TRANSFORMATIVE AND IMPACTFUL INITIATIVES FOR RESILIENT HIMALAYA

G. B. Pant National Institute of Himalayan Environment (GBP-NIHE)

(An Autonomous Institute of Ministry of Environment, Forest and Climate Change, Government of India)

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G. B. Pant National Institute of Himalayan Environment (GBP-NIHE)

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मंत्री
पर्यावरण, वन एवं जलवायु परिवर्तन
भारत सरकार

सत्यमेव जयते

भूपेन्द्र यादव
BHUPENDER YADAV

MINISTER
ENVIRONMENT, FOREST AND CLIMATE CHANGE
GOVERNMENT OF INDIA

MESSAGE

The G.B. Pant National Institute of Himalayan Environment (GBP-NIHE) has been playing a pivotal role in addressing the diverse environmental and developmental challenges in the Himalayan region through its integrated research, development, and demonstration initiatives. By bridging traditional knowledge with modern science, and linking community participation with policy and technology, the Institute has developed replicable models that strengthen ecological resilience, promote sustainable livelihoods, and enhance environmental management across the Indian Himalaya.

Some of the key initiatives and outcomes encapsulated in this compendium reflect GBP-NIHE's commitment to sustainable mountain development and its alignment with national priorities such as Vision@2047 for "*Viksit Bharat*", Atmanirbhar Bharat, Swachh Bharat Mission 2.0, and Skill India Mission. These replicable efforts also contribute meaningfully to global frameworks, including the UN Sustainable Development Goals and the Kunming-Montreal Global Biodiversity Framework.

I commend the Institute's dedicated scientists, researchers, collaborators, and community partners for their continued and dedicated efforts to conserve the natural wealth of the Himalaya while advancing inclusive and resilient development pathways. I am confident that this compendium will serve as a valuable reference for policymakers, researchers, and practitioners working towards a sustainable and prosperous Himalaya.

(Bhupender Yadav)

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कीर्तवर्धन सिंह
KIRTI VARDHAN SINGH

सत्यमेव जयते

राज्य मंत्री
पर्यावरण, वन एवं जलवायु परिवर्तन और
विदेश मंत्रालय,
भारत सरकार
MINISTER OF STATE
ENVIRONMENT, FOREST AND CLIMATE CHANGE &
EXTERNAL AFFAIRS,
GOVERNMENT OF INDIA

MESSAGE

The Himalayan region stands as one of India's greatest natural and cultural heritage landscapes. It is home to invaluable ecosystem services, diverse ethnic communities, and major river systems, yet it faces unprecedented challenges driven by accelerated climate change, biodiversity loss, land degradation, socio-economic transitions, and increasing disaster risks.

In this context, it is imperative to adopt impactful, science-led approaches that enhance the resilience of both Himalayan ecosystems and the communities that depend on them across mountain ranges, valleys, and downstream regions. Building a resilient Himalaya requires interventions that are grounded in scientific research, strengthened through active community participation, and guided by the principles of sustainability.

I am pleased to note that the G.B. Pant National Institute of Himalayan Environment (GBPNIHE) has developed practical and replicable solutions to address these emerging challenges through its integrated research, development, and demonstration approach across the Indian Himalayan Region (IHR). These models not only help bridge contemporary science with traditional knowledge, but also support strong linkages between science, policy, and practice, thereby enabling informed decision-making and enhancing ecological resilience and environmental sustainability in the IHR.

I am confident that the initiatives and practical solutions presented in this compendium by GBPNIHE will help address the pressing challenges faced by Himalayan communities and guide governments in developing effective policies and programmes that safeguard both people and ecosystems. The scientists and researchers of the Institute deserve great appreciation for their hard work and dedicated efforts.

I urge researchers, civil society, and local governance institutions to work collaboratively to replicate and scale these scientific initiatives, driving meaningful change on the ground and strengthening sustainability and resilience across the Himalayan region.

(KIRTI VARDHAN SINGH)

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TANMAY KUMAR

सत्यमेव जयते

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भारत सरकार
पर्यावरण, वन और जलवायु परिवर्तन मंत्रालय
SECRETARY
GOVERNMENT OF INDIA
MINISTRY OF ENVIRONMENT, FOREST
AND CLIMATE CHANGE

FOREWORD

The Indian Himalayan Region (IHR), a global biodiversity hotspot, stands as a vital ecological lifeline, supporting unique ecosystems, regulating climate, and sustaining millions of livelihoods. Yet it faces escalating threats from climate change, habitat loss, overexploitation of resources, and socio-economic changes, undermining community resilience and environmental stability. The G. B. Pant National Institute of Himalayan Environment (GBP-NIHE) has been addressing these challenges with science-based, integrated, and scalable strategies that blend cutting-edge research, technological innovation, and strong community engagement.

