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Harmony with Nature and Sustainable Development

Editor's Note

The relationship between humanity and the environment has reached a critical turning point. As development accelerates at an unprecedented pace, the idea of *harmony with nature* has shifted from a poetic aspiration to an urgent necessity. For centuries, economic growth has often come at the expense of natural ecosystems. Forests have been cleared, rivers polluted, biodiversity depleted, and the climate destabilized. While such actions delivered short-term gains, they also exposed a dangerous truth: development that ignores nature ultimately undermines itself. Environmental degradation now threatens food security, public health, livelihoods, and even global stability. Sustainable development offers a balanced path forward by meeting present needs without compromising the ability of future generations to meet their own. This approach recognizes that economic growth, social well-being, and environmental protection are deeply interconnected. True progress cannot exist without healthy natural systems. Living in harmony with nature requires respecting ecological limits and understanding that humans are part of the environment, not separate from it. This means conserving biodiversity, using resources responsibly, reducing waste, and transitioning to cleaner energy sources. Practical solutions already exist, including renewable energy, climate-resilient agriculture, sustainable cities, and circular economies. What is needed now is collective commitment and responsible action. Governments must enact policies that promote environmental justice and green growth. Businesses should move beyond profit-only models and embrace long-term sustainability. Individuals, through everyday choices related to consumption, energy use, and waste, also shape the planet's future. Education and awareness are vital in driving this transformation, while indigenous knowledge systems offer valuable lessons on coexistence with nature. Harmony with nature is not about halting progress, but redefining it. Sustainable development is both a moral responsibility and a practical necessity, and the choices made today will determine the legacy left for generations to come. The views in this newsletter vol. 22 (1&2), 2025 is the views of the concerned authors. Therefore, they do not necessarily reflect the views of the editors or EIACP Centre and the Institute. We look forward to come up with the policy interventions for the holistic and sustainable development of the Himalayan region. The comments/suggestions for further improvement of the EIACP Newsletter are welcome.

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EIACP Centre on Himalayan Ecology

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The "EIACP Centre on Himalayan Ecology" is housed at G.B. Pant National Institute of Himalayan Environment (GBPNIHE), Kosi-Katarmal, Almora, Uttarakhand, which is an autonomous Institute of Ministry of Environment, Forest & Climate Change (MoEF&CC), Government of India, New Delhi, India.

The **"EIACP Centre on Himalayan Ecology"** collects, collates, compiles and builds quantitative and qualitative databases of information in the fields related to the Himalayan Ecology. The information is disseminated regulary via online as well as hardcopies to several valuable stakeholders and various users such as DICs, universities, institutions along with other EIACP Centres across India to support overall Environmental Information System in India.

Inside the issue ...

Ecophysiology and Carbon Sequestration in Himalayan Forests: A Nature-Based Solution for Climate Resilience

The Indian Himalayan region, renowned for its rich biodiversity and complex ecosystems, is also critical for maintaining the balance between climate resilience and sustainable development. Central to this balance is the concept of nature-based solutions (NbS), which harness the power of natural systems to address climate challenges. In the context of the Himalayas, forest ecophysiology and carbon sequestration play an essential role in mitigating climate change and enhancing ecosystem resilience. By integrating these natural processes into the broader framework of sustainable development, the region can better address the pressures of climate change while promoting harmony between human societies and nature.

Ecophysiology of Himalayan Forests and Its Role in Climate Resilience

The ecophysiology of forests in the Indian Himalayan region focuses on the adaptive processes that allow these forests to thrive under diverse climatic conditions. From temperate to subalpine zones, the ecophysiology of forests here is intricately linked to the region's ability to withstand and recover from environmental stressors, such as temperature shifts, soil erosion, and water scarcity. The diverse forest types of the Himalayas, such as those dominated by deodar (Cedrus deodara), oak (Quercus spp.), pine (Pinus spp.), and rhododendron (Rhododendron spp.), have evolved unique mechanisms to optimize water usage, carbon storage, and biodiversity preservation under extreme conditions (Joshi *et al.,* 2024). This ecophysiological adaptability directly influences the carbon sequestration capacity of Himalayan forests. By capturing carbon dioxide through photosynthesis and storing it in plant biomass and soils, these forests help regulate the atmospheric carbon balance. The carbon storage provided by these forests is a crucial nature-based solution (NbS) for climate resilience, as it not only helps mitigate the effects of rising greenhouse gases but stabilizes the region's climate, promoting a healthier environment for local communities. Carbon Sequestration as a Nature-Based Solution for Climate Resilience Carbon sequestration in Himalayan forests serves as a vital climate mitigation strategy by reducing the amount of carbon dioxide in the atmosphere. The slow growth rates of high-altitude trees, while limiting their rapid biomass accumulation, result in significant carbon storage over time. The combination of forest biomass and soil carbon in these ecosystems makes them powerful carbon sinks that mitigate climate impacts at both the local and global levels. Furthermore, Himalayan forests contribute to climate resilience by stabilizing local microclimates. These forests play a significant role in regulating water cycles, reducing soil erosion, and buffering communities from extreme weather events, such as floods, droughts, and landslides, which are becoming increasingly frequent due to climate change. The forests' ability to store carbon while simultaneously providing these other ecosystem services underlines the region's importance as a nature-based solution for climate resilience (Watham *et al.,* 2020).

Table 1: Role of ecophysiology and carbon sequestration in climate resilience (Rawat *et al.,* 2013; Singh *et al.,* 2011; TERI, 2021).

Mechanism	Role in Climate Resilience	Example
Stomatal Regulation in Plants	Controls transpiration and CO_2 uptake, thereby enhancingwater-use efficiency during extreme conditions.	Higher plant water potentials promote sustained stomatal conductance and CO_2 uptake, enhancing carbon gain.
Photosynthetic Acclimation	Adjusts photosynthetic capacity under stress.	Understanding forest–environment interactions provides insights into species fitness in suboptimal environments.
Mycorrhizal Associations	Enhances nutrient uptake and soil carbon storage.	Mycorrhizal fungi hold 50 to 70 percent of leaf litter and soil carbon.
Forest Carbon Storage	Sequesters large amounts of carbon in biomass, mitigating climate change.	Forests play an essential role in regulating global carbon cycles.
Wetland Conservation	Stores floodwaters and filters pollutants, reducing flood intensity and improving water quality.	Wetlands can help mitigate the impacts of flooding due to their function of floodwater storage.
Agroforestry Practices	Integration of trees into agricultural systems, enhancing carbon storage and biodiversity.	Agroforestry systems yielded up to 21% higher economic returns.
Urban Green Infrastructure	Reduces urban heat islands and manages stormwater, improving urban resilience.	Employment of green infrastructure concepts, including permeable pavements and wetlands, effectively built urban flood resilience.
Soil Carbon Sequestration	Captures atmospheric CO_2 and stores it in soil organic matter, improving soil health.	Soil carbon sequestration plays a crucial role in reducing atmospheric CO_2.

Integrating Nature-Based Solutions for Climate Resilience in the Indian Himalayas

Incorporating nature-based solutions (NbS) into sustainable development strategies for the Indian Himalayan region is essential for fostering climate resilience. NbS involves the sustainable use and conservation of natural ecosystems to mitigate the impacts of climate change and build community resilience. Himalayan forests' diverse and adaptive nature provides an ideal foundation for implementing these solutions. **Forest Restoration and Conservation:** Forest restoration is one of the most effective NbS for enhancing climate resilience. By restoring degraded forest areas, especially in high-altitude zones vulnerable to erosion and extreme weather events, the carbon sequestration potential of these ecosystems can be significantly enhanced. Additionally, conserving existing forests helps maintain their role as carbon sinks, ensuring they continue contributing toclimate mitigation and adaptation. **Agroforestry:** Integrating agroforestry practices, where trees are planted alongside crops, offers a sustainable way to enhance carbon sequestration while supporting agricultural productivity. This practice can improve soil fertility, conserve water, and reduce deforestation pressures on natural forests. Agroforestry in the Himalayas contributes to climate resilience by increasing carbon storage and provides an additional income stream for local farmers, thus contributing to sustainable livelihoods. **Sustainable Land Management Practices:** Sustainable land management practices, such as preventing soil erosion and enhancing water conservation, are key NbS strategies for climate resilience. Inthe Himalayas, where landslides and floods are common due to rapid runoff and deforestation, these practices can help maintain the integrity of forest ecosystems, enhancing their capacity for carbon sequestration and supportinglocal climate adaptation efforts. **Ecosystem-Based Adaptation (EbA):** Ecosystem-based adaptation refers to using natural ecosystems to support communities adapting to climate impacts. Protecting and enhancing forests through EbA strategies can reduce the risks of extreme weather events in the Himalayan region. This includes leveraging forests to reduce flood risks, prevent soil erosion, and protect local communities from climate-induced disasters, while ensuring long-term sustainability.

Conclusion:

Promoting Harmony with Nature through Nature-Based Solutions By understanding the ecophysiology of Himalayan forests and utilizing their inherent carbon sequestration potential, the Indian Himalayan region can effectively address the challenges of climate change while promoting sustainable development. Nature-based solutions such as forest restoration, agroforestry, and sustainable land management can significantly enhance the region's climate resilience, supporting environmental conservation and community livelihoods. These strategies align with the broader goal of harmony with nature, fostering a balanced coexistence between human

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societies and natural ecosystems. As the region faces the growing impacts of climate change, integrating these NbS into local and national policies will be critical to securing a sustainable and resilient future for the Himalayan ecosystems and those who depend on them.

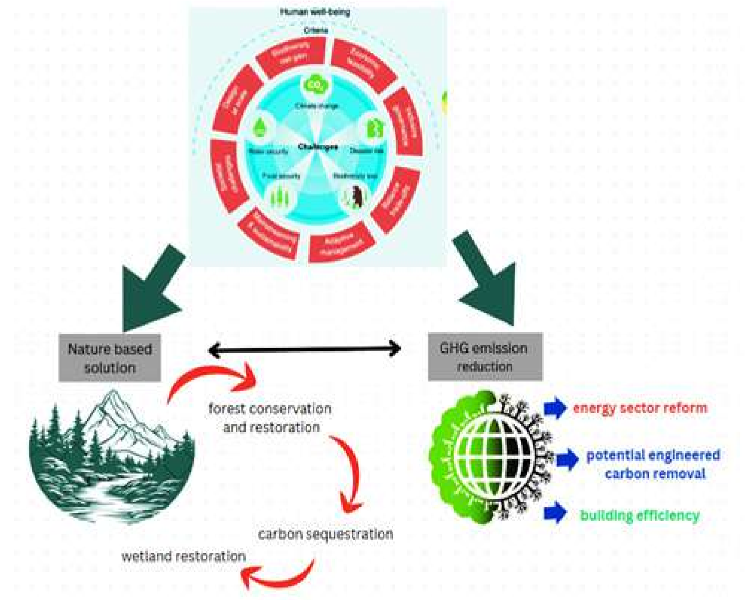
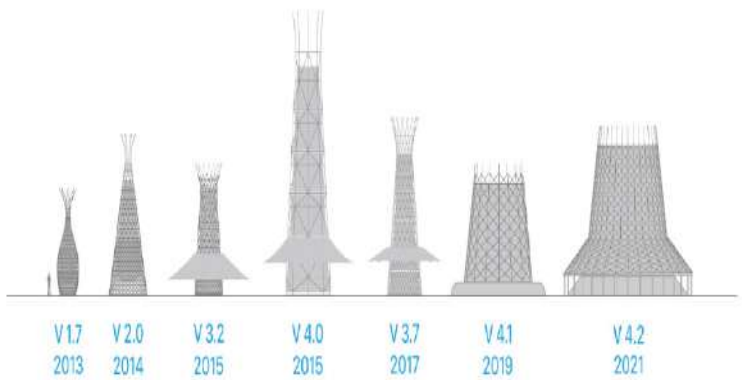


Fig.1. Role of Nature-basedsolutions in mitigating climate change



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Nature-Based Strategies for Carbon Sequestration and Climate Resilience in IHR

IHR is one of the richest reservoirs of biological diversity in the world due to its diversified climatic conditions, altitudinal range and habitat. Nonetheless, it is recently experiencing negative impact of climate changing scenarios caused with a rising trend of extreme warm events, increasing events of drought, cold bursts and floods, variations in rainfall patterns and changing in flowering and fruiting season. These climatic variations occurring in IHR led to severe consequences such as melting of glaciers, temperature rising, erosion of soil and loss of biodiversity. To combat these challenges, nature-based strategies are considered as a sustainable solution for C sequestration and climate resilience in IHR (Meetei *et al.,* 2023). The challenges addressed by these global processes are deeply interconnected and do not stop at national borders, yet are often dealt with in isolation. In this context, have come to the forefront for their potential to address multiple challenges in parallel while providing wider long-term benefits. Nature-based solutions (NbS), especially terrestrial-based NbS, involved working with and enhancing nature to aid in addressing societal challenges by encompassing a wide range of actions, such as the protection and sustainable management of natural ecosystems. NbS have potential to tackle both the climate and ongoing C crisis while also contributing to sustainable development.C sequestration and storage in forest ecosystem services supported by biodiversity. C sequestration contributes in the restoration of degraded soils, improved grasslands and managed forests. Conversion of degraded soils under agriculture and other land uses into forests landuse enhance the SOC pool. According to forest management surveys, IHR'sforestsequester about 65 Mt of C yr-andabout 5.4 Gt of C. In India, the sum of annually C sequestered is approximately equivalent to 15% of CO2 emissions from fossil fuels. Thus, forests of the Himalayas considered as crucial global carbon reservoirs that contribute carbon dynamics sequestration.

Contribution of Himalayas in C sequestration

In IHR, vivid fluctuations in altitude enables a variety of foliage including, subtropical forests, alluvial grasslands, alpine meadows and conifer mountain forests which contributes its substantial potential of C sequestration. Furthermore, low soil temperature in the Western Himalayas permits elevated storage of SOC in soil by limiting the rate of decomposition. It is found that soils with perpetually frozen layers haveinsufficient drainage and can cryoturbation. Consequently, permafrost soils along with wetlands and peat lands normally have higher C densities and can contribute towardsmassive C stocks worldwide. They are crucial to both the global C cycle and potential climate change feedbacks as well. Forests are the most productive entities in terrestrial ecosystem, owing to the biotic elements and Csequester in their tissues.

Nature-based strategy for C sequestration

Since, the industrial Revolution, CO_2 levels have surged, with annual global emissions now exceeding 35 billion tones, C emission rates from fossil fuel utilization increased by 40% from 1980-2000. However, the amount of CO2cumulating in the environment remained constant amid this period as the surplus CO2emitted has been removed by soil, oceans, forest vegetation and other habitats. Afforestation of vulnerable land use soils or degraded soils has a large potent of SOC sequestration. The range and rate of SOC sequestration along with afforestation depends on climate, type of soil, andcompost management. The potential for SOC sequestration through agricultural intensification is significantly high occur with conversion to a permanent forest. Implementing NbS for forest C management delivers options for actions to promote integrating climate change considerations into C management activities, vital to support land managers interested in enhancing forest C stocks and the capacity to sequester additional C into the future (Lupp and Zingraff-hamed, 2021). These strategies aid in regulating global C dynamics and contribute in climate resilience directly contributing in achieving sustainable development goals including: Climate Action, Life on Land, Clean Water and Sanitation, Zero Hunger and No Poverty. These approaches reduce GHGs concentrations, conserve biodiversity, enhanced productivity, improve soil health and reducing land degradation.

Fig.1. Nature-based Solutions (NbS) in enhancing C sequestration in IHR. Nature-based strategy for climate resilience

Although native people have owed some traditional methods to preserve this ecological gem however, incorporating and implementing NbS and sustainable development norms is crucial (Chakraborty *et al.*, 2023). In last 10 years, interest has increasedin the capability of NbS to meet global targets for GHG emission reductions to mitigate global change, demonstrating significant roleof biological systems as GHG sources and sinks. In the 21st century, negative C emissions pose an intricate and complex challenge to both science and policymakers, looking for feasible and practical pathways to accomplish the climate outlined set by the Paris Agreement, 2015. For being resilient to climate change, it is vital to reduce the accumulation of GHGs in the environment by enhancing soil C sequestration.The transformation of marginal cropland to forest, rapidly enhance soil C sequestration process. Increased long-term sequestration of Cin soils,beneficial in climate change resiliency (Bai & Cotrufo, 2022). Furthermore, NbS serves as cost-effective complement to technological interventions and further future recommendation for extensive scientific research in IHR.

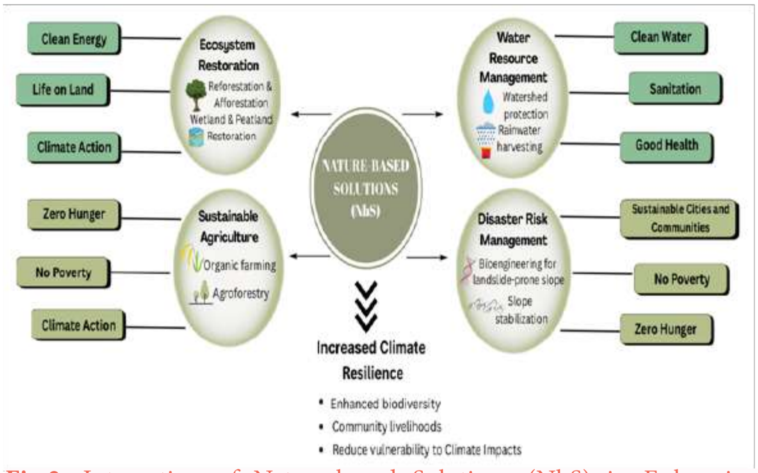

Fig.2. Integration of Nature-based Solutions (NbS) in Enhancing Climate Resilience and Achieving SDGs in the IHR

NbS represents immense potential in providing a sustainable, affordable and effective approach for enhancing C sequestration and fostering climatic resilience in the IHR. Approaches such as utilization of IHR's rich biodiversity, forest cover, sustainable land management and native ecological knowledge effectively addressing both adaptation and mitigation goals. Maintaining native forest biodiversity, encouraging agro-forestry, increase soil organic carbon through sustainable land management vital for C sequestration while preserving biodiversity and livelihoods. However, in order to realize the fully potential of NbS requires integrated policies, cross-border collaborations and active engagement of local citizens. Securing long-term potency required thoughtful investment in developing skills, capacity building, advancing scientific research exploration and establishing monitoring systems. As the Himalayas continuously facing the pressure of climate change and human endeavors, scaling up nature-based solutions serve as a key component for a resilient and sustainable future of this magnificent region. As climate change escalates, investing in NbS come up with a sustainable strategy to shield the Himalayas' ecological integrity and ensure climate resilience. By accentuating these NbS strategies, we can convert these challenges into opportunities, stimulating a balance between development and meteorological supervision is one of the worlds most endangered yet in vital regions.By integrating these strategies into environmental management, we can effectively support climate mitigation while ensuring long term-sustainability in a holistic manner.

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Greywater Management in the Western Himalayas: Scoping Nature-Based Solutions to Reduce Water Footprint and Enhance Climate Resilience

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The Western Himalayas, particularly the hilly districts of Uttarakhand, derive over 90% of their domestic water supply from springs and spring-fed streams (Kumar *et al.,* 2019; NITI Aayog, 2021). The reliability of these sources is declining under mounting anthropogenic and climate-related stresses. The pressure from the rising population, social acceptance of a large environmental footprint lifestyle, sprawl of amenity-driven tourism, etc., have all added to the mounting water demand. On the supply side, factors such as under-planned urban spaces, abandonment of terraced agriculture, forest degradation, and increased wildfire incidences, have disrupted the hydrological recharge cycles, leading to a reduction in spring resurgence and baseflow discharge. Additionally, the climate change (CC) impacts such as increasing acts of erratic precipitation patterns, warming winters, reduced snow retention, etc., further act as a multiplier that further diminishes the groundwater recharge (Rani *et al.,* 2022). This increasingly fragile water security scenario calls for a strategic shift toward diversified and adaptive water management practices. Among the least tapped yet highly promising alternatives is the reuse of greywater—wastewater generated from kitchens, baths, and laundry. In the Himalayan context, greywater offers a secondary, often overlooked, but significant water source, particularly suitable for non-potable and non-contact applications. When managed through decentralized and nature-based solutions (NbS), greywater can play a critical role in reducing freshwater dependency, supporting ecosystem health, and enhancing community-level climate resilience.

Management Potential of Greywater

Unlike blackwater, greywater contains significantly lower levels of pathogens and can be treated and reused safely for non-potable purposes, such as irrigation, toilet flushing, and even aquaculture. The composition of greywater varies depending on lifestyle and water use patterns but typically includes food particles, detergents, oils, and organic matter—making it moderately polluted but easily treatable using low-cost, decentralized methods. If left untreated, greywater can contribute to localized pollution, foul odors, soil degradation, and vector breeding. However, when treated effectively, it becomes a valuable input for domestic reuse, ecosystem restoration, and even livelihood diversification. Globally, greywater management has gained traction as a climate-adaptive strategy in water-stressed countries, e.g., Israel reuses over 85% of its wastewater, including treated greywater, for agricultural purposes, Australia and Spain have implemented greywater reuse guidelines for household irrigation and flushing., etc. Even in urban India, pilot projects in cities like Bengaluru and Pune have demonstrated that treated greywater can meet up to 25–30% of household non-potable demand, significantly reducing the load on freshwater systems. In the Himalayan context, greywater management remains largely unstructured and underutilized. However, its potential for supporting water conservation, ecological health, and local livelihoods, especially through nature-based and decentralized solutions, is immense—and urgently needs mainstreaming into rural and peri-urban water planning.

Available Treatment Technologies

Greywater treatment technologies span a range from physical and chemical methods to advanced biological and nature-based solutions. At the foundational level, physical systems such as sedimentation tanks, grease traps, and multi-layer filtration units (comprising sand, gravel, and charcoal) are often used for pre-treatment. These systems are effective in reducing suspended solids, fats, and odors, but require further treatment for pathogens and dissolved nutrients. In peri-urban areas with moderate greywater loads, compact electro-mechanical systems—such as aerated biofilters or ultraviolet disinfection—can be considered, though their reliance on energy and technical maintenance limits their scalability in rural Himalayan settings. Among the most promising and sustainable options are biological and nature-based systems, particularly constructed wetlands (CWs). Globally, CWs (Figure 1) have emerged as effective, low-maintenance solutions for greywater treatment, especially in countries like India, China, and Brazil. These systems utilize plants, substrates, and microbial consortia to achieve purification through natural processes like sedimentation, microbial decomposition, nutrient uptake, and phytoremediation. A wide range of aquatic macrophytes has shown success in different environmental settings. Notably, Phragmites australis and Typha spp. are recognized for their resilience and high removal rates of nutrients and heavy metals. Other species such as Scirpusgrossus, Lemna minor (duckweed), Azolla pinnata, and Eichhornia crassipes have demonstrated strong performance in various studies, including in colder and mid-altitude Himalayan regions.

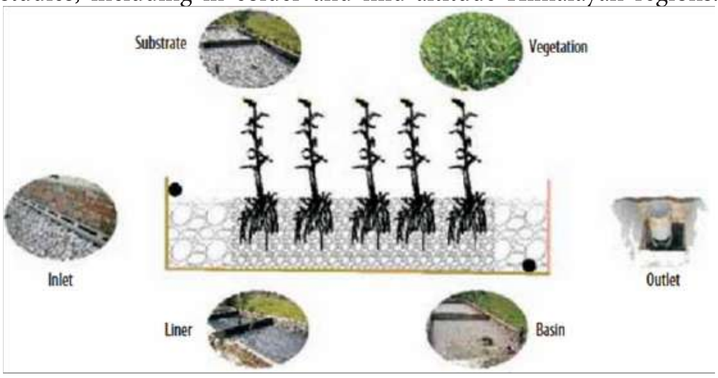

Fig. 1. Various components of CW (Source: Constructed Wetlands Manual (2008), UNHABITAT)

Recent innovations have focused on enhancing CW efficiency using improved substrates. Materials like biochar have gained popularity due to their high porosity, adsorption capacity, and ability to support microbial biofilms. Studies indicate that biochar-based CWs can achieve up to 98% removal of organic matter, 79% of ammonia, and over 60% of phosphorus, with further optimization possible through layering with natural or recycled materials. Hybrid wetland systems—such as vertical flow units followed by horizontal beds—are increasingly employed for staged treatment, with vertical flow wetlands offering superior oxygenation and nitrification potential, and horizontal systems enhancing denitrification (Figure 2). Collectively, these biological and substrate-enhanced systems are ideal for decentralized greywater management in the Himalayas. They align with the principles of low energy use, landscape compatibility, and multifunctionality, supporting both water purification and productive uses such as fodder production and soil moisture retention. Their adaptability across seasons, combined with the ability to be scaled for household, cluster, or institutional setups, make them central to climate-resilient water strategies in mountain areas.

