aquifers that differ significantly from those of the alluvial plains. In most parts of the Himalayas, groundwater is found in localised perched aquifers, which are recharged by snow melt, spring discharge, and rainfall, making it extremely sensitive to both climatic and anthropogenic pressures. Himalayan aquifers are isolated, site-specific, and controlled by lithological and structural heterogeneity as compared to plains, where the groundwater system forms extensive and connected basins. Thus, these fragmented aquifers render generalised national-scale guidelines like CGWB only partially applicable to the mountain context. Hence, region-specific approaches that account for local geological and hydrological variability are essential for sustainable groundwater management in the Himalayas.

Recent assessments have revealed growing concerns about changing climatic conditions in the Himalayan regions, which exhibit pronounced seasonal and spatial differences in their warming rates. The increasing trend in temperature has accelerated glacier melt, as documented through geodetic measurements and rainfall patterns, leading to an increasing number of lakes and greater river runoff[1]. The consequences are becoming increasingly apparent, with the monsoon seasons causing widespread damage to infrastructure, a situation exacerbated by unsustainable development that has ignored environmental constraints.

Within the Indian Himalayan region, states like Uttarakhand, Sikkim, and Himachal Pradesh are facing increasingly evident groundwater depletion, particularly in densely populated

valleys where pumping for irrigation and domestic use has intensified. This depletion is compounded by erratic precipitation patterns, which reduce recharge efficiency; heavy rainfall often enhances surface runoff instead of infiltration, further limiting groundwater replenishment. Simultaneously, groundwater contamination has emerged as a pressing challenge, with increased incidences of anthropogenic and geogenic pollution, especially from fluoride, arsenic, and iron reported in several mid-hill aquifers[3]. These combined stresses on groundwater quantity and quality have vast impacts on the broader water-energy-food nexus. As rainfall becomes more unreliable and surface sources diminish, dependency on groundwater for irrigation and drinking supply is projected to increase substantially. However, the scattered population across the mountainous terrain makes conventional water-supply infrastructure both energy-intensive and logistically challenging. Consequently, the expansion of groundwater-based irrigation, powered by grid electricity or diesel, will heighten energy demands. This creates a critical feedback loop: falling water tables require greater energy inputs for lifting water, thereby directly linking groundwater security to energy security. The agriculture sector is particularly vulnerable to this interplay of groundwater depletion and climate extremes. Intense rainfall events damage crops and reduce soil moisture retention, while limited access to reliable irrigation diminishes productivity, a situation further compounded by cold surface conditions and intermittent freezing. In the absence of sustainable groundwater management, such agricultural damage could intensify, severely affecting both food supply and rural livelihoods. Therefore, to reduce the carbon footprint of agricultural water use and enhance long-term resilience, the integration of green energy into groundwater irrigation, such as solar-powered pumps and micro-hydro systems, must be promoted.

Without managed recharge and wastewater reuse, the region risks entering a cycle of unsustainable extraction and rising energy consumption. A key strategy is the implementation of Managed Aquifer Recharge (MAR) structures, which should be specifically designed for the local topography and hydrogeology rather than relying on assumptions from lowland environments. The critical recharge parameters for MAR, including infiltration rate, depth, and water quality, must be calibrated to Himalayan conditions. Advanced techniques such as Ground Penetrating Radar (GPR) and isotope hydrology are essential for accurately identifying optimal recharge zones, thereby enhancing infiltration and stabilizing groundwater levels. At the local scale, community-based MAR systems offer significant co-benefits, including reduced energy consumption due to shorter water transport distances and a decreased need for energy-intensive deep pumping. When these localized MAR and distribution networks are coupled with green energy sources, such as solar power or micro-hydropower, they can provide sustainable, low-carbon water access to remote settlements. Furthermore, to ensure year-round functionality in a region where below-zero temperatures can disrupt conventional infrastructure, these systems must incorporate insulated or flexible designs suited for cold climates. Securing a reliable water supply in this manner directly supports both domestic needs and irrigation, thereby enhancing water security for food and livestock production. A foundational step for achieving long-term water sustainability is a detailed understanding of the hydrogeological system. This involves tracing the origin of spring water, quantifying its residence time, and identifying the connectivity between recharge zones and discharge points, which collectively inform effective and resilient water resource management.



This hydrogeological knowledge is vital not only for spring rejuvenation plans but also for understanding how changing climate and land use impact baseflow and aquifer dynamics. To strengthen aquifer resilience, nature-based solutions should be integrated, including spring-shed restoration, vegetative buffer zones, and the reuse of treated wastewater for irrigation. Implementing decentralized wastewater treatment and recycling systems can simultaneously reduce the burden on natural aquifers and provide an alternative water source for agriculture. This approach creates a circular water economy that aligns with the water-energy-food (WEF) nexus framework. However, the success of such practices depends on stringent water quality standards and continuous monitoring to prevent the secondary contamination of shallow aquifers.

Furthermore, the current trend of industrial expansion in Himalayan valleys requires critical assessment. Water- and energy-intensive industries can accelerate resource depletion and must be regulated. The focus should instead shift toward promoting low-impact, water-efficient economic activities that operate within the carrying capacity of the region's fragile mountain aquifers.

Thus, the escalating climate crisis, along with the anthropogenic activities in the Himalayas, marked by accelerated warming and erratic hydrology, is exerting severe pressure on its groundwater resources, with cascading effects on energy and food security. The path forward requires a decisive break from conventional, high-impact development. By embracing a synergistic strategy that combines localized, data-driven groundwater management, such as specialised MAR, with nature-based solutions and a transition to green energy, the region can build a resilient circular water economy. Ultimately, the future of the Himalayas depends on harmonizing human activities with the ecological limits of its vital aquifers, securing water, energy, and food for its communities sustainably and equitably.

Keywords: Groundwater in the Himalayas, Sustainable Management, Managed Aquifer Recharge, Climate Change, Water-Energy-Food Nexus

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Integrated Assessment of Glacial Lake Outburst Flood Susceptibility and Compound Flood Hazards under Extreme Climate Scenarios in the Himalayas

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Abstract

Glacial Lake Outburst Floods (GLOFs) are among the most destructive cryospheric hazards in the Himalayas, increasingly threatening downstream communities, infrastructure, and hydropower systems. Accelerated glacier retreat and rising frequencies of extreme precipitation events, both driven by climate change, have intensified the formation and expansion of glacial lakes, substantially heightening outburst potential. Addressing these interconnected processes requires an integrated, data-driven approach capable of evaluating spatial susceptibility and compound hazard interactions. This study develops a comprehensive framework for analysing spatiotemporal lake evolution, assessing GLOF susceptibility, and estimating compound GLOF-flood dynamics across the Himalayas, with a focus on the Sikkim Himalaya and the Beas and Sutlej River basins in Himachal Pradesh. A regional-scale hazard susceptibility mapping was undertaken for the entire Himalayan belt to identify potentially dangerous glacial lakes. A hybrid Frequency Ratio–Analytical Hierarchy Process (FR–AHP) model was employed to generate a Glacial Lake Outburst Flood Susceptibility Map (GLOFSM) (Figure 1). The hybrid approach combines data-driven frequency analysis with expert-based weighting, integrating empirical objectivity with physical understanding while reducing subjectivity in hazard classification. Twelve critical parameters were selected based on their physical relevance and recurrence in historical GLOF events, including lake area, slope, elevation, dam height, proximity to the parent glacier, glacier area, snowline altitude, avalanche susceptibility, rainfall intensity, and temperature. The model was calibrated using 25 documented GLOF events, and the resulting FR–AHP index was normalized and classified into five hazard levels using the Jenks Natural Breaks method.

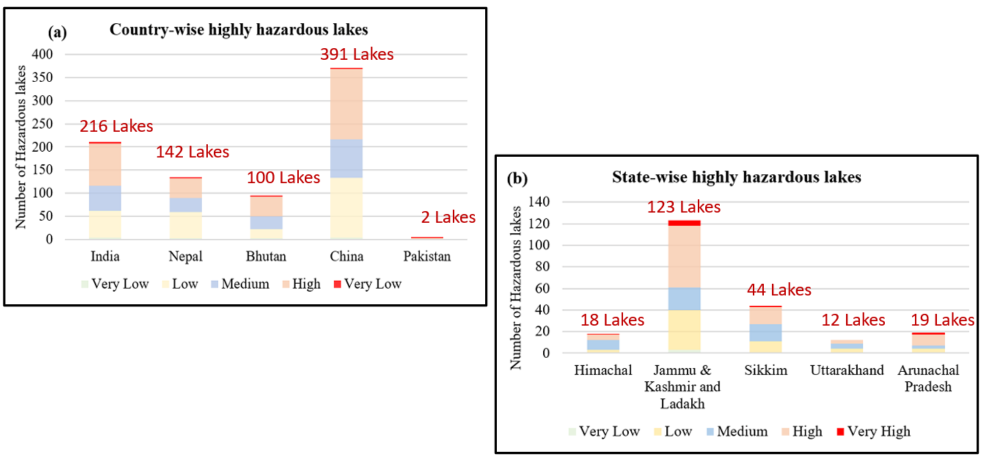

Figure 1: Hybrid FR-AHP approach for GLOF hazard assessment in the Himalayan region.

The analysis identified 324 lakes as high hazard and 50 as very high hazard, concentrated mainly in Sikkim, eastern Nepal, and Himachal Pradesh, where steep topography and intense glacier–lake interaction increase outburst probability. The results showed strong agreement with historical GLOF sites, confirming the model's reliability and providing a spatially explicit foundation for prioritizing lake monitoring and mitigation. To capture temporal changes, a spatiotemporal analysis was conducted for the Sikkim Himalaya using Landsat imagery (1990–2020). The number of glacial lakes increased from 309 to 440, and the total area expanded from 22.83 km² to 30.71 km², reflecting the rapid pace of glacier retreat and hydrological reorganization under a warming climate. Over 65% of the newly formed or enlarged lakes were directly connected to parent glaciers, indicating enhanced outburst susceptibility through increased meltwater and ice-contact instability. To further refine hazard evaluation, an enhanced framework integrating qualitative factors (e.g., ice avalanches, landslides) with a Fuzzy AHP (FAHP) approach and stochastic inundation modelling using the Monte Carlo Least Cost Path (MC-LCP) method was applied. Among the 51 lakes identified as potentially GLOF-prone, 13 were categorized as high or very high hazard, providing a strong scientific basis for targeted monitoring and emergency preparedness in the region.

Building on the susceptibility analysis, compound GLOF–flood scenarios were simulated for the Beas and Sutlej basins—two hydrologically active western Himalayan catchments characterized by dense hydropower infrastructure and steep terrain. Hydrological modelling using HEC-HMS captured runoff dynamics, while two-dimensional flood propagation and inundation were simulated using the HEC-RAS hydrodynamic model. Calibration and validation with observed discharge data from Pandoh (Beas) and Bhakra (Sutlej) dams yielded strong model performance, with Nash–Sutcliffe Efficiency (NSE) values exceeding 0.65 and 0.75, respectively. These validated models formed the basis for simulating design and extreme flood events under current and compound scenarios.

To incorporate hydro-climatic extremes, the Probable Maximum Precipitation (PMP) was estimated using the Hershfield statistical method, yielding values of 650.12 mm for the Beas Basin and 530.68 mm for the Sutlej Basin. Rainfall magnitudes corresponding to 2-, 10-, 25-, 50-, 75-, and 100-year return periods (figure 2) were derived from the Gumbel Generalized Extreme Value (GEV) distribution, ranging from 78.99 mm to 441.34 mm for the Beas and 90.65 mm to 274.86 mm for the Sutlej. The PMP-based rainfall estimates were used to simulate the Probable Maximum Flood (PMF), which was then coupled with GLOF hydrographs derived from the Froehlich breach model to produce worst-case compound GLOF–PMF scenarios.

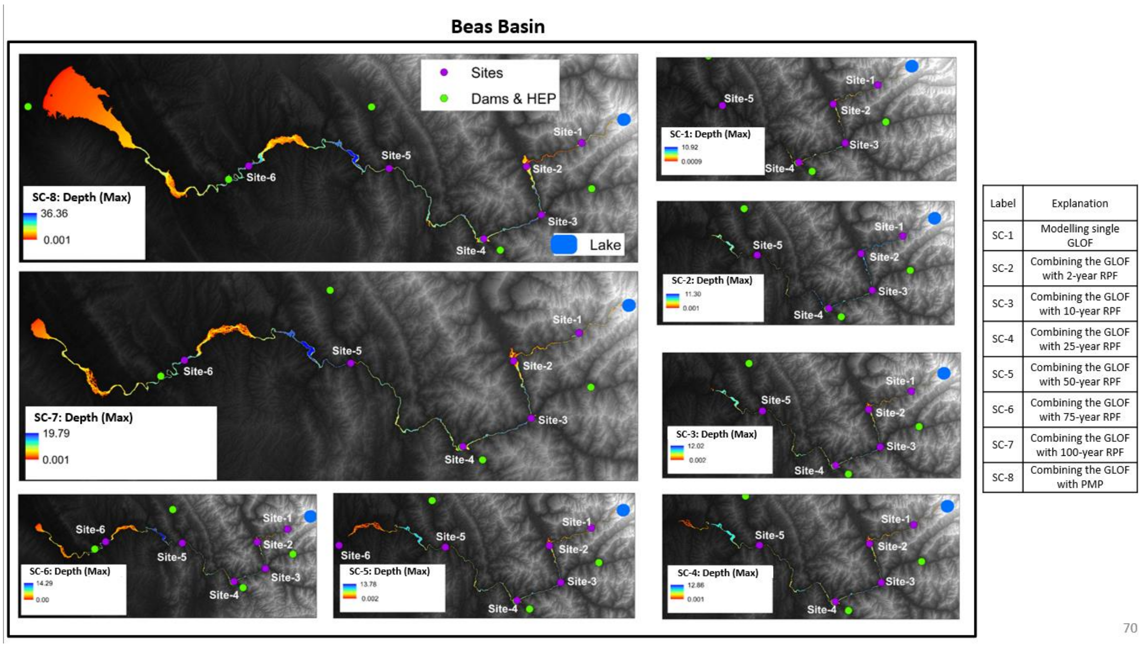

Figure 2: GLOFs under different scenarios in the Beas Basin.

Simulated PMF discharges reached 17,086 m³/s at Pandoh Dam and 23,478 m³/s at Bhakra Dam, while compound GLOF–PMF events generated peak discharges of 17,356 m³/s and 24,723 m³/s, respectively—an increase of about 2–5% over PMF-only conditions. Although modest in magnitude, these amplifications significantly increased downstream flood intensity due to the narrow, confined topography of Himalayan valleys. Inundation maps revealed extensive exposure of settlements and infrastructure, with 94 buildings, hydropower plants, and religious sites at risk in the Beas Basin, and more than 588 structures, including major hydropower and industrial facilities, threatened in the Sutlej Basin. These results demonstrate that ignoring compound GLOF–extreme rainfall interactions can lead to substantial underestimation of flood risk in existing hydropower safety frameworks.

The integrated analysis highlights that GLOF hazards cannot be treated in isolation from extreme hydrometeorological events. The coupling of cryospheric and climatic drivers provides a more realistic understanding of potential flood magnitudes and their cascading impacts. The employed susceptibility mapping, combined with time-series lake evolution analysis and coupled hydrological–hydrodynamic simulation, offers a transferable framework for multi-hazard assessment in other data-scarce mountain regions. By linking spatial susceptibility with dynamic modelling, this study enhances predictive capability for both local and regional hazard management.

The findings have significant implications for climate adaptation and risk reduction in the Himalayas. Continuous satellite-based monitoring is essential to track glacial lake expansion and moraine stability. Early warning systems integrating meteorological forecasts with lake monitoring can improve emergency preparedness. Hydropower design and dam safety standards should incorporate compound flood scenarios derived from PMP and GLOF simulations. Regional cooperation is also critical for building a shared GLOF database, developing rapid-response mechanisms, and mainstreaming hazard information into watershed management and land-use planning.

In summary, this study advances the understanding of Himalayan GLOF dynamics by bridging susceptibility mapping, temporal monitoring, and compound flood modelling under extreme climate conditions. The results emphasize the growing influence of climate-driven hydrological extremes on cryospheric hazards and their downstream consequences. The proposed integrated approach provides a scientific foundation for climate-resilient infrastructure planning, adaptive watershed management, and disaster-resilient development in the Himalayan region under ongoing climate change.

Keywords:

Glacial Lake Outburst Flood (GLOF); Compound flood hazard; Extreme rainfall events (ERE); Probable Maximum Precipitation (PMP); Frequency Ratio–Analytical Hierarchy Process (FR–AHP); Fuzzy AHP (FAHP); Hydrological–hydrodynamic modelling; HEC-HMS; HEC-RAS; Spatiotemporal lake evolution; Himalayan cryosphere; Climate change adaptation

Are recent Himalayan disasters a direct consequence of climate change?

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Abstract

Climate change, coupled with increasing anthropogenic pressure on the fragile Himalayan ecosystems, is posing a severe threat to their sustainability. A recent climate change synthesis report of IPCC 2023 indicated that human activities, principally through emissions of greenhouse gases, have increased the global surface temperature by around 1.1°C since the early 20th century. Studies implicate the rising temperature in the observed increase in climate extreme events, enhancing ecosystem vulnerability and threatening the vital infrastructure development projects in the Himalayan region. There are indications that the higher Himalaya (elevations >4000 m) is warming faster than its lower elevation counterparts due to a phenomenon called the Elevation Dependent Warming (EDW), and thus causing accelerated cryosphere degradation. For example, accelerated melting of glaciers, creation of moraine-dammed glacial lakes, and frequent mobilization of the paraglacial sediments during extreme weather events are some of the manifestations being witnessed in recent years. The frequencies of extreme weather events leading to disastrous floods and landslides are on the rise. The recent examples are the June 2013 Kedarnath, February 2021 Rishi Ganga, the 2023 Beas and Teesta valley floods, and, more recently, the August 2025 debris flow flood in the upper Bhagirathi valley.

Climate change is a reality, and its impacts are going to be quite severe in the time to come. However, the question is how long we will be using climate change as a convenient narrative for the increasing number of disasters in the Himalayan region? Such an approach in the past paved the way for encouraging reactive disaster policies; instead, what we require is proactive disaster preventive policies. Which, according to us, is achievable provided we listen to the timely warning of the scientists that accrue from a well-defined research-based approach. And more importantly, the authorities at the helm of the affair should have the will and commitment to implement the research-based solutions on the ground. In this presentation, we will try to touch upon some of these issues being faced by the people and terrain in the Himalaya.

Mapping and Assessing Peatlands in India Using Geospatial and Field-Based Approaches

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Abstract

Peatlands, despite covering only 3-4% of the global land surface, store nearly one-third of the world's soil carbon, making them crucial for achieving global climate targets. In India, however, the extent of peatlands remains uncertain due to limited research and a lack of systematic documentation. Different global assessments provide inconsistent and highly varied estimates of peatland extent. Consequently, peatlands remain largely absent from climate action and wetland management frameworks, increasing their vulnerability to degradation and loss.

To address this gap, a nationwide assessment was undertaken to establish a baseline on the extent, distribution, and condition of peatlands across India’s diverse biogeographic settings, including the Himalayas, Trans-Himalaya, Northeast, and Western Ghats. The approach integrates geospatial analysis with field-based validation to identify peatland probable locations and understand ecosystem characteristics. A peatland probability map was developed using multi-source environmental datasets, including satellite-derived vegetation and moisture indices, terrain parameters, and soil attributes.

Findings indicate that up to 0.4% of the geographical area in the Himalayan and Trans-Himalayan regions may contain peatlands or carbon-rich peatlands. Field validations were conducted at the modeled peatland areas to confirm peat presence and assess site conditions. The model successfully identified known peatland sites such as Khecheopalri, Chandertal, Tso Kar marshes, Mirgund, and several other wetlands in India. Most high-probability peatland areas fall within mid- and high-altitude rangelands and wetland classes. Lower-elevation land-use classes, such as active alluvial zones and agricultural fields, require refinement, as peat formation or occurrence is unlikely due to anthropogenic and natural disturbances. Field observations further highlight pressures affecting peatland integrity, including hydrological alterations, unsustainable grazing, dredging, tourism-driven disturbances, and land-use change.

The assessment reveals limitations related to scarce peat-specific datasets and limited ground validation, underscoring the need for expanded sampling across seasons and regions. Integrating region-specific indicators and applying advanced machine-learning approaches may improve mapping accuracy and support restoration planning and national GHG reporting.

Keywords: peatlands, inventory, carbon stock, climate change, remote sensing, and GIS

Wetlands and Peatland Ecosystems in the Northeastern Himalaya

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Abstract

Introduction

Wetlands and peatland ecosystems are integral to the ecological stability and climate resilience of the Indian Himalayan Region (IHR). These freshwater and floodplain systems regulate hydrology, store carbon, and sustain livelihoods; yet, they remain among India's most threatened and least-studied ecosystems. This abstract focuses on four Ramsar wetlands, Loktak Lake (Manipur), Deepor Beel (Assam), Pala Wetland (Mizoram), and Rudrasagar Lake (Tripura), as models for integrating wetland and peatland conservation into the Himalayan Action Plan (HAP) aligned with Vision 2047.

1. Ecological and Climatic Relevance

Wetlands are transitional ecosystems where land and water interact, regulating hydrology, supporting biodiversity, and acting as major carbon reservoirs (Gell et al., 2023). Peatlands, characterized by waterlogging and the slow accumulation of organic matter, store disproportionately large amounts of carbon, up to ten times more than tropical forests per unit area (Kumar et al., 2025; UNEP, 2022). In the Northeast Himalayas, these wetland–peat complexes function as nature-based solutions for both mitigation and adaptation, buffering floods, stabilizing soil, and maintaining dry-season flow in river systems. India's Northeast supports a mosaic of lowland floodplain wetlands and high-altitude peat-forming systems. Studies in Loktak Lake show high organic carbon concentrations in its unique phumdi (floating mat) zones—up to 1,442 g C m^{-2}—almost twice that of open-water areas (Caroline et al., 2024). Similar findings across Manipur's wetland complexes confirm that hydrological integrity strongly determines carbon sequestration capacity (Singh et al., 2025; Taran et al., 2023).