This compendium highlights GBP-NIHE's transformative initiatives, ranging from Long-Term Ecological Monitoring (LTEM) and Global Observation Research Initiative in Alpine Environments (GLORIA) sites that track climate impacts across altitudes, to Surya-Kunj and Prakriti Kunj-nature learning centres that foster experiential education and stewardship. Rural Technology Centres (RTCs) operating on a hub-and-spoke model have empowered over 35,000 individuals through more than 750 skill-building programs, promoting low-cost technologies in agriculture, energy, and waste-to-wealth initiatives such as pine needle valorization and Seabuckthorn enterprises. These efforts empower women, diversify incomes, and advance circular economies while conserving natural resources, including biodiversity.

Aligned with national visions such as Atmanirbhar Bharat, Skill India, Swachh Bharat Mission 2.0, and global frameworks like the UN SDGs and Kunming-Montreal Biodiversity Framework, GBP-NIHE's work in sustainable livelihoods, water security, environmental management, ecological restoration, bioresource conservation, low-cost rural technologies, and wild edible promotion delivers replicable models for fragile mountain ecosystems. By harmonizing indigenous knowledge with science, these initiatives enhance ecological resilience, environmental sustainability, food security, and socio-economic wellbeing.

As we confront mounting environmental challenges, strengthening and scaling GBP-NIHE's holistic approaches is imperative to safeguard the IHR's unique biological and cultural heritage and ensure a sustainable future for its communities and ecosystems. I congratulate the editors and contributors for bringing together this compendium of transformative initiatives led by GBP-NIHE, and I am confident that these initiatives will help frame strategic actions to upscale ecosystem-based approaches for creating a resilient Himalaya.

28/11/25
(Tanmay Kumar)

Place: New Delhi
Dated: November 28, 2025

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PREFACE

The Indian Himalayan Region (IHR) stands as one of the world's most ecologically diverse and culturally rich mountain systems, playing a vital role in sustaining biodiversity, regulating regional climate, and supporting millions of livelihoods. However, this fragile region is increasingly vulnerable to the compounded impacts of climate change, unsustainable resource use, and socio-economic transformations. Addressing these multidimensional challenges requires an integrated approach that combines scientific innovation, technological interventions, and community-based solutions.

The G. B. Pant National Institute of Himalayan Environment (GBP-NIHE), under guidance of the Ministry of Environment, Forest and Climate Change (MoEF&CC), Government of India, has been at the forefront of advancing such integrated models for sustainable socio-ecological development in the IHR. Guided by the principles of ecological integrity, community empowerment, and self-reliant growth, the Institute has developed and demonstrated innovative strategies that link biodiversity conservation, livelihood enhancement, and environmental sustainability across the IHR.

This compendium presents a synthesis of key transformative initiatives of GBP-NIHE that have delivered tangible impacts, both at community and ecosystem levels. The programme highlighted in this document, ranging from long-term ecological monitoring and germplasm conservation to sustainable livelihood innovations, water and waste management, and nature learning centres, reflect the Institute's holistic approach to harmonizing development with conservation. While addressing the regional priorities and stakeholder's needs, these initiatives are also aligned with national missions and contribute to global frameworks like the UN SDGs and the Kunming-Montreal Global Biodiversity Framework.

By showcasing these efforts, this document calls to inspire replication and up-scaling of successful models across mountain regions and beyond. It reaffirms GBP-NIHE's commitment to strengthening the ecological resilience and socio-economic well-being of Himalayan communities through science-policy-practice based participatory and sustainable pathways for the enhancing resilient future in the Himalaya.

Editors

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EXECUTIVE **SUMMARY**

The Indian Himalayan Region (IHR), a global biodiversity hotspot, supports unique ecosystems that sustain local livelihoods, regulate regional climate, and provide critical ecological services. However, the region faces increasing threats from climate change, habitat degradation, over-extraction of natural resources, and socio-economic pressures, leading to ecological vulnerability and affecting community resilience. Addressing these challenges requires integrated, scalable strategies combining scientific research, technological innovation, and community engagement.