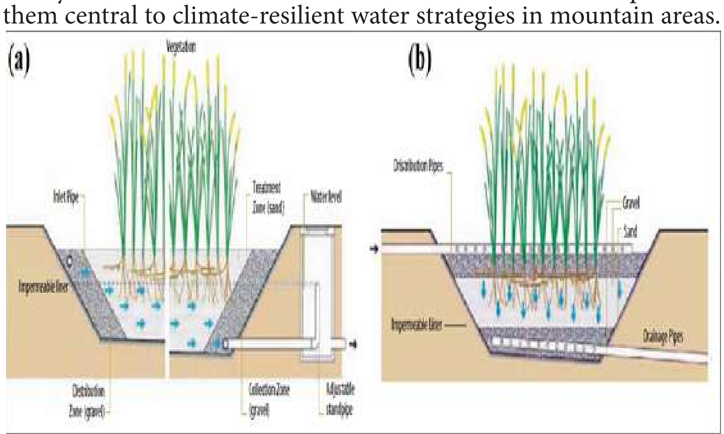

Fig. 2. Schematics of Typical Horizontal and Vertical CWs *(Source:Constructed Wetlands Manual (2008), UNHABITAT)*

Low-cost Decentralized NbS for the Himalayas

In the Himalayan context—marked by dispersed settlements, limited infrastructure, and terrain-induced constraints—the focus must be on decentralized, low-cost, and ecologically aligned technologies that can be managed at the household or community level. While the potential of greywater as a secondary water source is increasingly acknowledged, its practical utilization in the Himalayan region hinges on the deployment of cost-effective, decentralized, and ecologically compatible treatment systems. NbS,

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which mimic and enhance natural processes to treat wastewater, emerge as particularly suitable for the region's scattered rural settlements and topographically constrained landscapes. Unlike centralized systems that demand intensive infrastructure, NbS approaches can be implemented at household, hamlet, or institutional scale, with limited operational cost and technical dependence. One of the most scalable and low-maintenance NbS options is the CW. These systems combine engineered design with natural substrates and plants to filter and biologically treat greywater. Recent global evaluations confirm the growing efficiency of CWs through the use of enhanced substrates like biochar, oyster shells, and recycled construction debris (Santos *et al.,* 2024). Such materials improve pollutant retention, microbial colonization, and hydraulic performance. In Indian and Himalayan contexts, CWs planted with species such as Phragmites australis, Typha angustifolia, and Scirpusgrossus have demonstrated high performance for nutrient, metal, and organic load removal (Gunwal *et al.,* 2021). In locations with limited land availability, vertical flow wetlands and modular biofiltration beds provide compact alternatives. These systems optimize space use and enhance oxygen transfer, which is vital for nitrification. Floating treatment wetlands using duckweed or water hyacinths offer additional options for treating ponded greywater in institutional campuses or peri-urban clusters. Traditional and agroecological approaches also hold immense value. For instance, banana circle pits, filled with organic biomass and planted with banana or taro, treat greywater while yielding fruit and mulch. Similarly, bio-remediation trenches lined with vetiver or bamboo offer low-cost filtration in areas with porous soils. Filter beds composed of sand, gravel, and charcoal, combined with localized soakage structures, have been successfully implemented in multiple Himalayan pilot sites under rural development schemes. To address the rural paradox of low greywater volume but ample land, cluster-based shared treatment units—serving five to ten households—can help optimize both cost and efficiency. These decentralized NbS systems not only reduce environmental pollution but also deliver co-benefits such as fodder production and moisture retention. Ultimately, the application of NbS for greywater treatment in the Himalayas presents a unique opportunity to integrate resource recovery, ecological restoration, and water security in a cohesive, community-led model.

Livelihood Linkages and Resource Recovery

Nature-based greywater systems offer not only water security but also livelihood opportunities. Treated greywater can support kitchen gardens, fodder plots, and biofences, enhancing household nutrition and reducing input costs. Cluster-level systems with CWs can enable pisciculture, using nutrient-rich effluent to rear hardy fish species like Tilapia, provided quality is monitored.Additionally, low-cost hydroponics, fed by filtered greywater, can help cultivate vegetables or microgreens in water-scarce zones. Resource recovery is another benefit—substrates like biochar or oyster shells retain nutrients, which can be reused as soil amendments, while wetland biomass (e.g., Phragmites, Typha) can serve as mulch or compost.When integrated with productive uses, greywater management also income diversificationand community stewardship.

Non-contact Uses of Treated Greywater

Treated greywater, though typically not potable, has significant potential for non-contact applications that reduce demand on freshwater systems. One of the most impactful uses is toilet flushing, which can be implemented through bi-plumbing systems in homes, schools, and public institutions. This alone can save up to 25–30% of domestic freshwater use. Another key application is landscape irrigation—including lawns, roadside plantations, and non-edible ornamental plants—particularly useful in institutional or peri-urban areas. In agricultural settings, treated greywater can safely irrigate non-food crops, such as fiber crops, fuelwood species, or fodder grasses. Additionally, groundwater recharge through filtered soak pits or vegetated trenches is a viable strategy in sloping Himalayan terrain, especially when pre-treatment ensures low pathogen load. These non-contact applications minimize health risks while enhancing water conservation, making treated greywater an important component of climate-resilient water planning in both rural and semi-urban mountain environments.

Addressing the Space–Volume Paradox and Access & Benefit Sharing

A unique challenge in greywater management across the Himalayas is the space–volume paradox. In urban and peri-urban areas, greywater volumes are substantial, but space is scarce—limiting the feasibility of land-based treatment systems. Conversely, rural areas offer ample land, but scattered settlements generate small, dispersed greywater volumes that make household-level systems economically unviable. To bridge this gap, cluster-based greywater treatment units—shared by 5–10 households—present a viable option. These systems co-located on Panchayat or school land, reduce per capita costs and ease operation and maintenance. Ensuring fair use requires clear Access and Benefit Sharing mechanisms: community agreements should define responsibilities, access schedules, and maintenance roles, preferably coordinated by Village Water & Sanitation Committees or local Self-Help Groups. These strategies ensure that equity, efficiency, and ecological fit are embedded in decentralized greywater reuse systems.

Conclusion

Greywater management through decentralized, nature-based solutions offers a practical, climate-resilient pathway for water-stressed regions in the Himalayas. By treating and reusing greywater for non-contact and livelihood-linked applications, communities can reduce freshwater dependency, enhance ecosystem health, and promote sustainable rural development. Cluster-based systems, access-sharing mechanisms, and context-specific technologies like CWs, etc., ensure scalability and equity. To mainstream such practices, emphasis should be placed on awareness building, technical support, and integration into local water governance frameworks, such as the village action plans, Jal Jeevan Mission initiatives, etc. Then only the greywater which is often viewed as waste, can become a critical resource—helping the Himalayan communities to move toward low-footprint, water-secure, and pro-nature development.

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Organic Agroforestry in the Himalayas: Restoring Soils and Strengthening Climate-Resilient Farming

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Agroforestry in the Himalayas is a way of farming that combines trees, crops, and animals to protect the land and improve the lives of local communities. Farmers use different methods depending on the land and climate. In Jammu & Kashmir and Himachal Pradesh, fruit trees like apples and walnuts are grown with crops to make the soil healthier and increase earnings (Raj *et al.*, 2020). In the Western Himalayas, grazing is controlled so that grasslands can grow back and support livestock (Verma et al., 2023). In the Eastern Himalayas, Taungya farming helps trees grow while farmers plant crops (Keprate et al., 2024). Using certain trees like Alnus nepalensis helps enrich the soil (Raj *et al.*, 2020). Agroforestry also stores carbon, helping fight climate change (Singh *et al.*, 2024). Though challenges like a lack of market access and knowledge exist, strong policies can make agroforestry more successful (Keprate *et al.*, 2024).

Common agroforestry practices followed in the Himalayas

Agroforestry systems like agri-silviculture, agri-horti-silviculture, and silvi-pasture are common in the Himalayan region. In the Western Himalayas, farmers grow fruit trees like apple and plum with crops like wheat, maize, and pulses, using trees like Cedrus and Morus for timber and fodder. In the Eastern Himalayas, where shifting farming (jhum) is common, farmers grow banana, jackfruit, spices, and paddy with helpful trees like Acaciaand bamboo. These systems blend traditional knowledge with local needs, improving soil, water, and biodiversity. Practices like Taungya and shaded tea farming support nature and help rural families earn better incomes (Raj *et al.*, 2020).

Agroforestry: Contributions to Resilience Pathways Through Responses to Climate Change

Climate change threatens the Himalayan region's fragile ecosystems and food security. Agroforestry, growing trees with crops and livestock, offers a climate-smart solution by improving soil, biodiversity, and carbon storage. In Northeast India, soil carbon doubled under agroforestry, and Pinus roxburghii grasslands stored high carbon (Raj *et al.*, 2020). In the Central Himalayas, agroforestry stores 4 t C/ha/year, compared to 1.1 t in degraded forests. Globally, hedgerow cropping (India), alley cropping (Malaysia), and home gardens (Indonesia, India) aid carbon capture (Keprate, 2024).

Agroforestry as a climate-resilient farming system to address societal challenges (Enhancing Sustainability and Resilience)

Agroforestry is a traditional land-use practice that offers a powerful nature-based solution for building climate resilience, especially in vulnerable areas like the Indian Himalayas. As rising CO_2, erratic rainfall, and extreme weather threaten ecosystems and livelihoods, agroforestry provides a holistic approach by growing trees with crops and livestock. As shown in Fig. 1 (a), agroforestry also protects biodiversity and uses traditional ecological knowledge to ensure food security, water access, and income diversification. By integrating carbon capture, restoration, and community wisdom, agroforestry builds sustainable, climate-resilient landscapes and supports long-term rural development (Raj *et al.*, 2020).

The Significance of India's Conventional Agroforestry Systems in Fighting Climate Change

Traditional agroforestry systems in India provide a natural and effective approach to climate change mitigation by integrating trees with crops and livestock. As depicted in Fig. 1(b), various agroforestry models significantly contribute to carbon sequestration. Trees Outside Forests (TOF) store 934 Tg of carbon, highlighting the vital role of farm trees beyond forested areas. Fast-growing species sequester 6–8 Mg C/ha/year, while tropical agroforestry systems store 12–228 Mg C/ha, averaging 25 Mg C/ha. In the Central Himalayas, agroforestry sequesters 4 tonnes C/ha/year—more than degraded forests. The Himachal Pradesh model shows a carbon credit value of Rs.21.49/ha, opening avenues for carbon trading. Home gardensin Assam enhance carbon stocks by 6.51–8.95 Mg/ha in three years. Agroforestry also boosts soil health, microbial activity, water conservation, erosion control, and biodiversity. Despite limitations like land-use conflicts and initial costs, supportive policies and incentives can scale up these systems, helping India achieve its net-zero target by 2050 (Raj *et al.*, 2020).

Role of Agroforestry in Natural Resource Conservation in Himalayan Regions

Agroforestry in the Himalayan region emerges as a nature-based solution that enhances soil health, water conservation, and ecosystem resilience, contributing to both sustainable agriculture and climate adaptation. Figure 2 shows the role of agroforestry in conserving natural resources in the Himalayan region. There is a significant benefit, such as 98% soil loss reduction, 95% increase in vegetation cover, and 99% runoff reduction. Agroforestry also aids in reducing soluble salts (69%), dissolved nitrogen (67%), and potassium (43%), while enhancing organic carbon (53%). These results showthe role of agroforestry in improving soil health, controlling erosion, boosting biodiversity, and enhancing resilience against climate-induced degradation in mountainous ecosystems(Raj *et al.*, 2020).

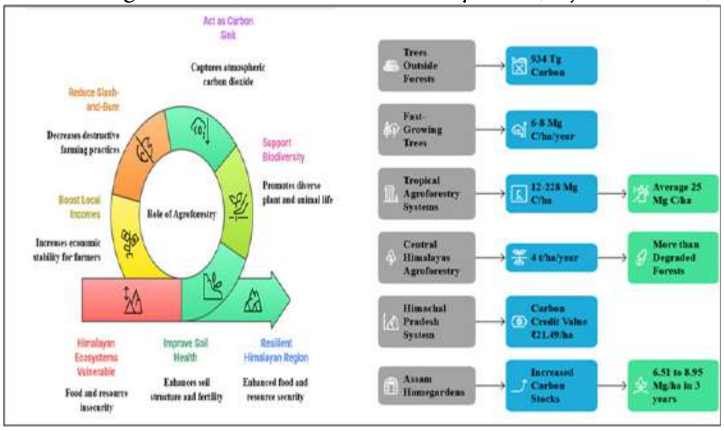

Fig. 1. (a) Multifunctional Role of Agroforestry in Combating Climate Change in the Himalayan Region,(Raj *et al.*, 2020) (b) Carbon Sequestration Potential of Diverse Agroforestry Systems in India, (Verma *et al.*, 2023)

Comparative Analysis of Investment, Returns, and Rate of Return across Agroforestry Systems

At the national level, various tree-based farming systems have the potential to generate additional 30–50 man-days of employment per hectare per year. Figure 3 compares six agroforestry systems based on investment, returns, and rate of return per year. Agri-horticulture gives the highest returns (over Rs.4500 crores), with high returns even after high investment. Agri-silviculture also performs well with high returns and the highest rate of return (over 160%). Silvi-pasture shows high investment but lower returns and the lowest return rate (around 90%). Agri-horticulture has the lowest investment and returns. Overall, irrigated systems give better profits than rainfed ones. Agri-silviculture and Agri-horticulture are the most profitable options based on return rates and income generated (Singh *et al.*, 2024).

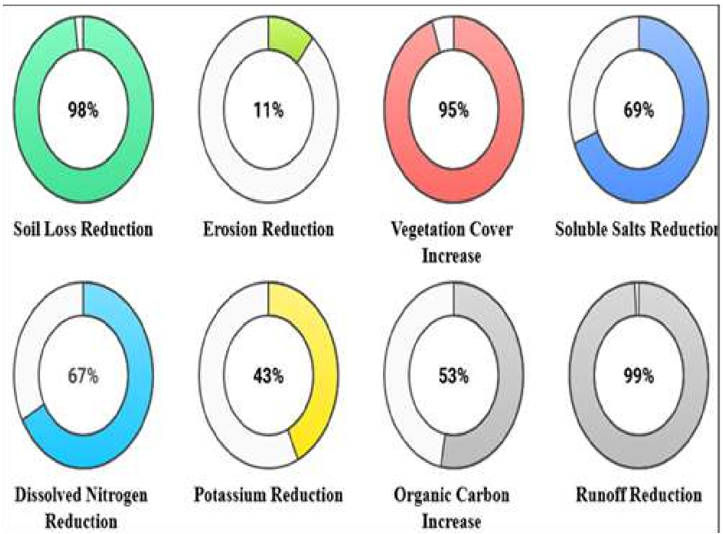

Fig. 2. Role of Agroforestry in Natural Resource Conservation in Himalayan Regions (Raj et al., 2020)

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Agroforestry in the Himalayas is a powerful approach that combines trees, crops, and livestock to restore soil health, protect biodiversity, and improve rural livelihoods. It helps prevent erosion, enhances water conservation, and stores carbon, making it a natural solution for climate change adaptation and mitigation. Different Himalayan regions use agroforestry practices suited to their environment, such as fruit-tree farming, seasonal grazing, and mixed cropping. Despite its advantages, problems including limited market access and knowledge gaps prevent its extensive use. By strengthening regulations and raising awareness, its full potential can be realized, providing sustainable farming and a resilient future for communities in the Himalayas.

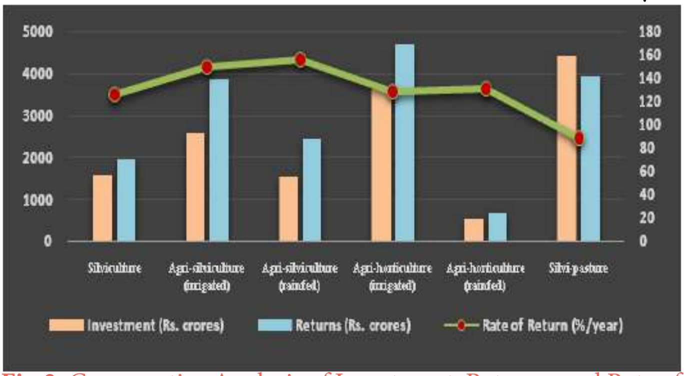

Fig.3. Comparative Analysis of Investment, Returns, and Rate of Return Across Agroforestry Systems (Singh *et al.*, 2024)

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Revitalising Himalayan agricultural practices through biochar in response to climate change adaptation

The Himalayas, a mighty mountain system known for its stunning display of nature grandeur, incredible biodiversityand vibrant traditional agricultural practices plays a pivotal role in influencing the climate across the region. The Himalayas are more than a natural marvel—they are home to millions who depend on agriculture for survival, yet amidst this beauty climate change is reshaping the landscape bringing unpredictable rains, degrading soils, and reducing the productivity of once-thriving agricultural systems (Tiwari *et al.,* 2020). Throughout history, Himalayan agriculture has revolved around a subsistence-based farming, centering family based agricultural production approach. The Himalayan agro-ecosystem has been described being fragile, isolated, and inaccessible and lack of infrastructure, despite of such constraints the agricultural system in the Himalaya has sustained over years but its sustainability power been severely challenged by ongoing climate change, predominantly affecting traditional agricultural practices in IHR followed by soil deterioration, erratic rainfall reduction and diminish soil fertility. As a result, SOM depletion, disappearing microbial communities and crops are struggling to thrive. To address these issues, researchers have been exploring sustainable solutions. Biochar is an eco-friendly, carbon-rich organic product generated through the pyrolysis of organic biomasses, including biochar-based material derived from renewable resources, under oxygen free conditions (Tomczyk *et al.,* 2020). It is a stable by-product of carbonizing plants, animals, and industrial wastes (Lehmann *et al.,* 2021) that improves soil physicochemical and biological properties.Ongoing impacts of climate change presents a serious threat to humanity and meeting global food security demands. Climate change concerns in the Himalayas are multifaceted encompassing floods, droughts, landslides human health, biodiversity, endangered species, agriculture livelihood, and food security (Mirzabaev *et al.,* 2023).The Himalayan states, facing the wrath of climatechange, productivity of traditional farming methods are beingincreasingly challenged due to various ongoing climatologicalchanges and natural disasters. Climate and the Himalayan agricultural system: Challenges The agricultural system of Himalayas, integrally related to the region's ecological equilibrium, encounters significant challenges from intensified climate change. The variability in topography and climate represents unique challenges. Region's geographical isolation, ecological vulnerability and limited accessibility exacerbated by some factors viz., moisture stress, GHGs emissions, less organic matter, incompetent nutrient absorption and declining soil health significantly retard agricultural productivity. Additionally, socioeconomic limitations including tiny landholdings, lack of infrastructure and labor, limit the utilization of resources, and provide less excess. The farming communities of Himalayas predominantly depend on subsistence farming, cultivating tiny rainfed plots along with limited irrigated farmland to sustain their livelihoods. The impact of climate change, manifested by uncertain weather phenomena such as floods, landslides, and ecological disturbances, further complicates the agricultural challenges in the Himalayan region. These factors have contributed to a rise in the abandonment of agricultural land in the Himalayan region (Tiwari and Joshi, 2015). In hill agricultures, fertilizer retention capacity of lands, till the crop roots uptake it, is limited due to shallow layer of soil, low to high degree of slope and frequent runoffs after stormy rains. Farmers traditionally use farm-yard manure (FYM) as a significant source of organic matters based on local knowledge and techniques (Bajracharya and Sherchan, 2009). With the advent of changing agricultural practices from low intensity (subsistence oriented) to more intensive cropping (commercial), farmers depend more on chemical fertilizers rather than FYM. Given the diminishing trend of FYM inputs throughout the country, some urgent measures to tackle the issue are imperative. Locally produced biochar could be a potential answer to this solution.

Bringing old and new together: Biochar and traditional farming

In the Himalayan foothills, where the undulating landscapes narrate tales of resilience and adaptation, traditional farming practices have sustained communities for generations. Sustainable agriculture envisages efficient utilization of agricultural waste in a way that it does not deplete the existing nutritious entities of the soil and replenish it in the long run soil (Komat suzaki and Ohta 2007). One of the approaches is locally produced biochar, a carbon-rich material, produced by the pyrolysis of organic biomass offers a promising pathway towards climate change mitigation and sustainable agriculture practice in IHR, hence referred as "waste to wealth"

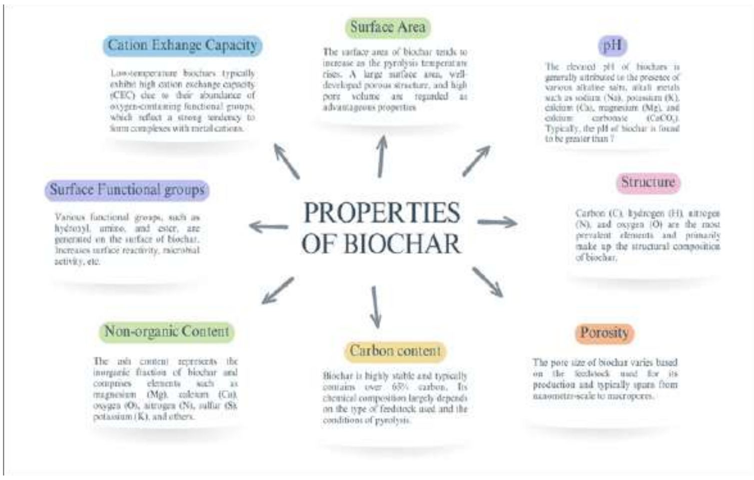

Fig.1. Physico-chemical properties of biochar

(fig 2.). Biochar has gained attention for its benefits in agriculture, especially for improving soil health and carbon sequestration. Physical and chemical properties, as well as production conditions, play an important role in functional properties such as adsorption characteristics, surface area, porosity, alkalinity and carbon content of biochar and its efficiency. The majority of biochar research has focused on the impact of biochar and its application potential in tropical agricultural soils, its use not only supports sustainable farming practices but also contributes to reducing the impacts of climate change Singh (Yadav *et al.*, 2023). Properties of biochar determine the way how biochar functions within soil and its potential to act as a route to sequestration of atmospheric carbon dioxide Figure1 (Downie *et al.*, 2009).