2. The Four Ramsar Wetlands of Northeast India

The Northeast is one of India's richest wetland regions, supporting a network of lakes, floodplain systems, marshes, and peat-forming wetlands. The National Wetland Inventory and Assessment (NWIA) Atlas, prepared by the Indian Space Research Organisation (ISRO) and Space Applications Centre (SAC), provides the most comprehensive mapping of wetlands across the eight Northeastern states. Although the Atlas does not present a consolidated regional total, the combined datasets indicate that the Northeast supports one of India's highest wetland densities relative to land area, underscoring its hydrological and ecological significance (ISRO–SAC, 2011).

Site	Designation Year	Significance	Major Threats	Key Management Needs
Loktak Lake (Manipur)	1990	India's largest freshwater lake; unique *phumdi* mats; only floating national park; habitat of the endangered *Rucervus eldii eldii* (Sangai).	Hydropower regulation, siltation, pollution, and encroachment.	Restore natural hydrology, implement carbon monitoring, and promote co-management.
Deepor Beel (Assam)	2002	Floodplain wetland and stormwater buffer for Guwahati; critical bird habitat.	Urban sprawl, landfill dumping, nutrient enrichment.	Urban–wetland integration, waste control, buffer-zone creation.
Rudrasagar Lake (Tripura)	2005	Supports Neermahal Palace; fishery and aquatic plant diversity.	Catchment erosion, eutrophication, and invasive weeds.	Integrated watershed management, pollution abatement, livelihood diversification.
Pala Wetland (Mizoram)	2021	Culturally revered site, high biodiversity, key water source.	Catchment deforestation, infrastructure projects.	Community conservation, eco-tourism, catchment restoration.

3. Loktak Lake in Maipur as a Flagship Carbon-Rich System

Loktak Lake illustrates the ecological and socio-economic importance of Himalayan wetlands. It supports diverse flora, fauna, and livelihoods (Mehrotra et al., 2024). The phumdi mats act as semi-peat systems storing large carbon stocks (Caroline et al., 2024). However, the Loktak Hydroelectric Project has altered water levels, fragmenting mats, and affecting carbon fluxes (Chingangbam & Khoiyangbam, 2023). In macrophyte-dominated zones, CO_2 and CH_4 emissions reach 8,362 mg and 228 mg m^{-2} d^{-1}, respectively, showing that vegetation structure influences greenhouse gas balance. Restoration must integrate hydrological regulation, carbon monitoring, and community-led livelihoods (Mehrotra et al., 2024; MoEF&CC, 2024).

4. Policy and Institutional Framework

India's wetland governance advanced with the NPCA Guidelines (2024), integrating wetlands into Vision 2047 and SDG frameworks (MoEF&CC, 2024). These guidelines institutionalize ecosystem-service valuation, carbon accounting, and community participation. ISRO's Atlas

(2011) provides the spatial baseline, and GBPIHED's "High Altitude Wetlands in the Indian Himalaya" identifies hydrology and biodiversity priorities (Sharma et al., 2020). The GBPIHED Annual Report (2023–24) highlights peatland carbon research under NMHS, reinforcing the institutional focus on Himalayan wetlands.

5. Community and Climate Linkages

Wetlands underpin local livelihoods and cultural heritage. Loktak's floating settlements face climate risk but possess strong indigenous knowledge systems (Mehrotra et al., 2024). NPCA (2024) and UNEP (2022) emphasize community-based management as essential for resilience. The High-Altitude Wetlands Report (Sharma et al., 2020) links degradation with reduced downstream water security, reinforcing the need for hydrological restoration and inclusive governance.

6. Integrating into the Himalayan Action Plan (HAP-IHR 2047)

The following strategic actions may be taken:

- Create a Himalayan Wetland–Peatland Mission under MoEF & CC and NIHE, focusing on mapping, carbon assessment, and climate–hydrology modelling.
- Integrate Ramsar wetlands into long-term carbon inventory programmes in collaboration with other partners.
- Promote hydrological restoration of degraded ecosystems to maintain a healthy ecosystem.
- Mainstream community-led stewardship as demonstrated in Loktak and Pala Wetlands.
- Adopt wetland-health indices for continuous evaluation using satellite data and citizen-science networks.

These align with NPCA (2024), UNEP (2022), and Vision 2047's dual goals of conservation and sustainable socioeconomic growth.

7. Conclusion

Wetlands and peatlands of the Northeast Himalayas represent living systems that regulate water, carbon, and climate. The four Ramsar sites, Loktak, Deepor Beel, Pala, and Rudrasagar, exemplify both the ecological richness and management challenges of the region. Integrating these ecosystems into the Himalayan Action Plan 2047 would consolidate India's leadership in ecosystem-based climate action. As the Global Peatlands Assessment (UNEP, 2022) asserts, the future of peatlands determines the future of the planet's climate. For India, that future begins in its Himalayan wetlands—where science, policy, and community stewardship must converge to ensure sustainable development by 2047.

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Environmental sustainability and climate action for resilience building in the Himalaya

Green Growth and Ecosystem-Based Solutions for Adaptation under a Changing Climate: Policy Imperatives for Vision 2047

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Abstract

The Indian Himalayan Region (IHR), spanning 13 Indian states and union territories and home to nearly 50 million people, is undergoing accelerating ecological, climatic, and socio-economic transformations that threaten its environmental stability and development trajectory. As one of the world's youngest, most fragile mountain ranges, the Himalaya is experiencing rapid glacier retreat, erratic monsoon patterns, intensifying landslides, biodiversity loss, river system degradation, air pollution, and growing risks to food, water, and livelihood security. Climate projections indicate a temperature increase of 1.5–2.0 °C by mid-century in many Himalayan sub-zones, with a 30–50 percent rise in extreme rainfall events, amplifying flash floods, river erosion, and glacial lake outburst floods (GLOFs) (IPCC, 2022). These changes pose immediate challenges not only for mountain communities but also for downstream populations dependent on the Himalayan ecosystem for water, energy, agriculture, and climate regulation.

Traditional, infrastructure-heavy "grey" development approaches are proving insufficient and often maladaptive in the face of climate stress. In contrast, Ecosystem-based Solutions (EbS)-including watershed restoration, afforestation, grassland regeneration, biodiversity corridor planning, spring rejuvenation, climate-resilient agriculture, climate-smart agriculture (CSA), and nature-based disaster buffers—offer a low-carbon, cost-effective pathway that links climate adaptation, livelihood enhancement, and green economic growth. The transition toward green growth, as envisioned in India's Mission LiFE, Panchamrit climate commitments, Nationally Determined Contributions (NDCs), and Vision India @2047 development blueprint, demands a Himalayan-specific governance, financing, and science-policy architecture.

The Himalaya is not only an ecological hotspot but also an agrarian region where climate impacts directly affect rural economies. More than 70 percent of households in the IHR depend on agriculture and allied activities, yet mountain farming is highly vulnerable to temperature anomalies, pest outbreaks, land degradation, and water scarcity. Yield losses in key hill crops such as apple, cardamom, millet, and traditional pulses have already been reported, with cascading effects on incomes, food security, and migration patterns (Sharma & Rasul, 2021). Climate-induced decline in crop suitability zones is projected to push mid-hill agro-economies into crisis unless climate-smart agriculture, agroforestry, organic value chains, and market-linked EbS models are adopted. The economic cost of climate-related disasters in the Himalayan states has crossed ₹1.3 lakh crore in the last two decades (MoEFCC, 2023), indicating the fiscal irrationality of ignoring nature-based solutions.

Despite multiple policies, including the National Mission for Sustaining the Himalayan Ecosystem (NMSHE), State Action Plans on Climate Change (SAPCCs), and the 1992 Himalayan Action Plan, governance challenges persist—fragmented institutional jurisdiction, weak multi-state coordination, inadequate climate financing, poor scientific data sharing, and absence of mountain-specific policy instruments. The Himalayan Action Plan now urgently requires a comprehensive revision aligned with Vision India 2047, integrating green infrastructure, circular bio-economy, carbon markets, climate-resilient agriculture, mountain tourism standards, and EbS-linked livelihood models. Unlike earlier plans, the revised framework must embed parliamentary oversight, inter-ministerial coordination, and long-term financing mechanisms such as Himalayan Green Bonds, Payment for Ecosystem Services (PES), and CSR-pooled eco-restoration funds.

The role of political leadership and parliamentary engagement is critical. A Parliamentary Himalayan Task Force—bringing together MPs from hill and downstream states—can institutionalize evidence-based policymaking, promote inter-state learning, and secure budgetary commitments for EbS interventions. Multi-stakeholder platforms involving NITI Aayog, ICIMOD, GB Pant National Institute of Himalayan Environment, IITs, agricultural universities, mountain research centres, and civil society networks can accelerate knowledge brokerage and community-led adaptation. The success of such a model is evident from Nepal's community forestry programs, Bhutan's Gross National Happiness (GNH) ecological policies, and Himachal Pradesh's PES-based watershed protection model, demonstrating scalable mountain-specific governance innovations.

EbS approaches are directly relevant for disaster risk reduction (DRR) in the Himalaya. Natural infrastructure—such as wetlands, alpine grasslands, river buffers, and forested slopes—reduces landslide intensity, regulates sediment flow, stabilizes glaciers, and delays flood peaks. Mangroves protect coasts; forests protect mountains. Yet the Himalayan states continue to witness unregulated road cutting, hydropower tunneling, and urban expansion on unstable slopes, weakening natural disaster shields. EbS-based land use zoning, ecological carrying capacity assessments, and nature-positive infrastructure codes must become mandatory in all Himalayan development projects.

Biodiversity conservation is not only an ecological priority but an economic asset. The IHR contains four global biodiversity hotspots, 30,000+ plant species, and 300+ mammal species, many of which sustain tourism, ethno-medicine, agrobiodiversity, and carbon sequestration. Linking biodiversity corridors with climate-smart ecotourism, community conservation reserves, and bio-enterprise incubation can generate green jobs for youth while enhancing ecosystem connectivity. A ₹10,000-crore Himalayan Green Transition Fund under the Ministry of Finance could anchor such initiatives.

To operationalize this transition, five policy action pillars emerge:

1. Mainstream EbS in state planning and public finance – make EbS a first-choice adaptation intervention in all Himalayan SAPCCs.

2. Create a multi-level Himalayan Green Growth Mission with parliamentary backing, integrating climate, agriculture, tourism, water, and energy sectors.
3. Establish EbS financing pipelines—Green Bonds, PES schemes, climate-resilient agriculture credit, and international climate finance windows.
4. Develop a Mountain Knowledge Grid that links research institutions, digital climate observatories, and community-based monitoring systems.
5. Launch a Mountain Agriculture Resilience Initiative to protect food systems, promote millets and traditional crops, expand agroforestry, and integrate carbon-credit-earning farm models.

The next two decades are decisive. By 2047, India will mark its centenary of independence. Whether the Himalayan region becomes a global model of climate-resilient green development—or an ecological disaster zone—depends on policy choices made now. EbS and green growth are not optional alternatives to conventional development; they are mandatory pathways for safeguarding water security, energy stability, biodiversity integrity, and livelihood resilience for nearly one-sixth of humanity dependent on the Himalaya.

A future-ready Himalayan strategy must therefore: (a) embed climate adaptation in economic planning, (b) re-orient environmental governance toward natural capital accounting, (c) connect mountain communities to green value chains, and (d) shift from disaster compensation to prevention through EbS-driven resilience. The Indian Himalaya stands at a turning point, and the next phase of policy innovation must treat ecology not as an externality, but as the foundation of development itself.

Ecosystem-based approaches: a nature based solutions (NbS), for Bio-resource Conservation: a paradigm shift

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Abstract

Ecosystem (ES) based approach known worldwide for bioresources conservation but nowadays, nature-based solutions (NbS) are gaining popularity in science and politics, but their capacity for revolutionary transformation is still untapped. NbS offers a platform for evaluating the factors that could trigger revolutionary change and presents a people cum nature-based perspective on science for a society that promotes sustainability. It has the potential to support a variety of human values about nature and knowledge, community participation, and management practices (restoration, ecosystem monitoring, and nature protection). Here, I will discuss various facets of biodiversity, ES vs NbS, particularly those related to Himalayan region, as well as their challenges, potential, and gaps.

Keywords: Ecosystem Based Solutions, Nature Based Solutions, Himalaya, Social Scientists, Sustainable Development

Managing Carrying Capacity for Sustainable Tourism:
Linking Carrying Capacity to Sustainable Goals

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Abstract

Linking carrying capacity to the Sustainable Development Goals transforms it from a technical, environmental concept into a “strategic framework for holistic destination management”. It provides a clear, measurable pathway to ensure that tourism contributes positively to the planet, its people, and shared prosperity. By managing not just the number of tourists, but their type, behavior, and distribution, destinations can use tourism as a powerful tool to achieve the 2030 Agenda for Sustainable Development.

‘Tourism Carrying Capacity’ is defined as the maximum number of visitors that a destination can accommodate without causing unacceptable deterioration of the physical, ecological, social, and cultural environment and without diminishing the quality of the visitor experience. Managing carrying capacity is not about finding a single "magic number" of visitors, but about establishing a “dynamic management process” that ensures tourism development does not exceed the environmental, social, and economic limits of a destination. When effectively linked to the Sustainable Development Goals (SDGs), carrying capacity becomes a powerful, actionable tool for achieving holistic and long-term sustainability, transforming tourism from a potential threat into a positive force for change. The following types can be described – (i) Physical Carrying Capacity: The sheer number of people an area can physically hold, (ii) Ecological/Environmental Carrying Capacity: The limit beyond which environmental damage occurs (e.g., pollution, habitat destruction, strain on water resources), (iii) Social Carrying Capacity: The point at which the host community's tolerance for tourism is exceeded, leading to social friction, loss of cultural identity, or resentment, (iv) Infrastructural Carrying Capacity: The limit of local infrastructure (e.g., water supply, waste management, transportation, electricity), (v) Economic Carrying Capacity: The level of tourism that remains economically beneficial without displacing local industries or causing excessive inflation, and (vi) Perceptual Carrying Capacity: The threshold beyond which the visitor's sense of crowding or diminished experience begins to degrade satisfaction.

Tourism is a major activity in the hilly states of India (Indian Himalayan Region – UTs of J&K and Ladakh, Himachal Pradesh, Uttarakhand, Sikkim, and the other seven Northeastern states), but is now facing many issues. Tourism related problems are highlighted by the Ministry of Tourism which include (i) Environmental Degradation, (ii) Overcrowding & Carrying Capacity, (iii) Waste Management Issues, (iv) Water Shortages, (v) Unplanned Urbanization, (vi) Landslide and Disaster Risk, (vii) Cultural Erosion, (viii) Seasonality and Unstable Incomes, (ix) Impact on Wildlife, (x) Strain on Transportation, and (xi) Health and Safety Concerns. These and reflected in both national and state-specific analyses of tourism impacts.

Addressing these challenges requires better planning, stronger environmental regulation, improved waste management, controlled capacity, and inclusive community involvement.

Managing carrying capacity is a practical mechanism for achieving several of the SDGs goals in the context of tourism - (A) Achieving Environmental Protection by addressing (i) SDG 6 (Clean Water & Sanitation) - Preventing overuse and pollution of freshwater resources by managing tourist numbers and infrastructure, (ii) SDG 7 (Affordable & Clean Energy) - promoting energy efficiency in hotels and transport, and can incentivize renewable energy to serve tourism loads, (iii) SDG 12 (Responsible Consumption & Production) - Reducing waste generation, promoting local and sustainable food sourcing, and managing resource use, (iv) SDG 13 (Climate Action) - Mitigating tourism's carbon footprint through visitor management, promoting low-carbon transport, and conservation, (v) SDG 15 (Life on Land) - Protecting terrestrial ecosystems from degradation by controlling access, preventing pollution, and preserving habitats. (B) Maintaining Socio-Cultural Well-being by addressing (i) SDG 8 (Decent Work & Economic Growth) - Ensuring tourism growth is stable and sustainable, creating long-term, quality jobs rather than seasonal, exploitative ones, (ii) SDG 11 (Sustainable Cities & Communities) - Preserving cultural heritage, reducing overcrowding, and maintaining residents' quality of life, making communities inclusive and resilient, (iv) SDG 16 (Peace, Justice & Strong Institutions) - Requiring transparent governance and stakeholder participation (including local communities) in planning, fostering trust and justice. (C) Targeting Economic Sustainability by addressing (i) SDG 1 (No Poverty) & SDG 10 (Reduced Inequalities) - Ensuring tourism revenue is distributed more equitably by supporting local SMEs and creating local employment, reducing leakages, and (ii) SDG 8 (Decent Work & Economic Growth) - Moving the focus from volume to value. Higher-value, lower-volume tourism can generate more revenue with less impact.

To achieve these SDGs framework for managing carrying capacity is required, effective administration is required as a continuous cycle of adaptive management, which is key to long-term resilience. The following steps are recommended - (1) Establishing Sustainability Objectives (The "Why"), (2) Assessing and Monitoring Key Indicators (The "What"), (3) Defining Acceptable Limits of Change (The "How Much"), (4) Implementing Management Strategies (The "How") which include deployment of suitable strategies, for example (i) Regulatory Tools: Zoning laws, caps on visitor numbers, protected area permits, (ii) Economic Tools: Differential pricing (high season vs. low season), tourist taxes earmarked for conservation, entry fees, and (iii) Soft Tools like Visitor Flow Management, Communication & Education, Product Diversification, etc. and (5) Monitoring, Evaluation, and Adaption to continuously track the indicators. One of the effective examples is from the Himalayan Kingdom of Bhutan, where Multiple SDGs have been addressed to the problem of preserving culture and environment in the face of globalization. Bhutan has done Carrying Capacity Management through the "High Value, Low Volume" policy, including a “daily sustainable development fee”. These funds support carbon-neutral development (SDG 13), free healthcare and education (linked to SDG 3 & 4), and preserve cultural heritage (SDG 11).

Time to time, efforts have been made at the National level of Administrative and Judicial Governance to provide directions and regulations to address some of the issues of immediate concern. For example, the Ministry of Environment, Forest, and Climate Change (MoEFCC) has issued several key directives and guidelines concerning tourism in India, especially for environmentally fragile and hilly regions, which are designed to balance tourism growth with environmental stewardship and the well-being of local communities, especially in hilly and ecologically sensitive regions. Some of them are: (a) Ecotourism and Sustainable Tourism Policy (2024), (b) Environmental Impact Controls, (c) Land, Landscape & Biodiversity Protection, (d) Green Tourism Certification & Digital Tracking, and (e) Specific Directives for Hill States, etc. Besides that, the Supreme Court of India (July 2025, August 2023) and several other high courts in the country, e.g., Jharkhand (June 2025), Kerala (September 2024), Madras (March 2025), etc., have given rulings and orders on matters related to tourism. National Green Tribunal (NGT) has issued orders concerning hill tourism in India on – (i) Carrying Capacity Controls (assessment and enforcing carrying capacity limits, online registration of tourists in overcrowded hill stations, entry or environmental fees, Green Cess), (ii) Zoning, Construction, and Development Bans (classification of areas into "prohibited, regulated, and development zones" to check haphazard construction, illegal tree felling, and harm to lake catchments, and strict restrictions on building heights, density, slope angles, and ground coverage in hill towns), Construction beyond two storeys (plus attic) is generally barred and slopes above 45° are off-limits for most constructions, (iii) Eco-Sensitive Zones and Conservation Strategy (NGT directed the Ministry of Environment, Forest & Climate Change to weigh strategies for declaring the "Higher Himalayas" as an eco-sensitive zone- bans on single-use plastics, mandatory environmental audits, waste management- geotechnical studies before approval of hotels/roads, and inclusion of local community in conservation efforts; Early warning systems for landslides, floods, and abnormal weather events), (iv) Enforcement and Monitoring (Joint committees to monitor illegal activities, mandated hillside afforestation and slope stabilization, Periodic compliance reports submission to the NGT and act on all recommendations).

Judicial orders aim to strike a balance between tourism-driven economic growth and the conservation of India's vulnerable hill ecosystems. They target overcrowding, construction, pollution, and ecosystem strain, and promote registration, capacity controls, strict zoning, practical conservation steps, and penalties for violations. MoEFCC's directives are designed to balance tourism growth with environmental stewardship and the well-being of local communities, especially in hilly and ecologically sensitive regions. The focus is on regulated capacity, green infrastructure, community engagement, and strict compliance with environmental and sustainability norms.

Waste to Energy Initiatives for Sustainable Waste Management in the Himalaya, India

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Abstract

Solid waste is one of the major environmental problems in the Indian Himalayan Region. The present attempt explains the possible ways to manage the ever-increasing load of waste studied in 14 case studies (i.e., 6 hill towns, 5 hill spots, 2 trekking regions, and 1 Pindari glacier) in the northwestern Indian Himalayan states. Here, the increasing populations, including floating populations and residents, have exacerbated the waste problem. Based on the waste compositions analyzed from these case studies, the locations of human habitation are adversely affected more, measuring biodegradable waste from 65.5% at Kullu to 78.3% at Mandi, compared to trekking and expedition locations from 66.4% at Pindari to 90.1% at Chandratal. Since biodegradable waste is ever loading the urban locations, microbial biocomposting technology is recommended to be applied with a combination of traditional as well as automation techniques.