The G.B. Pant National Institute of Himalayan Environment (GBP-NIHE) promotes sustainable development across the IHR by addressing key challenges such as biodiversity conservation, climate adaptation, environmental sustainability, and socio-economic empowerment of indigenous communities. Its initiatives align with national priorities, including Vision @2047, Atmanirbhar Bharat, Swachh Bharat Mission 2.0, Skill India, and international frameworks, such as the Kunming-Montreal Global Biodiversity Framework and the UN Sustainable Development Goals (SDGs). The significant initiatives of NIHE that have led to an impact on the ground span ecological monitoring, nature education, sustainable livelihoods, waste-to-wealth innovations, water conservation, and germplasm preservation. The key programs, such as Long-Term Ecological Monitoring (LTEM), Air and Climate monitoring, Nature Interpretation Centre, and Rural Technology Centres (RTCs), integrate research, technology, and community participation to strengthen environmental sustainability, ecological resilience, diversify incomes, and promote sustainable, self-reliant rural economies. Initiatives targeting local bioresources, such as Seabuckthorn-based enterprises, pine needle valorization, and indigenous honey production, empower women and marginalized groups while supporting circular economy principles. This compendium describes key impactful initiatives of the institute over the years, which have led to transformations at the community and ecosystem level. These initiatives are summarized below and described under various thematic sections as seperate chapters in the document.

Nature Learning and Conservation Centres: The ***Surya-Kunj*-Nature Interpretation and Learning Centre (Almora)** and the ***Prakriti Kunj*-Himalayan Nature Learning Centre (Sikkim)** have been developed as hybrid public–private initiatives combining conservation, education, and sustainable resource management. These centres promote hands-on experiential learning, strengthen ecological understanding, and enhance environmental stewardship. By integrating scientific approaches with community participation, they foster awareness, capacity building, and responsible natural resource use. These centres serve as replicable models for holistic ecosystem management, demonstrating the importance of connecting education, conservation, and livelihoods in biodiversity-rich regions.

Ecological Monitoring and Climate Adaptation: Robust ecological data is critical for effective conservation planning. The Long-Term Ecological Monitoring (LTEM) initiative has established permanent forest plots across altitudes of 700–3800 meters in the Western Himalaya to track forest structure, species composition, and key ecological indicators. Complementing this, GLORIA observation sites at high altitude regions in Himalaya monitor alpine vegetation dynamics, soil temperature, and precipitation patterns, providing insights into the impacts of climate change on sensitive ecosystems. These initiatives inform adaptive management strategies, enhance ecosystem resilience, and support national biodiversity conservation priorities.

Sustainable Livelihood Innovations: Fragile ecosystems and climate variability challenge traditional livelihoods. Innovative solutions combine indigenous knowledge with modern technologies. In Sikkim, integrating indigenous beekeeping (*Apis cerana*) with large cardamom and medicinal plant cultivation has improved pollination, productivity, and community

resilience. In Ladakh, solar-powered hydroponic systems using the Nutrient Film Technique (NFT) enable year-round vegetable production under extreme climatic conditions, ensuring food security and nutritional benefits.

Rural Technology Centres and Community Empowerment: The NIHE has established six Rural Technology Centres (RTCs) across the region, operating on a Hub-and-Spoke model to promote low-cost, eco-friendly technologies. These centres provide research-based demonstrations, training, and technology dissemination, bridging the gap between scientific research and rural communities. Over 750 training programs have benefitted 35,000+ individuals, demonstrating technologies in agriculture, energy, water management, and livelihoods. Notable innovations include pine needle-based products for forest fire mitigation and income generation, along with promotion of small-scale enterprises in ecotourism, beekeeping, and local food processing.

Promotion of Wild Edibles: Wild edibles like Seabuckthorn (*Hippophae spp.*) have been leveraged to improve livelihoods, food security, and women's empowerment in remote Himalayan regions. Integrated value chains, combining technology, processing infrastructure, training, and market linkages, have enabled tribal women to generate sustainable incomes, strengthen ecological sustainability, and preserve regional identity. Initiatives in Ladakh and Himachal Pradesh highlight scalable models for utilizing wild edibles while conserving biodiversity.

Water and Waste Management Innovations: Water scarcity and improper sanitation pose severe environmental risks. Low-cost greywater and faecal sludge treatment systems, utilizing locally available resources such as *Pinus roxburghii* needles and employing ecosystem-based purification through plants, demonstrate eco-friendly, self-regenerating solutions. Pilot projects in Ladakh illustrate circular economy principles, integrating treated wastewater into agriculture and hydroponics, enhancing water security, and promoting sustainable livelihoods.