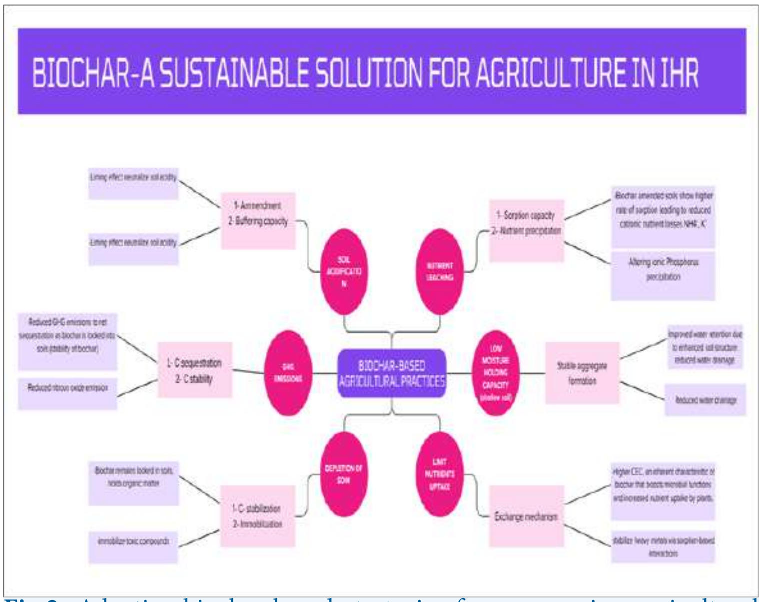

Fig.2. Adaptive biochar-based strategies for overcoming agricultural limitations considering climate change in the IHR

Conclusion

Since the Himalayas face the mounting challenges of climate change, it's time to rethink agriculture not just as a way to survive, but as a way to heal. In this fragile yet fiercely resilient region, biochar offers more than just a fix for tired soil. It tells a story of renewal. It breathes life back into the land, holds carbon where it belongs, and gives farming communities a stronger foothold in an uncertain future. However, the most potent thing about biochar is how it unite worlds. It embraces modern innovations with profound knowledge that has been passed down through generations. It satisfies the current urgency of the moment but keeps its roots firmly in the future. In the Himalayas, where every patch of earth matters, biochar isn't just a soil enhancer it's a bridge between past and future, survival and regeneration, people and planet. Biochar presents a promising, sustainable solution to the agricultural and environmental challenges of the Indian Himalayan Region. By enhancing soil health, improving crop productivity, and sequestering carbon, it offers a path toward climate-resilient farming. However, its effectiveness depends on factors like feedstock, production methods, and long-term ecological impact. With careful application and further research, biochar can play a vital role in revitalizing traditional Himalayan agriculture while supporting climate change adaptation. Biochar could help rejuvenate Himalayan agriculture and offer a way towards solution of climate uncertainty. Himalayan smallholder relies on traditional agricultural practices such as terrace farming, organic composting, mixed cropping, and livestock integration. These practices maintain soil health and support biodiversity. However, these practices are facing multiple vulnerabilities in response to climate change including soil erosion, drought and yield declination. Himalayan agriculture encouraged through scientific innovations such as biochar that must be consolidated with traditional wisdom to build resiliency in response to climate change.

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Nature-Based Solutions for Climate Resilience: Integrating Biodiversity into Sustainable Development in Himalayan Agroecosystems

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The Indian Himalayan Region (IHR) is a vital ecological area that influences the climate and freshwater systems for a significant portion of South Asia. It hosts a wealth of biodiversity and culturally rooted knowledge systems, yet this area is currently facing intense challenges due to climate change, land degradation, and the decline of traditional livelihoods. The effects are particularly severe in agroecosystems, where smallholder farmers rely greatly on natural resources and biodiversity for their existence. In response to these challenges, Nature-Based Solutions (NbS) strategies that protect, restore, and sustainably manage ecosystems to tackle societal issues have surfaced as a promising approach to align human well-being with ecological stability. This article examines how Nature-based Solutions (NbS), which are based on the biodiversity found in Himalayan agroecosystems, provide effective and scalable methods for climate adaptation, sustainable development, and food security. By referencing practical field experiences and case studies gathered from the region, we analyse how the incorporation of biodiversity into agricultural practices benefits both the environment and communities (Fig.1).

Fig.1. Nature-Based Solutions (NbS) Solutions: Traditional Practices and their impact on Himalayan Ecosystems

Biodiversity-Rich Farming: A Time-Tested Tradition

The traditional agricultural methods in the Himalayas are naturally rich in biodiversity. Farmers grow a variety of crops like millets, pulses, tubers, and indigenous vegetables alongside fruit trees and medicinal herbs. These diversified cropping practices not only decrease the chances of crop failure but also enhance soil health, promote water retention, and aid in pest management. For instance, in Uttarakhand's mid-hills, it is common for farmers to sow madua (finger millet), jhangora (barnyard millet), and legumes in the same field. This variety serves as a built-in safeguard against unpredictable weather and pest issues (Pande *et al.*, 2016). Raising livestock and incorporating agroforestry contribute to the overall resilience of the system. The fallen leaves from trees serve as compost, and the animals offer manure and labour. This mutual reliance among the various elements establishes a self-sustaining cycle, lessening the need for external resources like chemical fertilizers and pesticides.

Agroforestry: Trees as Climate Allies

One of the most efficient nature-based solutions in Himalayan agriculture is agroforestry, which involves incorporating trees into farming systems and landscapes. In Himachal Pradesh and certain areas of Sikkim, species such as Alnusnepalensis (alder), Quercus spp. (oak), and Grewiaoptiva are often grown alongside grains and vegetables. These trees help stabilize slopes, prevent soil erosion, improve local climate conditions, and increase soil organic carbon levels. In addition, they provide essential resources like timber, fodder, and fuelwood, which are vital for households in mountainous regions (Devi *et al.*, 2023) Agroforestry enables farmers to adjust to climate-related threats while also reducing carbon emissions. Research indicates that farms featuring tree cover capture much more carbon in both plant material and soil compared to monoculture farming. This supports India's Nationally Determined Contributions (NDCs) as outlined in the Paris Agreement, emphasizing Nature-based Solutions (NbS) as a key instrument in climate policy.

Landscape Restoration: Reviving Degraded Lands and Springs

Climate change has resulted in the depletion of springs and heightened soil degradation throughout the Himalayas. Restoration of landscapes through community involvement has shown effectiveness in mitigating some of these issues. In Uttarakhand, participatory initiatives have targeted the revival of damaged watersheds by implementing trenching, replanting native vegetation, and constructing contour bunds. These initiatives enhance groundwater recharge, lower the risk of landslides, and rehabilitate habitats for plant and animal species (Pant *et al.*, 2024). Spring rejuvenation initiatives, especially, have produced extensive positive effects. Revitalized springs not only guarantee water supply for drinking and agriculture but also foster biodiversity-rich areas like riparian forests and grasslands. These initiatives flourish when backed by local organizations such as Gram Panchayats and Biodiversity Management Committees, merging ecological restoration with community empowerment. Case Study: Women-Led Biodiversity Farming in Almora In a cluster of villages near Almora, women farmers have demonstrated how traditional knowledge and biodiversity can lead to climate resilience. With support from local NGOs, these women have revived abandoned terraces using organic techniques and traditional seeds. Crops such as mandua, jhangora, and kulath (horse gram) have replaced chemical-intensive hybrids. These varieties are drought-tolerant, nutritionally rich, and culturally significant (NMHS Reports, 2023). The initiative has resulted in:

- Improved household nutrition through diverse diets.
- Increased incomes by selling high-value traditional grains in niche urban markets.
- Enhanced soil health and water retention through organic practices.

This model is now being scaled up in neighbouring districts, illustrating how biodiversity-led NbS can support both livelihoods and ecosystems.

Bridging Policy and Practice: Scaling Nature-Based Solutions

Although traditional methods are crucial for Nature-based Solutions (NbS), appropriate policy frameworks need to facilitate their integration. The National Mission on Himalayan Studies (NMHS) and the State Action Plans on Climate Change already prioritize ecosystem-based adaptation. Nevertheless, the execution remains disjointed (Bhatt *et al.*, 2020). To effectively expand NbS, the following steps are necessary:

- Institutional Support: Empowering Biodiversity Management Committees and Van Panchayats to oversee local resource management.
- Incentives: Acknowledging and compensating for ecosystem services such as soil carbon sequestration and pollination.
- Capacity Building: Educating farmers, particularly women and youth, in agroecology and climate-smart agricultural practices.

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•Market Linkages: Developing value chains for traditional crops to guarantee economic sustainability.
Digital tools such as participatory GIS, e-commerce platforms for local products, and community radio can improve awareness and adoption of NbS while honouring cultural contexts.

Conclusion

Nature-Based Solutions encompass more than just technical approaches they are avenues to restore balance with the natural world. In the agroecosystems of the Himalayas, these solutions are integral to age-old traditions that harmonize biodiversity with resilience and progress. By revitalizing and modifying these practices to confront emerging challenges, communities in the Himalayas are not only preserving biodiversity but also actively crafting a more sustainable and inclusive future. As we celebrate the International Day for Biological Diversity, let us acknowledge that the Himalayas can set an example in illustrating how the integration of biodiversity with human development can become a source of strength and sustainability. Investing in Nature-Based Solutions today represents a commitment to a climate-resilient Himalaya for generations to come.

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Exploring Mammalian Biodiversity and Conservation Challenges in a Fragile Himalayan Ecosystem of Sainj

The Sainj Valley is a vital part of the Great Himalayan National Park Conservation Area (GHNPCA), a UNESCO World Heritage Site known for its exceptional biodiversity, and is tucked away deep within the Western Himalayas of Himachal Pradesh. Sainj Valley is scattered across 528.99 square kilometers, this valley is roughly 49 kilometers from Kullu. It is situated between latitudes 31°43'3" to 31°54'51"N and longitudes 77°13'28" to 77°35'48"E. A diverse range of ecosystems, including alpine meadows and subtropical woods, are supported by its altitudinal range of 981 meters to 5,366 meters. A vital hydrological function in the area is played by the Sainj River, which rises from the Raktisar Glacier (+5500 m) and its tributaries, which support aquatic life and feed into the Beas River. An average temperature of 20.6°C and 1,387 mm of rainfall per year characterize the valley's climate, with the upper reaches seeing the most of the region's substantial 345 millimeters of snowfall per year. The Sainj Valley has many urgent conservation issues despite its biological significance. Despite its biological significance, the Sainj Valley confronts numerous severe conservation challenges. Road expansion, hydropower construction, and agriculture are all causing habitat fragmentation, which is deteriorating natural corridors that are critical for wildlife movement. Climate change affects species distribution, migration patterns, and food availability. Illegal hunting and animal trade continue to pose risks, while unregulated tourism to picturesque areas such as Shangarh, Pundrik Rishi Lake, Lapah, Shakti, and Marore causes human-wildlife conflict and environmental pressure in this delicate terrain. The purpose of this study is to document Sainj Valley's animal biodiversity and investigate conservation threats. A questionnaire survey was used to collect data from 224 houses across the region. Residents' ecological knowledge was reinforced with secondary data from peer-reviewed literature, government databases, and the Himachal Pradesh Forest Department. The rich and diverse mammalian diversity of the Sainj Valley is one of its most important biodiversity components, and it is essential to preserving the area's ecological integrity. Numerousecologically significant animal species—many of which are native to the Western Himalayas and under peril worldwide—can be found in the valley. These include the Himalayan Brown Bear (Ursus arctos), the Himalayan Tahr (Hemitragus), the Musk Deer (Moschus), and the rare and endangered Snow Leopard (Pantherauncia), all of which rely on untouched alpine and subalpine environments to survive. As keystone herbivores, apex predators, and regulators of prey, these mammals perform essential ecological roles that support the balance of the environment and healthy trophic relationships. This Valley supports mammals like Yellow-throated Martens, rodents, and bats. These species aid in seed dispersal, soil aeration, and ecosystem stability while serving as bioindicators of environmental health. Preserving this mammalian diversity is vital for ecological balance and the unique evolutionary heritage of the Himalayas. This article integrates ecological data with community viewpoints to demonstrate the abundant animal life in the valley. To preserve the area's natural and cultural heritage, it emphasizes the critical need for community-based conservation, habitat preservation, education, and anti-poaching measures.

Table 1. Mammalian Species Recorded in Sainj Valley with Verification Sources

Sl. No.	Zoological Name	Common Name	Range	Reference
1	Pseudois	Nayaur	Above tree line	mammals-great himalayan national park
2	Ursus arctos	Himalayan brown bear	Alpine medow	mammals-great himalayan national park
3	Panther a unica	Snow leopard	Above tree line	(Pandey *et al.*, 1997)
4	Hemitragusjeml ahicus	Himalayan tahr	Above tree line	(Pandey *et al.*, 1997)
5	Moschus Moschiferus	Musk dear	2000-3000m	mammals-great himalayan national park
6	Nemorhaedus sumtraensis	Serow	2000-3000m	mammals-great himalayan national park

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7	Muntiacus muntijak	Barking dear	2000-3000m	mammals-great himalayan national park
8	Naemorhedus goral	Ghoral	2000-3000m	mammals-great himalayan national park
9	Ursus thibetanns	Black Beer	2000-3000m	(Pandey *et al.*, 1997)
10	Panthera pardus	Common leopard	2000-3000m	mammals-great himalayan national park
11	Macaca Mulatta			
12	Semnopithecus schistaceus	Central Himalayan Langur	1600-3400	(Gaston *et al.*, 1981)
13	Petaurista Petaurista	Red Giant Flying Squirrel		H.P. Forest Department records
14	Alticola roylei	Royle's Mountain Vole		(Sharma *et al.*, 2017)
15	Hystrix indica	Indian Crested Procupine		H.P. Forest Department records
16	Apodemus Pallipes	Himalayan Field Mouse		(Sharma *et al.*, 2017)
17	Rattus rattus	Common House Rat or Black Rat		(Sharma *et al.*, 2017)
18	Mus booduga	Little Indian Field Mouse		H.P. Forest Department records
19	Mus musculus	House Mouse		(Sharma *et al.*, 2017)
20	Lepus nigricollis ruficaudatus	Rufous-tailed Hare		(Sharma et al., 2017)
21	Ochotona roylei	Indian Royle's Pika		(Sharma *et al.*, 2017)
22	Prionailurus bengalensis	Leopard Cat		H.P. Forest Department records
23	Lynx lynx	Eurasian Lynx		(Sharma *et al.*, 2017)
24	Paguma larvata	Masked Palm Civet		(Sharma *et al.*, 2017)
25	Herpestes edwardsii	Indian Grey Mongoose		(Sharma *et al.*, 2017)
26	Canis aureus	Golden Jackal	1600-4000	(Gaston *et al.*, 1981)
27	Vulpes vulpes montana	Red Fox	1600-4000	(Gaston *et al.*, 1981)
28	Lutra lutra	European or Eurasian river or Common otter		(Sharma *et al.*, 2017)
29	Martes Foina	Beech or Stone Marten		(Sharma *et al.*, 2017)
30	Martes Flavigula	Yellow throated Marten	1600-3700	(Gaston *et al.*, 1981)
31	Mustela siberica	Siberian Weasel		(Sharma *et al.*, 2017)
32	Sus scrofa	Wild Pig		(Sharma *et al.*, 2017)
33	Moschus leucogaster	Himalayan Musk Deer		H.P. Forest Department records

Faunal Species in Sainj Valley

The biodiversity was assessed using questionnaire surveys of 224 houses in the Sainj Valley. Additionally, the list of animals mentioned was validated with other academic articles and government agency websites (Table 1).

Conservation Challenges

Habitat Fragmentation

Road building, hydropower infrastructure, and growing agricultural are the main causes of habitat fragmentation in the Sainj Valley. These operations affect the travel and breeding routines of species by dividing the continuous forest cover into separate patches. Because they require large areas, large species like the snow leopard and Himalayan tahr are most impacted.

Climate Change, altering migration patterns and food availability

Climate change is altering global temperature and weather patterns, impacting wildlife habitats. Many mammals have varied migration patterns and seasonal behaviours. Changes in food supply and environmental conditions threaten their survival and reproduction. Overall, climate change raises stress and jeopardizes the stability of animal populations worldwide.

Poaching and Illegal Trade

The Sainj Valley's mammalian biodiversity can be seriously threatened by poaching and the illegal wildlife trade. The demand on the illicit market is fueled by the fact that many animals might be targeted for their valuable body parts. Ecological balance may be upset and population levels may decline as a result of this illegal action. Stronger law enforcement and community involvement are necessary to combat poaching and safeguard these endangered species. However, the forest department is doing an outstanding job in this field.

Tourism Pressure in sensitive zones

The Sainj Valley's delicate ecosystems are under further stress due to tourism pressure in vulnerable areas including Shangarh Meadows, Pundrik Rishi Lake, and Barshangarh Waterfall. Well-known locations like the Great Himalayan National Park and the Shangchul Mahadev Temple draw large numbers of tourists, which disturbs the environment and causes pollution. Uncontrolled tourism disturbs the behavior and reproduction of wildlife in these regions. Ecological biodiversity is further threatened by increased foot traffic and trash production. In order to preserve these priceless natural and cultural landmarks, sustainable tourism must be promoted.

Recommendations and Way Forward

Research on important species and their habitats must be strengthened, as well as ecological monitoring, to guarantee the long-term preservation of mammalian biodiversity in the Sainj Valley. Finding and preserving wildlife corridors will help to promote species mobility and lessen habitat fragmentation. Expanding community-based conservation and ecotourism programs is necessary to offer sustainable livelihood opportunities and encourage stewardship among residents. To reduce the ecological effects of development projects, such as roads and hydropower, stringent controls are also required. The maintenance of conservation efforts in this delicate Himalayan ecosystem will also depend heavily on awareness and capacity-building initiatives, particularly those aimed at young people and regional stakeholders.

Conclusion

The Sainj Valley's mammalian biodiversity faces a number of serious conservation obstacles. Wildlife corridors are disrupted and populations are isolated as a result of habitat fragmentation brought on by growing agriculture, road building, and hydropower projects. By changing migratory patterns and decreasing the amount of food available to many animals, climate change makes survival even more difficult. Direct dangers come from poaching and illegal trading, which target animals for valuable body parts and cause population decreases. Furthermore, wildlife is stressed and habitat is disturbed by the strain of tourists in delicate areas like Shangarh Meadows and Pundrik Rishi Lake. To address these issues and protect the valley's distinctive animal species, comprehensive, community-inclusive conservation initiatives are needed.

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Role of Women in Biodiversity conservation: Challenges and Opportunity

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The 21st century global community is facing severe environmental stress like climate change, biodiversity loss etc. directly linked to anthropogenic activities. In this crucial setting,Women's contributions to biodiversity protection are not just complementary but essential. From their crucial involvement in scientific research and policy advocacy to their essential traditional ecological knowledge and leadership in grassroots efforts, this article examines the diverse contributions made by women. Principle 20 of the "RIO Declaration on Environment and Development (1992)"states that "Women have a vital role in environmental management and development". In 1991, the World Bank stated that "Women play an essential role in the management of natural resources, including soil, water, forests and energy and often has a profound traditional and contemporary knowledge of the natural world around them". Their full participation is therefore essential to achieve sustainable development. Women have walked a long way to reach from consumers to decision-makers, however their role is still limited to the selection and storage of seeds, managing livestock, cultivating different plant variety etc. This article shed light on the challenges faced by women community and various opportunity which has strengthened their role in the society.

Traditional Ecological Knowledge (TEK)

Women are the custodian of Indian Traditional Ecological Knowledge (TEK) which includes knowledge of medicinal plants, food production, water governance, and sustainable natural resource management. This information is frequently transmitted orally and through practical experience across generations.Rich biodiversity and healthy ecosystem go hand in hand and are the foundation for human wellbeing. Home garden serves an essential additional food source and financial support to women community alongside species conservation and diversification. Women play important roles in herbal medicine. The world's oldest and most popular cultivation systems are home gardens, which are maintained by women. Within the QUINCHUA tribe (EQUADOR), female herbalists are able to describe the efficacy of herb-disease combinations, which employ roughly 350 plants (Pal, 2014).Shiva and Dankelman (1992) conducted a survey in Dehradun and recorded over 140 plant species that the local female population knew about and used. The successful Chipko Movement of 1973 in Uttrakhand witnessed the active participation of women to raise awareness about the protection and conservation of forest ecosystem.

Feminization of Agriculture

It's believed that women have been involved in plant management and conservation for as long as agriculture.Throughout the ages, women have maintained and conserved plants because of their domestic requirements, including food, medicine, building and craft supplies, adornment, revenue generating, religious activity, and trade. The FAO has reported increasing role of women in the agriculture

Fig. 1. Women participation in Capacity building Training

sector. It should be noted that women hold title to less than 2% of the world's private land. Their role is also limited due to financial dependency as there are more than 70% of them under poverty in the world (Deda & Rubian, 2004). There are little incentives for women for their role in agriculture. Lack of access to education limits their role to traditional knowledge only. It is estimated that 90% of the women in the world gain their survival form land. In developing nations, women leads 30% of households, they accounts for 80% of the food production in sub-Saharan Africa, compared to 60% in Asia and 50% in Latin America (Mahour, 2016). A per World Band data, the female participation in agriculture has increased from 1.2% to 1.4% in 2011-2014. As per National Sample Survey Organization (NSSO) data, almost 84% of women worked in agriculture in 2004–05, compared to 67% of men. The feminization of agriculture is majorly due to outmigration of men for better financial opportunities, as small land holding does not fetch enough revenue to support whole family.

Table 1. Workforce Participation rate.

CENSUS YEAR	WORKFORCE PARTICIPATION RATE (%)		TOTAL FEMALE PARTICIPATION (%)
	Men	Women	
1991	51.5	22.3	28.6
2001	51.8	25.6	31.6
2011	53.3	25.7	31.2

Source: I. (Pattnaik *et al.,*)

Limited representation in Decision making

Various International forums such as Rio Declaration, Rome Declaration, and UN Women Conference have advocated increased women's participation and acknowledged their contribution in food security.The Convention on Biological Diversity (CBD) emphasized on the women's role as in policy making as the crucial component for biodiversity conservation. However Leadership and Decision – making platform are heavily dominated by men. Traditional gender norms and innate prejudices that are still pervasive in many countries lower the overall effectiveness of conservation projects. As per the statistical records of global platform, Women make up fewer than 30% of worldwide conservation professionals (WWF), only 23% of senior positions in environmental organizations (IUCN), and just 17% of members of environmental governing bodies (UNEP). With higher participation of women in policy making reflects more environmental related treaty and laws passed.

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Nurturing Young Minds for a Sustainable Future

Low participation of women in Research and Development

Globally, women are still underrepresented in research and development. According to UNESCO, 2024 women accounts for only 31% of researcher community worldwide. Compared to the US, Australia, and Germany, India has a greater percentage of female STEM graduates (42.7% in 2018). However, as they move from STEM school to careers, a sizable portion of them drop out. According to World Bank figures, women make up just 27% of India's STEM employment. In India Govt. has started various initiatives to increase women's participation in STEM such as Fellowships for higher education, increased quota in seats for women reservation etc.

Ecosystem degradation

Ecosystem degradation and climate extremities severely affect women lives and livelihood. As a "threat multiplier," climate change exacerbates pre-existing social and economic strains that contribute to a rise in child marriage, human trafficking, and gender-based violence in vulnerable and conflict-affected regions. Additionally, there are serious health effects; excessive heat raises the risk of stillbirth, and rising global temperatures aid in the spread of vector-borne diseases including dengue fever, and malaria. Moreover, the loss of biodiversity threatens sustainable practices and traditional knowledge, which in turn threatens women's safety, identity, and agency as well as the general well-being of the community and cultural heritage.

Conclusion:

The SDG 5 on "Gender Equality" focuses on upliftment of women's role in Science and technology, decision-making, conservationist to enhance biological diversity. Despite these obstacles, women remain important change agents in the conservation of biodiversity.From keeping the home clean to serving as a prime example of Rachel Carson's "Silent Spring" in bringing attention to the damaging use of pesticides, women's power has become a global standard.Women's empowerment is not just a social justice issue; it is also a critical environmental sustainability strategy. Uplifting women's stature in global platform is in concurrence with Environmental protection and Biodiversity conservation.