Introduction

Solid waste is a human-induced environmental problem. It has been discussed a lot among the scientific community for a long time that the Himalayan Region, due to increasing population (floating population and natives), the urban locations, tourist spots, trekking and expedition locations are going to be adversely affected due to indiscriminate throwing and dumping of solid waste. The waste problem is continuously expanding in areas mainly having mass tourism, whether these are recreational areas or pilgrimage sites. If we look into the regional scenario, the waste congestion is being observed more in the states of the northwestern Indian Himalayan Region, where tourism and native populations dominate as compared to other northeastern parts of the Himalaya. The other feature of the waste problem again is noticed to be decreasing along the altitudinal gradient from hill towns to hill spots and then trekking location to expedition summits, indicating further the impact of the volume of populations.

Method and Approach

Based on the scientific methods, waste amount and volume need to be estimated at any place, location, or site. This helps a lot in determining the degree of the problem as well as an idea of the techniques developed to be followed in managing the waste. Based on the methods developed by Kuniyal et al. (1998), Kuniyal (2002), Kuniyal (2005 b), and Kuniyal et al. (2003), the waste generation is estimated after collecting waste in one tin box (1 foot3). The waste generated by selected households in a family at a location was requested to deposit their waste continuously for 24 hrs for three days. Based on the total number of households in a family and total waste on a fresh weight as well as volume basis, per capita waste generation is estimated (Kuniyal and Thakur, 2013-14). This way, estimating the total waste generation at a place or site with the total number of populations within a geographic area or municipal limit could become possible. In case the situation or geographic location changes, such as trekking region, the primary sources of waste generation, such as stalls or shops along the trek, such as the Valley of Flowers and Hemkund Sahib, or other similar sites, are the primary sources. The sample box of tin was filled with waste generated by the surveyed stalls, unloaded, segregated, and weighed by a top balance, with a composition-wise analysis. The sample box was filled, unloaded, and weighed using a fresh weight basis (weight and volume) in case of old waste lying in the trekking or expedition locations or any other place.

Results

The results based on fourteen case studies from Himachal Pradesh and Uttarakhand states showed that the biodegradable waste dominates in hill towns and hill spots, while non-biodegradable waste dominates in trekking and expedition locations. This indicates that the locations predominating with human habitation whether floating tourists or local populations dominating mainly with tourist accommodations like hotels generate food waste like waste food, vegetable rinds, and others which under controlled environment may become or disintegrate within a couple of weeks and while segregating, such waste was categorized as readily biodegradable waste (RBW) which in hill spots/towns ranged 65.5% to 78.3%. However, some biodegradables, like paper, grass, etc., may take a couple of months to break down or decompose and comprise 29.5%. The wastes that could not decompose for years, like polythene, plastic, rubber, metals (tin, iron), soft drink bottles, etc., are found under the non-biodegradable category. Collectively, biodegradable waste (RBW and BW) comprises 78.3% in hill towns and hill spots.

Under the waste-to-energy initiatives, there is a combination of options that seek a complete and sustainable waste management of biodegradable and non-biodegradable compositions. In view of biodegradable compositions and seeking immediate solutions to maintain the health conditions of the surrounding populations, microbial biocomposting technology was developed by way of constructing a pit (3×1×1 m) covered by a polyethylene UV-resistant sheet having a capacity of 500 kg of raw waste. There is also a need to maintain 40% moisture within the pit, which requires oxygen with the help of an aeration pipe fixed in a diagonal way. As the temperature increases, the decomposition takes place faster and vice versa. Within the pit, of stones fixed vertically at the base of the pit would not enable the rainwater to seep from its surroundings. As the temperature increases, the decomposition takes place faster and vice versa. A matured biocomposting takes 55±5 days in summer and 65±5 days in winter. The experiments showed that 33.4% (i.e., 167 kg) of the final product, as biocompost, may be obtained within a duration of about two months in summer and three months in the winter season.

It was found that the treatment of municipal solid waste (MSW) compost produced without using the standard doses of NPK recorded the maximum return of yield of peas and beans when using such produced biocompost in various vegetable crops under different replicates. While applying NPK mixing with MWS biocompost, it recorded the highest return in these crops under the experiments. It indicates that if such biocompost is prepared without using any of the inoculants or any other culture, and the waste material is segregated precisely without mixing any medical or contaminating hazardous waste, the biocompost is organic, and the crops that are harvested from it are organic.

Reuse, recycling, and other options are available for non-biodegradable garbage depending on its composition. The tourist locations could be developed with small waste eco-parks around the spots or along the trekking routes. NBW was measured as the highest 90.1% in Chandratal and the lowest 66.4% in Pindari Glacier. The polythene may be used in metalling the roads. The other non-biodegradable waste not found fit for any other use may be ultimately recycled.

Way forward

- Waste segregation at its source of generation is required, without which all the scientific efforts will go to waste, while considering its sustainable management.
- There are many mechanical waste segregators available, but once again, they cannot efficiently and fairly separate biodegradables from non-biodegradable waste. Observations from different locations show that these have their own limitations.
- Biocomposters are another option for composting, although they only break down biodegradable trash. Such materials do not undergo an aerobic process, so they may not acquire the inherent characteristics of biocompost.
- Given these limitations, we also need perfect automation in case of accelerating the process of microbial technology to turn the waste from base to up and vice versa.
- Because of these limitations, automation is necessary to speed up the microbial technology process that turns waste from base to up, spreads microbes all around the waste material, and vice versa.
- Segregation techniques require automation; otherwise, the issue would remain unresolved.
- After the reuse and recycling of non-biodegradable garbage, a prototype needs to be created and propagated.

Summary

In summary, the waste problem is created by human beings, and solutions are again within the hands of human beings. The techniques and tools need to be applied with a combination of manual as well as automation techniques. So it will be a sustainable practice if one applies a combination of traditional as well as modern techniques with the lessons learnt from the existing success stories, successful techniques, and tools.

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Climate Change and Air Pollution - Assessment, Emerging Scenarios, and Long-Term Monitoring

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Abstract

Aerosol pollution and air quality are global issues, and linked to climate as the amount of the pollutants present at the surface and in the column govern the physical and optical characteristics of aerosols which in turn determine their radiative forcing. The radiative forcing due to aerosols is negative (cooling) and masks the global warming (positive) due to greenhouse gases. Atmospheric aerosols are a mixture of solid or liquid particles suspended in the medium of air. The sources of aerosol emissions are widely different that include both natural and athropogenic, as a result their physical (size, shape and texture), chemical and optical properties vary over sub-micron and super-micron radius ranges, consequently their removal processes, and their residence times differ significantly. Aerosols play a vital role in cloud formation and air pollution among others. The knowledge and information on ground level aerosol pollution is a key concern from air quality and public health perspective. The impact of air pollution on human health is a serious public health crisis across Asia, where around 92% of the region's population is exposed to particulate air pollution levels in excess of the World Health Organization (WHO) guidelines 2005. The space-time variations in aerosol characteristics, and aerosol types arise due to different aerosol sources, and atmospheric dynamics which include boundary layer, temperature, relative humidity variations, and long-range transport. Aerosols continue to remain a highly uncertain component in global climate and climate change. The complexity, heterogeneity and strong variability of their global distribution make aerosols a very difficult object of study, and their radiative effects exhibit large spatial and temporal variations. Recent results obtained on air pollution, assessment (trends), emerging scenarios, and their linkages to climate on global and seasonal scales, with a particular emphasis on Asia, will be discussed. The complexity and challenges involved in simulating the spatio-temporal patterns of aerosol properties in addition to the critical need for long-term monitoring will be outlined.

From Data to Policy: Operationalizing AI-Driven Forest Biomass Monitoring for Climate Action and Sustainable Management in the Himalayas.

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Abstract

The Indian Himalayan Region (IHR), covering nearly 17% of the geographical area of the country, contains around 41% forest cover and contributes over 30% to India's total forested area. Renowned globally as a biodiversity hotspot, the Himalaya also serves as a significant carbon reservoir, albeit distributed unevenly across altitudinal and ecological gradients. Carbon stock ranges from below 50 tons per hectare in the deciduous forests in the dry zone to over 300 tons per hectare in the wet evergreen/ moist deciduous forests. Additionally, more than one-fourth of the Himalayan landscape is composed of grasslands and alpine meadows, which act as substantial yet under-monitored carbon sinks.

Despite its ecological significance, conducting systematic, field-based, large-scale biomass inventories across the Himalaya remains challenging due to rugged terrain, accessibility constraints, and the complexity of forest structures. However, advancements in satellite remote sensing now provide an unprecedented opportunity to overcome these challenges. Remote sensing enables consistent, scalable measurement of above-ground biomass (AGB) across space and time, particularly when integrated with robust in-situ field observations. Artificial Intelligence (AI) and machine learning methods are transforming this integration process by linking field-sampled biomass data with diverse biophysical, structural, and topographical variables derived from multi-sensor Earth Observation datasets. These AI-driven frameworks not only upscale field-based estimates to regional biomass maps but also quantify uncertainties, enhancing the reliability of biomass assessments.

Recent progress in active remote sensing technologies has further strengthened forest biomass estimation capabilities. NASA's Global Ecosystem Dynamics Investigation (GEDI) LiDAR, onboard the International Space Station, has provided forest canopy height data, enabling precise estimation of biomass and carbon stocks with well-characterized uncertainties. The NASA-ISRO Synthetic Aperture Radar (NISAR) mission, launched in July 2025, with its dual-frequency L- and S-band sensors, offers frequent, high-resolution radar observations sensitive to forest dynamics and biomass changes. Complementing these missions, the European Space Agency's BIOMASS mission, launched in April 2025, employs P-band SAR to penetrate dense vegetation canopies, generating measurements of forest structure under all-weather, day-and-night conditions. IIRS has undertaken studies demonstrating AI capabilities in precise modelling of biomass of Himalayan vegetation with synergistic use of optical, LiDAR, and SAR data.

Integrating the data from an optimally designed field biomass observations network across the Himalaya with the multi-sensor datasets within AI-based analytical frameworks can operationalize scalable and transparent Monitoring, Reporting, and Verification (MRV) systems tailored to the Himalayan context. Such systems can provide continuous, data-driven insights into carbon stock changes, forest health, and land-use dynamics, directly supporting climate mitigation strategies and sustainable forest management.

Scaling Climate Resilience Frameworks for Broader Application in India

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Abstract

Resilience in nature is not a static condition, but a dynamic equilibrium between disturbance and renewal. The Himalayan region has long served as a living observatory, allowing the delicate balance between environment and society to be studied in its purest form. In recent years, the Climate Smart Villages (CSV) initiative has deepened this understanding by developing scientifically validated frameworks that examine resilience not as an abstract concept but as a measurable, applicable process of adaptation.

These frameworks were tested across three distinct Himalayan landscapes—Lahaul-Spiti, Rudraprayag, and Karbi Anglong—each representing a unique socio-ecological condition. The studies combined systematic field data, spatial analysis, and indigenous knowledge, resulting in five interrelated methodological instruments: the Community Resilience Assessment Framework, the Vulnerability and Risk Analysis Framework, the Five Capitals Model of adaptive assets, the Land Use and Land Cover (LULC) Change Analysis, and the Perception-Based Climate Risk Framework. Together, these tools provide a comprehensive picture of how ecological, infrastructural, and social systems respond to climatic stress.

The results affirm that resilience in mountain systems does not depend solely on physical infrastructure, but also on the dynamic equilibrium among natural capital, social networks, traditional wisdom, and institutional support. These methodologies demonstrate that adaptive capacity can be scientifically assessed, spatially represented, and aligned with policy.

Extending these frameworks beyond the Himalayan region offers a promising pathway to strengthen climate resilience across India's diverse ecological zones. They can guide watershed management in arid areas, inform land-use planning in the Indo-Gangetic plains, and enhance livelihood resilience in forested and agrarian landscapes. Embedding these science-based tools into development and planning institutions will enable India to shift its climate adaptation discourse from reactive interventions to anticipatory, ecosystem-aligned strategies. Such an approach reaffirms the principle that sustainable development must emerge from the wisdom of the land itself—observed, understood, and applied through the rigour of science.

A need to develop plant based monitoring framework for long term climate change assessment in the Indian Himalayas

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Abstract

Future projections on global temperature suggest more rapid warming in three poles (Antarctica, Arctic and Himalaya). Therefore, it is expected that, the signals of global climate change can be more prominent in these regions. The Indian Himalayan Region (IHR), extending various states from Jammu & Kashmir to Arunachal Pradesh, is among the world's most ecologically fragile and climatically dynamic mountain systems. IHRs serves as the headwater for major rivers, sustains vast biodiversity, and supports millions of people. However, over the past few decades, the IHR has been experiencing rapid environmental changes due to global climate shifts. The rising temperatures, changing precipitation patterns, retreating glaciers, and altered vegetation zones are transforming the region's ecological balance. Despite ongoing climatic and glaciological studies, there remains a critical gap in understanding the biological responses to these changes.

However, climate change manifests profoundly in the Himalayas due to its steep elevation gradients and microclimatic variability. Small changes in temperature or precipitation can result in significant ecological consequences, including altered phenology, treeline shifts, species migration, and community restructuring. Current monitoring programs in the IHRs often focused on meteorological data or glaciological observations, lack integration with biological indicators. This limits our understanding of how climate change directly impacts ecological processes and biodiversity patterns. Plants, by contrast, serve as excellent bioindicators. Presence of plants in the coldest regions and their sensitivity makes them unique and effective indicators. They respond to climatic fluctuations through observable physiological, phenological, and distributional changes. Parameters such as flowering and leafing times, growth rings, photosynthetic activity, and species composition reflect both short-term variability and long-term climate trends. Resembling higher plants, the lower groups (Lichens, Algae, Bryophytes, Pteridophytes), being highly sensitive to temperature, moisture, and seasonal variations, will serve as reliable indicators for long-term climate assessment. This underscores the urgent need for a lower group of plant-based monitoring charter that systematically tracks ecological responses to climate change across the Indian Himalayas. A plant-based monitoring framework would therefore fill a critical knowledge gap by linking meteorological changes with ecological responses.

The lower as well as higher groups of plants exhibit measurable responses to climatic variations through changes in traits, distribution, growth, phenology and physiological processes. These changes can provide insights into both short-term climate variability and long-term trends. A

plant-based monitoring framework would link meteorological data with ecological observations, allowing for more holistic climate assessments. Such a context would involve selecting suitable bio indicator communities including temperature-sensitive cryptogams, trees, alpine herbs, and endemic flora representing various altitudinal and climatic zones. Establishing long-term ecological monitoring sites (LTEMs) across various altitudinal gradients can capture diverse ecosystem responses, forming the foundation for a Himalayan Climate Biodiversity Observation Network (HCBON).

The development of such a framework necessitates a multi-tiered approach combining traditional ecological knowledge, field-based monitoring, and technological aspects. Modern tools such as AL/ML, remote sensing, GIS-based vegetation mapping, phenocams, UAV-based surveys and past herbarium records can be integrated with traditional field observations to create a robust data system along with statistical modelling can further refine trend analysis, enabling prediction of future vegetation responses under various climate scenarios. Furthermore, local and indigenous knowledge offers valuable context on historical vegetation patterns, seasonal changes, and species behaviour, enriching scientific monitoring with community-based insights. Merging technological innovation with traditional ecological knowledge will enhance data accuracy, coverage, and sustainability of monitoring efforts. The network would also enhance collaboration among research institutions, forest departments, and local communities, ensuring that scientific findings translate into adaptive management and policy decisions

A long-term, plant-based monitoring framework would not only advance scientific understanding of climate vegetation interactions but also fortify conservation planning, biodiversity management, and climate adaptation strategies. It may aligns with several other monitoring programmes of different institutes and contribute to global climate models. In assumption, plants are natural recorders of environmental change, and developing a dedicated monitoring framework in the IHR is crucial for detecting early warning signals of climate stress, informing policy, and ensuring the resilience of both ecosystems and human livelihoods dependent on them.

Ultimately, the need for developing a plant-based monitoring framework for long-term climate change assessment in the Indian Himalayas arises from the growing realization that climate change is not just a meteorological phenomenon but a deeply ecological one. Plants, through their responses and adaptations, record the signatures of climate change across decades and elevations. A scientifically designed, community-supported, and technologically enabled monitoring system can serve as an early-warning mechanism, guiding conservation actions and climate adaptation strategies. It can bridge the gap between climate science and ecological management, ensuring that policies are grounded in empirical, long-term biological evidence.

Keywords: Highest summit points (HSPs), Cryptogams, Herbarium records, altitudinal variations

Urbanizing Himalaya and its Socio-ecological Implications Under Climate Change: Options for Climate Resilient Urban Ecosystems Development in Himalaya

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Abstract

Rationale

Urbanization has become one of the most significant drivers of global environmental change, profoundly reshaping mountain ecosystems worldwide. In the developing world, this process of urban transformation is particularly intense and largely unplanned, leading to extensive environmental degradation, resource-depletion and socio-ecological disruption. The Himalayan region - recognized as one of the most ecologically sensitive and geo-dynamically fragile mountain systems - has undergone rapid urban growth in recent decades. This expansion has intensified land-use pressures within both urban cores and their peri-urban catchments, resulting in widespread ecological imbalance, environmental inequalities, and increasing socio-economic disparities. Superimposed upon these dynamics, climate change has further stressed urban ecosystems through rising temperatures, altered precipitation regimes and the escalating frequency of extreme weather events. Collectively, these processes have heightened the vulnerability of Himalayan urban populations, particularly the poor and marginalized, to multiple climate-induced risks including flash floods, landslides, slope failures, debris flows, and water and food insecurity.

Objectives

This study aims to (i) understand the process of urban growth in Himalaya and assess the socio-ecological impacts of unplanned urbanization across the Indian Himalayan Region (IHR); (ii) identify the underlying drivers of urban expansion and associated vulnerabilities; and (iii) propose adaptive strategies for sustainable and climate-resilient urban development in mountain environments.

Methods

The research employed a mixed-methods approach integrating qualitative and quantitative data collected over a ten-year period. Data sources included published literature, government and institutional reports, focus group discussions, key informant interviews, satellite data interpretation, field observations, and geospatial analysis and mapping. Comparative case analyses of diverse Himalayan townships and emerging urban centres were conducted to elucidate spatio-temporal patterns of urban growth, land-use change, and hazard exposure. Socio-economic and environmental indicators were synthesized to evaluate urban vulnerability and ecosystem degradation under combined pressures of urbanization and climate change.

Results and Discussion

Findings reveal that extensive portions of the Himalaya, particularly within the Lesser Himalayan ranges, have experienced accelerated and largely unregulated urban growth. Over the past three decades, urban built-up areas have expanded by more than 100%, predominantly replacing agricultural land, forests, spring-sheds, floodplains and steep slopes. Approximately 65% of this new urban area has developed within environmentally unsafe zones, including landslide-prone slopes and river floodplains. Urban areas exposed to landslides are expanding at an estimated rate of 15 km^2 per year in the region. Presently, nearly 30% of urban built-up land and 48% of the urban population are exposed to multiple natural hazards, with more than 60% of townships situated above 2000 m elevation exhibiting high susceptibility to landslides and related disasters.

The study recorded significant ecological and socio-economic consequences of this unplanned growth: (i) a 17% decline in groundwater recharge; depletion of natural springs (35%), urban wetlands (11%), and biodiversity (27%); (ii) reduction in agricultural land (15%) and forest cover (7%); (iii) increased populations residing in environmentally unsafe zones (31%), poverty (19%), and slum formation (11%); and (iv) heightened vulnerability of 55% of households, primarily those occupying anthropogenically modified sensitive zones, to flash floods, slope failures, landslides, and water and food insecurity. The analysis highlights that poverty, livelihood insecurity, inadequate civic amenities, and climate-induced stresses have collectively driven rural outmigration and intense urbanization in the Himalaya. The concentration of low-income groups in hazard-prone areas has deepened socio-spatial inequalities and undermined urban resilience. The absence of spatial planning, environmental governance, and risk-informed development further amplifies ecological fragility and human vulnerability.

Conclusions and Way Forward

As in other regions urban growth in mountains cannot be stopped, but it must be steered in more sustainable ways. Therefore, the question is not whether or not mountains should urbanize, but rather how and where they should urbanize. The findings underscore the urgent need for a paradigm shift toward adaptive, risk-sensitive urban environmental planning in the Himalaya. This includes:

- Comprehensive hazard and risk-zone mapping for informed spatial planning;
- Conservation and restoration of green–blue infrastructure, including spring-sheds, wetlands, forests and farmlands;
- Integration of socio-economic equity and environmental justice in urban governance; and
- Development of region-specific frameworks for climate-resilient urban socio-ecological systems.

These insights not only inform sustainable urban policy for the Indian Himalayan Region but also offer valuable lessons for other high-mountain landscapes in the developing world undergoing similar urban-environmental transitions.

Keywords: Global environmental change, peri-urban catchments, food security, socio-economic equity and environmental justice, sustainable urban policy

Energy Efficiency Standards in the Building Sector for the Himalayan Region: A Pathway to Sustainable and Climate-Resilient Development

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Abstract

The Indian Himalayan Region (IHR) is one of the world's most ecologically fragile yet culturally rich mountain systems. It acts as a climatic regulator, a biodiversity hotspot, a freshwater storehouse, and a socio-economic lifeline for millions. As India approaches its Vision 2047 trajectory, development pressures, climate vulnerabilities, rapid urbanization on, and strategic geopolitical considerations make it imperative to rethink and redesign-built environment practices in the Himalayas. Energy efficiency in buildings, integrated with holistic sustainability strategies, now stands at the forefront of shaping a resilient Himalayan ac on plan.