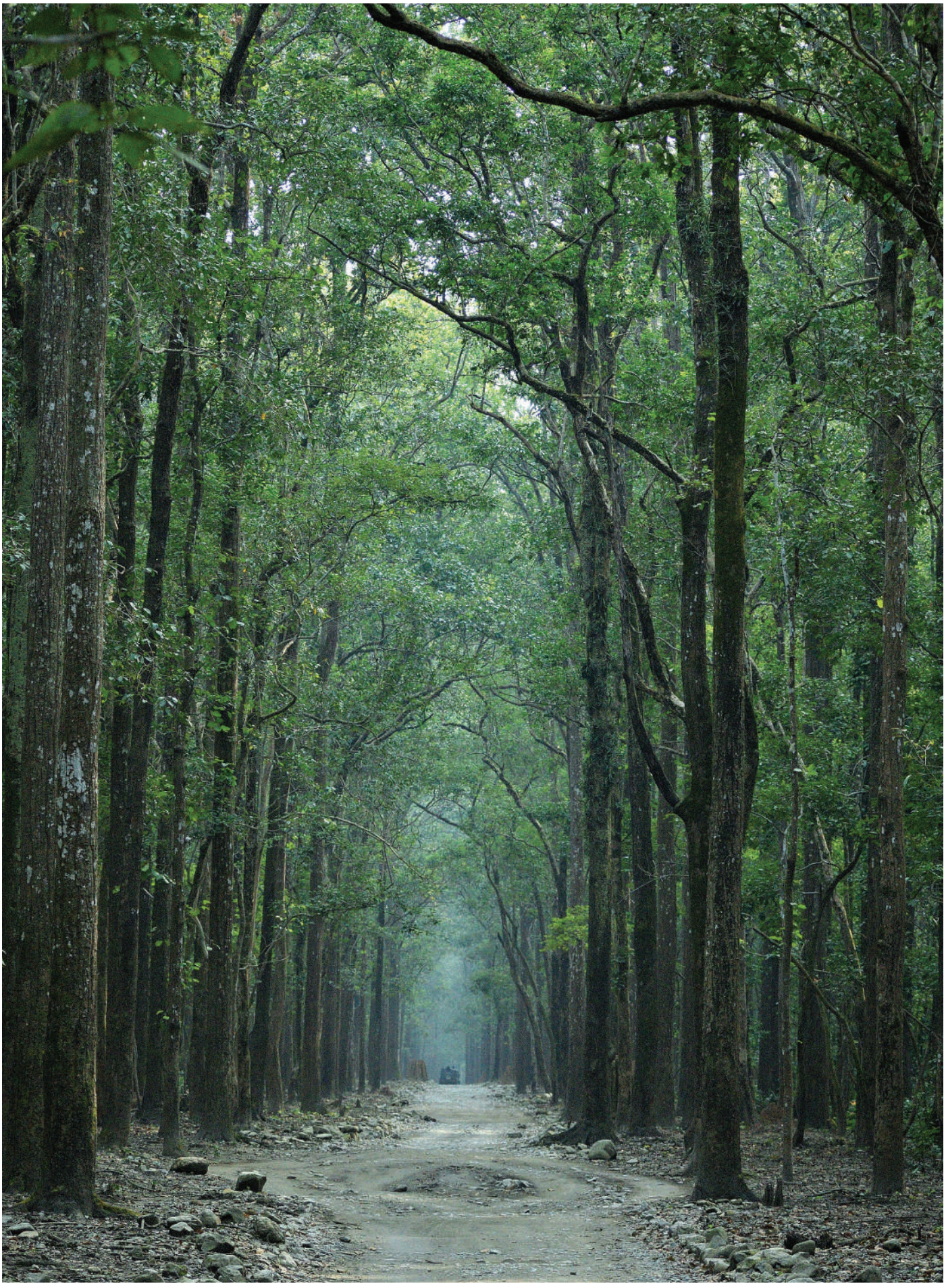
Germplasm Conservation: Preserving Himalayan germplasm is critical for maintaining genetic diversity, supporting climate-resilient agriculture, and sustaining fragile ecosystems. Conservation of traditional crops (millets, buckwheat, amaranth) and wild edibles ensures resistance to pests and environmental stresses, stabilizes agro-ecosystems, supports pollinators, and enables year-round cultivation of vegetables. Germplasm programs also preserve cultural heritage and provide opportunities for value-added products, strengthening both ecological and economic resilience.