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The rapid decline in biodiversity and increasing environmental deterioration underscore the urgent need for formal education to be refocused on empowering local people and addressing environmental and developmental issues. The involvement of the younger generation is essential to this change, as they will be the ones making decisions in the future and are also the ones most affected by current environmental decisions. As the primary stakeholders, they have the legal and ethical right to be involved in determining the laws and policies that will affect their future (Natori *et al.*, 2025). Recognizing this, global initiatives in eco-smart biodiversity and environmental education that extend beyond traditional classrooms are strategic attempts to advance sustainability and conservation, contributing to the achievement of SDG Goal 4 ("Quality Education"). National initiatives in India have played a significant role in expanding the reach of conservation education by promoting experiential and community-based learning. Together, these efforts are transforming environmental education into a powerful tool for cultivating ecological awareness, local stewardship, and long-term resilience. This approach is especially important in the ecologically fragile, culturally significant, and biodiversity-rich Indian Himalayan region. In this context, reoriented education can help mountain communities, particularly young people, care for their unique habitats, ensuring that conservation is based on both scientific understanding and traditional ecological knowledge. Students as Environmental Ambassadors Students play a crucial role in global environmental sustainability as emerging conservation advocates. They bring fresh perspectives, genuine concern, and natural curiosity to environmental challenges. As future inheritors of the earth, children can actively shape the present through environmental education that promotes a connection to nature and responsible behavior. When students understand the importance of clean air, water, healthy forests, and balanced ecosystems, they develop mindful habits such as reducing waste, conserving energy, and reusing materials. These practices, when consistently reinforced, lay the foundations for environmentally conscious adulthood. Students serve as effective environmental ambassadors through various means (Table 1).

Area of Impact	Role of Students
Communication and Advocacy	Express environmental concerns through school projects, writing, art and digital media.
Direct Action	Engage in tree planting, clean-up drives, and awareness campaigns to demonstrate stewardship.
Family and Community Influence	Share classroom learning at home to promote eco-friendly habits and inspire community change.
Leadership Initiatives	Organize clubs, lead sustainability projects, coordinate recycling, join global movemets.
Innovation and Solutions	Offer creative and simple solutions to complex environmental problems.
Peer Education	Communicate environmental messages effectively within their age group for relatable impact.

Core Training Modules and Activities

Global organizations, such as UNESCO and the Earth Charter initiative, advocate for shifting from conventional teaching to nature-based, hands-on, and experiential pedagogy. These approaches bridge classroom instruction with real-world experiences, promoting a deeper understanding of biodiversity conservation and encouraging active stewardship among students, teachers, and communities.India's National Education Policy (2020) envisions environmental learning integrated into the grassroots curriculum. Various schools, educational institutions, and NGOs work to sensitize future leaders through nature-based and extracurricular activities. For mountainous regions, (Dhar *et al.*, 2002) outlined six key training modules (Figure 1): biodiversity definition and dimensions, status assessment and monitoring, value and value addition, maintenance, methods for re-vegetating degraded lands, and linking biodiversity with ecosystem components. Common experiential learning activities include rapid appraisal techniques, drawing and storytelling exercises, group discussions, on-site demonstrations, waste management activities, nature treasure hunts, trail visits, camps, and eco-clubs. "Citizen science" involves students filling biodiversity data gaps worldwide through tools such as eBird, iNaturalist, the Indian Biodiversity Portal, Season Watch, and Migratory Watch.

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Fig.1. Key conservation education modules developed by GBPNIHE

Photoplate 1: Training and Awareness activities at Suryakunj, GBPNIHE

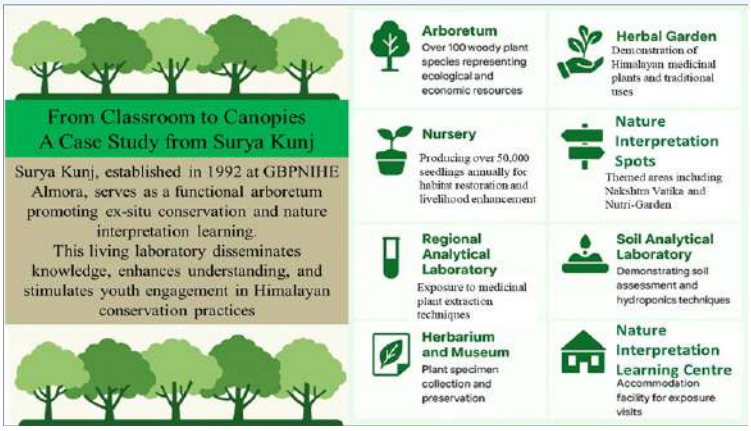

Fig.2. A Case Study from Surya Kunj, a 71-acre eco-restoration site established in 1992 at the Govind Ballabh Pant National Institute of Himalayan Environment (NIHE) in Almora, India, as an example of participatory forest management and restoration (Mishra and Uniyal., 2024).

Awareness to Action

Conservation education creates ripple effects that transform communities from global to local scales. It builds sustainable futures by helping students and communities understand, care for, and take responsibility for nature. When implemented effectively, it transforms thinking and behavior, influences communities, and shapes policies while providing the knowledge and skills necessary to face environmental challenges. Nature based education (NBE) improves students environmental attitudes more than traditional classroom teaching (Collado et al., 2020). It utilizes outdoor settings to provide real-life environmental experiences, helping students develop a deep understanding and emotional connection with nature. Studies show NBE improvestudent's environmental attitudes more than traditional classroom teaching (Collado *et al.*, 2020). Outdoor settings rich in sights and sounds spark curiosity, enhance learning, create lasting memories, and shape students worldviews, building foundations for lifelong environmental care and respect. For instance, Internationally, Costa Rica's turtle protection programs have turned former poachers into guardians, while Kenya's environmental education has driven public support for a plastic ban, and Rwanda's gorilla education has transformed hunters into tourism guides. In India, this global momentum found expression through grassroots movements, such as the Chipko movement of Uttarakhand, where forest education led women to embrace trees and secure logging bans. The National Environment Awareness Campaign (NEAC) engages school children in tree planting, waste management, and water conservation, while the Centre for Environment Education develops innovative programs that link education to sustainable development action. Project Tiger initiatives converted poachers into nature guides, while Odisha; coastal communities shifted from turtle egg collection to beach protection. Kerala's sacred grove conservation connected traditional beliefs with biodiversity science. The Himalayas showcase regional transformation through Ladakh's snow leopard programs, where herders became wildlife trackers and Uttarakhand's community forest management, where tree cutters now guard forests. These instances demonstrate how conservation education translates into collective environmental action across scales. India is home to a diverse range of grassroots initiatives that emphasize community participation, sustainability, and biodiversity conservation. From waste management and plastic-free campaigns to wildlife protection and eco-tourism, these efforts highlight how local communities, educators, and conservationists are taking the lead in environmental stewardship. The table below highlights five notable initiatives across various regions of India, detailing their core activities, key stakeholders, and significant outcomes that demonstrate the impact of conservation education and collective action in achieving sustainable development goals.

Table 2. Success Stories: Effectiveness of conservation based education programme.

Initiative	Location	Key Actors	Core Activities	Outcomes/ Impact
Yuksam's Zero Waste Revolution	Yuksam, Sikkim	Community members, teachers, students, tourism, stakeholders	Monthly waste management activitys, environmental education	Transformation into a "Green and clean GPU", recognzed nationality; community-driven sustainability
Kantar Abhiyan (Container Campaign)	Uttarakhand	Mr. J. P. Tiwari (teacher), students, community	Replacing plastic with traditional containers, cloth bags; awareness campaigns	Youth-led plastic-free movement; widespread behavioral change; community adoption of sustainable practices

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Tigers forever program	Kaziranga, sundarbans, orther tiger habitats	WCS, Panthera, local communities	Anti-poaching patrols, habitat restoration, eco- tourism initiatives	Boosted tiger populations; reduced poaching, empowered local communities in conservation
Jagat Singh Chaudhary - "Forest man of Uttarakhand"	Jasoli, Uttarakhand	Mr. Jagat Singh Chaudhary, local community	Agroforestry development using personal effort and local resources	Revived barren land; biodiversity restoration; empowered women; inspired regional agroforestry
Singchung Bugun Village Community Reserve	Arunachal Pradesh	Bugun tribal community	Biodiveristy protection, eco-toursm, daily patrolling	Protected critically endangered Bugun liocichla; restored biodiverstiy; created sustainable incom; national recognition

Conclusion

Studentsare key to shaping better futures through their curiosity, creativity, and kindness. However, many students and communitieslack direct nature experiences, creating an "extinction of experience" that weakens connections to the natural world and willingness to protect it. Nature engagement through walks, stories, and play increases the likelihood of care, forming emotionaland environmental bonds.Students arenot just observers—they lead change. Their energy and ideas influence families, friends, and communities, challenging harmful habits and advocating greener choices. With proper support, education, and experiences, theybecome committed Earth stewards. The journey toward harmony with nature and sustainable futures is shared, but students canplay major leadership roles. They possess special abilities that enable them to connect with nature and inspire others. Therefore, by catching them young and connecting with nature, can build a generation that values and protects the planet, fostering futures where people and nature thrive together.

Recommendations

To raise a generation that protects nature, coordinated steps are essential. Transforming students from passive learners into active contributors through structured roles and responsibilities can also prove helpful.

•Include Conservation in School Curricula: Early, meaningful conservation education adapted to local environments with properly trained teachers and adequate resources (Fraijo-Sing *et al.*, 2020).

•Provide Universal Nature Access: Ensure all studentsexperience nature through accessible parks, green spaces, and school gardens, including both free play and guided activities.

•Build Strong Partnerships: Foster collaboration among schools, families, communities, and environmental groups while including students in environmental decision-making through youth councils (Costa & Schuler, 2020).

•Respect Indigenous Knowledge: Incorporate traditional ecological wisdom, offering holistic views of living in balance with nature, preserving culture while enriching environmental learning.

•Training students to become local nature guides who can lead community walks, explain local ecosystems and promote environmental awareness among visitors and residents. Students can also be engaged in the preparation of People's Biodiversity Registers (PBRs) by documenting local flora and fauna as well astraditional ecological knowledge. This will help in creating valuable community resources while building scientific skills.

•Trained students to know their ecology and environment where students can become experts in conducting surveys, monitoring environmental changes, and sharing findings with their communities. Involving students in citizen science initiatives, such as birdwatching clubs, phenology studies, and biodiversity assessments, can help contribute to real data.

•Students can be empowered to create environmental awareness campaigns, nature documentaries, community newsletters, and social media content that promotes conservation messages in culturally relevant ways. Overall, these practical roles will help ensure that students develop an emotional connection to nature and tangible skills for environmental stewardship, creating a generation well-equipped to address conservation challenges through direct action as well as community engagement.

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Passive Water Harvesting in the Indian Himalayan Region: Nature-Inspired Solutions in Indigenous Traditions, Emerging Technologies, and Future Relevance

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Water availability across the Indian Himalayan Region (IHR) is increasingly strained by population pressure, widespread adoption of modern amenity-driven and resource-intensive lifestyles, under-planned anthropogenic interventions, and climate change (CC) impacts, that often have disrupted the regional hydrological cycles. While the IHR contributes significantly to India's water security, many mid- and high-altitude communities face acute seasonal shortages, especially during the pre-monsoon months. In this context, passive water harvesting—a strategy that collects water using natural forces like gravity, condensation, and infiltration without the use of mechanical and electrical energy—has emerged as a sustainable and low-impact approach. Unlike active systems that depend on pumps or electricity, passive systems are rooted in nature-inspired solutions and biomimicry, often aligning with traditional and community-managed water practices. From stone-lined naulas for harvesting water emanating from springs to gravity-fed kulsfor irrigation, rooftop tanks, and infiltration trenches, the Himalayan landscape is already home to several time-tested models of water management. At the same time, newer atmospheric water harvesting technologies, such as fog nets and condensation towers, are being explored as scalable nature-based solutions for remote and water-stressed zones (Klemm *et al.,* 2012; Warka Water Inc., 2025). This article frames passive water harvesting as a continuum of tradition and innovation, examining indigenous systems and modern adaptations, and scoping their relevance across the diverse landscapes of the IHR.

Traditional Passive Water Harvesting in the IHR: A Legacy of Ecological Harmony

For centuries, communities across the IHR have practiced traditional forms of passive water harvesting. These systems reflect deep ecological intelligence and have supported agriculture, drinking water supply, and cultural rituals in one of the world's most challenging mountain environments (Bey *et al.,* 2025). In Ladakh, artificial glaciers and zing dams were created to capture and store winter runoff, providing meltwater for crops in early summer. Similarly, chorus/churres used a cascade of channels—tokpo, zing, yura, nangyu—to manage irrigation in harsh terrains. In Himachal Pradesh, kuhls—gravity-fed irrigation channels—brought water to farmlands, while nawn and baudi systems stored spring water in stone-lined wells. In Uttarakhand, naulas (sacred stepwells) and dhans (seasonal ponds) harvested seepage and rainwater for domestic and livestock use, often integrating spiritual elements into their maintenance. In Sikkim and Nagaland, mohaan and the zabo system showcased how forest catchments, livestock shelters, and irrigation ponds could be integrated on hill slopes to conserve water and soil nutrients. The bamboo drip irrigation systems of Meghalaya, dong channels of Assam, and ngaralui systems of Manipur also exemplify the ingenious adaptation to diverse geographies, from humid hills to dry uplands. Despite their value, many of these systems have declined due to increased disconnectedness, apathy, and ignorance of the residing populace, urban encroachment, and modern alternatives like piped water and borewells. Yet, they continue to offer ecologically sustainable, culturally rooted, and cost-effective solutions that remain highly relevant amid the growing water stress in the region.

Emerging Atmospheric Harvesting Innovations

While the IHR has long relied on indigenous water harvesting systems, emerging climate challenges call for innovations that work in ecological alignment with mountain geographies. One such frontier is atmospheric water harvesting (AWH) — a suite of passive technologies that extract moisture from the air, fog, or dew to provide decentralized water supply solutions. These systems are particularly promising for remote mid- and high-altitude areas where spring discharge is declining, groundwater access is limited, and climate variability affects seasonal water availability. AWH systems are biomimetic in design, often drawing inspiration from natural systems like the Namib desert beetle, which collects dew on its textured exoskeleton. Among the most notable is the Warka Water Tower, an architectural innovation designed by Italian architect Arturo Vittori. Standing nearly 10 m tall, the Warka Tower uses a bamboo or metal exoskeleton with a polyester mesh that condenses water vapor from the air—especially during early mornings and fog events (Fig. 1). First developed for rural Ethiopia, pilot implementations have been initiated in fog-prone Nepalese highlands, revealing its potential to yield up to 100 l of clean potable water per day under suitable humidity and temperature conditions. Another effective AWH method is the use of fog harvesting nets, widely implemented in Chile's Atacama Desert, the highlands of Morocco, and the coastal regions of South Africa. These systems consist of vertical mesh screens, often 1–2 m wide and 10 m tall, suspended between poles. As wind drives fog through the mesh, microdroplets condense, coalesce, and drip into a gutter for collection. Depending on the local climate, a single square meter of mesh can harvest between 4 and 14 l of water per day (Klemm *et al.,* 2012). Such a system could be deployed on south-facing slopes of the mid-Himalayas, particularly in Uttarakhand, Sikkim, and Kalimpong, where fog events are frequent and forested ridges favor condensation. Additional innovations include dew condensation plates and radiative condensers, which cool surface materials (e.g., metal, ceramics, treated polymers, etc.) during clear nights, allowing dew to form and be collected. Dew yield varies from 0.3 to 2 l/m^2/night depending on altitude, temperature, and surface treatment. Systems using hydrophilic coatings and optimized angles have been tested in Israel, India, and France for both household and agricultural applications (Sharan *et al.,* 2007). Furthermore, solar chimney condensers represent a hybrid passive-active solution where solar heating induces upward airflow, and water condenses on internal cool surfaces due to the temperature gradient. While not widespread, such systems have been explored in India and Tunisia and could be adapted for high Himalayan villages where diurnal temperature variation is significant (Park *et al.,* 2013).These innovations are not intended to replace traditional systems, but to fill critical seasonal and locational gaps in water availability. They are material-efficient, independent from manmade energy supply, and can be fabricated using local resources like bamboo, mesh, and earthen basins. When deployed strategically—such as near schools, ridgeline villages, or degraded spring zones—AWH systems offer a resilient, modular, and climate-responsive layer in the water security framework of the IHR.

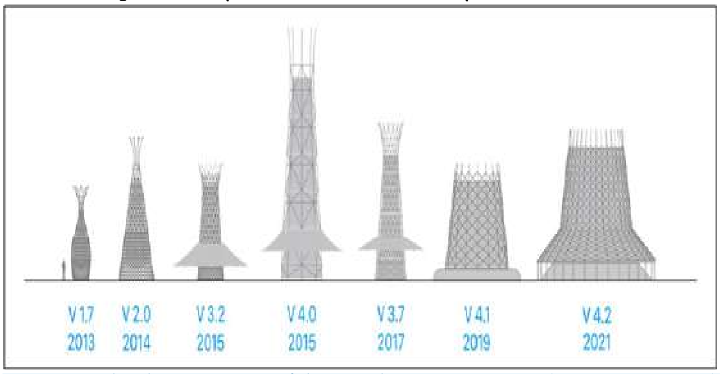

Fig. 1. Multiple iterations of the Warka Water Tower (a passive AWH) that have been developed over time(Source: https://warkawater.org/warkatower/)

Adaptation Potential in the Himalayas

IHR, with its complex terrain, variable climate, and shifting water regimes, presents both challenges and opportunities for implementing passive water harvesting systems. The region's Mid-Himalayas (1000–2500 m), characterized by forested ridges, terraced agriculture, and frequent fog events, are particularly well-suited for fog nets, dew condensers, and radiative cooling plates. These innovations can supplement water supply during the pre-monsoon dry season, especially for hilltop settlements and school premises that currently rely on spring flows, piped supply systems, or distant sources. In the High Himalayas (>2500 m), where winter temperatures are low and diurnal variation is high, technologies like ice stupas and solar chimney condensers hold strong potential. These systems can extend water availability into early summer, aiding in high-altitude farming and livestock management where traditional irrigation methods are limited. Crucially, many of these innovations are material-light and design-

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flexible, allowing for adaptation using local resources such as bamboo, stone, and mesh fabric. Moreover, when integrated with traditional systems—they can fill critical seasonal gaps, reduce overdependence on groundwater, and improve community resilience.The key to successful adaptation of these emerging interventions lies in co-designing these systems with local communities, testing them through decentralized pilots, and ensuring that any introduction of technology complements, rather than replaces, the cultural and ecological intelligence that has sustained water security in the Himalayas for generations.

Conclusion

As the IHR faces increased water scarcity, either acute or chronic, the revival and reimagining of passive water harvesting systems offer a compelling way forward. Rooted in indigenous ecological traditions and now strengthened by nature-inspired innovations, these systems exemplify how development can harmonize with natural processes. From fog nets toWarka towers, passive approaches offer not just technical solutions but a philosophy of coexistence with the landscape.By combining community knowledge, local materials, and biomimetic design, one can create water systems that are adaptive, low-cost, and sustainable. What's needed now is a shift in policy and practice—from viewing these systems as marginal or outdated to recognizing them as central to climate-resilient water futures in the Himalayas. The way forward lies in blending tradition and innovation, not as two ends of a spectrum, but as complementary threads in the region's ecological fabric.

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Sacred Groves: Living Bridges Between People and Nature

The protection and preservation of forests by local communities due to their religious or cultural beliefs are known as Sacred Groves (SGs) (Ray *et al.,* 2014). The concept of SGs dates back approximately 3,000–5,000 years BC when humans relied heavily on forests for food; later, with the advent of agriculture, small forest areas were dedicated to ancestors and local deities as a form of tribute (Prasad, 2025). SGs are of three major types: Traditional, temples and groves around the burial or cremation site. These are a type of Community Conserved Areas (CCA) mainly protected by local communities rather than the government or NGOs. If local people do not conserve these groves, they will deteriorate, leading to the loss of ecological value and threatening plant and animal species. Under International Union for Conservation of Nature and Natural Resources (IUCN) categories V & VI, local communities are granted the right to protect Sacred Natural Sites (SNS) as part of protected areas (IUCN, 1994), but this is not sufficient, since local communities protect these sites primarily because of their religious and traditional beliefs; therefore, it is essential to ensure they feel a sense of ownership and rights over these areas (Barrow, 2025). For conservation, NGOs such as Conservation International, with its Faith-Based Initiatives Program in the USA, and the C.P.R. Environmental Education Centre (C.P.R. EEC) in Chennai, India, promote religious groups in developing their environmental programs focused on conservation, beliefs, and values. Other programs, such as the Ministry of Environment, Forests, and Climate Change (MoEF&CC) and the All India Coordinated Research Project on Ethnobotany (AICRPE), focus on conserving this cultural heritage to achieve sustainable development and strengthen the relationship between these groves and the people. The Traditional Knowledge Digital Library (TKDL) is an initiative taken by the Government of India to document the traditional medicinal knowledge of various communities, thereby protecting intellectual property rights (Asokan, 2015).

Importance

A large population depends on SGs for their socio-economic reasons, such as the food they eat and all NTFPs, which are the source of employment generation. Other roles include (Table 1) Ecological Value (Biodiversity Conservation, Raw Material production, and maintaining ecological balance), Religious Value (spiritual, aesthetic, and traditional values), soil and water conservation by preventing erosion, preserving endangered flora and fauna, carbon sequestration, and conserving cultural heritage. According to Malhotra et al. (2007), the estimated number of SGs in India is approximately 100,000-150,000, mostly present in the Western Ghats, Northeast, and Central India (Notermans *et al.,* 2016). The primary reason for protecting these groves is their rich biodiversity, which people utilize, and most of these services are unquantified. There is a need to develop a methodology to quantify these resources and services for their sustainable utilization. Besides, urbanization, unregulated tourism, invasive species encroachment, overexploitation of resources, changing attitudes among people, fragmentation, and forest fires are among the emerging threats (Table 1) to SGs (Onyekwelu, 2021). Recognizing the importance of local community participation in conserving SGs, awareness and capacity-building programs can be organized in villages and schools, in collaboration with NGOs, to educate people about the significance and sustainable management of these groves. The cultural beliefs and traditions that consider these groves sacred further motivate local communities to protect them. SGs lack legal protection, as there is no strong law for it. The government protects these groves by making them part of wildlife sanctuaries, protected or reserved forests, and national parks. However, SGs deserve unique identification, as local communities play a major role in their conservation due to their religious beliefs. Therefore, some policies, rights, incentives, and recognition should be developed to make them more enthusiastic about SGs' protection.

SG & SDGs

Sacred groves are a form of In-Situ conservation, and by protecting them, we directly contribute to United Nations Sustainable Development Goals (SDGs). The rich biodiversity of the groves provides food, fruits, fodder, medicine, and other non-timber forest products (NTFPs) helping to achieve the Zero Hunger goal (SDG 2). Communities protecting these groves prevent illegal deforestation and promote the sustainable use of resources, including non-timber forest products (NTFPs), thereby supporting Responsible Consumption and Production (SDG 12). Dense SGs vegetation helps rainwater retain in the soil for a longer period,

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allowing it to slowly seep into the ground and ensure the recharge of ponds, springs, and spring-fed streams. The rich litter layer and ground vegetation in SGs reduce surface runoff, increase soil moisture retention, and filter out contaminants, resulting in a clear and high-quality water supply, which supports Life Below Water (SDG-14). Additionally, these groves maintain nutrient cycles, prevent soil erosion, and protect endangered flora and fauna, thereby supporting Life on Land (SDG-15).

Integration of SGs & KM- GBF

Table 1. Value, threats, conservation practices & future direction for sacred groves

Value	Threats	Conservation practices	Future directions
Ecological Value	- Urbanization - Encroachment - Fragmentation - Forest fires - Invasive species	-Community-based protection -Integration into protected areas -NGOs involvement -Awareness programs	-Legal recognition of SGs -Mapping of SGs -Incentives for local communities
Socio-Economic Value	-Overexploitation of resources -Changing attitudes -Unsustainable harvesting	-Sustainable NTFP collection -Training & workshops -Documentation of traditional knowledge (TKDL)	-Develop sustainable livelihood models -Quantify and valuation of ecosystem services
Religious & Cultural Value	-Modernization -Lack of youth engagement -Change in people's belief	-Cultural festivals & rituals -Community ownership	-Policy support -Incentives for cultural value
Soil & Water Conservation	-Deforestation -Land conversion -Pollution of water bodies	-Protection of degraded SGs -Community monitoring of natural resources (pond, well, stream, etc.)	-Restoration of degraded groves - Plantation and reforestation activities
Medicinal & Genetic Value	-Loss of species -Biopiracy -Lack of documentation	-Documentation (TKDL) -Ethnobotanical research -Capacity building/ awareness	-Promote research and access & benefit-sharing -Participatory bioprospecting

Sacred grove conservation aligns with the Kunming-Montreal Global Biodiversity Framework (KM-GBF) objectives, supporting Targets A and B, as sacred groves are home to many endangered floral and faunal species and protect ecosystem integrity. KM-GBF Target A and Target B focus on sustainable management practices, and the use, and protection of biodiversity-rich areas. These areas are rich in biodiversity and protected by the local community due to their own value and beliefs, ensuring the sustainable management of these groves.