Energy Efficiency Standards for the Himalayan Building Sector

The Himalayan climate is extremely diverse-ranging from cold desert conditions in Ladakh to humid subtropical climates in lower Himalayan foothills. Energy demand in such regions is driven primarily by heating requirements, poor insula on, inefficient building envelopes, and limited renewable integration. Region-specific adaptation of the Energy Conservation Building Code (ECBC) and promo on of ECBC-H (Himalayan adaptation) are essential for optimizing building performance. Passive design strategies—proper orientation, minimized openings on windward sides, optimized window-wall ratio, solar passive heating, thermal mass optimization, and insulated roofs/walls—significantly reduce heating loads. High-performance glazing, air tight construction, double-skin façades, and the use of appropriate insula on materials reduce dependency on electric or diesel-based heating systems. Reduced energy demand directly contributes to lower emissions, which is vital in a region where diesel generators are frequently used due to unreliable grid connectivity. Decentralized renewable energy clusters—micro-hydel, solar PV, solar thermal, and hybrid wind-solar systems—can create energy-secure communities that are less vulnerable to grid disruptions caused by landslides, snowfall, or disasters. Smart metering, building automation systems, and demand-response techniques further enhance efficiency while reducing operational energy wastage.

Sustainable Site Features for Himalayan Terrain

Site planning must respond to fragile mountain ecology. Building on steep slopes increases the risk of landslides, erosion, and hydrological disruption. Sustainable site development emphasizes minimizing cut-and-fill, retaining natural contours, preserving vegetation, and reducing impervious surfaces. Ecologically sensitive areas—river corridors, riparian zones, forest edges, and avalanche-prone slopes—must be protected from construction. Using native vegetation for slope stabilization prevents erosion, strengthens soil binding, and enhances biodiversity. Sustainable mobility solutions—pedestrian-friendly pathways, e-vehicle infrastructure, and restricted vehicular movement—reduce pollution and conges on at tourist-heavy locations.

Water Conservation: A Critical Priority

Despite the Himalayas being the source of multiple river systems, water scarcity at the local level is a growing concern due to glacier retreat, erratic precipitation, and tourism-based demand surges. Water conservation strategies must therefore operate at both building and watershed levels.

Building-level solutions include:

- Rainwater harvesting systems sized to local rainfall.
- Greywater recycling systems for flushing and landscaping.
- Low-flow fixtures and smart metering to reduce wastage.
- Decentralized wastewater treatment (DEWATS).

Traditional water systems such as naulas, baoris, zings, and kulhs provide climate-resilient alternatives that need revival and modernization. Community-led watershed restoration in upper catchments ensures improved downstream water availability.

Material and Resource Efficiency

Material selection in mountainous regions directly influences environmental impacts, transportation emissions, and construction feasibility. Locally available, low-carbon materials—stone masonry, bamboo, timber from certified forest areas, compressed stabilized earth blocks—should be prioritized over high-carbon alternatives requiring long-distance transport.

Lightweight prefabricated systems reduce transportation and on-site construction challenges. Efficient material use must be supplemented by construction waste management plans that promote reuse and recycling of excavated rock, aggregates, and demolition debris. Implementing circular economy principles minimizes resource consumption and waste generation.

Resident Health and Well-being

Resident comfort is essential for psychological and physiological health in high-altitude areas. Poor insula on leads to cold indoor environments, causing respiratory issues and increased indoor pollution due to excessive biomass burning. Energy-efficient construction improves indoor thermal comfort, reducing reliance on traditional stoves and lowering indoor air pollution.

Daylighting and natural ventilation enhance well-being, improve visual comfort, and reduce respiratory ailments. Acoustic insulation reduces noise from wind, rainfall, and tourist activity. Non-toxic construction materials improve indoor air quality and safeguard long-term health.

Innovation Strategies

Innovation in the Himalayan building sector must merge modern technology with traditional wisdom. Digital tools like GIS-based climate analysis, Building Information Modelling (BIM), drone-based site surveys, and AI-driven energy modeling can significantly improve planning accuracy. Smart energy systems, IoT-based sensors, and automated building controls optimize energy use and monitor structural health in real me.

Innovation also lies in socio-economic inclusion—training local youth in green construction, promoting local craftsmanship, and engaging communities in sustainable tourism and energy management.

Life Cycle Analysis (LCA) and Life Cycle Cost (LCC)

Life cycle assessment ensures materials and systems are evaluated for their full environmental impact—from extraction to disposal. This is critical in the Himalayas, where transportation energy, maintenance difficulty, and disaster vulnerability increase the environmental footprint of materials. Life cycle cos ng helps policymakers and builders choose solutions that are durable, energy efficient, and cost-effective over long term, rather than op ng for cheap short-term construction that deteriorates quickly in harsh mountain conditions.

Urbanization, Tourism, and Socio-cultural Distortion

Rapid urbanization driven by uncontrolled tourism has altered land-use pa erns, stressed water resources, created infrastructural overload, and disrupted socio-cultural identity. Construction of hotels, homestays, and commercial facilities without carrying capacity assessment has led to degradation of local ecology.

Tourism-driven cultural dilution, commercial exploitation of local traditions, and increased dependency on external economic systems threaten Himalayan social fabric. Sustainable tourism models focusing on carrying capacity, decentralized accommodations, community owned tourism, and waste management are urgently needed.

Climate Change, Glacier Melt, and Downstream Impacts

Accelerated glacier melt due to rising temperatures is causing devastating consequences - flash floods, glacial lake outburst floods (GLOFs), unpredictable river flows, and long-term water scarcity. Downstream regions in Central India face alternating cycles of floods and droughts due to altered Himalayan hydrology. Emission reduction through energy-efficient buildings helps mi gate glacier retreat.

Strategic and Geopolitical Importance

The Himalayan region serves as India's frontline defense zone. Resilient, energy-efficient infrastructure enhances military operability, reduces maintenance costs, and ensures reliability in extreme conditions. Development must balance security needs with environmental protection to safeguard both national sovereignty and ecological sustainability.

Conclusion

Achieving sustainable and resilient Himalayan development requires a holistic integration of energy efficiency, ecological preservation, water security, material sustainability, social inclusion, innovation, and climate resilience. By strengthening building standards, promoting renewable energy, and embedding traditional knowledge into modern design, the Himalayan region can secure its environment, communities, and strategic stability in alignment with India’s Vision 2047.

Integrated Management Approaches for Enhancing the Resilience of Himalayan Wetlands

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Abstract

The Himalayan wetlands, encompassing glacial-fed high-altitude lakes, riverine marshes, and floodplains, are vital yet fragile ecosystems that regulate hydrology, store carbon, support migratory waterbirds, and sustain local livelihoods. However, they are increasingly threatened by climate change, hydrological alterations, infrastructure development, and unsustainable land use, leading to biodiversity loss and habitat degradation.

This study synthesizes insights from integrated management planning and field-based interventions undertaken in wetlands of the Indian Himalayas, encompassing a range of wetland types, including natural and human-made systems, freshwater and brackish water bodies, and sites situated both within and outside protected areas, extending to high-altitude wetlands. The management plans emphasize multi-scalar interventions, such as the prioritization of microwatersheds for soil erosion control, restoration of hydrological linkages with adjoining marshes, climate risk assessments under projected scenarios, and the promotion of sustainable livelihoods and green economy opportunities for local communities. Additionally, the studies highlight the application of flood simulation models, carrying capacity assessments for livestock grazing and tourism, targeted management of threats to high-altitude wetlands, and the conservation of peat soils to safeguard carbon storage and ecosystem resilience.

Together, these examples demonstrate ecosystem-based management approaches that integrate scientific knowledge, policy linkages, and community participation to strengthen the resilience, functionality, and sustainable management of Himalayan wetlands.

Keywords: Integrated Management; ecosystem-based approaches; landscape-scale; climate risk

SOCIO- ECONOMIC DEVELOPMENT AND SUSTAINABLE LIVELIHOOD IN THE INDIAN HIMALAYAN REGION

True Value Accounting – a Tool for Bringing Nature's Values into Economic Decisions and Policy

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Abstract

Sustainable food systems need Nature, not just agriculture. Agriculture and food systems provide sustenance for mankind, but at the same time are becoming deleterious to the source of their own sustenance, i.e., Nature. Without economic evidence that holistically integrates the impacts and dependencies of production and manufacturing on natural, human, and social capital, and instead relies solely on traditional metrics like yield per hectare and/or other tangible outputs, we risk losing sight of where a given pathway may truly lead. Till recently, it was a challenge to quantify the intangible elements of agriculture. Even when quantifiable, many elements were not assigned a value. However, standardised tools are now available for the quantification of non-marketed/non-marketable goods and services, contributing to a more comprehensive understanding of the "True Value" of the impacts of agricultural practices and food systems. Hence, True Value Accounting (TVA) is providing economic evidence to policymakers to address such distortions through the implementation of policies that provide incentives for food systems transformation. It is also important to remember that agriculture and food systems are central to achieving the majority of the Sustainable Development Goals and the targets set under the Kunming-Montreal Global Biodiversity Framework. But due to an inadequate understanding of how environmental change is affecting markets and livelihoods, these are not taken into consideration in policy formulation and programmatic interventions. Herein comes the role of The Economics of Ecosystems and Biodiversity (TEEB), a UNEP-led global TVA initiative launched in 2007, which endeavours to make "Nature's Values Visible".

Recognizing the agriculture sector's deep dependence on biodiversity and ecosystem services, the TEEB for Agriculture and Food (TEEBAgriFood) framework was launched in 2018 to provide a comprehensive approach to evaluate the true costs and benefits of agriculture and food systems. The approach moves beyond conventional food production metrics of yield per hectare, promoting a more holistic evaluation of agriculture processes. The global initiative is also being implemented in India (Uttar Pradesh, Uttarakhand, and Assam), earlier 2019-23 under EU funding and currently from 2023 to 27 with funding from the IKEA Foundation. There is a private sector engagement as well in the project based on the TEEBAgriFood Guidelines for Business, which is important as the driving factor for what is or what should be grown, changing the discourse of 'farm to fork' to 'fork to farm'. The India project is studying the impact of Govt policies and programmes on scaling organic farming and agroforestry on the 4 capitals for illustrating the holistic benefits on livelihoods and natural resources, nudging a sustained switch by the farmers to sustainable agriculture. The public and private sector work

streams are being done in the same three States and the same value chains so that complete production to consumption is addressed.

The Himalayan States are caught in the conundrum of conservation imperatives and development for economic growth, compounded by the increasing effects of global warming. This precarious area is especially prone to natural disasters which can only be mitigated through inter alia appropriate retention of forest cover, conservation of the natural springs, judicious urban and industrial waste management, meticulous scrutiny of proposed land-use changes, to minimise ecological degradation, which in turn directly impacts livelihoods of the local communities but also has far reaching implications of water, food and energy security in the downstream plains. The TEEBAgriFood studies in Uttarakhand showed the potential of land restoration in the Kosi and Kailash watersheds by scaling agroforestry and organic farming by decreasing erosion rates and associated costs for conservation measures by 4.2 – 11 percent by 2030 and 4.6 – 16.8 percent by 2050, leading to an estimated savings of USD 0.85 million. Similarly, the potential of agroforestry in mitigating disaster risk by increasing water holding capacity and soil erosion control, thereby reducing surface run off in the eco sensitive watersheds has been quantified. The social capital was analysed using the Sustainable Livelihoods Security Index (SLSI).

India has one of the lowest female employment participation rates globally, making up only 92 percent of the workforce. The agriculture sector is an exception, where the share of female workers is 64.4 percent as against 36.3 percent of men, being described as feminisation of Indian agriculture. This phenomenon is starker in the Himalayan region, with the men having migrated to bigger cities in search of better employment avenues, leaving behind women-headed households managing somehow to eke out a living for the family. The out-migration situation in Uttarakhand is so grave that a Rural Development and Migration Commission has been set up under the chairmanship of the Hon'ble Chief Minister. Detailed discussions have led to the conclusion that revival of market-led agroforestry on the fallow lands could reduce the hardship faced by the women and, together with a switch to organic farming, which is already a focused activity by the State Government, help ameliorate the effects of climate change as well. A mix of modern pharma and upscaling and branding of the traditional knowledge of the communities would give impetus to medicinal plants and bamboo-based agroforestry in the Himalayan region. A simultaneous capacity building of women, including market dynamics and financial literacy, would enable true empowerment.

Though institutional finance flows to agriculture have increased, a large portion of small and marginal farmers still depend on non-formal sources like money lenders, middlemen, etc. A cue for innovative approaches to incentivise farmers to adopt and continue sustainable agriculture can be taken from the success of blended finance through Development Impact Bonds in India, especially in the education and health sectors. Key measurable outcomes could include soil health, water efficiency, productivity, and improved agro-biodiversity. The sustainable agriculture vertical within the Green Credit Program of the Ministry of Environment, Forest, and Climate Change is another such tool, the methodology for which is presently under discussion. TEEBAgriFood can assist in overcoming the major challenge of measurement and verification since the India project is already assessing and carrying out valuation of some key benefits of organic farming, providing economic evidence to dispel the apprehensions of investors in such projects, which have longer timeframes. The issue of low viability due to the small land holdings is being resolved through the mission-mode organisation of farmers into FPOs and Cooperatives. Hence, there is tremendous potential for impact investment in the agriculture sector, given the Govt's promotion of natural and organic farming, green finance on one hand, and standardised tools available for setting baselines and measuring outcomes in a comparatively challenging sector like agriculture.

The research outcomes and policy implications of the EU-funded phase (2019-23) have been summarized in a policy brief, which can be accessed at https://www.unep.org/resources/report/promoting-sustainable-agriculture-and-food-sector-india. The underpinning of the success is sustained Science – Policy translation to strengthen the programmatic interventions of the national and State Governments. For this, it is imperative that audience-appropriate communication material is prepared for wide dissemination and adoption/application by the public and private sectors. Food systems transformation using the TEEBAgriFood framework would enable sustainable agri value chains but requires a multi-sectoral and interdisciplinary pooling of knowledge and resources to enable India to fulfil the aspirations of the country's annadata (producers of grain – food), moving toward a Viksit Bharat by 2047.

Role of Social Science Institutions and Local Communities in Shaping the Himalayan Action Plan

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Abstract

As given to understand, India 2047 Mission envisages a transformed Nation into a developed economy through adopting sustainable growth and equitable Development, and concomitantly Socio-Economic boost in the people's quality of life and happiness in their milieu of a well-balanced, safe environment presently alleged to be reeling under pressure of Global warming and Climate Change all around, Indian Himalaya being no exception to it. In the recent past Indian Himalaya has faced unprecedented havoc of excessive rains, Cloud bursts, floods, loosening of mountains, massive soil erosion, roads and buildings being washed away; even some rivers and streams seemed to be changing their course, causing damage to the man-made assets. Recently, the States of Uttarakhand and Himachal Pradesh have suffered the most.

The social canvas of the Indian Himalayan region tells us that there are different groups of people living in its lap, which forms nearly four % of the Indian population, represented in 30% ethnic group identity. Significantly, there are 34 tribes in the western, Central, and eastern Himalayan region. Some tribes have further subgroup identity, like the Naga have five subgroups. Looking into the subject of people's part of the Himalayan region makes the social science role inevitable in visualizing any roadmap or vision framework.

The people living in the Himalayan region are said to have faced harsh environmental conditions, but have adopted a symbiotic relationship with the region. For this, they have acquired indigenous cultural practices and traditional wisdom to cope with the situation.

For a long time, the Himalayan regions and the people remained in isolation, being remote and inaccessible. But with opening the area and developmental efforts, the region has gained much to its advantage, and losses to be felt in due course. It may be noted here that the induced changes have posed a threat to the loss of indigenous culture and traditions. Not considered the assessment of bearing capacity of the region in terms of proper land use, carrying capacity to sustain load of various types viz. influx of people in large numbers in form of tourists and creation of Hotel industry and mega power projects etc. the adverse effect of monolithic development plans are now coming under scanner for rethinking about strategies to be adopted for mega projects in the area of infrastructural facilities, power generation and other uses of land.

In the recent past, say 55 years or so, the Indian Himalayan Region (IHR) has experienced hazards on one hand on account of changing climate, deforestation- massive tree felling for modern Development projects, disturbed Land use, and shrinking of pastureland; while on the

other hand, dearth of opportunities in Himalayan villages for better socio-economic life. Such constraints forced village exodus by the youth, resulting in an imbalanced village demography. Also, gender equality remained deprived of useful schemes envisaged for them in the Development corridor, wanting a change in laws related to land ownership and decision-making power.

Social Science: Capacity, Role, and Responsibility

Social Sciences are known to be basic to understand Humanity, Man in his totality, rather holistically, for deliberating and formulating any plan at the Mega or Micro level, envisaging betterment for the people vis-à-vis safeguarding or protecting the natural land and hills {IHR in the present context}. Social Science contribution is a basic prerequisite to any Development/safeguarding planning and its execution. Prior knowledge of the area {Geography and Topography} and the people living there as stakeholders {Social world} is an essential key to the planners/Agencies. In the case of IHR, Social Sciences, especially Anthropology, have tremendous capacity to deal with the problem, for the anthropologists are known to study Society and its integral contents, both the Social and Physical arenas. In-depth studies and ethnographic studies portray every detail, minute of cultural strains. In a simple sense discipline of Anthropology studies man from every aspect, be it social, cultural, economic, political, religious, art& folklore, music, and material culture. In short, there is no area concerning man and his community that remains left and uncovered in the anthropologist's domain. One caution I would like to make is that all social sciences are devoted to studying and providing understanding about the communities or social groups, yet they concentrate and are constrained to focus on the essence of their discipline, resulting in wanting a holistic solution to give a balanced formulation incorporating people vis-à-vis the IHR for sustainable Development. However, their role and contribution to the planning process for IHR will be of immense help on a specific requirement basis. The canvas of people living in IHR presents a diversity of communities. A substantial number of them belong to tribes, distinct from the plain or coastal area people, for they live in the cold desert, in a high altitude area with prolonged winter conditions and harsh environmental conditions as well. For formulating any substantial plan for the sustainable livelihood of these people and promoting concepts of green economy, Circular economy, and social inclusion, as well as mainstream gender equality, anthropologists seem to be valuable partners. It is a matter of relief that in IHR exists a Regional Centre of The Anthropological Survey of India fully devoted to the issues and problems of the North-Western Himalaya, covering Uttarakhand, Himachal Pradesh, Jammu Kashmir, and UT of Ladakh, Leh, besides Uttar Pradesh. Its initial focus was to conduct Ethnographic studies in the Border area, which brought out tremendous knowledge about the socio-economic lifestyle and cultural perspectives of various tribes and some communities living in IHR for the larger interest. Some such elaborate ethnographic studies were done in Kargil and Ladakh, then in Jammu Kashmir, Lahaul & Spiti, and Kinnaur in Himachal Pradesh, and Chamoli and Uttarkashi in Uttarakhand. I was lucky enough to be part of this project while pursuing my Doctoral Thesis in Kinnaur. Also, there is a Regional Centre of the Survey in Shillong catering needs of Eastern Himalayan people and providing knowledge material for the formulation of sustainable, eco-balanced livelihood projects. The Arunachal Regional Centre of this Institute can seek interaction for effective project planning.

Furthermore, under the aegis of the Ministry of Tribal Affairs three Tribal Research Institutes have been made operational in all the three Himalayan State -Jammu Kashmir, Himachal Pradesh and Uttarakhand to cater the need of pushing sustainable development plans and projects besides culling out and document traditions, customs, Indigenous knowledge, rich cultural heritage of the tribes dwelling in these states for larger dissemination.

For promoting the plans and projects among the stakeholders for an eco-friendly, sustainable livelihood, social science can offer well-tested, effective Communication models and strategies. These tools can be of help in taking a long way towards the concept of 'Green economy' and 'Circular economy' among the IHR people for effective livelihood and protecting the environment.

Approach to Vision:

Gigantic Mission like India2047, having focus on safeguarding IHR and assuring sustainable livelihood for its inhabitants, needs inclusiveness of Institutions, Individual experts, Researchers, NGOs, and Development administrators, etc. While making attempts to harness such inclusiveness, extension to include institutions like the Indian Council of Social Science Research (ICSSR), Anthropological Survey of India (ASI), Tribal Research Institutes (TRI), and State-run Institute of Development (IDS) may be considered. Soliciting a Multilateral coordination between and among the line agencies and individual experts of the subject Matter (working or retired), one may hope, will be a strong force to accomplish the task.

Methodological Challenges in Measuring and Valuing Ecosystem Services of Mountain Agroecosystems

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Abstract

The Himalaya hosts diverse agroecosystems shaped by altitude, climate, and traditional knowledge. In the eastern Himalaya, the Apatani tribe of Arunachal Pradesh practices mixed wet rice–fish farming, an integrated system with short growing cycles, high nutritional output, and sustainable water use. Central Himalayan terrace farming in Uttarakhand and Nepal supports multi-cropping of millets, pulses, and vegetables, enhancing soil fertility and food diversity despite modest yields. In the western Himalaya, barley–wheat rotations and apple orchards dominate high-altitude zones of Himachal Pradesh and Ladakh, offering niche crop value and long growing cycles adapted to cold, arid conditions. Agro-pastoral systems in trans-Himalayan regions combine yak and sheep rearing with buckwheat cultivation, maintaining ecosystem balance and nutritional diversity. Across these systems, biodiversity, resilience, and cultural adaptation are key, with each agroecosystem optimized for local ecology, ensuring year-round sustenance, ecological stability, and livelihood security in fragile mountain environments. Traditional knowledge of the mountain communities is highly relevant to climate change, offering adaptive strategies—crop diversification, water harvesting, soil conservation, and seasonal forecasting—to enhance resilience against extreme weather, erratic rainfall, and temperature shifts.