Monitoring Atmospheric and Forest Ecosystem Responses to Climate Change in the Himalayan Region: Monitoring atmospheric conditions and forest ecosystem processes with high temporal resolution is essential for detecting early signals of climate change and understanding their cascading impacts on biodiversity, water resources, forests, and human well-being. In this context, GBP-NIHE has established an integrated monitoring framework that combines continuous atmospheric observations of meteorological parameters, gaseous pollutants, with ecosystem-level carbon, water, and energy flux measurements across representative Himalayan sites. A major component of this initiative is the deployment of in-situ air pollution monitoring systems at two climatically and topographically distinct locations—Kullu in Himachal Pradesh and Almora in Uttarakhand. These stations record high-resolution data on particulate matter ($PM_{2.5}$, PM_{10}), ozone, carbon monoxide, nitrogen oxides, and related meteorological parameters. Continuous observations allow the Institute to quantify diurnal and seasonal variations in pollutant loading, identify pollution episodes, and evaluate background vs. transported pollution. When integrated with atmospheric chemical transport models, these data support diagnostic assessment of long-range pollutant transport, sources, dispersion pathways, and the chemical evolution of regional pollution load and transport mechanism. This evidence base is crucial for understanding how changing climate regimes, biomass burning, and anthropogenic activities collectively influence air quality in mountain environments.

Complementing atmospheric measurements, GBP-NIHE operates two Eddy Covariance (EC) flux towers—one located at Almora and the other at Gangolihat (Pithoragarh)—which provide continuous observations of carbon dioxide exchange, evapotranspiration, energy partitioning, and micrometeorological dynamics in Pine-dominated and Oak-dominated forest ecosystems, respectively. These EC systems represent the first long-term flux monitoring infrastructure established by an Indian institution within the entire Himalayan region. By capturing ecosystem-scale responses at 30-minute temporal resolution, the flux towers enable accurate estimation of Net Ecosystem Exchange, photosynthesis and respiration dynamics, latent and sensible heat fluxes, and ecosystem-level water use. Such measurements offer mechanistic insights into how Himalayan forests respond to warming, altered rainfall regimes, and shifts in microclimate. Combining these flux data with meteorological and climatological variables allows the Institute to evaluate the productivity and resilience of pine and oak forests under changing environmental conditions. Seasonal and inter-annual variability in carbon uptake, water use efficiency, canopy conductance, and soil respiration is also assessed to understand how temperature, vapor pressure deficit, soil moisture, and radiation regulate forest functioning. Further, annual carbon and water budgets are derived to quantify whether these ecosystems act as net carbon sinks or sources—a critical input for regional climate mitigation and forest management planning. Together, GBP-NIHE's atmospheric observatories and ecosystem flux towers establish a scientifically rigorous, Himalayan-specific monitoring network. The integrated dataset provides foundational knowledge for climate-smart forest management, improved air quality forecasts, carbon accounting, ecosystem vulnerability assessment, and evidence-based policy formulation for the Indian Himalayan Region.

GBP-NIHE's initiatives support national programs such as Atmanirbhar Bharat, Skill India, Swachh Bharat Mission 2.0, National Food Security Mission, National Beekeeping and Honey Mission, Skill India Mission, and Jal Shakti Abhiyan, while contributing to UN Sustainable Development Goals, including poverty alleviation, food security, gender equality, clean water, responsible production, climate action, and biodiversity conservation. Through a combination of research, technology, and community-led models, NIHE fosters sustainable livelihoods, ecological resilience, and replicable frameworks for the holistic development of the IHR, demonstrating a balance between environmental stewardship and socio-economic advancement.

The integrated initiatives of NIHE across the Himalayan region, covering biodiversity conservation, nature education, environmental and waste management, sustainable livelihoods, water management, and germplasm preservation, demonstrate that holistic, community-engagement approaches can enhance ecological resilience, food security, and socio-economic well-being. By combining traditional knowledge with scientific innovation and scalable technologies, these models provide replicable pathways for sustainable growth in fragile mountain ecosystems. Strengthening, scaling, and replicating such initiatives is essential to safeguard the unique biodiversity of the Himalayan region and ensure long-term ecological, social, and economic sustainability amid escalating environmental challenges.