Conclusion

Sacred groves are the best example of how people and nature coexist in harmony. These groves are protected by the local community because of their religious and traditional value. In return, SGs support these people by providing various ecosystem services and maintaining the livelihoods of those who depend on them for their survival. SGs demonstrate that, when nature and people support each other, they develop a mutualistic behavior, providing benefits to each other.

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Sustaining Harmony in the Highlands: Pastoralism and Biodiversity in the Changthang region of Ladakh

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The Changthangplateau of Ladakh is one of South Asia's most ecologically and culturally unique landscapes. Characterized by sweeping grasslands, permafrost terrain, endorheic salt lakes, and a freezing, dry continental climate, this fragile steppe alpine ecosystem is home to the nomadic Changpa pastoralists, who have practiced seasonal transhumance for centuries to support their livelihoods. Amid the accelerating pace of global climate change, the Changthangregion emerges as both a sentinel of environmental shifts and a repository of indigenous ecological wisdom. As the world observes the 2025 International Day for Biological Diversity under the theme "Harmony with Nature and Sustainable Development," the lessons on community-driven biodiversity conservation from Changthang resonate more than ever(Pandit *et al.*, 2024).The Changpas' traditional grazing systems—anchored in deep ecological understanding through rotational mobility, and sustainable herd sizes—have ensured the long-term viability of grasslands without resorting to intensive land use practices. Their lifestyle not only supports local livelihoods but also contributes to maintaining the ecological integrity of the region. Moreover, the Changpa pastoralists have been using these grasslands sustainably on a rotational basis to prevent over-grazing for years (Bhasin *et al.*, 2023). In other words, Changpas' seasonal movements naturally limit grazing pressure, supporting both livestock and wild herbivores. Many keystone species, such as the snow leopard (Panthera uncia), black-necked crane (Grus nigricollis), and Tibetan wild ass (Equus kiang), thrive in this open rangeland precisely because of the cultural and ecological balance maintained by pastoralism (WWF-India, 1997;Chundawatand Qureshi, 1999). However, this balance has been increasingly tested over the past few decades. Climate-induced changes in temperature, snowfall patterns, and precipitation regimes are reshaping seasonal patterns in vegetation, potentially misaligning with traditional grazing cycles. Moreover, socio-economic pressures—ranging from unregulated tourism to fencing, unplanned development, and policy-induced land-use transitions—are further destabilising this intricate socio-ecological system. Keeping this in view,we havefocused on mapping natural grasslands and monitoring vegetation dynamics in the Changthangregion using a multi-sensor remote sensing approach. Using time-series satellite data, including MODIS Net Primary Productivity (NPP), Landsat NDVI (Normalized Difference Vegetation Index), and EVI (Enhanced Vegetation Index), LST (Land Surface Temperature), we analysed long-term vegetation productivity (Fig. 1) across the years ranging from 2014 to 2024 using GEE (Gorelick *et al.*, 2017). Additionally, we used geospatial tools such as ArcGIS (version) and Python libraries (NumPy and Pandas) to perform statistical and spatial analysis on climate variables (i.e. mean LST)from Landsat 8 OLI datasets for the period of 2014–2024. Our findings reveal mixed signals on the annual NPP variation. Interestingly, NPP has shown an overall increasing trend (i.e. annuallyincreasing at the rate of ~2%) over the last two decades, as shown inFigure 1. At first glance, this greening may appear positive, suggesting improved biomass availability for grazing. On the other hand, increased NPP in a warming context could signal a more complex, and potentially concerning, ecological shift. Rising productivity could result from early snowmelt, longer growing seasons, and increasing temperature(FAO, 2019).Moreover, high interannual variability in NPP trends suggests that the ecosystem isunder stress may or may not be due to anthropogenic disturbance and/ fluctuations in the environmental and microclimatological conditions.In this context, it is apt to note that in areas where precipitation has become erratic, vegetation shows signs of degradation and reduced resilience(Singh 1991). However, grasslands under community and private management—those where traditional grazing rotations are followed, demonstrated relatively greater stability, emphasizing the value of indigenous practices and localized stewardships (ICIMOD, 2020).

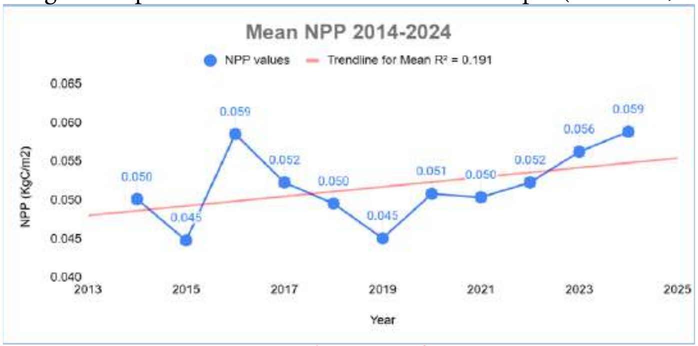

Fig.1. Mean net primary productivity from 2014 to 2024 over the Changthangregion in Ladakh.

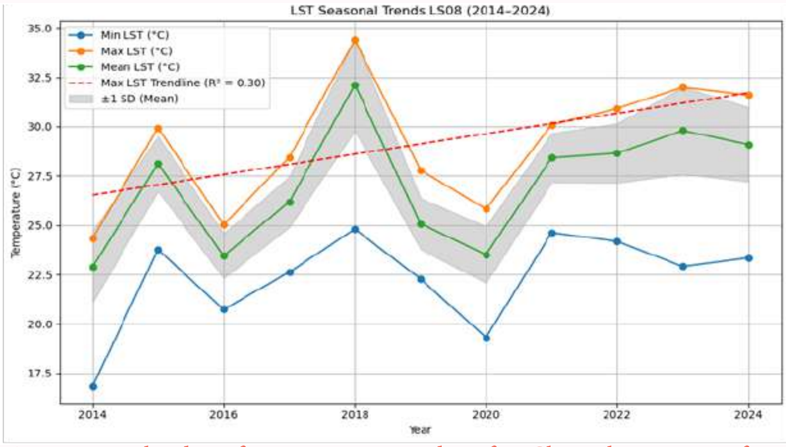

Fig.2. Mean land surface temperature data for Changthangregion from 2014 to 2024

Contrary to widespread perceptions, pastoralism,when practiced in harmony with ecological cycles,can support biodiversity conservation. The semi-nomadic Changpas, by clinging to seasonal mobility and ecosystem-based decision-making, prevent overgrazing and allow grasslands to regenerate (Bhasin *et al.*, 2023). Their grazing practices createheterogeneous landscapes that are beneficial for many endemic and migratory species. Unfortunately, developmental interventions like sedentarization policies, land allotments, and linear infrastructure (i.e. roads, fences, tourism facilities) have begun to disrupt these time-tested systems. Observations near Leh town show increasing habitat fragmentation, crowding of pasture zones, and rising conflict between wildlife conservation goals and livelihood security (Singh 1991). These tensions underscore the urgent need to integrate pastoralist voices into conservation dialogues and recognize their landscapes as conservationcompatible. Changthangregion is one of those places in earth which experiences exacerbated impact of climate change. Our remote sensing observations suggest possible changes in the vegetation greening cycles. Initial assessment suggests that the growing season begins earlier, followed by earlier vegetation peaks. These shifts risk creating mismatches between forage availability and

Photoplate 1. depicting a ChangpaHerder and field work in Changthang's Grasslands

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herding patterns, which are guided by centuries-old ecological calendars. Meanwhile, rising land surface temperatures,as shown in Figure 2, are altering soil moisture dynamics, which could negatively impact shallow-rooted native grasses despite an apparent rise in NPP (FAO, 2019). Therefore we intend to assessif increasing NPP is good or bad for the grass land ecosystem of trans-Himalaya? The answer is not binary. While it may suggest rising biomass, it may also reflect ecological stress responses, increased evapotranspiration, or degraded vegetation quality. Without understanding species composition and forage value, NPP alone cannot be assumed as an indicator of ecological improvement. Therefore, it is apt to highlight that to foster genuine harmony with nature, policies must evolve beyond conservation and embrace hybrid models that value both science and tradition. Consequently, it is recommend that:

- Pastoral landscapes to be recognized within a protected area as "working conservation zones".
- Real-time grassland monitoring using remote sensing tools needs enhancement.
- Traditional ecological calendars need to be incorporated into climate adaptation strategies.

These recommendations align with the broader global shift toward nature-based solutions (NbS), where ecological restoration and community resilience are achieved together. Changthang is more than a remote plateau. It is a living landscape of movement, and adaptation. Amid high-speed winds and shifting seasons, people and nature continue an ancient relationship built on respect, reciprocity, and resilience. Yet, the climate is changing, and the signals are mixed: increasing NPP, yes, but at what cost? We must move beyond simplistic interpretations of greening and recognize the intricate balances that sustain high-altitude grasslands.With the right mix of technological innovation, community participation, and responsive policymaking, Changthangregion can remain a beacon of sustainability. As we mark this year's Biodiversity Day, the Changpa way of life reminds us of that of harmony with nature is not just a slogan,it is a daily practice forged in some of the planet's most unforgiving environments.

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Governing for Nature: India's Policy and Constitutional Approach to Environmental Sustainability

As India, now became world's largest populus country with 1.4 billion people, it faces challenge of prioritizing economic development while also preserving its vast and diverse ecosystems with rich natural heritage.The concept of living in harmony with nature is deeply enrooted within in Indian culture hence the Indian government has developed a comprehensive policy framework aimed at sustainable development and environmental conservation. This article explores theses policies, governance mechanisms, and initiatives undertaken by the Indian government in past and how in present they promote harmony with nature.

Constitutional and Legal Foundations

Indian Constitution provides a strong foundation for environmental governance with some provisions/Act which form the backbone of India's environmental policy framework, guarantying legal mechanisms for conservation and sustainable use of natural resources.

Table 1. Constitutional Provisions and Key Environmental Laws in India

Provision / Act	Year	Purpose / Objective
Article 48A	1976	Directs the State to protect and improve the environment and safeguard forests and wildlife.
Article 51A(g)	1976	Imposes a duty on every citizen to protect and improve the natural environment.
The Wildlife (Protection) Act	1972	Provides for the protection of wild animals, birds, and plants.
The Forest (Conservation) Act	1980	Aims to conserve forests and regulate the diversion of forest land for non-forest purposes.
The Environment (Protection) Act	1986	An umbrella legislation for environmental protection and improvement.

Source: Constitution of India

Governance Mechanisms

The Ministry of Environment, Forest and Climate Change (MoEFCC) serves as the nodal agency for environmental governance in India. It coordinates with various other ministries, state governments, and local bodies to implement environmental policies and programs. (Fig. 1).

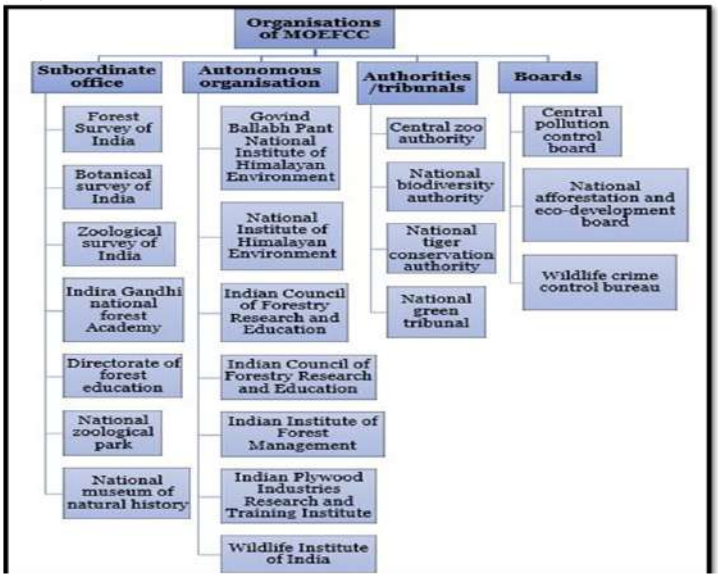

Fig. 1. Organization of MOEFCC, Source: MOEFCC

Also, The National Biodiversity Authority (NBA), State Biodiversity Boards (SBBs), and Biodiversity Management Committees (BMCs) at the local level form a three-tier institutional structure for biodiversity governance, ensuring effective implementation at all levels (Economic times 2024).

National Environmental Policies, Missions, and Legal Instruments

India has implemented a net of national policies and missions to achieve environmental sustainability and climate resilience. The National Action Plan on Climate Change (NAPCC), launched in 2008, includes eight missions such as the National Solar Mission, Green India Mission, and National Mission on Sustainable Agriculture, integrating climate concerns across developmental sectors (MoEF&CC 2021). The National Biodiversity Action Plan (NBAP) aligns with global biodiversity targets, emphasizing community involvement and mainstreaming biodiversity into policy-making. The National Agroforestry Policy, 2014 was the first of its kind globally, aiming to merge trees with agriculture for climate adaptation and sustainability. Additionally, Mission LiFE, introduced at COP26, (PIB, 2024) promotes eco-conscious lifestyles to tackle environmental degradation. Legal principles such as the "polluter pays" doctrine are also enforced through environmental compensation mechanisms, as demonstrated by Haryana's pollution board actions. However, enforcement remains a challenge, evident from partial penalty recoveries (TOI, 2025).

Table 2. Key National Environmental Policies, Missions, and Legal Instruments in India.

Initiative / Policy	Year	Objective / Focus	Reference
National Action Plan on Climate Change (NAPCC)	2008	Strategy to address climate change through 8 national missions.	(MoEF&CC 2021)
National Solar Mission	2010	Promote solar energy; achieve 100 GW capacity by 2022	(MoEF&CC 2021)
National Mission for Sustainable Agriculture	2014-15	Make agriculture productive, sustainable, resilient via integrated farming, soil & water conservation	(MoEF&CC 2021)
National Biodiversity Action Plan (NBAP)	2008	Conserve biodiversity and integrate it into policies.	
National Mission for a Green India (GIM)	2014	Enhance forest cover through Protection	(PIB, 2024)
National Agroforestry Policy	2014	Integrate trees into agriculture for sustainability.	(PIB, 2024)
National Clean air Programme	2019	Improve air quality	(PIB, 2024)
Nagar Van Yojana	2020	Developing green spaces in urban areas	(PIB, 2024)
Mission LiFE (Lifestyle for Environment)	2021	Inspire individuals toward eco-conscious living and global action.	(PIB, 2024)

Conclusion

Public awareness and participation play a critical role in the successful implementation of environmental policies in India. A recent nationwide survey conducted by the Yale Program on Climate Change Communication in collaboration with CVoter between December 2024 and February 2025 highlighted that while over half of Indian adult's express serious concern about climate change, an alarming 32% of respondents admitted they had never heard of global warming (Times of India, 2025). This reveals a substantial gap in climate literacy and the urgent need to expand education and outreach initiatives. Despite India's progress in formulating a comprehensive environmental policy framework, significant challenges remain, particularly in policy enforcement, public engagement, and timely data availability. The delay in the Census of India 2021 continues to hinder evidence-based environmental planning and resource allocation. Furthermore, mechanisms for ensuring compliance with environmental regulations, such as the "polluter pays" principle, often fall short, as seen in the case of Haryana where only Rs.132 crore of the Rs.499 crore in environmental fines have been recovered from violators (Times of India, 2025) However, opportunities abound—especially in leveraging digital technologies for data monitoring, improving enforcement transparency, and strengthening local institutions. Enhanced citizen participation, particularly in the form of community-based conservation, localized planning, and environmental stewardship programs, can bridge the gap between policy and practice. In conclusion, India's constitutional and legislative commitment to environmental protection, complemented by national missions such as NAPCC, NBAP, and Mission LiFE, underscores a long-term vision of ecological balance. By ensuring that policy implementation is grounded in public participation, scientific data, and inclusive governance, India can move decisively toward achieving true harmony with nature while supporting sustainable development goals.

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From Rocks to Roadmaps: Lichen as Drivers of Biodiversity Conservation in Achieving the Sustainable Development Goals

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Lichens play a crucial role in biodiversity conservation, particularly in the context of achieving the Sustainable Development Goals (SDGs).Lichens unique characteristics as bioindicators and their contributions to ecosystem health underscore their importance in monitoring environmental changes and promoting sustainable practices. The roadmap constitutes a coherent vision and provides specific actions and pathways to move toward sustainable trade. This is relevant in many other contexts. Currently, Asian medical industries across a range of traditional medicine systems, including in China, India, Japan, South Korea, and Mongolia, are undergoing an industrial revolution characterized by increased industrialization, commercialization, and globalization while continuing to rely on renewable environmental products as inputs (Kloos, 2022).A recent global synthesis warns against a tendency to focus on short-term economic gain at the cost of sustainability (Shelton *et al.,* 2024). Despite harsh climates, their distinctive biodiversity supports the stability and functioning of ecosystems in the Himalayan region. Ecological plasticity and sensitivity to environmental gradients are evident in their regional distribution, and contribute to primarysuccession,species like (Rhizocarpon geographicum) soil formation, and atmospheric nitrogen fixation, and thrive in various terrestrial environments (fig.1.). The conservation planning, climate monitoring, and ecosystem restoration efforts, contributing to air quality, ecosystem health, and the achievement of UN Sustainable Development Goals (Perez-Moreno *et al.,* 2024) This article provides an overview of the distributional ecology of lichens, and importance in preserving biodiversity, and in potential contribution to achieving Sustainable Development Goals (Fig.2.) and explores the topic of biodiversity conservation, sustainable developmental goals, and climate change.

Challenges and Future Directions

The main challenges to roadmap success are that the roadmap acknowledges recent advances in understanding how environmental product conservation and trade are unofficially regulated and

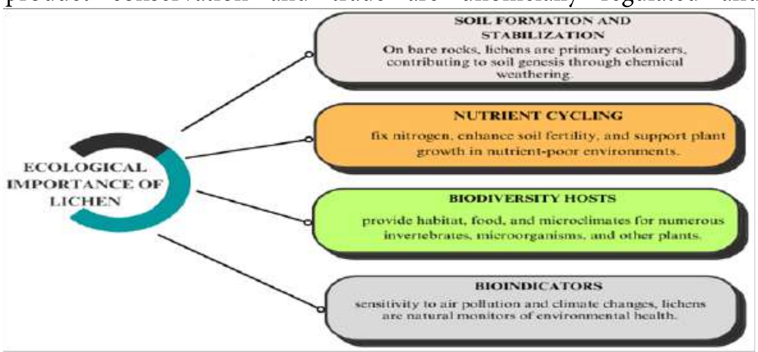

Fig.1. Showing Ecological importance of Lichens

practiced, as well as the importance of incorporating this into implementation plans for actions to promote feasible interventions; however, the existing political ecology of the production network poses a challenge, support domestic businesses, there is an opportunity to transition from raw material export to secondary processing. Anthropogenic and Climate Stressors: Lichens are declining in environmentally sensitive areas like Nainital, Dehradun, and Gangtok due to urbanization, tourism, deforestation, and rising air pollution. Climate change is also causing altitudinal shifts in species like Usnea longissimaLobariapulmonaria,CladoniarangiferinaXanthoria parietina, indicating ecosystem destabilization. Despite their alignment with several Sustainable Development Goals (SDGs), lichens are not yet operationalized in national and international monitoring indices. Lichens can contribute to the SDGs and biodiversity conservation by enhancing molecular and taxonomic research, creating open-access digital databases, and integrating them into biodiversity regulations. Integrating lichens into national Red List evaluations and Biodiversity Management Committees can help resolve taxonomic difficulties and improve species identification and tracking. (Morillas *et al.,* 2024). Lichen-rich places in montane and forest habitats should be designated as Biodiversity Heritage Sites and Ecosystem-Based Adaptation areas. Forest management plans should include standardized lichen diversity

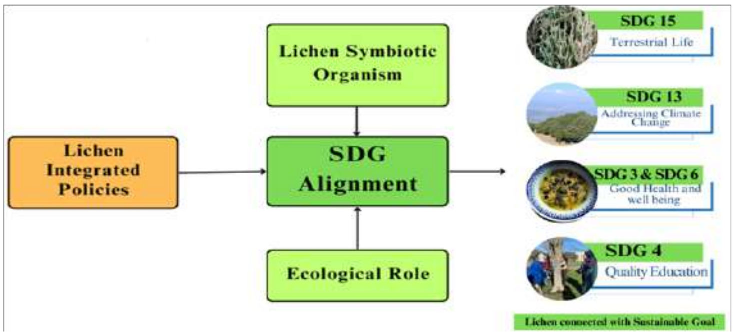

Fig.2. Representing the Connection of Lichens with Sustainable developmental goals

indexes and pollutant accumulation profiles. Lichen-based community monitoring can provide a cheap way to track ecosystem health. Collaborative research amongst ecologists, climatologists, politicians, and indigenous populations is critical. Regional collaboration among Hindu Kush Himalaya nations can enhance lichen-based monitoring for climate adaptation and biodiversity resilience. The roadmap demonstrates that it is possible to establish stakeholder-wide consensus on priority activities to improve the sustainability of environmental product trade at the national level, even in the context of hundreds of traded items and a lack of species-level data. The roadmap represents a refocused, more integrated, and regionally coordinated approach to promoting sustainable harvest and trade. The method prioritizes economic incentives, decentralization of resource management, and increased simplicity and transparency, all while laying a stronger foundation for gathering valid and trustworthy trade data and forecasting future demand. The roadmap should be designed to enlighten policymakers and decision makers at all levels, and it should include difficulties as well as proposals for how to put the recommended activities into practice.

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Gender Participation in Community-Based Institutions (CBIs) Across Diverse Ecological and Socio-Cultural Settings: Insights from the Khangchendzonga Landscape, India

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The Khangchendzonga Landscape (KL)-India, located in the Eastern Himalaya, encompasses the state of Sikkim and parts of North Bengal. It is renowned for its rich ecological diversity and cultural heritage (Badola *et al.,* 2016; Gaira *et al.,* 2018; Pandey *et al.,* 2022). Covering a spatial area of 14,126.36 km² and ranging in altitude from 40 m to 8,586 m above sea level, the landscape spans a variety of ecosystemsfrom tropical lowlands to alpine highlands. It includes 17 Protected Areas (PAs), four of which have transboundary settings with neighbouring countriesnamely Nepal and Bhutan (ICIMOD, 2017).The broader Khangchendzonga Landscape (KL), officially delineated in January 2014, is a transboundary region extending across eastern Nepal, Sikkim and northern West Bengal in India, and western Bhutan. Geographically, it stretches between 26°21'40.49" and 28°7'51.25" N latitude and 87°30'30.67" and 90°24'31.18" E longitude, encompassing the southern slopes of Mount Khangchendzonga (8,586 m asl)the world's thirdhighest peak and a vital part of the Eastern Himalayan biodiversity hotspot.In recognition of its ecological and socio-cultural significance, the Khangchendzonga Landscape Conservation and Development Initiative (KLCDI) was launched. Coordinated by the International Centre for Integrated Mountain Development (ICIMOD), Nepal, the programme aims to promote conservation and sustainable development through integrated resource management approaches.This unique landscape is home to diverse communities who depend on the land and forests not only for their livelihoods but also as a foundation for their identity and cultural practices (ICIMOD *et al.,* 2017). To support natural resource management and local development, these communities have established various grassroots institutionsincluding Self-Help Groups (SHGs), conservation committees, eco-development bodies, and local NGOsthat collectively form what are known as Community-Based Institutions (CBIs). These CBIs are designed to facilitate inclusive decision-making and shared leadership, giving local people a meaningful voice in shaping the future of their environment.However, an important question remains: how inclusive are these institutions in practice, especially with regard to gender participation? While CBIs aim to be inclusive, gender disparities in leadership, involvement, and decision-making often persist and remain insufficiently studied across different ecological and socio-cultural contexts within the KL.This study, conducted under the KLCDI-India programme, seeks to address this gap by examining gender participation in CBIs across three ecological and socio-cultural distinct pilot sites of KLCDI-India programme namely Dzongu, Bandapani and Barsey-Singalila.