Mountain agroecosystems provide multiple ecosystem services (ES)—from provisioning food and fodder to regulating water flows, soil fertility, and carbon sequestration, as well as supporting biodiversity and cultural heritage. In the Himalayas, these services protect fragile landscapes, recharge springs, prevent erosion, and provide cultural and medicinal resources. Recognizing and valuing them is crucial for sustainable development, climate resilience, and long-term well-being of upstream and downstream communities. Yet quantifying and monetizing these services presents methodological complexities. ICIMOD emphasizes that "mountain ecosystems are dynamic and multifunctional, and their components interact in complex ways … data collection and monetary valuation should therefore be a continuous and multi-institution effort."

In the Himalayan context, agroecosystems provide the following ES: (1) Provisioning Services: Food crops, fruits, livestock, dairy products, medicinal and aromatic plants (MAPs), and non-timber forest products (NTFPs). (2) Regulating Services: Climate regulation, CO_2 sequestration, soil and water conservation through terraced farming and agroforestry (harvesting rainwater, recharging groundwater, reducing erosion and landslides), pollination and pest control by insects and birds, and air purification. (3) Cultural Services: Indigenous

practices such as Baranaja (mixed cropping in Uttarakhand) reflect ecological wisdom; aesthetic and recreational value of scenic landscapes supports eco-tourism; agro-pastoral lifestyles, festivals, and cuisines embody cultural identity. (4) Supporting Services: Nutrient cycling via organic farming, soil formation from forest litter and terraces, habitat provision for biodiversity including pollinators, seed dispersal and agrobiodiversity maintenance, and fire risk management to protect crops.

Agroecosystem services valuation quantifies economic, ecological, and social benefits—provisioning, regulating, supporting, and cultural—guiding sustainable management, policy, and conservation decisions. Values are categorized as: (1) Use Values: (a) Direct Use Value: Ecosystem resources directly harvested (grain, vegetables, fodder, firewood, medicinal plants, fruits, nuts). (b) Indirect Use Value: Benefits from ecosystem functions without harvesting (soil fertility, pollination, aesthetic value), and (c) Option Value: Preserving the potential to use services in the future. (2) Non-Use Values: (a) Existence Value: Satisfaction from knowing a species or ecosystem exists. (b) Bequest Value: Preserving ecosystems for future generations. (c) Altruistic Value: Satisfaction from others benefiting from services. Economists combine these to estimate Total Economic Value (TEV) = Direct Use + Indirect Use + Option + Non-Use Value. Given the complex nature of ES in mountain agroecosystems, the following methodological challenges arise:

1. Complex, multifunctional services in heterogeneous terrain: Himalayan agroecosystems vary sharply with altitude, slope, aspect, microclimate, and land use. Services are often bundled (e.g., agro-pasture land contributes water regulation, biodiversity habitat, and microclimate buffering), making it difficult to isolate individual services for valuation.

2. Data scarcity and spatio-temporal variability: Accurate quantification requires long-term, fine-scale data on ecosystem processes, land use, yields, hydrology, and soil dynamics. In mountain regions, such data are often fragmented. Temporal variability (glacial melt, seasonal flows, extreme events) and spatial heterogeneity (slopes, aspects) complicate extrapolation.

3. Valuation of non-market, supporting, and cultural services: While provisioning services have observable market values, regulating (water regulation, soil conservation), supporting (nutrient cycling, habitat), and cultural (heritage, spiritual) services are difficult to monetize. Assigning monetary value to indirect and non-use services (e.g., future ecosystem benefits) remains challenging.

4. Institutional, governance, and stakeholder issues: Multiple stakeholders—upstream farmers, downstream beneficiaries, government agencies—are involved. Property rights, benefit-sharing, and governance structures are often weak. Services are supplied in bundles, interlinked and interdependent. Without strong institutions, valuation may not translate into mechanisms like Payments for Ecosystem Services (PES) or green bonds.

5. Methodological approaches and valuation tools: Context-sensitive methods are needed. Contingent valuation, choice experiments, benefit transfer, replacement cost, and avoided cost approaches have limitations in remote, heterogeneous terrain. For example, a study in Garhwal

Himalaya using contingent valuation showed that while villagers recognized many services, willingness to pay (WTP) for conservation was low due to perceptions of rights and benefits. Assumptions, baseline scenarios, discount rates, and handling non-linearity in ecosystem collapse further complicate valuation.

6. Scaling from site to landscape: Even detailed site-level studies are difficult to generalize regionally. Altitude, microclimate, land use, and community practices vary dramatically. Scaling must account for interactions between services and avoid double counting. Reviews indicate provisioning services dominate studies, while regulatory and cultural services are underrepresented, limiting integrated assessment.

Recommendations to address these challenges for including in True Value Accounting Framework:

- Develop long-term monitoring across altitudinal gradients for hydrology, soil, biodiversity, and land use.
- Use mixed methods combining biophysical indicators and participatory valuation to capture both market and non-market services.
- Institutionalize stakeholder engagement with clear benefit-sharing and capacity building.
- Apply context-specific valuation tools including scenario modeling, threshold analyses, and sensitivity to non-linearity.
- Ensure scaling by stratified sampling across zones, avoiding overgeneralization.
- Embed valuation into policy instruments linking services to finance mechanisms like PES, green bonds, and biodiversity credits within Himalayan action plans.

Conclusion:

Quantifying and valuing ecosystem services of Himalayan agroecosystems is essential for conservation, sustainable livelihoods, and climate resilience. Methodological challenges—heterogeneity, data scarcity, service complexity, non-market valuation, governance gaps, method selection, and scaling—are substantial. Strengthening institutions, investing in robust data, and adopting context-sensitive valuation methods can translate the hidden value of these ecosystems into actionable finance and policy. This enables informed decisions and trade-offs, supporting ecological and economic sustainability in fragile mountain agroecosystems.

Climate-Resilient Livelihoods, Homestays, and Human Development: Nature-Based Solutions for Sustainable Mountain Futures in Uttarakhand, India

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Abstract

Uttarakhand, India's 27th state, is celebrated for its majestic Himalayas, rich biodiversity, and deep-rooted cultural heritage. Agriculture remains the principal livelihood for much of its rural population. However, traditional farming has increasingly become subsistence-based due to erratic rainfall, fragile terrain, declining soil fertility, and growing human–wildlife conflict. These challenges, compounded by modern aspirations and climate change, have driven many mountain families away from farming, resulting in land abandonment, erosion of agro-biodiversity, and rising rural outmigration. Recognizing these interconnected challenges, AAROHI, a grassroots non-profit organization working across the Kumaon Himalaya since 1992, has developed an integrated model of Nature-based Solutions (NbS)—where ecological restoration, livelihood diversification, and cultural and human development are woven together to strengthen mountain resilience. AAROHI's initiatives span over 500 villages in Uttarakhand, linking climate-resilient agriculture, bioresource-based enterprises, community-managed homestays, mountain health, and education to create a holistic ecosystem for sustainable rural development.

Reviving Climate-Resilient Agriculture

AAROHI has revitalized traditional mountain farming systems that are inherently adaptive to climatic variability. Mobilizing over 1,750 farmers—of whom 245 have adopted climate-resilient niche crops—the organization promotes the cultivation of millets (finger, barnyard, foxtail, and amaranthus), pulses (kidney bean, horse gram, black soybean), and herbs and spices (turmeric, ginger, rosemary, thyme, basil). These crops are naturally suited to rainfed conditions, require low external inputs, and enhance both nutrition and soil health. Over the past two years, 10 metric tons of produce—7 tons of millets and 3 tons of spices—have been harvested and processed, generating an income of INR 13 lakhs. Farmers are trained through exposure visits, field demonstrations, and collective marketing efforts. Individual success stories—such as Naveen from Meora, who returned to farming after years of land abandonment, and Durga Kapil from Simayal, a widow who achieved economic independence through greenhouse vegetable cultivation and millet processing—demonstrate the transformative social and ecological impacts of these interventions. To ensure economic sustainability, AAROHI established DHARA, a Self-Reliant Cooperative integrating value-chain development, local processing, and market linkages. Traditional watermills (gharats) have been modernized to process grains and spices, combining indigenous wisdom with appropriate technology. These efforts have reclaimed fallow lands, restored biodiversity, and revived confidence in agriculture as a viable livelihood in the mountains.

Bioresource-Based Rural Enterprise

For more than three decades, AAROHI has turned local bioresources into sustainable livelihoods through its Livelihood Unit in Satoli, Nainital. Working with 1,385 individuals and community-based organizations from 182 villages, the initiative transforms local biodiversity into value-added products such as cold-pressed oils from wild apricot and peach kernels, herbal wellness and cosmetic products, and a variety of culinary herbs and teas (rosemary, mint, oregano, sage, thyme, basil). These enterprises not only generate income but also ensure sustainable resource use and waste valorization—for example, converting waste fruit kernels into high-value oils. Annually, the initiative supports about 1,300 households, enhancing average family income by INR 16,500 and providing year-round employment to 26 community members (25% women). Approximately 45 quintals of apricot kernels and 9.8 quintals of herbs are processed annually, yielding an average annual revenue of INR 79.45 lakhs. AAROHI also integrates conservation measures, with over 9,400 apricot, peach, and chyura seedlings planted, achieving a survival rate of nearly 75%, and 25 hectares under herb cultivation. These activities link ecosystem regeneration with livelihood enhancement, reinforcing that sustainable economies can coexist with ecological balance.

Homestays: Linking Livelihoods, Culture, and Conservation

Complementing its agricultural and enterprise programs, AAROHI's Homestay Programme integrates sustainable tourism with cultural and environmental preservation. Partnering with 33 families in three villages, the initiative enables rural households to host visitors in traditional Kumaoni homes, generating an average income of INR 1 lakh annually per family. More than just an income source, the homestay model serves as a platform for cultural conservation and pride. Visitors engage with local communities through authentic experiences—participating in farming, cooking traditional cuisine, attending folk performances, and exploring heritage trails. This not only preserves Kumaoni architecture, crafts, and customs but also inspires youth to stay connected to their roots rather than migrate to cities. The program reinforces AAROHI's belief that livelihoods, culture, and conservation can flourish together through community stewardship.

Integrating Health and Education: The Human Face of Nature-Based Development

AAROHI's approach to sustainable mountain development recognizes that human well-being is central to ecological sustainability. Alongside its livelihood and conservation programs, AAROHI has established long-standing initiatives in healthcare and education—both rooted in the same nature-based ethos. Through its Community Health Programme, AAROHI provides primary healthcare to over 40,000 people annually in remote Himalayan villages. Its health model emphasizes preventive care, women's and child health, nutrition from local foods, and training of community health workers, including nurses and midwives. The organization also operates mobile health camps and supports government health programs, creating synergies between local knowledge and institutional systems. In education, Aarohi Bal Sansar (Aarohi School) serves as a model for contextual, experiential learning that connects students with their environment. The school integrates environmental education, local crafts, and agricultural learning into its curriculum, nurturing students as future custodians of their mountains. Plans are underway to upgrade it to a Senior Secondary School, broadening access to quality rural education. Together, these programs exemplify AAROHI's conviction that sustainable livelihoods, health, and education must progress hand in hand for holistic community resilience. Each initiative—whether in farming, enterprise, tourism, health, or learning—is a component of a larger, interconnected NbS framework that restores both ecosystems and human dignity.

Nature-Based and Community-Led Outcomes

Across its initiatives, AAROHI demonstrates that community-driven Nature-based Solutions can yield multiple, interlinked benefits:

- Ecosystem restoration through natural, rainfed agriculture on previously abandoned lands.
- Sustainable resource use via bioresource-based enterprises.
- Cultural preservation through homestay-led tourism and traditional knowledge revival.
- Economic resilience through diversified, climate-compatible livelihoods.
- Gender inclusion through women's participation in agriculture, processing, and leadership roles.
- Health and education linkages that sustain community well-being and adaptive capacity.

Conclusion

AAROHI's three-decade journey in the Central Himalayas demonstrates that locally driven, nature-based models can simultaneously advance conservation, climate adaptation, and human development. Its integrated approach—combining climate-resilient agriculture, bioresource enterprises, homestays, health, and education—offers a replicable framework for sustainable mountain economies. By merging traditional knowledge with modern enterprise, community participation with ecological wisdom, and livelihood creation with social equity, AAROHI shows how mountain regions can build resilience from within. As research and experience affirm, such approaches are vital for curbing outmigration, restoring biodiversity, and ensuring a dignified, sustainable future for mountain communities. In AAROHI's vision, nature, livelihoods, health, and education are not separate pursuits but interconnected expressions of a single goal—a thriving, resilient Himalaya where people and the planet prosper together.

Keywords: Nature-based solutions (NbS); Climate-resilient agriculture; Bioresource-based enterprise; Homestays; Health and education; Ecosystem restoration; Livelihood diversification; Cultural heritage; Community-based adaptation; Sustainable mountain development

Bee Keeping: Natural Resource Based Sustainable Livelihood Solutions

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Abstract

Rationale

Natural resource based sustainable livelihood solutions is a way to manage natural resources like land, water, forests etc. for community welfare as a permanent means of livelihood without causing any damage to the environment, extracting the natural resources within replenishable limit.The Himalayan region is rich in natural resources which can provide opportunities for livelihood like developing small scale enterprises that use natural resource sustainably.

In today's context, beekeeping in Himalayan region has vast potential for providing long term sustainable livelihood solution to the communities due to its richness in biodiversity, as Himalayan region is one of the biodiversity rich hotspots of the world. Abundance of floral diversity in the region provides the optimal conditions for beekeeping to be adopted as a livelihood option.

Beekeeping has a potential to increase household income of rural communities. Beekeeping not only creates a valuable income stream, which reduces pressure on natural resources, it also actively supports biodiversity in the region where more than 75% flora is dependent on insect pollination services for survival. Fortunately, there are possibility to make the farming system more profitable by increasing productivity through promoting beekeeping as distinct agro-climatic conditions of the region are favourable for the development of horticulture, mainly for production of fruits, vegetables and floriculture.Rural communities can be economically empowered through establishing beekeeping as sustainable livelihood activity.

Bee keeping has potential to play important role in poverty alleviation, as the miraculous substance produced by bees- Honey- is a well-known energy booster since ancient times. Due to its amazing properties, it is high in demand and has potential to fetch good prices.

Production of Honey by bee keeping can be taken up as an entrepreneurial activity. While producing honey by honey bees, some other by products are also produced- bee wax, resin, royal jelly, pollen etc. These by products have high monetary value.

Beekeepingis a natural resource based activity that directly depends on the region's flora, forests, and agriculture, while also supporting ecological balance through pollination. It can play key role in poverty alleviation if taken up as a career option. This can be started with minimum available resources without devoting much time, only a few hours daily would be enough to sustain the venture. Today, when many people have come back to their roots and are

resorting to agriculture activities, bee keeping can give a boost to crop yield, which is otherwise below subsistence level. Bee keeping will give them direct income by the sale of honey and other byproducts, cross pollination would give them indirect benefit in the form of higher crop yield. In recent years, beekeeping has emerged as one of the most sustainable and eco-friendly livelihood options for rural communities in Uttarakhand's hilly regions, especially for women, youth, and small farmers.

The best thing about beekeeping is that it requires minimal resources and investment. Moreover, it contributes significantly to the enhancement of crop yields through pollination services, thereby improving food security and biodiversity conservation. Promoting beekeeping as a sustainable livelihood in the hill districts of Uttarakhand thus aligns perfectly with the principles of environmental conservation, income diversification, and socio-economic development of rural areas of hill districts of Uttarakhand.

Beekeeping also offers scope for various value-added items, besides honey as primary product:

- Processed Honey: Bottled and branded mountain honey can fetch premium prices.
- Beeswax Products: Candles, balms, and cosmetics are increasingly popular.
- Pollen, Propolis, and Royal Jelly: These are in demand in the health and wellness industries.
- Medicinal and Single-Floral Honeys: Honey from specific flowers have specific
- properties and flavours.

When every human activity is adding to climate change/ global warming, adopting bee keeping can create a win-win situation for all. It can be taken up as a career option, which not only has the potential to bring income but also can strengthen biodiversity and ecology.

Community-led sustainable bio-resource management (CLSBM) for economic and ecological resilience in Western Himalaya

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Abstract

The western Himalayan region, though immensely rich and critical in terms of bioresources and ecosystem services, is marginal in terms of conventional socio-economic indicators of development. Over the last few decades, with the improvement in accessibility, the region has been more influenced by the market economy and other external forces. A cultural transformation from traditional subsistence to a subsistence-market integrated economy is progressing in parallel to global climate change and conservation-development policy changes. Achieving sustainable development has been at the forefront of global concerns since 1987. Articulated in different terms, sustainable development essentially implies promoting ways and means of proper integration of environmental, economic, and social development concerns. While several international/national policies/programmes have been implemented to promote sustainable development, their outcome/results are far from expectations, largely because of inadequate scientific knowledge on how to foster ecological and socio-economic development as an integrated objective across spatial (local to global) and temporal (present to future) scales. Community-led sustainable bio-resource management (CLSBM) is based on the idea that it sustainably maintains biodiversity, provides goods and services for humanity, and supports the environmental conditions necessary for sustainability and resilience. It attempts to strike a balance between protecting nature and supporting traditional communities' self-governance, rights, and economic development. It also champions traditional and indigenous ecological knowledge as a guide to sustainable use and management. Though the various approaches have been successfully implemented in the western Himalayan region while involving local communities in managing and restoring degraded waste land, reviving traditional water resources, enhancing livelihoods through bioprospecting of wild edibles and medicinal plants, conflict resolution in protected areas management, agrobiodiversity conservation through community participation, often by reviving traditional systems and integrating them with scientific innovation. However, there is still a need for designing and implementing innovative approaches for sustainable bioresource harvesting/management, which enhance the livelihoods and income of marginal communities, coupled with environmental conservation to the benefit of the wider regional/global communities, which is a challenge to scientists as well as development practitioners and policy planners.

Western Himalaya: Treasure of unique bioresources

With a whole range of traditional/tribal/ethnic communities, the human dimension of bioresource utilization and management is enormous, indeed. For centuries, bioresources of both cultivated and wild origin have played a vital role in the subsistence economy of the traditional communities living in the Himalaya. However, there is strong evidence that the life support systems on which our economies depend are being overloaded, and unless a shift is made towards sustainable development, we might face severe or irreversible damage to our environment and bioresources. Thus, improving scientific understanding of natural and social processes relating to humanity's interactions with its environment, providing information useful to decision making on resource use, promoting the conservation of biodiversity as an integral part of land management, enjoying the efforts of local communities, scientists and policy makers in problems solving ventures, mobilizing resources for field activities, strengthening of regional cooperation and coordination. Institutions in the region have been increasingly exploring decentralised, community-led sustainable bio-resource (CLSBM) approaches. What is perhaps most remarkable about these approaches is their range and diversity: from community-initiated efforts to state-initiated ones, from those in which communities are only receiving some benefits to those in which they are the sole decision-making and benefitting party, from those that depend on external inputs like NGOs and donor agencies to those that are running entirely on local steam. But the move towards CLSBM, and the resulting processes, is not without hurdles and problems. The major challenges have been to build on local knowledges and practices, safeguard livelihoods based on sustainable use of resources, provide incentives for continued conservation, devise alternatives for unsustainable resources extraction, tackle inequalities in local decision making and benefit sharing, and enhance the management capacity of community-based institutions.

Linking cultural diversity with sustainable utilization of bioresources

Bioresources are at the center of many religions and cultures, which influence how resources are used and managed. Apart from the economic potential of the bioresources, many traditional communities rely on these resources for social, cultural, and religious functions. The socio-cultural belief systems have often played a significant role in controlling over-exploitation, leading to conservation of potential bioresources, in many traditional communities. The cultural practices and regulations indicate the conservation and management ethics. Through the application of traditional knowledge and customs, unique and important bioresources have often been protected and maintained in many of these areas inhabited by indigenous/traditional communities.

Strategies for Community-led Sustainable Resource Management (CLSRM) in Western Himalaya

- Investigate the economic, social, and environmental implications of Niche agro-horti-crops and wild bio-resources of high value (NTFPs, MAPs, -biomass for fuel and bamboo) towards bioeconomy.
- Science and Technological interventions and skilling in mountain-specific appropriate, affordable, cost-effective, and climate resilient technologies in all the sectors (agri-horti-culture, animal husbandry, and forest resources).

- Promotion of small-scale bio-industries at village /household level (cottage industries) based on locally available resources, value addition, product development, value supply chain
- Promote a program to resolve human-wildlife conflicts (HWC) and provide economic incentives for people to stay in the region, which is possible only through strong coordination with the forest department and adopting best land use management practices or agroforestry on their land, rather than migrating to urban areas.
- Develop appropriate policy initiatives, environmental governance, and legalized and regulatory approaches for effective conservation and sustainable use of high-value resources, providing the best practices and successful models for livelihoods and income generation

Under the impact of modernization, globalization, and liberalization, the influx of outside forces and population growth, traditional controls and practices that have conserved and protected the Himalayan bio-resources to a large extent for centuries are now being overwhelmed. Local traditional communities need to find ways to strengthen and adapt these controls and practices to new circumstances. The guiding principles of bioresource utilization and conservation cut across the very disciplinary realms. We have to make a series of compromises in order to satisfy our current needs, at the same time allowing for a variety of options for the future. Institutional arrangements have to improve people's participation through a bottom-up rather than top-down approach, ensuring that each household takes part in the decision-making process at the lowest level in the hierarchy, and with special dispensation for the marginal, weaker, and vulnerable sections of society. The components of the bottom–up approach of bioresource utilization, conservation, and management could be identified based on an in-depth analysis of local traditional knowledge and institutions. If bioresources is to be used as a potential option for livelihood enhancement and income generation of local/traditional communities for their sustainable development, one has to identify and deal with problems/opportunities related to prioritization of potential bioresources under different categories (economic plants), market-demand-supply trends-value chain, mechanisms of resisting competition in market, equitable distribution of economic benefits and maintenance of socio-ecological and bio-cultural integrity. Therefore, linking cultural diversity with bioresources as the basis for sustainable development, leading towards a bio-economy and sustainable livelihood, is to be seen as the way out to ensure the well-being of the marginalized and neglected sections of humans, including those who often are referred to as indigenous, tribal, ethnic, or traditional communities inhabited in the western Himalayan Region.