Chapter 1

Synergizing Conservation, Education, and Livelihoods in the Himalayan Region

The Himalayan region, one of the world's major biodiversity hotspots, supports unique ecosystems that sustain local livelihoods and influence regional climate. However, its rich biodiversity is under growing threat from habitat degradation, over-extraction of natural resources, climate change, and increasing human pressures. These challenges are driving many species toward vulnerability or extinction, emphasizing the need for innovative, integrated, and scalable conservation strategies that balance ecological and socio-economic priorities. Conventional efforts in the Himalaya often lack integration between in-situ (on-site) and *ex-situ* (off-site) conservation practices, limiting holistic biodiversity management and community involvement. Addressing this gap, the "Surya-Kunj -Nature Interpretation and Learning Centre (NLC)" has been developed in Almora as a hybrid public–private partnership model that unites conservation, education, and sustainable resource management. It combines scientific approaches with community participation, promoting awareness, capacity building, and responsible use of natural resources. The Himalayan Nature Learning Centre (Him-NLC), established in Sikkim, seeks to educate, engage, and empower diverse stakeholders. Through on-site, experiential learning, it enhances ecological understanding, environmental skills, and stewardship toward nature. By integrating conservation science with education and stakeholder's participation, Him-NLC demonstrates a scalable and replicable model for biodiversity conservation in the Himalayan landscape. It provides a platform to strengthen ecological resilience, promote sustainable livelihoods, and foster long-term environmental consciousness.

These models of Nature Learning Centres exemplify a forward-looking approach to nature conservation that bridges science, community engagement, and education. By integrating in-situ and *ex-situ* strategies, fostering local participation, and promoting sustainable livelihoods, Him-NLC offers a replicable model for holistic ecosystem management. Such initiatives are crucial not only for safeguarding the unique biodiversity of the region but also for building environmental awareness, resilience, and adaptive capacity among communities. Strengthening and scaling these efforts can ensure the long-term ecological, social, and economic sustainability of the Himalayan region in the face of escalating environmental challenges.

Surya-Kunj
Nature Interpretation and Learning Centre (NILC)
A Public-Private Partnership Ecological Restoration Model for Himalayan Landscapes

Situational Analysis & Rationale

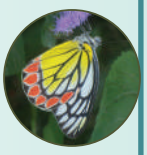
- Biodiversity across the Himalayan region is under severe and multifaceted threats driven by habitat degradation, over-extraction of natural resources, climate change, and anthropogenic pressures.
- These threats are pushing many flora and fauna species towards vulnerability or extinction.
- There is a critical need for innovative, scalable conservation approaches that integrate socio-economic and ecological priorities while promoting sustainable resource management.
- Lack of integrated conservation models combining *in-situ* and *ex-situ* techniques limits opportunities for holistic management and community participation.

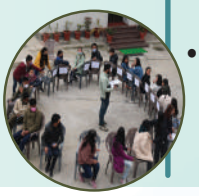
Activities & Innovations

- Surya-Kunj, developed as a Nature Interpretation and Learning Centre, a hybrid public-private partnership conservation model integrates in-situ and *ex-situ* practices.
- Alongwith biodiversity conservation, it also addresses cross-sectoral challenges including conservation education, capacity-building, and sustainable resource use.
- A scalable and replicable conservation model for the Himalayan landscape.

Key Steps & Processes

- Rehabilitation of a degraded pine forest slope through restoration and introduction of diverse species.
- Establishment of partnerships between public and private entities to pool expertise, resources, and technology.
- Integration of R&D projects to leverage funds and technical know-how.
- Synergy-building and convergence with institutions, organizations, and line departments to enhance implementation efficiency.
- Development and application of propagation protocols for over 90 threatened and multipurpose plant species.
- Capacity-building programs and awareness campaigns to engage stakeholders, including students, local communities, and visitors.





Key Highlights

- Restoration through Surya-Kunj transformed a degraded forest slope into a vibrant biodiversity refuge.
- Conservation and propagation initiatives of over 230 plant species, including more than 31 species of high conservation value.
- Establishment of over 20 conservation facilities and models, such as herbal garden, nursery, herbarium, and "Pine-Oakia" model.
- More than 20,000 individuals sensitized through conservation education and science outreach programs.

Outcomes

A degraded slope of Pine forest, with rehabilitation and introduction of new facilities/models have evolved into Nature Interpretation and Learning Centre catering diverse need of the visitors, while providing refuge to different Himalayan biodiversity elements.