Photoplate 1. Dzongu (Mayal Lyang),land of the Lepchas, where tradition and nature live as one.

Methodology

This study employed a household survey approach to assess participation in Community-Based Institutions (CBIs) at the household level, with a particular emphasis on gender dynamics specifically, whether participation involved men, women, or both members of the household. The survey was conducted across three ecologically and culturally significant pilot sites within the Khangchendzonga Landscape in India: Dzongu, Bandapani, and Barsey-Singalila. A total of 610 households were surveyed using a stratified random sampling method to ensure representation across diverse demographic and ecological contexts. Data were collected through a structured questionnaire designed to gather demographic and socio-economic information, document household participation in various CBIs, and identify the gender of participating members. The questionnaire included a list of commonly found community-based institutions, such as farmers' groups, self-help groups (SHGs), village associations, non-governmental organizations (NGOs), cultural and religious groups, mothers' groups, youth clubs, health and sanitation committees, and conservation-linked committees like Eco-Development Committees (EDCs) and Joint Forest Management Committees (JFMCs).

Findings, Key Observations and Discussions

Dzongu: A Model of Inclusive and Balanced Community Engagement

Nestled in the Mangan district of Sikkim, Dzongu stands out as a good example of how communities can come together to shape a more inclusive and balanced local development process. Home to the indigenous Lepcha people, Dzongu is more than just a place, it's considered the cultural heartland of the Lepcha community, where tradition, spirituality, and nature are deeply intertwined.With its low population density and rich biodiversity, Dzongu is recognized not only for its ecological significance but also for its strong cultural roots. The region falls within the Khangchendzonga Biosphere Reserve (KBR) and is connected to the UNESCO World Heritage Site, giving it both national and global importance. These factors have drawn attention from various research and conservation efforts, bringing in a mix of state and central government projects aimed at development and environmental protection.One of the most noticeable outcomes of these efforts is the rise of nature-based tourism, especially homestay programs run by local communities. These provide not just an income stream but also create opportunities for cultural exchange and environmental education, benefiting both locals and visitors.What truly sets Dzongu apart, though, is the way the community is actively involved in shaping its own future. Self-Help Groups (SHGs), local NGOs, and village governance bodies are all playing key roles in supporting livelihoods, conserving biodiversity, and advancing social development. What's particularly encouraging is the level of female participation in these efforts. Women are not just included;they're leading in many ways. In fact, the data tells a powerful story: 32.78% of households report female participation in community institutions, compared to 24.90% for men. Additionally, 16.18% of households report that both men and women participate together, showing a trend toward shared responsibility and more equitable involvement. These numbers suggest that Dzongu is moving in the right direction when it comes to gender balance and inclusive development. It shows what can be achieved when communities are empowered, local leadership is proactive, and institutions are designed to include everyone.Still, challenges remain. About 26.14% of households surveyed said they weren't involved in any community-based institutions at all.These points to a broader issue, one that isn't just about gender, but about deeper systemic barriers that may prevent people from engaging. Whether the reasons are social, economic, geographic, or institutional, it's clear that some residents feel left out.To truly make Dzongu's development inclusive, these gaps need to be addressed.

Bandapani: Struggling for a Voice amid Challenges

Bandapani, a remote village placed near the Bhutan border, tells a very different story when it comes to community participation. Unlike more engaged areas, Bandapani faces a complex set of structural challenges that have made active involvement in local institutions incredibly difficult for its people.Geographically isolated, the village has long struggled with limited access to roads, markets, and essential & basic services. The local economy revolves almost entirely around subsistence farming, yet even this basic livelihood is constantly under threat from human-elephant conflict, an ongoing issue that endangers both crops and lives.The lack of job opportunities has also pushed many young people to migrate to cities in search of work. This steady out-migration has not only created a demographic imbalance but has also weakened the community's social structures and leadership, the very foundations needed for successful community-based development.The numbers reflect this reality basically. More than 80% of households surveyed reported no involvement in any kind of community-based institution (CBI). Male participation stands at a mere 4.02%, and while female participation is slightly higher at 15.08%, it remains very low overall. Joint participation by men and women is almost non-existent.These figures highlight a worrying disconnect between the community and the institutions designed to support their development. The reasons are likely many: the economic pressures that drive migration, cultural norms that limit women's public engagement, low trust in institutions, lack of awareness, and past experiences that may have left people feeling excluded or disappointed by such initiatives.Bandapani's situation calls for urgent and thoughtful intervention. Rebuilding trust and reviving participation will take more than just policy, it requires real, context-sensitive strategies.

Barsey-Singalila: Progress and Gaps in Gender-Inclusive Community Participation

Barsey-Singalila offers a promising, yet layered, view of community participation especially when it comes to gender roles. This area is a part of the Khangchendzonga Landscape Conservation and Development Initiative programme (KLCDI-India), includes a group of villages spread around the Barsey Rhododendron Sanctuary (BRS) in West Sikkim and the Singalila National Park (SNP) in West Bengal, Darjeeling district.Famous for its beautiful trekking routes, flourishing homestays, and organic farming mainly potatoes, beans, and cabbages, Barsey-Singalila is a vibrant blend of nature and culture. The Sherpa community forms the backbone of this region, with their traditional ecological knowledge and deep respect for nature playing a key role in local conservation.When it comes to community-based institutions (CBIs), the numbers here are encouraging especially for women. Female participation is at 34.12%, the highest among all three study sites, while male participation stands at 20.29%. This suggests a shift toward female empowerment, likely supported by local social norms and possibly targeted interventions promoting women's leadership. However, a deeper look reveals a more complicated picture. Despite the relatively high involvement of women, joint participation where both men and women in a household are involved together is surprisingly low at just 5.88%. This points to a gender divide in how community roles are shaped. In many cases, it appears that men and women are participating separately rather than collaboratively. On top of this, nearly 40% of households reported no involvement at all in CBIs, highlighting that many community members, regardless of gender, remain on the margins of institutional processes.This dual reality reflects both progress and persistent barriers. On one hand, Barsey-Singalila stands out for the steps it has taken to empower women. On the other, the lack of integrated, joint decision-making shows that traditional roles and institutional limitations still influence who gets a seat at the table and who doesn't. Coming out to the larger Khangchendzonga Landscape in India, the study found that nearly half 47.54% of respondents reported no involvement in CBIs at all. This signals that barriers like limited access, lack of trust, and questions around institutional relevance remain widespread. Among those who do participate, women outnumber men (27.38% vs. 16.89%), but joint household participation stays very low at 8.20%.What this tells us is that while efforts to increase women's roles in local governance are gaining ground, most institutions still operate in a gender-segregated way men and women participating in parallel lanes, rather than together. Building truly participatory, inclusive, and effective community-based institutions will require a shift toward shared leadership models that reflect the lived realities and needs of entire households, not just individuals.

Conclusion and recommendations

The study of community participation across the Khangchendzonga Landscape, India highlights the complex and varied ways in which gender influences local governance. While community-based institutions (CBIs) are meant to be inclusive spaces for driving development,

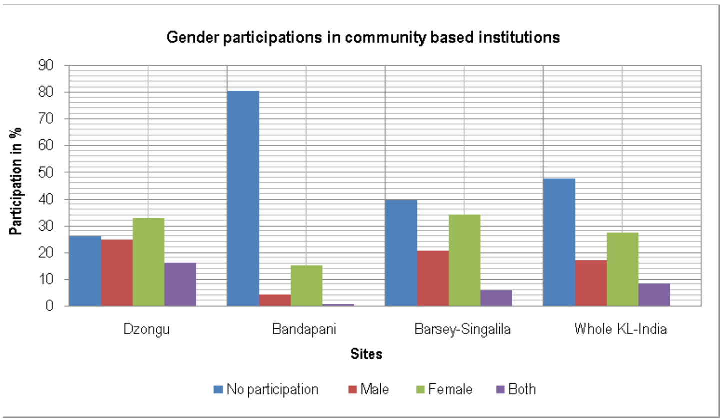

Fig. 1. Gender participations in Community-Based Institutions (CBIs) in Khangchendzonga Landscape, India.

managing natural resources, and empowering rural communities, the reality on the ground reveals a more complicated picture. Each site within the landscape offers a different experience. Dzongu shows relatively balanced engagement, Bandapani reflects deep-rooted marginalization, and Barsey-Singalila presents a more hopeful but still divided pattern of participation. A consistent trend across all three areas is that women are more likely to be involved in CBIs than men. However, a crucial gap lies in joint participation. With only 8.20% of households reporting shared involvement between men and women, it's clear that true collaborative decision-making within families and communities remains limited. This pattern of gender-separated participation reflects the lasting influence of traditional norms and institutional barriers. As a result, CBIs often fall short of their potential to be truly inclusive and representative. More broadly, the high rate of overall non-participation nearly 48% of households across the sites points to deeper issues. These include geographic isolation, limited infrastructure, economic migration, low trust in institutions, and broader social exclusion. To move forward, simply increasing the number of participants is not enough. What's needed is a more holistic approach that reshapes how institutions work, encourages shared leadership, and supports gender-equitable engagement grounded in the local cultural context.

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Building community resilience through Krishi Updates Model

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The communities residing in Indian Himalayan Region (IHR) dependsextensively on natural resources for sustaining their livelihood. But climate change, unsustainable tourism, undulating topographical conditions, establishment of projects and unplanned urbanization, is posing threats to the sustainability of these natural resources. "Krishi Updates Digital agriculture model" is an open access and socially inclusive digital platform that provides robustInformation and Communication Technology (ICT)infrastructurefor satisfying the information needs of the farmers. The blended learning courses offered by the platform are community driven and helps in capacity building of mountain communities in sustainable natural resources management. By developing a systems thinking and consciousness facilitation approaches,the ICT tools of model are building resilience of mountains social-ecological systems. By training needs assessment and documentation of collective wisdom, followed by farmer to farmer knowledge exchange through community of practicebuildspsychological resilience and capacity in agroecology,for sustainable mountain development. A study carried out by Awasthi, 2024 revealed that use of ICTs improves the reach of conventional extension services, and strengthens marketing of mountain products. Use of model in Kullu district of Himachal Pradeshshowed good acceptability among the rural community with ninety percent (90%) of the farmers agreeing to recommend Krishi updates to other fellow farmers, and adopt collective farming (85%), with institutional linkage with Krishi Updates platform. Climate change and deteriorating natural resources, is putting various natural resources under stress leading to major shifts in agricultural system and loss of agrobiodiversity. The change in farmer's choices from cultivating traditional crops to cash crops is guided by food requirements, productivity of farms, and monetary value. Study carried by (Negi *et. al.,* 2018) revealed that cash crops performed better as compared to traditional crops in terms of monetary efficiency, however for energy output–input ratio of traditional crops was found more efficient. Major shifts from traditional crops to cash crops had reduced the resilience of mountain communities, increasing dependency on chemical fertilizers. The shift in crops choices has exposed mountain communities to higher risk of pest/ disease attack, and adverse climatic conditions that occur with climate change.Integrating agrobiodiversity into food systems propose new food production strategies that can be implemented in a changing environment, promoting diversified crops and increased variety as a strength in agro-ecosystems. Study carried by Awasthi and Thakur (2022) in Sarchi village revealed climate change (40%) and lack of irrigation facilities (33.33%) as major constraint in crop production. The region lacks avenues for skill and entrepreneurship development programs, but the focus group discussion with farmers showed their interest in pursuing capacity building programs for fruit production (36.67%), followed by eco-tourism (26.67%), vegetable production (16.66%), beekeeping (10%) and sericulture (10%). The studies emphasizeon the need for imparting skill development training for building resilienceof mountain communities in face of climate change.

Material and Methods

The present study was conducted during a capacity building workshops at Bhuntar in Himachal Pradesh and at Ludhiana in Punjab. For creating interest of communities in video-mediated learning using 5G technology, two videos were produced in year 2023 as part of the "Krishi Updates Business Plan Challenge". Data were collected in face to face interviews from active learners who participated in the capacity building workshops and joined Krishi Updates community of practice. The questionnaire was prepared in Hindi. The questions arising in communities of practice post sharing of online content, and social media analytics of the posts were recorded to evaluate the reach and improvement in understanding of targeted audience.

Results and Discussion

Perception of Communities to adverse Impacts of Climate Change In our study, 47.95 percent (35) of the respondents strongly agreed that climate change is impacting their livelihood adversely and advocated for significant policy changes to address it, followed by 36.98 percent (27) and 15.07 percent (11) who responded agreed and neutral, during the face to face discussion.

Acceptability of Community Driven Capacity Building Courses

Designing need based training programs, plays a vital role in ensuring post-training implementation of the innovation. Post delivery of training during the workshop 23.29 percent of the active learners responded "Climate resilient Crops" as the most suitable training course followed by 21.92. 19.18, 17.81, 10.95 and 6.85 percent for "Sustainable Water Management for Mountain Agriculture", "Scientific Beekeeping", "Krishi Updates Digital Agriculture Model for Organic & Natural Farming", "Entrepreneurship avenues through KU Model" and "Agrotourism for Enhancing Farmers Income", respectively.

Impact of Community Driven Capacity Building Workshops in Learning Outcomes

The workshops and online community of practice, upskilled farmers and facilitated sharing of location-specific information. Post workshop 39.73 percent of the farmers (29) responded increase in understanding about climate resilient crops, followed by 30.14, 17,81 and 12.32 responding improved knowledge on Digital Literacy, Ecosystem Services and Water Management, respectively.

Impact of 5G Mobile Communication on Information Dissemination

The digital content (Videos, Blogs and Webinars) was posted in Social Media (Facebook, Youtube, Ecoagtube, and LinkedIn) followed by sharing in Community of Practice (CoP), through mobile phones and 5G internet. Around 58.90 percent of the respondents agreed that 5G technology has ensured faster speeds, lower latency and reliable access to location-specific information, followed by 23.29, 13.70 and 4.1 percent responding that it has only facilitated faster access to entertainment content, increased exposure to misinformation and has not at all impacted their lives significantly, respectively.

Community perception on Video-based learning

Videos showcasing location-specific best practices enhances the uptake rate of innovation by the farmers. In our study, 67.12 percent (49) farmers agreed to adopt organic faming and diversifying to agro tourism or climate resilient crops post watching of videos.

Conclusion

The rural communities are adversely impacted by climate change as their livelihood depends on the natural resources. Fostering climate resilient communities through capacity building and digital technologies becomes important for their sustenance. 5 G technology, ICT-mediated learning and need based capacity building workshops ensures that such communities are equipped with required knowledge and skills, to tackle these issues. Designing and delivery of need based training programs, plays a vital role in ensuring post-training implementation of the innovation. Further creating of communities of practice facilitates regular exchange of information and ensures that right interventions are initiated at right time for community upliftment. Delivery of digital content over 5G network showed satisfaction among 58.90 percent of the respondents ensuring faster speeds, lower latency and reliable access to location-specific information.

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Photoplate1. Webinar on Capacity Building of stakeholders through ICTs


Photoplate2. Webinar on Capacity Building of stakeholders through ICTs

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Nature-Based Solutions in action: Harnessing Community managed forests for Global climate resilience

In the face of escalating climate change and ecological uncertainty, restoring harmony between human societies and nature has become an urgent global priority. Nature-based Solutions (NbS), as defined by the International Union for Conservation of Nature (IUCN), offer a promising pathway by protecting, managing, and restoring ecosystems to address societal challenges while delivering benefits for both people and biodiversity. This article examines the pivotal role of Community Managed Forests (CMFs) as effective NbS for climate resilience. Drawing on global case studies from Nepal, Tanzania, and Bhutan, as well as local initiatives such as the Van Panchayats in Uttarakhand, India, the article demonstrates how participatory forest management enhances carbon sequestration, biodiversity conservation, and ecosystem services. The analysis highlights the mechanisms through which CMFs contribute to climate mitigationnamely carbon sequestration, conservation, and substitutionwhile also supporting local livelihoods and socio-economic development. Despite their proven benefits, CMFs face challenges including limited resources, policy recognition, and governance issues. The article concludes that scaling up and integrating community-led forest governance models into national and global climate strategies is essential for achieving long-term climate resilience and sustainable development.

Keywords
Nature-based Solutions (NbS), Community Managed Forests (CMFs), Climate resilience, Carbon sequestration, Van Panchayats, Ecosystem services

As the world faces unprecedented ecological uncertainty and rAs the world faces unprecedented ecological uncertainty and rising global temperatures, the imperative to restore harmony between human societies and nature has never been more urgent. Climate change disrupts both environmental systems and the very fabric of human life. In this context, Nature-based Solutions (NbS) have emerged as a vital strategy. The International Union for Conservation of Nature (IUCN) defines NbS as "actions to protect, sustainably manage, and restore natural and modified ecosystems in ways that address societal challenges effectively and adaptively, to provide both human well-being and biodiversity benefits" (IUCN, 2020). NbS encompass activities such as the restoration, management, and protection of ecosystems-ranging from coral reefs and mangroves to forests and grasslands. This analysis explores how Community Managed Forests (CMFs) serve as effective NbS, particularly in managing and reducing carbon emissions through participatory forest management strategies at both global and local scales.

Community Forest Management: A Natural Shield Against Climate Change

Forests provide a range of critical ecosystem services, including carbon sequestration, water regulation, biodiversity conservation, and livelihood support. Community Managed Forests (CMFs) and Participatory Forest Management (PFM) systems, which involve local communities in forest stewardship, have proven especially effective in advancing forest restoration, biodiversity conservation, and enhanced forest coverall of which

Fig.1. Depicts a Community-Managed Forest in Almora, Uttarakhand

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contribute to absorbing carbon emissions (Pant& Bhatt, 2023).

Mechanisms of Carbon Management

CMFs mitigate climate change through three primary mechanisms:

•Carbon Sequestration: Absorbing atmospheric carbon dioxide via photosynthesis and storing it in biomass and soils.

•Carbon Conservation: Preventing the release of carbon by protecting existing forests from degradation or deforestation.

•Carbon Substitution: Using sustainably harvested forest products as alternatives to fossil fuels or energy-intensive materials (Bass *et al.,* 2000).

Key strategies include agroforestry, afforestation, reforestation, improved forest management, and strong community participation (Fig.1).

Global Case Studies

A comparative analysis of CMF models in Nepal, Tanzania, and Bhutan highlights their climate mitigation potential (Table 1) shows the diversity.

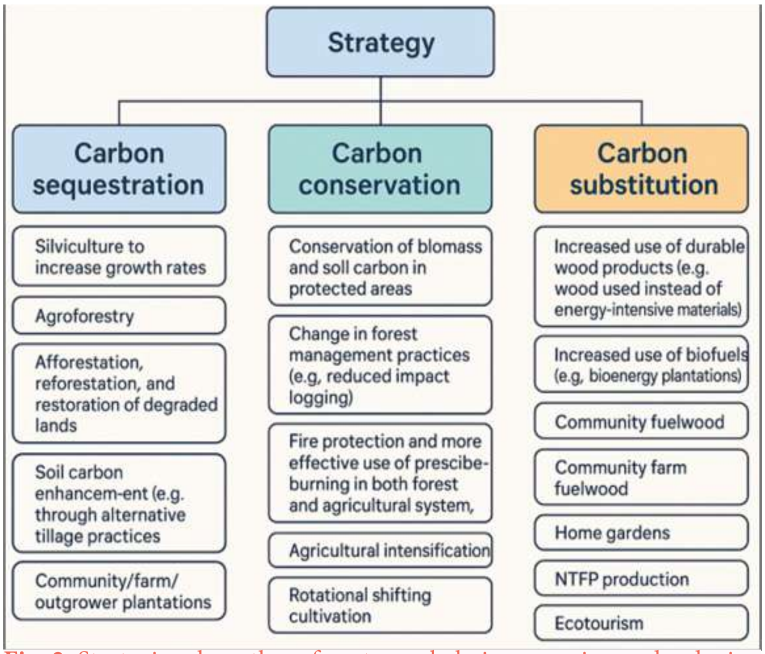

Fig. 2. Strategies along these forests can help in managing and reducing the carbon

Table 1. Major case Studies across the globe towards CFM and climate change mitigation

Country	Community Forest Model	Climate Change Mitigation Aspect	Key Findings/ Highlights
Nepal	Community Forest User Groups	Carbon sequestration via collective action	CMFs sequester more carbon due to effective local governance
Tanzania	Participatory Forest Management (PFM)	Local community carbon monitoring for REDD+	Communities effectively monitor carbon stocks aiding REDD+ initiatives
Bhutan	Community forests (Nationwide)	Sustainable harvesting provides carbon stocks and carbon sequestration	Community-managed have significant potential for increased carbon sequestration

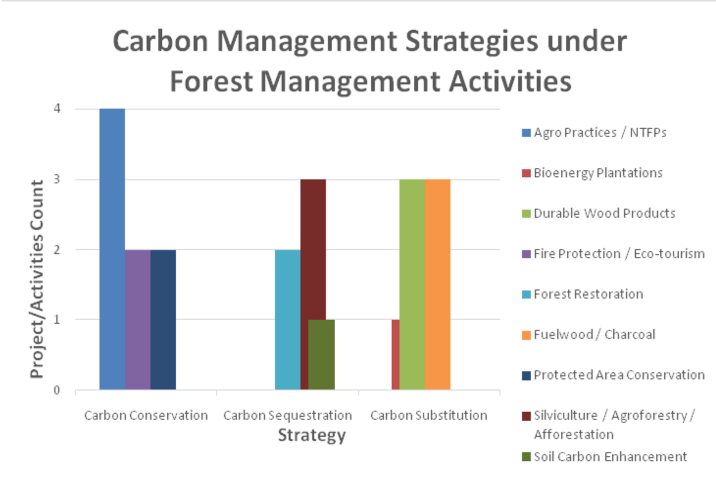

Fig. 3. Carbon management through various strategies practiced by local community led forest management systems(adopted from Bass *et al.,* (2000)

Nepal: Community Forest User Groups have demonstrated that collective local action leads to significantly higher carbon sequestration rates, thanks to effective governance and participatory management (Bluffstone *et al.,* 2016). **Tanzania:** Participatory Forest Management enables local communities to monitor forest carbon stocks, directly supporting REDD+ (Reducing Emissions from Deforestation and Forest Degradation) initiatives and ensuring that carbon benefits are realized at the community level (Katani *et al.,* 2016). **Bhutan:**Nationwide community forests have shown that Bhutan: Nationwide community forests have shown that sustainable harvesting practices not only maintain but also enhance carbon stocks, with substantial potential for increased carbon sequestration (Tshering *et al.,* 2024).

Key Insights:

•Active community involvement leads to improved carbon sequestration and sustainable resource use.

•Carbon credits provide financial incentives for local communities (Fig.2).

•CMFs deliver co-benefits such as biodiversity conservation, soil conservation, and water regulation (Banskota *et.al.,* 2007).

Fig. 4&5. Depicting the role of community in NbS actions

Local Initiatives: The Case of Van Panchayats in Uttarakhand, India

Uttarakhand's Van Panchayats represent a decentralized governance model where village communities manage forests on

the Such systems not only strengthen local climate resilience but also offer a replicable model for other regions seeking to enhance carbon management and reduce forest degradation.

Connecting Local Actions to Global Movements as the local models like Van Panchayats exemplify how community management enhances carbon sequestration and ecosystem resilience through sustainable practices and participatory governance (Figure 4 and 5).