- Encourage the start-ups programme on sustainable use of bioresources under Aatmanirbhar Bharat Abhiyaan linked with the Govt. of India vision 2047 and to set up Bio-incubators Nurturing Entrepreneurship for Scaling Technologies with a major focus on capacity building and training of farmers, youth, and women bio-entrepreneurs.
- The Himalayan bioresource knowledge product to be promoted and developed with the major highlights on "Globalizing local knowledge and localizing global technologies.

- So far, the value of the western Himalayan bioresources is not fully reflected in the Country's GDP, and therefore, there is a need for scientific valuation of bioresources of WHR and their contribution to the national economy, when we talk about bio-economy/green economy from bio-resources.

Tribal Wisdom and Green Innovations: Integrating Indigenous Knowledge for Sustainable Himalayan Economy

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Abstract

The life and livelihood of the tribal communities in the Himalayan ecosystems are an amalgamation of nature and culture. An examination and analysis of the interlinks between nature, culture, and resources of the tribal communities becomes even more complex from the perspectives of Himalayan ecosystems, as the ecosystems are unique centers of biological and cultural diversity. In tribal societies, the traditional knowledge, innovation, and practices (TKIP) are intricately linked with the natural environment. The tribal population in India, constitutionally recognized as "Scheduled Tribes," numbered 10.43 crore as per the 2011 Census. Known differently, such as Adivasis, Van Vasi, Janjati, etc., the tribal populace constitutes about 8.60% of the total population of India and occupies over 18.70% of the nation's total geographical area. In 30 States/Union Territories, till date, 705 Scheduled Tribes have been notified, out of which 75 are notified as Particularly Vulnerable Tribal Groups (PVTGs). In the 11 states of the Indian Himalaya (excluding the Darjeeling district of West Bengal), as many as 272 Scheduled Tribes inhabit, constituting over 22.91 per cent of the total population of the region (MoTA, 2013). The tribal ecosystem, perpetuated through culture, develops tools, technologies, and innovative techniques for sustaining their production system in balance with their social heritage, economic conditions, and ecological specificities. These culturally evolved and socially patterned ecosystem tools, techniques and technologies constitute integral parts of appropriate innovative strategies and practices, otherwise known as indigenous knowledge system, which effectively conserves resources, identifies opportunities for their optimal use and contributes to the sustenance of the people (Chambers et al., 1989; Kloppenburg, 1991; Berkes & Folke, 1992; Gadgil et al., 1993; Berkes et al., 1995; Samal et al., 2003). Understanding this tribal wisdom is of paramount importance not only for the sustainable development of tribal communities but also from the perspective of its integration with policy planning, which will lead to evolving adaptive strategies in the inclusive development of the Himalayan economy. Across the Indian Himalayan states, with a tribal population of over 14.6 million, many green economies, such as eco-tourism, ethno-medicine, technology backstopping, cottage industry, agro-horticulture, etc., have evolved with their multifaceted contribution to the economy and conservation of resources, particularly of biological diversity. Ecotourism, as studies reveal (TIES, 1990; Anonymous, 2015), apart from diversifying and enhancing income generation, has helped conserve and promote the Himalaya's rich natural and cultural heritage. However, defined policies need to be evolved that will identify and promote ecotourism sites within and outside protected areas by diversification of a range of ecotourism activities, develop standards and norms ecotourism certification specific for a state, ensure active involvement of the local and indigenous

communities in ecotourism planning, development and implementation, enunciate a mechanism to establish partnerships between all stakeholders, build capacity of all stakeholders in natural and cultural heritage interpretation, focus on local culture and nature, enable the development of a sustained and effective marketing strategy, and plan for economic development of local communities. The dependence of the Himalayan tribal communities on traditional medicine and traditional healing practices is a result of multiple factors, i.e., cost-effectiveness, accessibility, faith, and assurance etc. The traditional healer establishes faith and assurance in the patients by virtue of sharing the common cultural beliefs and practices of the patients. Indigenous healthcare practices and ethnomedicines remained highly sought after and cost-effective medicinal practices among the tribal and other traditional communities of the Himalaya (Samal et al., 2002; Samal et al., 2010). In remote and difficult ecosystems of the Himalaya inhabited by tribal and other traditional communities, where modern health infrastructure and veterinary infrastructure are poor, both quantitatively and qualitatively, the locals have evolved indigenous health care practices to cater to human healthcare needs and to maintain their livestock population. However, the ethnomedicinal knowledge and the traditional treatment practices of the Himalayan tribes are threatened as the dependent bioresources are depleting with weakening and disappearances of regulatory safeguards and practices evolved by the community under diverse factors such as anthropogenic pressure, policies, and acts that are alienating tribal people from their traditional resources and resource use practices. The ruthless collection of medicinal plants by pharmaceutical industries is also disturbing the regulatory practices, threatening and endangering plants of medicinal value (Samal et al., 2004). The indigenous knowledge system, for its continuation, demands protection and conservation of bioresources, which is being carried out by the tribal communities. Conservation through scientific interventions is essentially required. In northeast India, shifting cultivation, commonly known as jhum, a primary and often the only agricultural practice, is available to address the need for food security of the majority of the upland communities (Ramakrishnan, 1990). The agro-ecosystem is besieged with conflicting views in regard to the degradation/conservation of the ecosystem and the way of life for the upland people (Choudhury and Sundriyal, 2003). Several socio-cultural institutions and practices of the tribal communities play a crucial role in managing this agro-ecosystem. The traditional practices involved with management of shifting cultivation are ecological viability, maintenance of soil fertility and cropping pattern, land tenure and customary practices, community dynamics, indigenous soil and water conservation practices, mixed cropping for crop security, weed management, and many other factors (Anonymous, 2005). The disintegrating and disappearing traditional knowledge system is one of the major factors that is weakening the inherent sustainable characteristics of shifting agriculture. There is a lack of viable, simple, and low-cost technological interventions accessible in the form of technology backstopping to the practitioners for soil conservation, soil nutrient management, and yield enhancement. Technologies for this agro-ecosystem are not adapted to local conditions and are not based on the principles of Low External Input for Sustainable Agriculture (LEISA) (Samal et al., 2016).

To conclude, the role of indigenous and traditional knowledge, innovation, and practices is pivotal in the Himalayan ecosystems inhabited by tribal communities in the sustainable use, management, and conservation of bioresources. However, their traditional knowledge, innovations, and practices in productive sectors are fast disappearing, resulting in a loss of resources. It is, therefore, strongly suggested that sustainable development options for tribal communities in the Himalaya necessitate a faithful documentation of their indigenous knowledge. Any planned intervention on development for tribal communities must understand, respect, and strengthen their indigenous knowledge and cultural principles. The documentation must include data based on indigenous and traditional knowledge, innovation, and practice in the management and conservation of bio-resources, prioritization of components of utilization, management, and conservation of bio-resources and their mechanism, and exploring possibilities for value addition and validation of traditional practices and potential bio-prospective. The documentation of the indigenous knowledge would help in understanding (i) how they exist as an autonomous knowledge system, (ii) how they contribute to the economy and welfare of the tribal communities in the Himalaya, (iii) how they help conserve resources, (iv) what options they offer as an integral part of the modern knowledge system and (v) how they will serve as knowledge base for future use. Addressing the issues of sustainable resource use and conservation in tribal communities in the Himalayan ecosystems necessitates a complete understanding of the indigenous knowledge system. This will further lead to building participatory conservation alternatives for Himalayan tribes through an understanding of the long-term natural and cultural interactions, dependent on local-level governance systems materializing into traditions of participatory, culture-based management of natural resources.

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Landscape-Level Sustainable Livelihood Strategies through Community-based Natural Resource Management in Mizoram, Northeast India

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Abstract

Eastern Himalayan region is located within the Indo-Burma biodiversity hotspot having vast biodiversity, diverse ethnic communities and fragile ecosystems holding enormous probability for developing natural resource based sustainable livelihood solutions. Forests play an important role in sheltering huge biodiversity, diverse community structure and function as well as wide range of ecosystem services. This region represents 8% of the land area and approximately 25% of India's forest coverage. In addition to different forest types, numerous other tree-based ecosystems like traditional agroforestry, home gardens, plantations, and secondary forests that offer livelihood prospects for the rural population are commonly found in the area. It helps in conservation of habitats, reduction of soil erosion and mitigation of climate change along with various resources of sustaining livelihood of locals. The greater species richness, diversity, structural complexity, and ecological stability in different areas protected and inaccessible area serves as clear evidence of the negative disturbance impacts. However, like other parts of the country, this region also faces pressing challenges such as deforestation, soil erosion, loss of traditional knowledge, and socio-economic vulnerabilities driven by climate change and limited livelihood opportunities. Hence, sustainable utilization of natural resources like forests, water, medicinal plants, bamboo, and agro-biodiversity-can play a pivotal role in enhancing rural livelihoods while conserving the environment. The state of Mizoram, is mostly agrarian in nature require resources database, models and methods to assist various integrated landuse management system like agroforestry models to find an integrated scientific way for shifting cultivation. This also necessitates mapping on availability and suitability of agricultural land, crop suitability analysis, soil erosion modelling, screening of climate resilient crops and sustainable practices. Further, requirement includes identification of research gaps to develop region specific models for afforestation, agroforestry, plantations and soil carbon enhancement and sustainable management practices. As for sustainable management of natural resources requires precise data analysis and modelling so application of remote sensing, process-based and Artificial Intelligence and Machine Learning techniques can play an important role for landscape studies. Site specific species recommendation for different forestry and agroforestry programs along the different agro-climatic zones for enhance land productivity. Climate resilient forestry management practices are yet to be developed for different regions. Sustainable ecotourism having high potential attracting visitors to rural areas to experience agricultural activities, local traditions, and natural landscapes. Despite its potential, challenges such as inadequate infrastructure, lack of marketing, limited policy support, and insufficient training for stakeholders often restrict its growth. Several studies were carried out on land cover and biomass, soil attributes, climate change, population

dynamics, crop suitability analysis, wetlands, soil erosion, niche modelling and bamboo forests using geospatial techniques. Key concern of present days includes database on land availability for sustainable afforestation and agroforestry programs. Research initiatives must focus on assessing biodiversity along the agroclimatic regions and formulate guidelines for sustainable forest management. Assessments of the impact of projected climate change on natural resources and ecosystem services. Exploration of key drivers, challenges, and strategies necessary for promoting sustainable ecotourism that balance economic, environmental and social goals. Revitalizing the rural traditions, cuisine, handicrafts, festivals, and indigenous knowledge systems. It also requires strengthening of public–private partnerships and local governance for promoting rural tourism, organic and horticulture farming. Community-based natural resource management (CBNRM) can lead to improved income generation and livelihood security among rural households. Integration of traditional ecological knowledge with modern sustainable practices for enhancing long-term resilience of livelihood systems. Value addition of non-timber forest products (NTFPs), bamboo, and medicinal plants for contributes significantly to local economic development. Ecotourism initiatives for environmental conservation and socio-economic empowerment. The study requisite involving local stakeholders in wetland mapping, sediment removal, and creation of vegetative buffers. Encouraging native fish cultivation and aquatic plant control to boost earnings while protecting biodiversity. Creating birdwatching routes, guesthouses, and community-managed eco-lodges close to important forests, agriculture and wetlands, alongside training in guiding and hospitality services. Advocating for eco-cottages powered by solar energy, separating waste, and tourism without plastic. Educating young people to become nature guides, storytellers, local artisans, and digital content creators. Guaranteeing fair income distribution and reinvesting into ecosystem preservation and community development. Locating recharge areas via hydrogeological mapping, applying infiltration trenches, vegetative check dams, and contour bunds. Encouraging traditional intercropping, terrace reinforcement, and organic agriculture in recharge areas. In most mountain villages, springs serve as the main sources of drinking water and for livestock requirements. Increasing income by means of beekeeping, bamboo crafts, growing medicinal plants, and eco-friendly products. However, changes in intensity and periodicity in precipitation trends may result in water shortages in certain areas while heightening flood risks in others, impacting the consistency of water supplies for human use and complicating the ability to fulfill the need for clean and safe drinking water. Undertaking the effects of climate change on water resources for human use necessitates comprehensive strategies that encourage water conservation, improve water efficiency, safeguard water quality, and strengthen resilience against climate-related threats. Sustainable practices in water management, including watershed management, water recycling, and ecosystem restoration, are crucial for securing access to clean and safe drinking water for current and future generations, particularly given the impacts of climate change. Strategies for sustainable livelihoods based on natural resource management are essential for achieving a balance between ecological integrity and socioeconomic welfare.

Keywords: Biodiversity, Ecotourism, Forests, Mitigation measures, Natural resources, Mizoram, Remote sensing and GIS, Soil chemistry.

Nature-Based Livelihood: Showcasing Local Culture, Promotion of Community-led Homestays, and trained Eco Guide for Responsible Tourism

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Abstract

The Himalayan Region is amongst the most ecologically sensitive and culturally diverse mountain systems in the world, but it faces an increasing dilemma between economic aspirations and environmental integrity. As our country looks ahead to -2047, it becomes authoritative to envisage a model of development that harmonizes development with environment. This paper, "Towards Sustainable Tourism: Redefining Development for the Himalayas," calls for a model shift from a human-centric to an eco-centric approach, distinguishing humanity as an integral part of our mother earth, rather than its master. The traditional development narrative in the Himalayas has taken a mainly short-term view of economic growth, usually at the cost of long-term ecological balance. It is this anthropocentric model that has brought about deforestation, loss of biodiversity, glacier retreat, soil erosion, and unplanned urban expansion, along with the silent crisis of out-migration from mountain villages. These unoccupied countrysides stand as witness to environmental degradation and destruction of socio-cultural fabric and traditional livelihoods. Now, the Himalayan region demands an urgent redefinition of progress-one that values ecological stability as a prerequisite for economic resilience.

The paper argues that, as far as the sustainability of the Himalayas is concerned, mandate holistic approach to conservation and development. Environmental protection can no longer remain a fragmented set of initiatives but has to form the footing of every policy, enterprise, and community action. Recognizing the interconnectedness of all life forms is central to this shift. The survival of humanity is inseparable from the vitality of its ecosystems; hence, humility must replace authority as the guiding philosophy of development.

Tourism is one of the mainstays of the Himalayan economies, capturing both the promise and the perils of growth. It provides revenue and jobs, but unregulated mass tourism has already exceeded the regional carrying capacity, straining water resources, creating waste, polluting sacred landscapes, and diluting the local culture. The fragile Himalayan environment, which heals very slowly, cannot support the untenable pressure of visitors anymore. This paper underlines the fact that sustainable tourism is an existential imperative, not an alternative model, if the future of the region is to be secured. Tourism will have to be realigned with sustainability through strategic interventions at the following levels:

1. Responsible Tourism: Promote eco-friendly and community-led home stays, and eco-guide for responsible tourism operations.

2. Carrying Capacity: Scientifically determined visitor limits to protect sensitive ecological areas from depletion of resources.

3. Community Empowerment: Inclusion of host communities, particularly youth and women, in tourism planning and benefits so economic benefits reinforce cultural and environmental stewardship.

4. Environmental Education and Research: Integrate the principles of sustainability into academic curricula, train eco-guides, and foster student-led conservation projects and endorse Green Credit System that will nurture a cohort of environmental stewards.

Youth engagement is at the core of the discussion. The transition to sustainability in the Himalayas has to be both in the classroom and in the community. Undergraduate and postgraduate students have to be encouraged to apply environmental learning through fieldwork, research, and local action. Cultivating love among youth for nature is not peripheral but foundational to a long-term ecological ethic. That would ensure that the process is intergenerational so that the spirit of conservation endures beyond policy cycles.

The paper conveys out the ethical and philosophical dimensions of Himalayan development. True progress cannot be measured by GDP alone, then by the health of the natural resources, and societies. It is a demand to spiritual ecology that weaves together traditional Himalayan wisdom based on reverence for nature with a modern scientific understanding offering a moral compass for Himalayan development path toward 2047.

Safeguarding the Himalayas calls for collective responsibility from one and all concerned. It involves a set of adaptive policies by the governments, which must be rooted in the local realities; research and data-driven insights by scientists; green innovations by industries; and sustainability as a way of life by citizens. The future of the Himalayas depends not on isolated acts but on shared commitments—between state and society, science and spirituality, economy and ecology.

This paper envisions an Indian Himalayan Region in 2047, a mountain economy based on ecological integrity, community participation, and cultural continuity. A Himalaya where tourism sustains livelihoods, but does not exhaust landscapes; where youth lead from the front with environmental wisdom; and where human development flourishes within the limits set by nature. Diverging from exploitation toward stewardship does not happen as a policy choice but is representative of a moral obligation and community destiny.

Keywords: 2047 Vision, Youth Empowerment, Community Participation, Sustainable Tourism, Environmental Conservation, Socioeconomic Growth, Indian Himalayan Region (IHR), and Eco-Centric Development.

Listening to the Land: Indigenous Knowledge, Commons, and Climate Resilience in the Eastern Himalaya

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Abstract

The Himalaya is often described as a biodiversity hotspot, but it is equally a biocultural hotspot, a landscape where ecological and cultural diversity have co-evolved. Across the eastern Himalayan ranges, Indigenous communities have developed intricate systems of Traditional Indigenous Knowledge (TIK) that blend observation, practice, and ethics into a living philosophy of coexistence. This knowledge is not a relic of the past but a contemporary framework for sustainability and climate resilience.

1. Knowledge as Living Ecology and Landscape Governance

Indigenous communities manage their territories not merely as farms but as living landscapes, integrating forests, rivers, settlements, and fields into a single ecological and social fabric. Planning occurs at macro levels, through community zoning, seasonal restrictions, and customary law, and is executed at micro levels through family and clan practices. This allows ecological, social, and cultural considerations to co-exist: soil and water conservation alongside livelihood security, equity, and social cohesion.

The Indigenous food system of the Eastern Himalaya encompasses both cultivated and uncultivated foods. Fields yield grains, pulses, and vegetables; forests provide tubers, fruits, herbs, and mushrooms; rivers offer fish and aquatic greens. Hunting and fishing, too, were once guided by community rules and taboos that safeguarded regeneration. Traditional hunters and fishers understood that their own survival depended on restraint. Modern weapons and commercial exploitation have undermined these balances, but the ancient ethics of reciprocity still offer powerful lessons for contemporary conservation.

In this holistic system, farmers are polymath scientists and systems thinkers, soil scientists, meteorologists, ecologists, and plant geneticists in one. They read the land by its texture, colour, and wind, and predict rainfall by observing the flowering of wild species or the movement of birds. Their fields are laboratories of agrobiodiversity: a single jhum plot may hold over 25 crop varieties, each selected for a different ecological purpose. Such diversity is both a scientific and cultural insurance against climatic uncertainty.

Women are the custodians of this knowledge. Through seed selection, weaving, songs, and folklore, they preserve ecological memory and social ethics. Every motif and melody encodes lessons about species, seasons, and care. In recognizing this, we must understand that TIK is not just about resources but about relationships between land, labour, and life.

2. Custodianship and the Knowledge of the Commons

At its heart, Indigenous knowledge is a philosophy of custodianship. Land and forests are not owned but held in trust for future generations. The Commons, forests, rivers, grazing lands, and even knowledge itself, are co-managed and co-shared, irrespective of formal ownership. This ensures not only sustainable use but also social equity. Rights come with responsibilities, and every act of use implies a duty of renewal.

Such systems are underpinned by institutional memory, the unwritten archives of customary law, ritual, and collective decision-making. They record how communities survived floods, droughts, and landslides, long before modern planning existed. In essence, Indigenous institutions are the governance infrastructure of resilience. Stewardship, not ownership, defines belonging.

However, these systems face increasing strain. Market integration, land privatization, and externally imposed committees have eroded community authority. Customary institutions that once governed the commons are now marginalized or replaced by parallel structures. The result is a quiet unravelling of the collective fabric that sustained both ecology and equity.

3. Adaptation and Resilience Capacities

For Indigenous communities, adaptation to change is not new. Their systems evolved precisely to manage uncertainty. Small family-based traditional farmers, such as jhum cultivators, are among the world's most experienced practitioners of climate adaptation. They plan for diversity and variability: mixed cropping, rotational fallows, intercropping trees and grains, and flexible labour arrangements spread risk across time and terrain. These are not isolated traditions, but nature-based solutions refined through experience.

Agrobiodiversity acts as a buffer against failure; if one crop fails due to drought or pests, others thrive. Soil fertility is restored through organic matter and forest fallows. Knowledge of slope, soil type, and aspect determines what to plant where and when. Social structures reinforce resilience through shared labour, collective food storage, and community assistance during crises. In every sense, adaptation here is social, ecological, and ethical, not merely technical.

4. Challenges and the Erosion of Knowledge

Despite its sophistication, TIK is rapidly eroding. Out-migration and the shift from land-based livelihoods are disconnecting younger generations from experiential learning. As oral traditions fade, the ecological vocabulary that encoded centuries of wisdom is disappearing.

Policy frameworks have yet to appreciate the full depth of Indigenous epistemologies. Development and climate programs often treat communities as beneficiaries rather than partners. Indicators of success measure outputs, not ecological regeneration or strengthened community institutions. Meanwhile, research and documentation remain weak. Much of TIK survives orally and is rarely studied as a system of knowledge in its own right. Indigenous researchers themselves are seldom supported or cited.

Without recognition, TIK risks being lost precisely when its relevance is greatest. Its decline is not inevitable; it stems from undervaluation. Reviving it requires respect, reciprocity, and partnership, a willingness to see Indigenous systems as co-equal sources of innovation.