Total plant species: >230 species

Angiosperms (> 205 species); Gymnosperms (4); Pteridophytes (21 species); Medicinal plant(>75 species); Lichens(>22 species); Bryophytes (>85 species)

Plant species of threatened categories and high conservation value > 31 species

Angiosperm 11; Gymnosperm 3; Orchids 14; and Pteridophytes 3

Propagation protocols developed: > 90 plant species of threatened and multipurpose use value

Conservation education and science outreach :

> 20,000 individuals (school students, teachers, community groups and individuals, and government representatives) sensitized

Outcomes *continued...*

Avifauna :>150 species (Some threatened species include Bengal Vulture , Indian Scavenger Vulture, King Vulture and Cheer Pheasant)

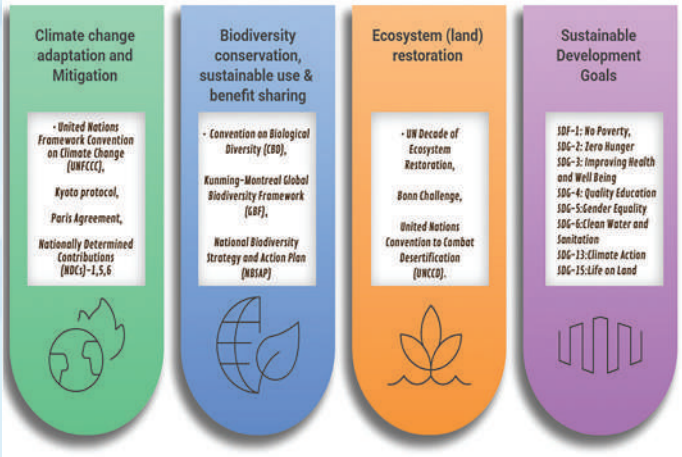
Mammals : >10 species (Some notable species include Leopard, Asiatic Jackal, Wild Boar, Yellow Throated Marten, Himalayan Palm Civet, Porcupine, Rhesus Macaque, Grey Langur and Barking Deer)

Butterflies : >100 species (Great Windmill; Spangle, Common Punch; Common Jezebel; Common Leopard, etc.)

Other insects : > 80 species (Honey bee, Cicada, Grasshopper, Dragon and Damselflies, etc.)

Conservation facilities and models developed : > 20 (Some notable ones are: Herbal garden, Herbarium, Nursery , Pine-Oakia, etc.)

Impacts & Policy Relevance



- National Action Plan on Climate Change (NAPCC)
- National Ayush Mission, 2014
- Doubling the income of farmers
- Conservation education and science outreach
- Skill development and capacity building
- Fulfilling community needs with improved availability of bio-resources (fuel and fodder)

Linkages with National Priorities & International Goals

- The Surya-Kunj model aligns with major global frameworks, such as Kunming-Montreal Global Biodiversity Framework (GBF) by supporting ecosystem restoration, species conservation, and sustainable use of natural resources.
- It contributes to the Convention on Biological Diversity (CBD) through *in-situ* and *ex-situ* conservation efforts targeting threatened species and habitat management.
- It advances the goals of the Paris Agreement (UNFCCC) by promoting climate resilience through ecosystem-based approaches and sustainable land management practices in the Himalayan region.

Way Forward & Scoping for Up-scaling

- Replicating Surya-Kunj model to other degraded Himalayan landscapes.
- Use of advanced technology like GIS and remote sensing for monitoring.
- Documentation of success for policy and replication.
- Building regional networks for collaboration and scaling.
- Promote eco-tourism and nature education for revenue and awareness.

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Prakriti-Kunj
Himalayan Nature Learning Centre (Him-NLC)
Promoting Nature Conservation and Environmental Consciousness

Situational Analysis & Rationale

- The eastern Himalayan region, a biodiversity hotspot, plays vital role in providing several ecosystem services and regulating regional climate.
- Conservation of natural resources and building environmental consciousness is essential for ecological, social, and economic well-being, and mitigating impacts of climate change.
- Conscious and integrated efforts to protect and sustainably manage the natural resources for ensuring healthy environment and awareness building are lacking in north eastern Himalaya.
- NLC can foster holistic growth by enhancing environmental awareness, academic learning, and practical environmental skills through on-site experiences.

Activities & Innovations

- Him-NLC is established in Sikkim Regional Centre of NIHE, supported by MoEF&CC, under National Mission on Himalayan Studies (NMHS).
- It aimed to educate, engage, and empower diverse stakeholders to positively impact the environment through conservation efforts and deeper onsite learning about nature.
- NLC strive to foster a sense of stewardship for the natural world and promote sustainable conservation practices.

Key Steps & Processes

- Develop a learning and interpretation centre for conservation of natural resources through various interactive models.
- Develop and demonstrate best practices on sustainable models of environmental conservation such as, waste management, water harvesting, etc.
- Promote participatory conservation action and efficient utilization and management of natural resource base for livelihood diversification.
- Promote eco-tourism for nature conservation and livelihood enhancement.
- Build capacity of stakeholders on conservation of resource base and develop of knowledge product for dissemination and awareness generation.