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When scaled regionally and nationally, these models can make significant contributions to national and global carbon sinks and climate strategies. Integrating traditional knowledge and collective governance is crucial for long-term ecosystem health and resilience. Strengthening community-led forest governance is thus essential for achieving global climate goals.

Challenges and Policy Recommendations

Despite their proven benefits, CMFs face several challenges:
- •Local Barriers: Lack of support, funding, training, and clear rules can hinder effective management. Conflicts over land use and tenure further complicate governance.
- •Global Recognition: Many national and international frameworks, including the Paris Agreement, do not adequately recognize or support CMFs.

Recommendations

- •Provide adequate resources, funding, and training to local communities.
- •Develop clear policies and legal frameworks that recognize and integrate CMFs into national and global climate strategies.
- •Foster mechanisms for sharing benefits, such as carbon credits, to incentivize sustainable management.

Conclusion: A Local Answer to a Global Crisis

Community managed forests are vital carbon sinks, naturally capturing carbon dioxide and supporting climate regulation. As cost-effective, community-driven NbS, they enhance biodiversity, stabilize ecosystems, and empower local communities. By blending traditional knowledge with sustainable practices, CMFs build resilience to climate change and offer a practical pathway toward both environmental sustainability and climate action. Recognizing and supporting these models at all levels can bridge the gap between sustainable development and effective climate action.

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Medicinal plants cultivation: a sustainable approach for conservation and utilization

According to the World Health Organisation (WHO) (2002), approximately 80% of the world's population, or around 4 billion people, use herbal medicine for some aspect of primary healthcare. The World Wildlife Fund (WWF) and the International Union for Conservation of Nature (IUCN) estimate that from 50,000 to 80,000 flowering plants are used medicinally worldwide (Chen *et.al.,* 2016). The global herbal medicine market size was estimated at USD 70.57 billion in 2023 and is projected to grow at a compound annual growth rate (CAGR) of 20.91% from 2024 to 2030, with a Forecasted Market Value of $328.72 billion by 2030 (GVR, 2025). Conferring the floral statistics of India (2017) hosted by the Botanical Survey of India, Kolkata, West Bengal, a total of 18,386 flowering plants (6.84% of the world) exists in India, and approximately 3000 plant species are known to have medicinal properties (Prakasha *et.al.,* 2010) among them 100 plants were used regularly (Joshi and Pant, 2012). The Indian Himalayan Region (IHR) is one of the world's hotspots for biological diversity (Table 1), with 1,748 plant species known to have medicinal values (Pandey *et al.,* 2019; Myers *et.al.,* 2000; Samant *et.al.,* 1998; Singh and Hajra, 1996). Medicinal plants (MPs) face various threats, including anthropogenic pressure, increased commercial collection, illegal or unregulated trade, harmful harvesting practices, and global habitat loss resulting from climate change (Mehta *et al.,* 2021). According to a study by (Dhar *et.al.,* 2000), over 90% of medicinal plant species are extracted from the wild, with a subsequent 69% of that material being extracted through destructive harvesting from their natural habitats, posing a significant threat to these natural resources (Polunin and Stainton, 1987). Various studies have indicated the conservation needs of these high-value species for their sustenance (Pandey *et.al.,* 2019; Tiwari *et.al.,* 2024). Considering the scenario, conservation through the cultivation approach for Himalayan medicinal plants is gaining attention, which ensures biodiversity conservation and, due to increasing market demands, becomes a source of alternative livelihood support to involved stakeholders. An optimal livelihood comprises willingness, new prospects, innovation, and the capacity of an involved person to cope with stress and livelihood uncertainty (Sati, 2020). However, certain physical constraints, such as remoteness and a lack of optimal resources in mountainous regions, are compounding the crucial limitations to livelihoods, which in turn lead to outmigration and various adverse effects, including human-wildlife interactions and land degradation. Domestication, cultivation, and marketing of wild MPs will help meet the increasing global demand and support livelihoods (Muhammad *et.al.,* 2006), ensuring the sustainable use and conservation of MPs. MPs are viewed as an important livelihood enterprise in India, which can support traditional agricultural systems and provide farmers with a reliable source of income (Negi *et al.,* 2010).

Medicinal plant cultivation in Uttarakhand

Located in a Himalayan biodiversity hotspot, the state of Uttarakhand is endowed with rich biodiversity. It occupies 17.3% of the country's land area, of which 92.57% is under hills and 7.43% under plains. It hosts 605 plants belonging to 94 families, with ethnomedicinal uses, and approximately 175 species that are being commercially extracted and traded (Sati, 2013). A large portion of the state's population is dependent on natural resources, as agricultural practices are challenging in this mountainous region due to geographical and climatic factors (Tewari *et al.,* 2020). An unselective gathering and overharvesting of MPs from their natural habitats have unfavourably affected their availability in the state (Phondani *et al.,* 2016). Hence, to conserve MPs and enhance the livelihoods of local people in the Indian Himalayan region, strategies for sustainable harvesting and cultivation must be developed, and they must be defended against current threats. The state of Uttarakhand was inscribed as the herbal state of India in 2003, and the state government promoted an agri-export zone in two phases. Phase one covered six districts of the state (Chamoli, Dehradun, Haridwar, Pithoragarh, Udham Singh Nagar, Uttarkashi) and promoted the cultivation of 10 high-value species in 500 ha of land. In the subsequent phase, the cultivation land and the number of districts and medicinal species were increased

(Sati, 2013). The treasure of medicinal plants in the state is vast, but most of the high-value MPs are under serious threat of extinction, and many of them are endemic. The endemicity and wildness of the MPs, along with a lack of awareness about their potential value in the market, are hindering the success rate of domestication or cultivation of medicinal plants and require focused research and development efforts.

Institutions involved in the cultivation of MPs

The National AYUSH Mission promotes medicinal plant cultivation through the National Medicinal Plant Board (NMPB) to reduce forest harvesting and ensure sustainable use, with implementation by state agencies (https://nmpb.nic.in/). Other organizations involved in the cultivation of medicinal plants in the state include the Central Institute of Medicinal and Aromatic Plants (CIMAP), Gopeshwar, Chamoli, Herbal Research and Development Institute (HRDI), G.B. Pant National Institute of Himalayan Environment (NIHE), Almora, High Altitude Plant Physiology Research Centre (HAPPRC), Srinagar, National Bureau of Plant Genetic Resources (NBPGR), Nainital, The Energy Resource Institute (TERI), Nainital, Forest Research Institute (FRI), Dehradun, and the Uttarakhand Forest Department.

Medicinal plant cultivation and SDGs

The Sustainable Development Goals (SDGs) are a universal call to action to end poverty, protect the planet, and improve the lives and prospects of everyone everywhere, implying that the cultivation of medicinal plants will help to achieve many goals simultaneously. The SDGs 1 (No poverty), by generating employment and easing poverty, SDGs 3 (Good health and well-being), by ensuring healthy lives and promoting well-being for all at all ages through traditional medicinal practices and providing many pharmaceutical raw materials, SDGs 8 (Decent work and economic growth), Promoting sustained, inclusive and sustainable economic growth, full and productive employment by new livelihood opportunity. SDGs 12 (Responsible consumption and production), ensuring sustainable consumption and production of medicinal plants and their byproducts, and SDGs 15 (Life on land) to protect, restore, and promote sustainable use of terrestrial ecosystems (Mountain biodiversity), and sustainably manage forests and MPs maintaining a balanced ecosystem for today and tomorrow.

Table 1. Overview of the Indian Himalayan Region

Diversity	Angiosperm	Gymnosperm	Pteridophytes	References
Phyto diversity	8700	51	766	(Mehta *et al*, 2021)
Endemic taxa	1061	3	12	(Tiwari *et al*, 2024)
Medicinal Plants (MPs)	1685	12	51	(Samant *et al*, 1998)
Threatened MPs	102	7	3	(Mehta *et al*, 2021)
Endemic MPs	38			(Tiwari *et al*, 2024)

Conclusion

Medicinal and aromatic Plant cultivation is emerging as a sector of self-employment, creating alternative livelihood opportunities. Since the medicinal plant cultivation is less labour-intensive in comparison to traditional agriculture, and is less/not affected by wildlife. Thus, besides contributing to conservation and livelihood generation, it will also help reduce drudgery. Cultivation will ensure the availability of raw materials for dependent pharmaceutical companies, maintain ecosystem balance, and promote the sustainable use of natural resources.

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Evaluating The Implementation of India's Biological Diversity Act (2002): The Role of Multi-Level Governance and Community-Based Biodiversity Management Committees

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India's rich natural heritage – spanning Himalayan peaks to tropical forests – supports millions of people. Despite covering just 2.4% of the Earth's land, India harbours about 7–8% of all known species i.e. roughly 45,000 plant and 91,000 animal species.(Ghritlahre *et.al.,* 2025)This makes the country one of 17 megadiverse nations. Protecting such biodiversity is crucial for food security and the overall human well-being. To safeguard its rich natural treasure. India, in 1992,joined the global Convention on Biological Diversity (CBD) and enacted the Biological Diversity Act (BDA) in 2002, whichset objectives like conserving species, sustainable use of resources, and fair sharing of benefits from genetic resources. Over the years, the vision of the Act has evolved alongside national and global priorities. The CBD's global mission of "living in harmony with nature by 2050" has become a guiding principle,aligning with this, Indiaadoptedthe National Biodiversity Strategy and Action Plan (NBSAP) 2024–30,which explicitly adopts this vision. (PIB report, 2024).Achieving the objectives of the BDA, 2002, an effective multi-level governance system was put in place, where each level—from national authorities to village committees—works collaboratively to conserve ecosystems, document traditional knowledge, and manage access to biological resources.(Ghritlahre *et. al.,* 2025) The Act recognized India's sovereign rights over its biological resources and emphasized the role of local communities as custodians of biodiversity. To implement this, a three-tier institutional structure was introduced: the National Biodiversity Authority (NBA) at the central level (established in 2003), State Biodiversity Boards (SBBs) in each state, and Biodiversity Management Committees (BMCs) at the level of panchayats and urban local bodies. (Ghritlahre *et. al.,* 2025)This structure was aimed at enabling both top-down policy coordination and bottom-up community participation in biodiversity governance. However, despite two decades of legal and institutional progress, the implementation of the Act remains inconsistent across states and communities. This article evaluates the effectiveness of the Act in practice, focusing on the role of multi-level governance and local Biodiversity Management Committees (BMCs).

The Act set up a three-tier institutional structure for governance

National Biodiversity Authority (NBA): Established under the Biological Diversity Act of 2002 with its headquarters in Chennai, the NBA regulates access to India's genetic resources and traditional knowledge by issuing "No Objection Certificates," negotiating benefit sharing agreements, and advising the central government; to date, it has processed over 250 Access & Benefit Sharing cases—such as neem export and patent approvals—and channelled royalties into national and local biodiversity funds, earning recognition as a global ABS model. (Ghritlahre *et.al.,* 2025; Sutar & Swain, 2011).

State Biodiversity Boards (SBBs): Each state has an SBB that operates under the state government. SBBs handle approvals for research use within the state, help enforce rules, and advise on conservation issues. They also coordinate with the NBA on state matters. (Ghritlahre *et.al.,* 2025) Kerala's SBB has activated more than 1,000 Biodiversity Management Committees and compiled thousands of species records in People's Biodiversity Registers, while integrating conservation efforts with climate resilience initiatives.(Kerala SBB report, 2024).

Biodiversity Management Committees (BMCs): Every local government (panchayat or municipality) is meant to set up a BMC. These grassroots bodies comprise maximum seven members to be nominated by the local body of whom not less than one third would be women and not less than 18% belonging to SC/ST. (Sutar & Swain, 2011) BMCs are tasked with creating a People's Biodiversity Register (PBR) that documents local species and traditional knowledge. They also have the power to grant consent for the use of community resources. In this way, BMCs ensure that village-level or urban communities have a direct say in how their biodiversity is used. (Kerala SBB report, 2024).

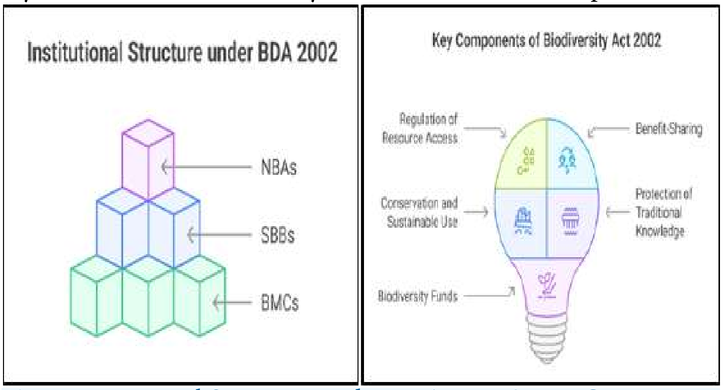
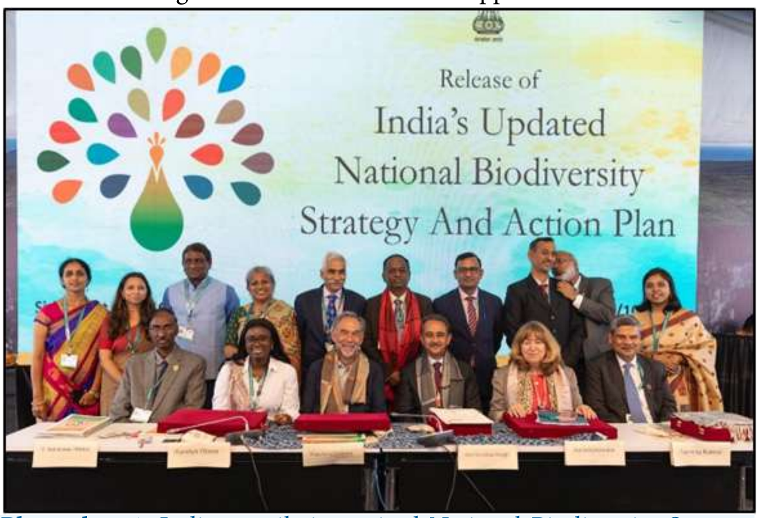


Fig.1. Institutional Structure Under BDA 2002 & Key Components of Biological Diversity Act 2002

Contributions and Success

The Act has institutionalized community involvement in a way few other laws haven't. Through the BMCs and People's Biodiversity Registers (PBRs), local people make an inventoryof all plant andanimal resources, along with the associated traditional/ indigenous knowledge, which areof both informational and social value. For example, based on the information of several PBRs in Kerala, the SBB declared several Biodiversity Heritage Sites, preserved rare ecosystems, and developed "biodiversity parks" to educate the public. These steps show that when the Act is fully embraced by state and local governments, it can significantly enhance conservation outcomes. In Kerala's case, active community participation has become a model of local biodiversity governance.(Kerala SBB report, 2024). At the national policy level, India's commitment to BDA has been reaffirmed by releasing the updated National Biodiversity Strategy



Photoplate 1. India unveils its revised National Biodiversity Strategy (2024–30) aligning with the Kunming-Montreal Framework. (Image Source: https://www.pib.gov.in/PressReleasePage.aspx?PRID=2070401)

Photoplate 2. UNEP's collaboration with Andhra Pradesh's BMC strengthens grassroots biodiversity efforts. Image Source:(https://www.unep.org/news-and-stories/story/shifting-needle-biodiversity-conservation-india)

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and Action Plan developed in consonance with the Kunming-Montreal Global Biodiversity Framework. This update explicitly adopts a "Whole-of-Government" and "Whole-of-Society" approach (PIB report, 2024), byaligning national strategies with the Act's framework helps to mainstream biodiversity into other areas like agriculture, forestry, and climate action. This policy integration is essential for "coexistence with nature" – for example, protecting mangroves for coastal resilience, or forest corridors for wildlife, while also supporting local jobs.

Table 1: Status of Biodiversity Management Committees (BMCs) and People's Biodiversity Registers (PBRs) in Indian States (as of March 2024). Data Source: NBA Annual Report 2023-2024 (http://nbaindia.org/content/103/37/1/reports.html)

State	Total No. of BMCs constituted at alllevels	Total No. of PBRs documented at alllevels
Andhra Pradesh	14157	14157
Arunachal Pradesh	1806	1806
Assam	2549	2549
Bihar	9101	9101
Chhattisgarh	12008	4948
Goa	205	205
Gujarat	14583	14716
Haryana	6444	6444
Himachal Pradesh	3776	3776
Jharkhand	4689	4689
Karnataka	6554	6554
Kerala	1200	1034
Madhya Pradesh	23557	23557
Maharashtra	28649	28649
Manipur	2260	199
Meghalaya	6484	6484
Mizoram	894	894
Nagaland	1276	1276
Odisha	7256	7256
Punjab	13599	13599
Rajasthan	11882	11882
Sikkim	196	196
Tamil Nadu	13615	13615
Telangana	13461	13461
Tripura	1264	1264
Uttar Pradesh	59407	59407
Uttarakhand	7991	7991
West Bengal	3830	3830
Andaman & Nicobar Islands	71	71
Chandigarh	1	1
Daman & Diu	44	44
Delhi	1	0
Jammu & Kashmir	4658	4366
Ladakh	195	6
Lakshadweep	10	10
Puducherry	15	0
Total	277688	268037

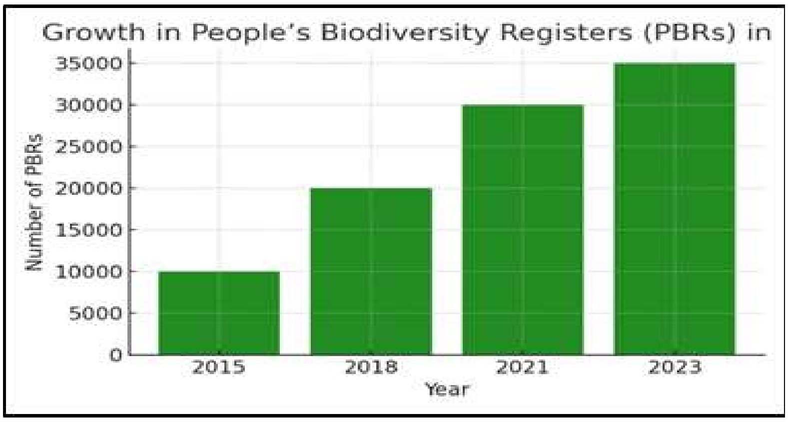

Fig.2. Growth in documented People's Biodiversity Registers in India from 2015 to 2023. Data Source: NBA Annual Reports (http://nbaindia.org/content/103/37/1/reports.html)

Implementation Challenges

There are many challenges with the Act's practical execution. Many expert reviewers note that implementation on the ground remains weak in several states. For instance, an NGO study found that in Madhya Pradesh the SBB claimed to have formed about 23,741 BMCs (one per Gram Panchayat). However, researchers on the project discovered that only about 1,000 village committees were actually active.(Sutar & Swain, 2011) This discrepancy suggests a gap between paperwork and reality: some officials may report full compliance, but many villages have not operational BMCs or funds. Similar gaps were noted in other states in that study. The RCDC report bluntly concluded that "actual implementation in many states is quite poor, and there is a lack of sincerity both at the levels of politicians and bureaucrats to remain committed to the spirit of the Act". (Sutar & Swain, 2011)In practice, this means local communities often remain unaware of their rights under the Act, and NGOs or volunteers must sometimes step in to create awareness.

Conclusion

India's Biological Diversity Act (2002) has created a unique, three-tier governance structure—NBA, SBBs, BMCs—to protect ecosystems, recognize traditional knowledge, and share benefits with communities. When fully implemented, as seen in Kerala's active BMCs and People's Biodiversity Registers, the Act helps empower local stakeholders and promotes conservation that aligns with sustainable development goals. However, uneven implementation—marked by inactive committees, low public awareness, and limited funding—still hinders the Act's full potential. By strengthening BMCs with training and financial support, improving transparency in benefit-sharing decisions and integrating biodiversity into broader development plans, India can move towards a nature-positive future by 2050. In doing so, the Biological Diversity Act can continue to serve as a cornerstone of policy that safeguards India's rich natural heritage while supporting livelihoods and resilient ecosystems for future generations.

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भारतीय हिमालय की अल्पाइन घासभूमियाँ (बुग्याल) सतत भविष्य हेतु जैव विविधता एवं आजीविका के संरक्षक

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भारतीय हिमालय क्षेत्र में 3000 से 5000 मीटर की ऊँचाई पर विस्तृत अल्पाइन घासभूमियाँ, जिन्हें स्थानीय रूप से बुग्यालकहा जाता है, पारिस्थितिकीय दृष्टि से अत्यंत महत्वपूर्ण और सांस्कृतिक रूप से समृद्ध परिदृश्य हैं। ये बुग्याल दुर्लभ एवं स्थानिक वनस्पतियों व जीवों को आवास प्रदान करने के साथ–साथ, पारंपरिक पशुपालन, जलवायु नियमन, जल संरक्षण, मृदा सुरक्षा तथा कार्बन अवशोषण जैसी महत्वपूर्ण पारिस्थितिकी सेवाओं में सहायक हैं। परंतु वर्तमान में ये क्षेत्र अत्यधिक चराई, आक्रामक प्रजातियों के प्रसार, जलवायु परिवर्तन, अनियंत्रित जडी–बूटी संग्रहण एवं अनियोजित पर्यटन विकास जैसे कारकों से तीव्र क्षरण की अवस्था में हैं। हिमालय ,पृथ्वी की सबसे कम आयु वाली वलित पर्वत श्रृंखलाएँ हैं जो प्राकृतिक सौंदर्य की अनुपम निधि हैं (काला और *अन्य*, 1998)। विविध ऊँचाई वाले क्षेत्रों में विभाजित हिमालय, जैविक विविधता के अनोखे आवासों का पोषण करते हैं। इनमें से अल्पाइन घासभूमियाँ विशेष रूप से उल्लेखनीय हैं, जो वृक्ष रेखा (ट्री लाइन) और हिम रेखा के बीच स्थित हैं और सदियों से वनस्पति, जीव–जंतु तथा मानव क्रियाकलापों के सह–अस्तित्व और सह–अनुकूलन से निर्मित विशिष्ट पारिस्थितिक क्षेत्र हैं (गुप्ता एवं नंदा, 1970 यादव एवं सिंह, 1977)। उत्तराखंड राज्य में ही अकेले ऐसी अल्पाइन घासभूमियाँ लगभग 3,869 वर्ग किलोमीटर क्षेत्रफल में फैली हुई हैं (गुप्ता, 1979)। ये न केवल जैव विविधता के भंडार हैं, बल्कि पर्वतीय समुदायों की आजीविका का भी आधार हैं। वर्तमान में ये परिदृश्य गंभीर पारिस्थितिकीय चुनौतियों का सामना कर रहे हैं, जिससे इनके समावेशी एवं सतत प्रबंधन की आवश्यकता और अधिक बढगई है।

जैव विविधता की दृष्टि से महत्त्वपूर्ण स्थल

अल्पाइन बुग्याल में लगभग 2,500 से अधिक पुष्पीय वनस्पतियों की प्रजातियाँ पाई जाती हैं, जिनमें से लगभग 200 संकटग्रस्त और 300 औषधीय महत्त्व की मानी जाती हैं (राउ, 1975 समंत *आदि*, 1996)। इनमें पिक्रोराइजा कुर्रोआ (कुटकी) अकोनिटम बालफूरी, सॉसुरिया कॉस्टस (कुष्ठ) तथा वैलेरियाना जटामांसी जैसी प्रमुख औषधीय प्रजातियाँ शामिल हैं। इसके अतिरिक्त, रोडोडेंड्रॉन, जुनिपेरस, सैलिक्स तथा कोटोनिएस्टर जैसे पेड़ो के समूह भी इन क्षेत्रों में विद्यमान हैं। वन्यजीवों में हिम तेंदुआ, हिमालयन थार, कस्तूरी मृग, नीली भेड (भारल) जैसे प्रमुख स्तनधारी तथा हिमालयी मोनाल, हिम तीतर, और हिमालयन स्नोकॉक जैसे पक्षी पाए जाते हैं (कुमार *आदि*, 2001 समंत *आदि*, 2001)। ये घासभूमियाँ न केवल प्रवास और प्रजनन के लिए उपयुक्त स्थल हैं, बल्कि जलवायु संतुलन के लिए भी महत्त्वपूर्ण हैं।