5. Bridging Knowledge Systems

In addressing climate change, the goal should not be to "integrate" Indigenous knowledge into science but to create dialogue between equals. Science offers precision and scale; Indigenous knowledge offers context, continuity, and ethics. Together, they can generate a more complete understanding of resilience.

Institutions like the GB Pant National Institute of Himalayan Environment (NIHE) are uniquely positioned to facilitate this bridging. Their role is to convene and connect, to bring scientists, local custodians, and policymakers into shared spaces of inquiry. This can include participatory mapping, oral-history archives, and youth apprenticeships with elders. Crucially, it means recognizing oral knowledge, ecological calendars, and folk taxonomies as valid and verifiable forms of data.

By valuing co-knowledge creation rather than top-down transfer, research institutions can help rebuild trust and relevance between communities and policy. The challenge is not to scale up practices mechanically but to scale up relationships of learning and reciprocity.

6. Conclusion: Toward a Philosophy of Coexistence

The Himalaya's crisis is not only environmental but epistemic, a loss of species accompanied by the loss of stories, languages, and ways of knowing. Yet fragments of continuity remain: in the rotational rhythm of jhum fields, in the seed baskets of women, in the unwritten laws that still protect community forests. These are not remnants of the past but templates for a sustainable future.

Indigenous knowledge teaches that resilience is relational. It arises from cooperation, diversity, and moral restraint. As India looks toward Himalayan Vision 2047, recognizing TIK as a living, evolving system is not an act of nostalgia but a necessity. The climate crisis demands not only new technologies but renewed relationships between people and nature, between generations, and between knowledge systems.

Stewardship's Value: Accounting for Socio-Cultural Dimensions in Mountain Ecosystem Services

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Abstract

Mountain agroecosystems deliver crucial ecosystem services (ES), from food and water to climate regulation and cultural heritage, which are fundamentally maintained by local mountain communities. While conventional assessments attempt to quantify the economic benefits of these services, they often fail by neglecting the essential socio-cultural values and local stewardship mechanisms that underpin them.

To address this gap, a shift toward true, holistic valuation accounting is imperative. This approach promises a comprehensive assessment that moves beyond market-based estimates by strategically integrating the socio-cultural dimension into the valuation framework. Methodologically, this includes accounting for externalities, such as the costs of land degradation or the benefits of cultural preservation, that are typically overlooked in traditional economic analyses. By embracing this holistic methodology, the true cost of maintaining these ES is revealed, and the value contribution of the caretaker communities is accurately recognized.

The primary policy outcome of this rigorous valuation is ensuring that compensation mechanisms for mountain farmers and communities reflect a true payment for the services provided, rather than inadequate subsidies. For example, evidence from the Mediterranean region, showing the total economic value of mountain ES at approximately €120/person/year (three times the current policy support), demonstrates the inadequacy of current funding models. Therefore, the implementation of holistic valuation methodologies, urgently needed in regions like the Himalayan agroecosystems, is essential for designing effective, equitable, and sustainable agro-environmental policies.

Sustainable Value Chains for Wild Edibles and High-Value Crops in the Indian Himalaya: Lessons from Conservation and Livelihood Integration Services

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Abstract

Indian Himalayan region (IHR) harbors large verity of wild edibles, medicinal, and high value crops, which provide vital nutrition to local communities and offer significant income potential to boost local economies. Some common examples of wild edible plants include fruits such as Myrica esculenta (Kafal/Box Myrtle), Berberis asiatica (Barberry), Rubus ellipticus (Yellow Himalayan Raspberry), Prunus armeniaca (Apricot), Rhododendron arboreum (Buransh-flowers used for chutney and juice), Aegle marmelos (Bel/Bengal quince), Hippophae salicifolia and Hippophae rhamnoides (Sea buckthorn), Ficus species (F. auriculata, F. palmata), and diverse other plants; vegetables such as stinging nettle (leaves used as a vegetable), fiddlehead fern (Diplazium esculentum, young fronds used as a vegetable or for pickles), white clover, watercress, Chenopodium album (White goosefoot, leaves and seeds used), etc., fungi (Morchella esculenta locally called as Guchchimushroom); and others such as Prinsepia utilis (edible oil from seed kernels), Juglans regia (wild walnut), Cannabis sativa (seeds used for consumption), and various wild herbs like mint and oregano. Local communities utilize a large variety of such plants for food often supplementing their diets as well as various other subsistence needs, and also serving as potential sources of income through value-added products (jams, pickles, squashes, etc.). The diverse agro-climatic conditions of the Himalayas also make it suitable for cultivating numerous high value cash crops that fetch premium prices in both local and urban markets. It comprised horticultural crops, some commercial fruits being (temperate fruits like apple, pear, peach, plum, litchi, apricot) as major crops; off-season vegetables (like potato, cauliflower, cabbage, broccoli, tomato, french beans, etc.) in hilly areas during off-seasons relative to the plains, allowing them to fetch good market prices; and spices and aromatic plants such as Saffron (a highly valuable cash crop specific to Kashmir valley), ginger, turmeric, garlic, and chili. All these species are important commercially with high productivity. Besides, the region is a rich repository of medicinal and aromatic plants (MAPs) that have high economic potential. There are many traditional crops with market potential, such as rajma (kidney beans), bhatt (black soybean), and gehat (horse gram) that are valued for their nutritional content and specific tastes, having a niche market. Many local millets such as finger millet (Eleusine coracana) and barnyard millet (Echinochloa frumentacea) are also gaining attention due to their high nutritional value and resilience. Tea is a significant plantation crop with high export value in certain Himalayan areas.

Sustainable value chains for such plants are highly desirable to integrate conservation with livelihood development by creating economic incentives for protecting biodiversity. This approach leverages the region's rich natural resources to develop value-added products that can boost local economies and food security. However, it requires proper resource management, valuing traditional knowledge, creating viable market access for local communities, and developing products that use the region's unique resources. The paper discusses important points related to value chain development of medicinal & aromatic plants, NTFPs, wild edible plants, and high value cash crops that are found across lengh and breadth of the Indian Himalayan region.

POLICY AND GOVERNANCE FRAMEWORKS- STRENGTHENING REGIONAL COOPERATION

Bridging Nature and People: Trans-disciplinary Solutions for Landscape Restoration in the Himalayas

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Abstract

Introduction

The Himalayas are experiencing cascading environmental and social challenges—ranging from ecosystem degradation, climate-induced disasters, and drying springs to growing human–wildlife conflicts and livelihood insecurity. Despite decades of conservation and development work, many interventions remain sectoral and fragmented, failing to capture the interconnectedness of ecosystems, livelihoods, and institutions. With fragmented approach the pace of solution fails to match the pace at which crisis is happening. In this context, trans-disciplinary approaches—which not only bridge sectors, but also science, policy, practice, community knowledge, and institutions—form the design foundation of effective Nature-based Solutions (NbS). The eight criteria of the IUCN Global Standard for NbS: addressing societal challenges, designing at the appropriate scale, ensuring net biodiversity gains, embedding economic and social benefits, balancing trade-offs, ensuring adaptive management, mainstreaming into policy, and securing sustainable finance provide a good basis for transdisciplinary thinking around co-designing, and co-implementing solutions.

Trans-disciplinarity as the basis for NbS design

ICIMOD's NbS design (figure 1) and scaling framework operationalizes these principles through a trans-disciplinary systems lens adding elements of relevance, inclusiveness, partnership and finances for sustainability. The design begins with co-definition of societal challenges, jointly identified by communities, scientists, and policymakers. This is comprehensive diagnostic process to identify root causes of key societal challenge and consequences to biophysical asset (e.g., land, water), ecosystems, and socio-economic systems (e.g., livelihoods, inequality, and exclusion). Trans-disciplinarity, in this context, is about co-sensing challenge context to inform holistic and integrated solutions. The careful unpacking of challenge ensures that NbS design responds simultaneously to ecological imperatives and human well-being outcomes. With careful unpacking of societal challenges, our thinking around solutions becomes more holistic and integrated. For instance, a combination of ecosystem interventions (soil and water conservation, wetland restoration, forest enrichment) to strengthen ecological functions; and livelihood interventions (green enterprises, value chain enhancement, climate-resilient agriculture) to build community economic resilience- can emerge. The aim is to move beyond sectoral intervention to intervention for resilience—one that balances both conservation goals with social aspirations. The landscape approach principles and use of GIS/RS technologies to inform decisions are needed here. Embedding Gender Equality and Social Inclusion (GESI) responsiveness and incentives for sustainability are regarded as twin pillars of NbS sustainability. ICIMOD's NbS design criteria explicitly embed GESI at every stage—from diagnosis to benefit-sharing. The GESI scale used in NbS

measures inclusion outcomes in terms of participation, decision-making, and equitable benefit access. Likewise, incentive mechanisms, such as payment for ecosystem services (PES), biodiversity-friendly certification, and local stewardship rewards, further align community economic development interests with conservation goals.

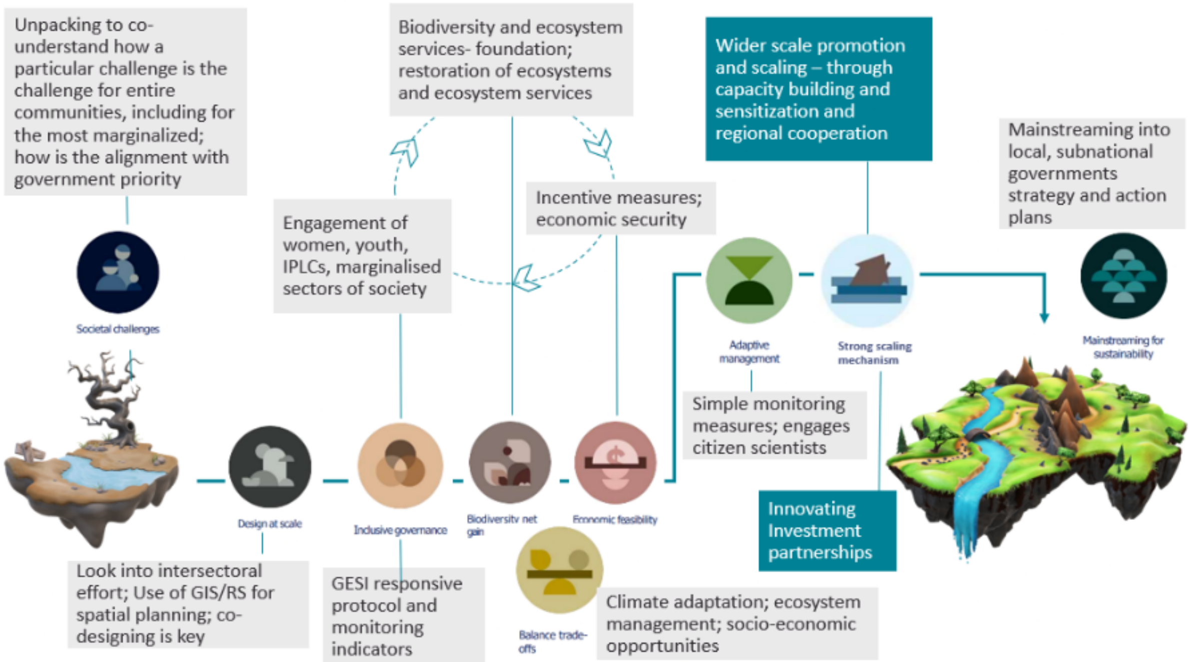

Figure 1. Transdisciplinary design of NbS in HKH facilitated through the Himalayan Resilience Enabling Action Programme (HI-REAP)

Managing trade-offs and building intersectoral partnerships is critical- such as between reforestation and grazing rights, conservation of wild biodiversity and food production, or hydropower and river ecology. Co-designing of solutions allows stakeholders to map and weigh trade-offs and support evidence-based negotiation between sectors. This is operationalized through intersectoral partnerships, where agencies working in different sectors - forest, agriculture, water, energy, culture, and local development jointly plan interventions. Mountain systems are dynamic, so NbS must also be dynamic. Element of adaptive management is indispensable for iterative monitoring, evaluation, and learning cycles. The data-driven feedback can refine practices (e.g., adjusting recharge structures, diversifying species composition, or revising institutional arrangements). The HKH solution platform hosted at ICIMOD allows tracking of environmental, economic, and social benefits, and comparison of similar solutions across different landscapes. Adaptive management transforms NbS from static interventions into learning hubs—building local capacity for experimentation, and resilience under uncertainty. Government mainstreaming of NbS remains key as long-term sustainability enabler. Our effort is to support governments integrate NbS principles into national planning frameworks, sectoral policies, and budgetary instruments. For example, integration of springshed management into Nepal's Water, Sanitation, and Hygiene (WASH) strategy under the Ministry of Water Supply; mainstreaming of rangeland restoration into Bhutan's Rangeland Strategy and Action Plan. Government ownership scales NbS from pilots to outcomes at scale policy pathways—anchoring ecological restoration within national development priorities. Innovative financing and regional cooperation are two other enablers for scaling. Traditional project-based funding is insufficient to sustain complex, multi-sectoral interventions. Our scaling framework therefore advocates blended finance models—combining public investment, private capital, and development finance aligned with climate and biodiversity goals. Green incentive schemes, such as ecosystem credits, eco-labelling, and restoration-linked microfinance remain key to wider scale adoption of NbS. For instance, programs that formally compensate upstream communities for maintaining forest cover that regulates water flow for downstream users create direct economic incentives for conservation. Similarly, the development of sustainable nature-based enterprises, non-timber forest products, and ecotourism generates local livelihoods while funding conservation activities, thereby aligning economic and ecological objectives.

Policy and practice recommendations

The following recommendations are necessary to innovate landscape restoration solutions in the Himalayas:

- Institutionalize transdisciplinary NbS design frameworks across national development plans, ensuring cross-ministerial ownership, long-term funding, and landscape level planning.
- Harmonise the foundational design of NbS across the Himalayan countries for effective monitoring and reporting of effectiveness and co-benefits evaluation. The Hindu Kush Himalaya Call to Action, endorsed by ministerial declaration from all eight regional countries, provide a framework for joint actions.
- Strengthen governance at the landscape level to make it more inclusive and integrated-formally recognising knowledge of local communities, and institutions. This calls for devolving management authorities to local stakeholders with equitable participation of women, youth and marginalised groups.
- Integrate Natural Capital Accounting (NCA) and ecosystem valuation into public finance systems to justify NbS design and investments. Develop mountain-specific financing instruments, such as ecosystem service bonds and mountain green investment facilities, including models that combine public funding, private investment, international climate and biodiversity finance and impact investments.

Conclusion

The Himalayan region stands at a critical juncture, facing unprecedented environmental challenges while simultaneously hosting innovative approaches to landscape restoration that integrate ecological and societal needs. The HI-REAP represents a comprehensive effort to scale NbS across the region through its unique transdisciplinary design - one that bridges traditional knowledge with contemporary science, connects local action with regional cooperation, and aligns conservation objectives with sustainable development goals. Thus, bridging actions for nature and people.

Policy and Governance Frameworks: Strengthening Regional Cooperation

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Abstract

Establishing and enforcing comprehensive policies that address the interconnected issues of environmental conservation, economic growth, gender equality, and social equity

Tourism is a ‘slippery’, ‘fuzzy’ concept; it is relatively easy to visualize, yet difficult to define with precision because its meaning changes depending on the context of its analysis, purpose, and use. Tourism is therefore a concept that, while initially appearing very easy to define, is actually quite complex.

Tourism, a phenomenal economic spinner around the world, also brings with it associated environmental, social, cultural, and ethical issues that are hard to efface. Its tremendous scope has led to its accentuation in various parts of the world, but like many other business activities, tourism also suffers from the give and take relation with the environment and society, where they are being operated. On the one hand, the positive impact imposed by tourism is of great importance to the destination in particular and the nation in general; simultaneously, the negative impacts are of prime concern in the current scenario for tourism development in the world.

There is ample hue and cry for environmental concern and the sustainability concept in tourism development, but the real picture is quite different from the issues raised. Tourists and the tourism system cannot be blamed for environmental issues, but the host community and humankind altogether have their share in these issues.

As India is urbanising, its urban population is growing at an average rate of around 3% per year. The average rate of growth of the urban population is not expected to change significantly during the next ten years or so. According to statistics in 2020-21, the average Indian will travel about thrice as many kilometres as they travelled in 2000-01. Absolute passenger mobility in India at the end of 2020-21 will virtually touch the mark of 13000 billion PKm. It is also found that road transport will play an extremely dominant role in India in providing passenger mobility to the people in the forthcoming years.

The expected greater reliance on roads will pose a challenge to the policymaker. As the availability of motorized transport, increases in household income, and increases in commercial and industrial activities have further added to transport demand.

Although car use is the most popular visitor transport mode, congestion, pollution, traffic problems, and demands for sustainable transport practices have led to a renewed focus on the importance of public transportation in urban tourism development. However, encouraging a

modal shift is not an easy task (Dickinson et al., 2009; Guiver et al., 2007; Le-Klähn et al., 2014; Lumsdon et al., 2006; Redman et al., 2013; Regnerus et al., 2007).

There is a crying need for a transportation system that is seamlessly integrated across all modes. The various modes of public transport, including intermediate public transport, have to work in tandem. The main aim of system integration should be to offer an attractive and easier-to-use transport system, leading to a better use of existing resources and improvement in the efficiency of service delivery and comfort for commuters. An integrated transport system has the potential to attract people away from private cars and two-wheelers and thus can contribute to congestion relief and environmental preservation (Singh, 2006).

Future Regional Institutional Mechanisms as an Option to Build Resilience of the Indian Himalayan Region

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Abstract

Sustainable Development Goal (SDG) 17, "Partnership for the Goals," is crucial for the success of the entire Sustainable Development Agenda, including the Mountain Agenda. For strengthening effective partnerships at global, regional, national, and local levels, operationalization of SDG 17-related activities is designed to forge collaborative frameworks that are essential for implementing all other SDGs. Positioned as a unique enabler, SDG 17 underscores that achieving meaningful progress across diverse goals requires concerted, inclusive, and well-supported efforts across sectors, geographies, and institutions. Among its five indicators, Use of Country-Owned Frameworks and Planning in Development Cooperation, and Progress in Developing Effectiveness in Support of the SDGs are two key ones.

Regional cooperation, whether inland (Between the Indian Mountain States) or transnational, essentially pivots on strengthening and leveraging multi-stakeholder partnerships for sustainable development. In fact, scaled-up efforts in policy, science, and practice are often reflected in the alignment of financing for development outcomes with human rights and gender equality principles, commitments, and obligations by ensuring that sufficient resources are available to achieve objectives. These may include poverty reduction and inclusiveness, or even biodiversity conservation, addressing climate change, and eliminating all forms of discrimination.

In the Hindu Kush Himalaya, of which the Indian Himalayan Region (IHR) is an integral part, our community stands at a pivotal juncture in its fight against climate change and environmental degradation, with its massive fallouts as seen in recent disasters (before and in 2025). Thus, the need for collective action and regional cooperation in addressing its impacts gains huge significance. Climate change's impacts cut across all sectors and levels of governance and across borders in the IHR, thus underscoring the necessity for regional cooperation through multi-stakeholder partnerships.

For regional cooperation, governments at the regional level must work together to coordinate activities, unify regulations, and create risk-reduction plans. In the world over and in South Asia, multiple initiatives have been taken for a shared framework for carrying out coordinated policy implementation. However, political and technical barriers have stymied efforts to suit the needs and benefits of partnering states. In this context, the International Centre of Integrated Mountain Development -an 8 Country Intergovernmental Knowledge Institution that includes India- in its suggested Global Framework for the Five Years of Action for the Development of Mountain Regions underlines:

- Deepen and accelerate collaboration among regional member states through high-level institutional mechanisms and ministerial mountain summits
- Generate credible evidence, such as landmark scientific syntheses and outlook reports, to close key knowledge gaps and strengthen science-policy dialogue on regional and transboundary issues.
- Build and strengthen regional knowledge networks to generate evidence and foster alliances to accelerate collaborative actions for a greener and more resilient Hindu Kush Himalaya.

The global framework proposes four interlinked global pathways to encourage all stakeholders to contribute to the Five Years of Action with initiatives, of which the enhancement of international cooperation, security, and multi-level governance in mountain regions is the prime one. However, it requires country-wise as well as mountain state-wise (In IHR) efforts to design, align, or strengthen policies, governance mechanisms, and institutions that lead to an enabling pathway to regional cooperation. In this context, a few major global agreements and frameworks such as the Sustainable Development Goals (United Nations, 2015b), Paris Agreement (United Nations, 2015a), Sendai Framework for Disaster Risk Reduction (United Nations International Strategy for Disaster Reduction, 2015), Agenda for Humanity (United Nations, 2017b) and New Urban Agenda (United Nations, 2017a) place a heavy burden of expectation on local governance actors to work collaboratively to implement them. World over and in South Asia, due to the current state of redundancy of the SAARC Agreement, several types of regional and country cooperative initiatives have emerged across the globe and can be categorized as:

Bilateral Treaties; Regional Agreements; National legislations; Local Arrangements, and Non-binding arrangements plans, platforms, and MoUs.

However, as seen in South Asia, such collaborative options for scaled-up conservation and development of IHR are hampered by several developments in the form of closure of borders, conflicting border situations, trade regulations, or transnational policy dilemmas as obstacles to regional cooperation. In the past decades, several regional initiatives have emerged and provided learning and lessons that could be utilized to drive regional cooperation, global trade, and climate policy in an era when multilateral cooperation appears to be in retreat. On the other hand, global power politics is increasingly supplanting collaborative initiatives, as tariff wars and shifting alliances threaten long-established trade rules. Growing complexity and ambitious state, national, and global development targets amplify the need for fostering an 'innovative institutional mechanism" that is flexible, acceptable, and doable for cooperating states and countries. This paper will present a case for strengthening Regional Collaboration for Sustainable Development by suggesting regional governance frameworks facilitating coordinated cross-border action to address the interconnected challenges of conservation, development, and climate change. A case from natural resource management (e.g., Rangelands, as these represent approx. 54% of the land area of IHR) will be presented as an option to forge inter-state as well as transboundary cooperation as a form for regional cooperation in IHR and between IHR and HKH.

The main assumption underpins that the implementation of the suggested above global framework is the continued political will towards sustainable mountain development. Which is expressed by governments through resolutions and cooperation frameworks, as the continued existence of and support by a global, regional and national multistakeholder movement in support of sustainable mountain development, represented by membership comprising governments, intergovernmental organizations, major groups and subnational authorities, and engaged in the promotion of sustainable development in its three dimensions – economic, social and environmental – in mountain regions. While testing such mechanisms regionally, over time, it is assumed that despite border conflicts and trade regulations, etc., the commitment to mountain conservation and development will manifest in policies and practices accompanied by scientific learning. This will also demonstrate that SDG 17, if successfully implemented, can have an impact on the achievement of other key SDGs.

GENDER EQUALITY AND SOCIAL INCLUSION FOR SUSTAINABLE DEVELOPMENT IN THE INDIAN HIMALAYAN REGION

Sustainable Tourism
Balancing Environmental, Social, and Economic Impacts
in Shaping a Himalayan Action Plan for Vision 2047

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Abstract

The Himalayan region, often termed the "Third Pole" and the "Water Tower of Asia," stands at a critical juncture. As India marches towards its centenary of independence with "Vision 2047," a future defined by a developed, self-reliant, and sustainable nation, the development trajectory of this fragile and vital biome demands a paradigm shift. Tourism, a primary economic driver for the region, has been a double-edged sword. While it generates essential revenue and livelihoods, its unregulated growth has precipitated environmental degradation, socio-cultural disruption, and economic leakage, threatening the very foundations of Himalayan resilience. This extended abstract posits that the formulation of a "Himalayan Action Plan" for Vision 2047 must be anchored in a robust, holistic, and actionable framework of sustainable tourism. This framework must meticulously balance the environmental, social, and economic pillars of sustainability, transforming tourism from a extractive industry into a regenerative force that secures the long-term well-being of both the mountains and their people.

1. The Imperative for a Sustainable Pathway

The current tourism model in the Indian Himalayas is largely characterized by volume-centric growth. Popular destinations like Nainital, Mussoorie, Shimla, Manali, Rishikesh, and Darjeeling face severe carrying capacity issues, especially during peak seasons. The consequences are stark:

- **Environmental Stress:** Deforestation for infrastructure, water scarcity exacerbated by hotel demands, solid waste management crises (particularly non-biodegradable plastic), pollution of pristine rivers, and disruption of wildlife corridors.
- **Social-Cultural Strain:** The commodification of indigenous cultures, alienation of local communities from land and resources, inflation, and a growing rift between hosts and guests.
- **Economic Vulnerability:** A high degree of seasonality, a preponderance of low-skilled, low-wage jobs, and significant economic leakage where profits are repatriated to out-of-state operators rather than circulating within the local economy.

This unsustainable path is incompatible with Vision 2047's core tenets of environmental stewardship and equitable development. Climate change acts as a threat multiplier, intensifying glacial retreat, altering precipitation patterns, and increasing the frequency of extreme weather events, thereby making the existing tourism infrastructure and practices even more precarious.

A business-as-usual approach risks irreversible damage, undermining not only regional stability but also the water and ecological security of the entire Indian subcontinent.

2. The Tripartite Framework for Balanced Sustainable Tourism

A visionary Himalayan Action Plan must be built on the integrated and non-negotiable balance of three pillars:

2.1. The Environmental Pillar: From Exploitation to Regeneration

The primary objective is to transition from minimizing harm to actively enhancing the environment.

- **Carrying Capacity Assessments & Zoning:** Scientifically determine the ecological and social carrying capacities of all tourist zones. Implement a zoning system that designates areas as "Core Preservation," "Buffer/Sustainable Tourism," and "Service/Infrastructure" zones, with strict regulatory enforcement.
- **Decarbonization and Green Infrastructure:** Promote a shift towards electric or hybrid vehicles for local transport, incentivize solar-powered accommodations, and mandate green building codes using local materials. Develop "low-impact" trekking and camping protocols, including a "Leave No Trace" ethos.
- **Circular Economy in Waste Management:** Establish decentralized waste management systems focusing on segregation, composting of organic waste, and recycling. Launch initiatives like "Plastic-Free Himalayan Destinations" and promote extended producer responsibility.
- **Water Security:** Implement mandatory water harvesting and greywater recycling for all commercial establishments. Promote water-saving fixtures and sensitize tourists to the region's water vulnerability.

2.2. The Social Pillar: From Spectatorship to Community Ownership

Sustainable tourism must be community-centric, ensuring that local populations are the primary beneficiaries and decision-makers.

- **Empowering Local Governance:** Strengthen institutions like Village Tourism Development Councils to manage tourism at the grassroots level. Ensure a significant portion of tourism revenue is reinvested into local community projects (health, education).
- **Safeguarding Cultural Heritage:** Move beyond cultural performances as spectacle to fostering genuine cultural exchange. Support homestays, local artisan markets, and heritage walks led by community elders to preserve and valorize intangible cultural heritage.
- **Capacity Building and Equitable Employment:** Invest in skill development for locals not just in hospitality, but also in roles as naturalist guides, heritage interpreters,

and waste management specialists. Ensure equitable employment opportunities for women and youth.

- **Tourist Sensitization:** Implement mandatory pre-arrival and on-site briefings on local customs, environmental ethics, and responsible behaviour to foster respect and minimize friction.

2.3. The Economic Pillar: From Leakage to Local Economic Resilience

The goal is to create a resilient, year-round local economy that is less susceptible to external shocks.

- **Promoting Local Sourcing and Value Chains:** Incentivize hotels and tour operators to source food, materials, and services locally. Develop brand and certification for "Himalayan Local" products.
- **Diversifying Tourism Products:** Move beyond sightseeing to develop niche segments like agro-tourism, wellness tourism based on local traditions (e.g., Ayurveda), spiritual tourism, and adventure sports that are managed by local experts. This will help distribute tourists geographically and temporally.
- **Fostering Social Entrepreneurship:** Create incubators and provide micro-finance for community-based tourism enterprises, from eco-lodges and guiding services to local craft cooperatives.
- **Digital Integration for Direct Benefit:** Develop a centralized digital platform that connects tourists directly with certified local homestays, guides, and artisans, reducing the commission taken by large online travel aggregators.

3. Envisioning the Himalayan Action Plan for Vision 2047

The proposed action plan is a 25-year roadmap with phased targets:

- **Phase 1 (2024-2030): Foundation and Regulation:** Focus on stringent policy reform, establishing carrying capacities, creating a "Sustainable Himalayan Tourism" certification standard, and launching large-scale capacity-building missions.
- **Phase 2 (2031-2040): Consolidation and Investment:** Scale up successful models, invest in green infrastructure (e.g., electric vehicle charging networks, decentralized renewable energy), and strengthen market linkages for local products.
- **Phase 3 (2041-2047): Maturity and Global Benchmarking:** Establish the Indian Himalayas as a global benchmark for mountain sustainability, with a self-sustaining, regenerative tourism economy that contributes significantly to regional GDP while enhancing ecological health and social equity.

Key Enablers:

- **Policy Coherence:** A single, overarching Himalayan Sustainable Tourism Act to harmonize policies across states.
- **Technology & Data:** Use GIS for monitoring, IoT for smart resource management, and data analytics for visitor management.
- **Multi-Stakeholder Partnerships:** Active collaboration between Central and State Governments, local communities, academia, the private sector, and NGOs.
- **Climate-Responsive Planning:** Integrate climate adaptation and disaster risk reduction into all tourism infrastructure and planning.

4. Conclusion

The journey to Vision 2047 offers a historic opportunity to redefine the relationship between tourism and the Himalayas. The choice is not between development and preservation, but between a short-sighted, extractive model that courts collapse and a visionary, regenerative one that builds enduring prosperity. By adopting a Himalayan Action Plan rooted in the meticulous balance of environmental integrity, social equity, and economic resilience, we can ensure that the mountains' majesty is not a relic for the last tourist to photograph, but a living, thriving heritage for generations of Indians to come. The time for decisive, collaborative, and visionary action is now.

Sustainable Tourism: Balancing Environmental, Social, and Economic Impacts in Shaping the Himalayan Action Plan – Vision 2047

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Abstract

Mountains support 27% of the global land area and over 720 million people, providing water, food, and energy to billions. The Indian Himalayan Region (IHR) is considered a globally significant ecological hotspot, covering almost16% of India's land area and encompassing all of the nation's glaciers and alpine terrain. This fragile region faces escalating pressures from climate change, unsustainable development, land degradation, outmigration, human-wildlife conflict, and waste pollution, threatening its water security, biodiversity, and local livelihoods. Both pilgrimage and mass tourism have long been integral to the Himalayan economy, but they also contribute to ecological and cultural degradation (Aayog, N. I. T. I.,2018). In India's Vision 2047 for the IHR, the goal is to "ensure a balance between environmental health and socioeconomic advancement". This comprehensive study examines how sustainable tourism can serve as a strategic driver to balance environmental, social, and economic objectives in shaping a Himalayan Action Plan for 2047. By definition, sustainable tourism "takes full account of its current and future economic, social and environmental impacts" and aims to benefit local communities while preserving ecosystems. When properly implemented, it can enhance local incomes and skills, empower marginalized groups, and generate funds for conservation. In the Himalayas, where tourism is already a mainstay of local livelihoods, this sector can only spur long-term development if it follows sustainability principles.

In the current study, we examine sustainable tourism within the Himalayan Vision 2047 context, with its environmental, social, and economic dimensions. Studies related to community-led ecotourism have made it evident that it can yield triple-bottom-line benefits: economic (job creation, diversified incomes), social (education, gender inclusion, cultural preservation), and environmental (habitat protection, low-impact practices) (Liu et. al., 2023). Lessons from comparative case studies (e.g., Nepal's Annapurna Conservation Area, Bhutan's high-value/low-volume policy, and community initiatives in Sikkim) illustrate best practices in aligning tourism with conservation and community empowerment. Finally, we outline policy implications for the Himalayan Action Plan 2047. Key recommendations include rigorous carrying-capacity limits, visitor fees dedicated to ecosystem services, strengthened community participation in tourism governance, and regional cooperation between India, Bhutan, and Nepal on sustainable tourism frameworks.

Environmental Sustainability through sustainable tourism

Traditional (unsustainable) tourism in the Himalayas has often harmed the very ecosystems that attract visitors. Poorly planned hotels and roads have replaced native forests and glacial landscapes with concrete structures, while inadequate waste systems lead to litter in fragile catchments. To the contrary, sustainable tourism seeks to minimize such impacts. By emphasizing conservation, ecological design, and low-impact travel, it can protect biodiversity and natural resources. For instance, eco-tourism projects often include forest cleanups, wildlife habitat restoration, and support for protected areas.

Community-managed tourism initiatives provide clear examples of ecological benefits. In Nepal's Annapurna Conservation Area Project (ACAP), local villagers are allowed to live within the protected area and manage trekking routes. ACAP collects entry fees from visitors and channels 100% of that revenue back into local conservation and development. This funding supports reforestation, trail maintenance, and sustainable infrastructure (like solar lighting), which helps stabilize the environment. Over the past 30+ years, ACAP has become a "model of participatory protected area" that balances ecosystem health with human needs (ACAP). It demonstrates how visitor revenues can incentivize forest preservation and waste management, reducing ecological footprints.

In the context of Vision 2047, sustainable tourism can thus serve as an environmental planning tool. It encourages site planning that respects carrying capacity, invests in renewable energy and waste systems, and avoids habitat fragmentation. For example, Bhutan famously limits visitor numbers and levies a sustainable development fee to fund conservation. This ensures that tourism expansion does not come at the cost of forest loss. In India, similar measures—zoning fragile zones, imposing eco-tourism fees, and enforcing wildlife-protection rules for tour operators—would help balance ecological integrity with visitor access. In summary, by internalizing environmental costs into tourism and using tourism revenue for habitat protection, sustainable tourism helps mitigate the Himalayas' ecological vulnerability.

Socio-Cultural Sustainability and Community Livelihoods

Community-led ecotourism yields social empowerment: women and youth receive skills training, and community members gain roles as guides, homestay hosts, or artisans. For example, homestay programs in Ladakh and Sikkim offer locals (including women) training in hospitality and management, enabling families to earn income by hosting visitors in traditional houses. This not only raises incomes but also revitalizes indigenous crafts and cuisine. Sikkim's recent Rural Tourism Meet (2025) explicitly showcased homestays featuring local food and crafts, aiming to "create authentic, participatory tourism models that directly benefit local families and preserve cultural heritage". In this way, tourism can help reverse outmigration by giving young people job prospects in their home villages.

Sustainable tourism also reinforces social inclusion. When communities participate in planning, the benefits are distributed more equitably. Many women and youth are engaged in the operation of guest houses, as guides, and as other service providers. By valuing local culture, sustainable tourism can also reinforce social cohesion. When travelers come to learn about folk music, traditional dress, or village festivals, locals gain pride in sharing their heritage. This mutual respect helps preserve the intangible cultural fabric of the Himalayas even as communities modernize.

However, poorly managed tourism can have adverse consequences, such as unregulated growth, cultural commodification, and the loss of the destination's spirit. Through Community involvement, a strong code of conduct, both for the community and tourists, these problems can be largely avoided. In sum, sustainable tourism can bolster social sustainability by providing inclusive livelihoods and reinforcing local identities. Key factors include community ownership of tourism businesses, equipping locals with necessary skills, and embedding tourism in education and development plans. When residents see tangible quality-of-life improvements (sanitation, income stability) from tourism, they have an incentive to steward the environment (e.g., Sarmoli Village, Munsyari, Uttarakhand)

Economic Sustainability and Livelihoods

Economically, tourism is one of the largest growth sectors in many Himalayan states. Trekking, pilgrimage routes, and hill-station resorts all attract domestic and foreign tourists. This influx brings much-needed cash into remote areas where agriculture alone may not sustain growing populations. For example, in Nepal, the travel and tourism industry supported over 900,000 jobs (direct and indirect) in 2016. Similarly, Bhutan’s tourism (though intentionally limited in volume) generated significant funds through its high fees. In all these cases, tourism spending injects income into hotels, guides, transport, and handicraft sales, boosting GDP and reducing poverty.

However, pure economic growth from tourism must be tempered by sustainability. Unchecked tourism can cause boom-bust cycles or concentrate wealth in a few hands (e.g., outside investors). The goal of economic sustainability is to maximize broad-based, stable livelihoods without exhausting natural capital. Sustainable tourism models encourage local ownership: when communities run guesthouses or trekking outfits, more money stays in the region. Moreover, by design, sustainable tourism often creates ancillary economic activities. For instance, building eco-lodges can spur local handicraft production (baskets, textiles) and organic farming (to supply hotels). Training local youth as guides builds human capital. The multiplier effect of tourism – money spent by tourists re-circulating through restaurants, shops, transport – can be substantial if leakages are minimized.

Policy and Governance Frameworks

Achieving the balance of interests discussed above requires robust policy frameworks and governance. The Himalayan Action Plan 2047 must integrate tourism into broader land-use and development policies. This means clear regulations on where and how tourism infrastructure is built – for example, zoning ecologically sensitive zones off-limits, mandating low-impact building codes, and enforcing waste disposal standards. Finally, governance must handle cross-cutting challenges like climate resilience (ensuring tourism development itself is climate-adaptive) and disaster response (evacuation plans for trekkers in case of floods/avalanches). Tourism agencies should work with environmental departments to monitor impacts. Funding mechanisms (like Bhutan’s mandatory fee) can institutionalize sustainability: fees collected from tourism can finance local education, health, and climate adaptation projects. In short, policy must align tourism incentives with Himalayan conservation goals. When regulatory safeguards and financial tools are in place, tourism becomes a disciplined instrument of development rather than a wild card.

Recommendations and Conclusions

To achieve a resilient and inclusive Himalayan future by 2047, sustainable tourism must be embedded as a cornerstone of regional planning and governance. Institutionalizing sustainability through mandatory low-impact infrastructure norms, ecological certifications, and visitor caps in ecologically sensitive areas will preserve the region's natural capital. Economic incentives, such as fee-based models akin to Bhutan's, can ensure tourism revenues directly support conservation and local development, while promoting high-value, low-volume experiences rooted in local culture and ecology. Empowering communities by formalizing their role in planning processes—through tourism committees, targeted skill-building, and equitable benefit-sharing—will anchor tourism within local economies and strengthen social cohesion. Cross-sector collaboration between tourism, environmental, and agricultural agencies will align infrastructure and conservation efforts, especially in the face of mounting climate risks. Finally, regional integration through a Himalayan tourism consortium involving India, Nepal, and Bhutan will foster policy harmonization, coordinated visitor management, and shared branding, positioning the Himalayas globally as a model of regenerative, community-led tourism. Together, these actions will shape a Himalayan Action Plan where tourism becomes not only a livelihood strategy but a catalyst for ecological stewardship, cultural resilience, and sustainable mountain development.

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Re-Envisioning Sustainable Tourism through a Community-First Approach: Balancing Environmental, Social, and Economic Impacts in Shaping the Himalayan Action Plan towards Vision 2047

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Abstract

Tourism across the Indian Himalayas has expanded rapidly in recent years, yet this growth has heightened ecological and cultural pressures on the region's limited resources. According to official statistics reported by the Uttarakhand Tourism Development Board (UTDB), 5.96 crore tourists travelled to the state in 2024, representing a nearly 62 percent increase since 2018. While such expansion brings income and visibility, it also intensifies stress on fragile ecosystems, cultural disruption, and raises concerns about control over tourism development. In the context of India's Vision 2047, which seeks a model of progress and development grounded in sustainability, equity and resilience, this talk deals with the future of Himalayan tourism depends on adopting a community-first approach, emphasising that sustainable tourism depends on local participation, where residents actively shape and benefit from tourism outcomes not merely as hosts but as custodians (UN Tourism, 2024; OECD, 2024). It argues that empowering Himalayan communities as planners, stewards, and beneficiaries of tourism offers the most practical pathway for aligning environmental conservation, social inclusion, and economic well-being.

- The argument draws on diverse empirical experiences from Uttarakhand: community-based tourism (CBT) initiatives in Sari, a village within the Kedarnath Sanctuary region (Gupta & Bhatt, 2009);
- Surveys of residents' attitudes towards tourism across rural destinations (Gupta & Bhatt, 2014); and
- Observations from the recent field visits of Byans Valley (Adi Kailash Region), a high-altitude border corridor.

These cases reveal how environmental conditions, social structures, and local economies interact under different governance arrangements. Supportive national policies/programmes such as Swadesh Darshan 2.0, which advocates channelling public investment toward sustainable, community-led destination development (Ministry of Tourism, 2023); the Uttarakhand Tourism Policy 2023, which aims to promote community capacity building and entrepreneurship (UTDB, 2023); and the Vibrant Villages Programme, designed to strengthen livelihoods and infrastructure in border communities (Ministry of Home Affairs, 2023).

Across these landscapes, several patterns emerge.

1. In protected-area settings such as the Nanda Devi Biosphere Reserve, top-down conservation and tourism regimes often exclude local people, creating hidden conflicts

that weaken both ecological and livelihood outcomes (Maikhuri et al., 2000; Rao et al., 2011).

2. The Sari eco-village demonstrates that locally managed tourism strengthens both income security and conservation outcomes (Gupta & Bhatt, 2009).
3. Studies of residents' perceptions indicate that public support for tourism is highly conditional—villagers embrace tourism only when it protects culture, shares benefits fairly, and conserves local resources (Gupta & Bhatt, 2014).
4. In the Byans Valley (Adi Kailash Corridor), visitor inflow has expanded from a few hundred a decade ago to nearly 30,000 tourists in 2024, signalling the need to embed community ethics, infrastructure limits, and climate-adaptation measures in all future planning (Times of India, 2024).

These insights collectively position the community-first framework as the foundation stone of the Himalayan Action Plan.

- Environmental dimension: Local institutions such as Van Panchayats, sacred-grove traditions, and culturally defined settlement boundaries provide indigenous mechanisms to maintain carrying capacity and ecological integrity (Negi et al., 2018).
- Social dimension: Strengthening indigenous governance, gender equity, youth-skill development, and cultural-heritage management shifts tourism from externally driven service provision to community-led development (UNDP India, 2023; UN Tourism, 2024).
- Economic dimension: Certification of green skills, local value-chain enterprises (homestays, agro-heritage products, eco-guiding), and performance-based incentives—as outlined in the Uttarakhand Tourism Policy 2023—help keep tourism revenue circulating within mountain economies (UTDB, 2023).

In keeping with global dialogues on destination stewardship and regenerative tourism (GSTC, 2022; OECD, 2024), Uttarakhand's evolving approach signals a transition from growth measured purely by visitor numbers toward an emphasis on the quality of experience, environmental protection, and community well-being. This approach gives priority to the small-scale infrastructure projects and locally operated enterprises that rely on regional resources and skills.

Placing communities at the heart of tourism planning is essential for a resilient and sustainable Himalayan economy. By empowering community members as planners, custodians, and beneficiaries, the Himalayan region can move closer to the Vision 2047 that thrives economically while preserving its ecology and culture for future generations.

Keywords: Community-First Approach · Sustainable Tourism · Uttarakhand Himalaya · Regenerative Tourism · Carrying Capacity · GESI · Vision 2047 · Destination Stewardship

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