सांस्कृतिक संबंध एवं आजीविका प्रणाली

अल्पाइन बुग्याल सदियों से स्थानांतरित पशुपालन पर निर्भर हिमालयी समुदायों जैसे भोटिया, ब्यांसी, जोहारी, और वन गुज्जर के लिए जीवन का आधार रही हैं। ये समुदाय गर्मियों में अपने पशुधन (भेड, बकरी, याक *आदि*) को उच्च हिमालयी चारागाहों में चराने हेतु ले जाते हैं। इसके साथ–साथ, ये समुदाय गैर–काष्ठ वन उत्पादों जैसे औषधीय जडी–बूटियाँ (कुटकी, जटामांसी, कुठ *आदि*), जंगली खाद्य पदार्थ एवं अन्य संसाधनों का सतत संग्रह भी करते हैं। ये उत्पाद पारंपरिक स्वास्थ्य देखभाल और बाजार से जुडी आय सृजन दोनों के लिए अत्यंत महत्वपूर्ण हैं। इसके अतिरिक्त, स्थानीय समुदायों के पास समृद्ध पारंपरिक पारिस्थितिक ज्ञान होता है। इस ज्ञान में मौसमी चराई के पैटर्न, सतत दोहन की तकनीकें, और औषधीय पौधों के गुण शामिल हैं, जो प्रकृति के साथ उनकी गहरी और स्थायी सह–अस्तित्व को दर्शाते हैं। (नेगी, 2012)। अल्पाइन क्षेत्रों में व्याप्त गरीबी को देखते हुए आजीविका के विविधीकरण की आवश्यकता है। इसके उपायों में नियंत्रित औषधीय पौधों का संग्रह, पारिस्थितिकी–पर्यटन और रोमांचिक पर्यटन का विकास, ऊन व बागवानी उत्पादों का व्यापार और वन उत्पादों का मूल्य संवर्धन शामिल है (नेगी, 2012)। औषधीय और सुगंधित पौधों की कृषि से वन्य संग्रहण पर दबाव कम हो सकता है तथा स्थानीय रोजगार उत्पन्न हो सकता है (सुंद्रियाल एवं शर्मा, 2016)। इन विविधीकृत तरीकों को आजीविका सुरक्षा और संरक्षण के लक्ष्यों से जोडना अत्यंत आवश्यक है।

प्रमुख चुनौतियाँ एवं पारिस्थितिकीय संकट

हाल के वर्षों में, अल्पाइन घासभूमियाँ अनेक प्रकार की मानवजनित तथा प्राकृतिक चुनौतियों का सामना कर रही हैं। क्षेत्रीय सर्वेक्षणों और वैज्ञानिक अध्ययनों के अनुसार निम्नलिखित समस्याएँ उभर कर सामने आई हैं।

अत्यधिक चराई एवं पशुधन का दबाव : सीमित चारागाह पर अत्यधिक पशुपालन से मृदा की गुणवत्ता घटती है, पोषक प्रजातियाँ जैसे सेलिनम, रूमेक्स, एवं डानथोनिया विलुप्त हो रही हैं तथा मृदा क्षरण बढरहा है (रिखारी *आदि*, 1992)।

आक्रामक विदेशी प्रजातियाँ: पोलिगोनम एवं सिर्सियम जैसी प्रजातियाँ स्थानीय घासों को प्रतिस्थापित कर रही हैं, जिससे पारिस्थितिक संतुलन प्रभावित हो रहा है।

अनियंत्रित औषधीय पौधों का संग्रहण: पुनरुत्पादन हेतु आवश्यक जडों सहित पौधों को उखाडलेने की प्रवृत्ति अनेक महत्वपूर्ण प्रजातियों को संकट में डाल रही है (समंत *आदि*, 1996)।

जलवायु परिवर्तन: बढते तापमान और हिमद्रवण चक्र में बदलाव के कारण वनस्पतियाँ ऊपर की ओर खिसक रही हैं, जिससे पारिस्थितिकीय क्षेत्रों की सीमा संकुचित हो रही है (सिंह *आदि*, 2013)।

पर्यटन और अवसंरचना विकास: असंतुलित पर्यटक गतिविधियाँ, ट्रेकिंग ट्रेल का विस्तार, एवं सडक निर्माण जैवविविधता के विखंडन और कचरे की समस्या को जन्म दे रहे हैं।

नीतिगत उपेक्षा: अल्पाइन बुग्याल अक्सर औपचारिक वन संरक्षण योजनाओं में समुचित रूप से सम्मिलित नहीं होते, जिससे इनके लिए पृथक नियोजन एवं प्रबंधन रणनीति का अभाव रहता है। (रावत एवं अधिकारी, 2015) के एक विस्तृत अध्ययन में पाया गया है कि 31प्रतिशत बुग्याल अत्यधिक अवनत, 39 प्रतिशत मध्यम रूप से, और केवल 8 प्रतिशत ही अप्रभावित स्थिति में हैं। ये तथ्य संरक्षित क्षेत्रों में विशेष रूप से पशुधन दबाव को नियंत्रित करने की आवश्यकता को दर्शाते हैं।

छायाचित्र.1. हिमालयी बुग्याल, गंगोत्री गोविंद भूदृश्य उत्तराखण्ड – भारत

पुनर्स्थापन और सतत विकास हेतु रणनीतियाँ

अल्पाइन घास के मैदानों के क्षरण को रोकने के लिए तथा सामुदायिक कल्याण को बढावा देने के साथ–साथ एक एकीकृत और सहभागी संरक्षण के लिए समग्र दृष्टिकोण अपनाना आवश्यक है। इसमें निम्न बिंदु शामिल हो सकते हैं:

पारिस्थितिक पुनर्स्थापन

1.क्षरित स्थलों का मानचित्रण करने तथा वनस्पति स्वास्थ्य का आकलन करने के लिए रिमोट सेंसिंग तथा जी.आई.एस. का उपयोग।

2. चरागाह क्षेत्रों में ऋतु आधारित अवकाश के माध्यम से सहायक प्राकृतिक पुनर्जनन।

3.अत्यधिक क्षरित क्षेत्रों में देशी घास तथा जडी–बूटियाँ लगाना।

4.आक्रामकप्रजातियों को यांत्रिक रूप से हटाना तथा उनकी जगह देशी वनस्पतियों को लगाना।

सतत चराई और संग्रहण

1.घास के मैदानों में चरने की चक्रीय पद्धति को लागू करना तथा पशुओं की चरने की क्षमता के आधार पर पशुओं को सीमित करना।

2.समुदायों को स्थायी गैर–लकडी वन उत्पाद (एनटीएफपी) संग्रह तकनीकों का प्रशिक्षण देना, जिसमें उखाडने के बजाय कटाई करना शामिल है।

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3.पौधों की फेनोलॉजी के साथ संरेखित मौसमी चराई कैलेंडर को बढावा देना। (नेगी, 2012)।

समुदाय आधारित प्रबंधन

1.चरागाहों के प्रबंधन के लिए वन पंचायतों और जैव विविधता प्रबंधन समितियों को सशक्त बनाना।
2.स्थानीय युवाओं को निगरानी, प्रलेखन एवं जागरूकता गतिविधियों में सम्मिलित करना।
3.पारंपरिक पारिस्थितिक ज्ञान को पहचानना और योजना में एकीकृत करना। (शर्मा, 2015)।

आजीविका विविधीकरण

1.इको–पर्यटन, औषधीय एवं सुगंधित पौधों की खेती, गैर मौसमी सब्जियों को बढावा देना।
2.मूल्य संवर्धन और हर्बल उत्पाद श्रृंखलाओं को प्रोत्साहन देना (सुंद्रियाल एवं शर्मा, 2016)।
3.पारंपरिक व्यापार, जैसे ऊन और सीमा–पार व्यापार का पुनर्प्रतिष्ठापन करना (नेगी, 2012)।

नीति और अनुसंधान सहयोग

1.राज्य जलवायु परिवर्तन कार्य योजनाओं में बुग्यालों को सम्मिलित करना।

2.दीर्घकालिक सामाजिक–पारिस्थितिक निगरानी करना।
3.औषधीय एवं सुगंधित पौधेप्रजातियों की कृषि तकनीकों का अध्ययन करना (सुंद्रियाल एवं शर्मा, 2016)।
4.भूमि स्वामित्व से जुडे विवादों का समाधान करना और सहभागी शासन तंत्र को बढावा देना (शर्मा, 2015)।

छायाचित्र.2. हिमालयी बुग्यालो में पशुचारण

निष्कर्ष

अल्पाइन घास के मैदान केवल सुंदर दृश्यों वाले चरागाह नहीं हैं, ये जटिल और परस्पर निर्भर सामाजिक–पर्यावरणीय प्रणाली हैं। ये घास के मैदान वन्यजीवों के लिए महत्वपूर्ण आवास प्रदान करते हैं, उच्च हिमालयी जलप्रवाह को नियंत्रित करते हैं, और पर्वतीय समुदायों की आजीविका को सहारा देते हैं। इनका क्षरण जैव विविधता, सांस्कृतिक विरासत और पारिस्थितिकी तंत्र की स्थिरता के लिए गंभीर खतरा है। प्रकृति के साथ सामंजस्यपूर्ण जीवन, जैसा कि वैश्विक जैव विविधता लक्ष्यों में कल्पित है, को साकार करने के लिए हमें अल्पाइन घास के मैदानों का संरक्षण केवल सुरक्षा के माध्यम से नहीं, बल्कि उन समुदायों के सहयोग से करना होगा जो इन्हें सबसे अच्छी तरह जानते हैं। वैज्ञानिक योजना, सामुदायिक संरक्षात्मक भूमिका और सहायक नीतियाँ मिलकर ही इन नाजुक परंतु आधारभूत परिदृश्यों को आने वाली पीढियों के लिए सुरक्षित रख सकती हैं।

संदर्भ सूची:

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Exploring Uttarakhand's Legume Diversity: Significant Findings from land racee valuation

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Uttarakhand, a Himalayan state is globally recognized as biodiversity hotspot and is home to several traditional crops maintained since generations by marginal farmers, making the state animportant region from conservation perspective (Semwal and Maikhuri, 2018).French bean (Phaseolus vulgaris), soybean (Glycine max. and Glycine soja), and horsegram (Macrotyloma uniflorum) are the most important source of nutrition and long-term livelihood for the rural people in Uttarakhand. These legumes are rich in proteins, carbohydrates, dietary fiber, essential minerals, vitamins and several bioactive compounds offering numerous health benefits. Legume consumption also alleviates several diseases such as cancer, diabetes, high blood pressure, obesity, urinary disorders, asthma, bronchitis, kidney and bladder stones etc. Despite their nutritional richness and genetic superiority, several traditional landraces have been underutilized as farmers have increasingly substituted these landraces with high-yield hybrid varieties to fulfil the market demands. The modern breeding procedures and cultivation of high yielding varieties narrowed the genetic base of many traditional varieties. Moreover, the cost and demand of these traditional legumes is very high in local as well as global market as compared to their production rates. Acknowledging the untapped potential of these crops, a research initiative was launched in 2022 by G.B Pant National Institute of Himalayan Environment, Almora funded by Uttarakhand Council for Biotechnology with the aim to promote it in future for its large-scale cultivation and breeding programs. The research included the collection of 73 landraces of French beans, 26 of soybeans and 15 of horse gram directly from the farmers field across different altitudes (926 - 4039 meters) of Uttarakhand. All the heterogenous seeds were then segregated based on the seed testa colour, size and then cultivated for three years (2022-2024) at two different locations (Mukteshwar, Nainital, India with latitude, longitude and altitude: 29° 28' 20.95'N, 79° 38' 53.59' E, and 2313 metersrespectively and at Rural Technology Complex of GB Pant National Institute of Himalayan Environment (NIHE), Kosi-Katarmal, Almora, with latitude: 29°37'46.9"N, longitude: 79°37'36.3'E, 1160 meters) following the standard agronomic conditions. Morphological characteristics of the uniformly cultivated plants were evaluated according to International Board for Plant Genetic Resources(IBPGR, 1982). Upon seed maturation, the seeds were harvested followed by evaluation for phytochemical, antioxidant and nutritional content.

Key findings

Based on the results of the morphological, nutritional and phytochemical characterization, a good diversity among the landraces was observed.

French Bean

French beans are the most demanding food legume specifically the high-altitude landraces that have attained special attention in terms of their taste and less cooking time.French bean samples showed greater variability in plant height (99.75±1.04 to 352.74±9.37 cm), seed length (8.66±0.22to 21.81±0.30 mm), width (5.93±0.20 to 8.64±0.27 mm) and 100 seed weight (11.60±0.42 to 67.13±0.58 g). All French bean samples are rich in protein and other biochemicals. While, black French bean from Sobala, Dharchulaemerged as an outstanding landrace due to its exceptionally high anthocyanin content (7.96 ± 0.60 mg/g dw) (Fig. 1). The maximum protein content was observed in black French bean of Harsil, Uttarkashi (23.09 ± 0.14%). Likewise, the highest antioxidant (FRAP assay) activity was observed in black colored seeds collected from Sobala, Dharchula (3.077 ± 0.107 mg AAE/g dw).

Soybean

Different coloured soybean landraces (black, green, and yellow) including the wild and cultivated soybeans were collected. Soybean landraces showed significant differences in plant height (70.67±0.72 to 222.33±0.54 cm), seed length (5.16±0.25 to 8.59±0.24 mm), seed width (3.24±0.27 to 7.03±0.26 mm) and 100 seed weight (7.10±0.18 to 19.00±0.18 g). Among all the samples, wild soybean species (Glycine soja) collected from Sobala, Dharchulaand Mukteshwar, Nainital displayed remarkable biochemical advantage over cultivated soybean. Soybean is majorly consumed for its protein content and wild soybean from Sobala, Dharchula and Mukteshwarexhibited higher protein content (39.69 ± 0.742%; 44.22 ± 0.280%) (Fig.1). Among soybean, black soybeans resulted in highest amount of protein and phytochemicals compared to yellow and green soybeans.The study highlights the need for preserving and utilizing wild soybean species in breeding and crop improvement programs aimed at developing high-protein soybean varieties with enhanced stress tolerance ability (Oli *et al.*, 2025).

Conclusion

The present study provides valuable insights into the morphological and biochemicals of the collected landraces from Uttarakhand. Anthocyanin rich French beans, protein rich wild soybeans and a wide range of horse gram landraces highlights state's prosperity in terms of legumes that can play an important role in enhancing the nutritional security and sustaining livelihood of the local people. Furthermore, mass cultivation might also help in preservation of such local landraces and their continued availability. Additionally, in this climate changing scenario several crop losses can be mitigated by specific crop improvement programs. For instance, genetic modification of cultivated soybean varieties through the gene insertion from wild soybean presents a promising strategy to improve the stress resilience. Such strategy is not only limited to the promotion of these nutrient rich legumes but also increase the food security and economic upliftment of the Himalayan agricultural communities.

Fig 1. Superior landraces: a)black French beans; b) wild soybean; c) horse gram

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Capacity building of highland border village communities on NTFP Product Development, Value Addition, and Market Linkages for livelihood diversification

Highland border villages in Pithoragarh district, nestled near international borders with Nepal and China (Tibet), rely heavily on forest resources for their livelihoods. Communities in villages like Lum, Khimling, Sagri, Dhakdhauna, Sumatu, Poting, Tidang, Seepu, Marcha, Rongkong, Panchu Gunth, Tola, Heera Gumari, Gunji, Kuti, Napalchu, Navi, Sela, Sobla, Garbyang, Dugtu, Dar, and Gumkana depend on Non-Timber Forest Products (NTFPs) such as medicinal plants, resins, gums, honey, and wild fruits for food security and income. However, their full economic potential remains untapped due to limited technical expertise, poor value addition, and weak market links. Capacity building initiatives focused on NTFP product development, value addition, and market access are vital for empowering these communities. Training in sustainable harvesting, processing, and packaging can help maximize the value of NTFPs while conserving forest ecosystems. Strengthening local enterprises and market connections can diversify livelihoods, reduce vulnerability, and promote inclusive growth. Geographical isolation is the primary challenge, with difficult terrain, harsh climate, and limited connectivity restricting access to basic amenities and government services. Infrastructure development—roads, electricity, communication—remains inadequate due to logistical and financial constraints. Socio-economic constraints include a predominantly agrarian economy, low agricultural productivity (due to fragmented land, lack of irrigation, and outdated techniques), and weak market linkages. This results in low, unstable incomes and persistent poverty. Out-migration of youth and working-age adults to cities weakens the social fabric and leads to loss of traditional knowledge. Women, children, and the elderly are left to cope with limited economic options. These border villages are also strategically important for national security. Their proximity to international borders makes them crucial for territorial integrity. The Government of India recognizes that vibrant, populated border villages act as a first line of defense. Depopulation and neglect can create security vacuums, increasing risks of infiltration. Government initiatives like the Border Area Development Programme (BADP) and Vibrant Villages Programme (VVP) aim to improve infrastructure and socio-economic conditions. However, sustainable development requires empowering locals through capacity building and livelihood diversification. Value addition—processing, packaging, and branding local resources—can create new income streams and foster resilience. The unique agro-climatic conditions, rich cultural heritage, and artisanal skills of the region offer opportunities for high-value crops, medicinal herbs, handicrafts, and eco-tourism. Yet, lack of technical know-how, organizational capacity, and market access prevents optimal resource use. A focused project on capacity building and value addition enterprises can bridge these gaps, unlocking the region's potential and supporting national development and security objectives, while honoring the aspirations of the people who call these remote frontiers home.

Objectives

- Exploring potential NTFPs for product development and livelihood diversification
- Prioritization of identified resources (based on the availability) for product development
- Engagement of experts for training on resource processing, preservation and packaging (3Ps)
- Attempt linking these products with existing co-operatives and farmer producer organizations (FPOs) for marketing

Methodology

1. Resource mapping
- Conduct a comprehensive baseline survey in the listed villages to assess existing resources, skills, infrastructure gaps, and potential value addition sectors.
- Engage local Gram Sabhas and village institutions for participatory planning.

2. Capacity Building and Training
- Design and deliver training modules on value addition techniques in agriculture (e.g., processing of medicinal plants, fruits, and herbs), handicrafts, food processing, packaging, and marketing.
- Include entrepreneurship development, cooperative management, quality control, and digital literacy.

3. Establishment of Value Addition Enterprises
- Facilitate formation of self-help groups (SHGs) or cooperatives to manage enterprises.
- Provide necessary infrastructure support such as small processing units, storage, and packaging facilities.
- Link enterprises with markets through local fairs, tourism promotion, and e-commerce platforms.
- Engage Border Guarding Forces and local administration for security and promotion of local products.

4. Monitoring and Evaluation
- Set up a District Level Committee including district officials, Border Guarding Forces, and community representatives for oversight.
- Monitor progress through outcome indicators at village, household, and individual levels.

Outcomes

- Enhanced skills and capacity of local youth and women in value addition enterprises.
- Establishment of at least 3 functional value addition enterprises in targeted villages.
- Increased income levels and employment opportunities, reducing seasonal and permanent out-migration.
- Improved infrastructure and market linkages for border village products.
- Strengthened community ownership and sustainability of enterprises.
- Promotion of local culture and tourism through value-added products.

Summary

This project aims to empower border villages of Pithoragarh district by building capacities and establishing value addition enterprises that leverage local resources and skills. Through skill development, infrastructure support, and market integration, the project will create sustainable livelihoods, improve socio-economic conditions, and contribute to the overall development and security of these strategically important border areas.

Potentilla atrosanguinea

Aconitum napellus

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The EIACP Centre on Himalayan Ecology, G.B. Pant National Institute of Himalayan Environment (GBPNIHE), Kosi-Katarmal, Almora, successfully organized a four-day capacity building program on "NTFP Product Development, Value Addition, and Market Linkages for Livelihood Diversification" from 04 to 07 November 2025. The programme was conducted under the EIACP Cell of the Ministry of Environment, Forest and Climate Change (MoEF&CC), Government of India, with the objective of strengthening livelihood opportunities in ecologically sensitive Himalayan border regions through sustainable use of Non-Timber Forest Products (NTFPs). The programme was organized in the border villages of Dharchula, District Pithoragarh, Uttarakhand (Latitude: 29.848413°N, Longitude: 80.545699°E). This remote Himalayan region is rich in forest biodiversity and traditional knowledge related to medicinal and aromatic plants, wild edibles, and other NTFPs, yet faces challenges related to market access, value addition, and income diversification. Conducting the training at the village level ensured strong local participation and contextual learning. The course was focused on structure and delivery of theory and practical sessions. It was structured into four modules:

1. Course Overview and Technical Skills for Value Addition
2. Entrepreneurship and Business Management
3. Capacity Building for Sustainable Operations, Linkages, and Networking
4. Field Visit and Practitioner Interaction

A total of 40 participants (sanctioned batch size 20+20) attended the programme. The target group primarily included rural women, SHG members, school dropouts, youth, and forest-dependent local villagers, with strong representation from Scheduled Caste and Scheduled Tribe communities, ensuring inclusivity and grassroots impact.

Resource Persons and Technical Inputs

The programme benefited from the expertise of experienced resource persons from government departments and GBPNIHE. The programme was enriched by the active involvement of distinguished resource persons and officials. Mr. Lalit Mohan Goswami, Block Development Officer, Dharchula, inaugurated the programme as the Chief Guest and highlighted the vast economic potential of Non-Timber Forest Products (NTFPs) in border villages, encouraging participants to adopt entrepreneurial thinking and stressing the importance of value addition, proper packaging, and branding to enhance household incomes. Mr. Vikram Gandi, Assistant Development Officer (Horticulture), attended as the Guest of Honour and shared valuable insights on market opportunities for NTFP- and horticulture-based products, the challenges

Punarnava roots (Boerhavia diffusa) Anemone rivularis

of marketing in border regions, and the role of collective action through Self-Help Groups (SHGs) in strengthening livelihoods. The technical sessions were led by Dr. Shailja Punetha, Scientist, GBPNIHE, who delivered comprehensive inputs on medicinal and aromatic plants (MAPs), sustainable and eco-friendly harvesting techniques, use of appropriate tools, value addition, and development of secondary products such as herbal teas, powders, sachets, and balms. In addition, Mr. Suraj, Assistant Agriculture Officer, Dharchula, provided practical and market-oriented guidance on post-harvest management, grading, quality control, packaging, branding, and the use of digital marketing platforms, effectively linking traditional practices with modern market requirements.

Community Participation and Learning Outcomes

Community participation was one of the strongest aspects of the programme. Participants actively engaged in interactive lectures, group discussions, hands-on demonstrations, and practical exercises. Women and SHG members showed particular enthusiasm during sessions on product development, packaging, and entrepreneurship. Group activities enabled participants to conceptualize their own NTFP-based enterprises, develop basic business models, and propose locally relevant product names and ideas. The field exposure visit provided real-world learning, allowing participants to observe NTFP processing units, interact with practitioners, and understand operational challenges and opportunities. On the final day, participants showcased sample products and prototype ideas developed during the training, reflecting improved confidence and practical understanding. Feedback sessions revealed that participants gained enhanced knowledge of sustainable harvesting, scientific processing, business planning, market linkages, and government schemes such as NRLM and SHG-based enterprise support. The programme concluded with a valedictory session and certificate distribution, reinforcing motivation and recognition for participants' efforts .

Conclusion

Overall, the four-day capacity-building programme successfully strengthened technical, entrepreneurial, and conservation-oriented capacities of border village communities in Dharchula. By combining scientific knowledge with traditional practices and strong community participation, the initiative contributed meaningfully to livelihood diversification, self-reliance, and sustainable management of Himalayan forest resources, aligning closely with the objectives of EIACP and MoEF&CC.

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