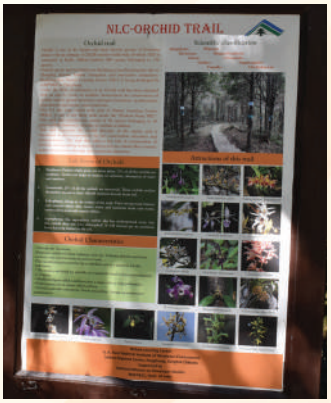
Key Highlights

- *Prakriti-kunj* is established in collaboration with state forest department, Sikkim .
- State-of-Art nature learning facility with different conservation and demonstration models.
- Trained youth, especially school and college students on nature conservation as para-conservationist.
- Alternate nature based livelihood generation for local people.
- Knowledge products on different themes and models in the forms of booklets, posters, maps, tags, training manuals, etc.

Outcomes

- Establishment of permanent study site within "Prakriti-kunj" for vegetation studies.
- Established Orchid trail and Orchidarium (152 sp.), Rhododendron trail (13 sp.) and Herbal garden (40 sp.).
- Live spring recharge and rain water harvesting model. Functional waste management models.
- Degraded land is restored and developed as a NLC having live models of nature conservation.

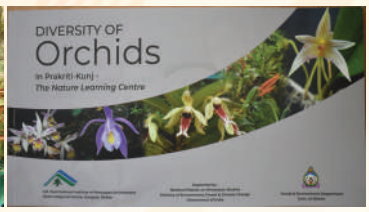
Thrixspermum formosanum (Hayat) Schltr



New record for flora of Sikkim

Taeniophyllum glandulosum Blume

Outcomes *continued...*


- Development of nurseries of multipurpose tree species, tea, large cardamom and Nakima (Tupistra clarkei)
- Trainings (330 participants), exposure visits to NLC (480 participants), nature camps (153 participants), awareness workshops (646 participants).
- Promotion of organic farming through off season vegetables and floriculture in Pangthang area.
- Creation of network of students and teachers form 7 schools and colleges. 21 para-conservationist identified.
- Development of knowledge product and dissemination materials: 2 booklets, 1 monograph, 4 dockets and fliers, 6 posters, 400 tags, stickers, etc

Impacts & Policy Relevance

- Prakriti-kunj serves as field based lab for conservation education and ecological studies
- A restoration-cum-nature conservation model with potential carbon sink.
- Cadre of nature sensitive youth and para-conservationists developed with a sense of responsibility for nature conservation.
- Conservation of critical element of biodiversity and natural resources.
- Replicated the good practices in schools and among communities.


- A network of students and teachers created, connecting ecoclubs of schools and colleges for participatory conservation education and efforts.
- Alternate livelihood for local farmers through off season vegetable and floriculture generated.

Linkages with National Priorities & International Goals

- SDG 4 -Quality Education: Providing knowledge and skill for sustainable development and sustainable lifestyle.
- SDG 15-Life on land: Ensuring conservation of mountain ecosystem and its biodiversity.
- SDG 13 and & Net Zero Targets- generating carbon sink substantial through restoration of a degraded land and increased vegetation cover.
- SDG 17- Partnership for the Goals: Effective networking and participation by communities, Line departments, and Institutions.
- Advances the goals of the Paris Agreement (UNFCCC)-promoting climate resilience through ecosystem-based approaches and sustainable land management practices.

Way Forward & Scoping for Up-scaling

- Potential for up-scaling and out scaling in other parts of Himalaya.
- Developing functional networks of schools & colleges with NLC.
- Linking conservation models of Him-NLC with school curriculum.
- Replication of the model to reverse the environmental degradation and losses.
- Periodical monitoring of the change using advance technology (e.g. AI/ML).
- Linking Him - NLC with tourism for promotion of ecotourism and conservation education leading to self sustainability.

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Chapter 2

Ecological Monitoring Networks for Sustainable Management of Himalayan Ecosystems

The Himalayan region, recognized as a global biodiversity hotspot, is experiencing warming at nearly twice the global average, leading to significant ecological disruptions, including shifts in species distributions, increased frequency and intensity of forest fires, and heightened vulnerability of fragile ecosystems. Lack of long-term, high-resolution ecological data limits ability to make accurate predictions and implement effective conservation planning, underscoring the urgent need for a comprehensive and systematic ecological monitoring network. In response, the Long-Term Ecological Monitoring (LTEM) initiative has established 10 permanent forest plots across the Western Himalaya, ranging from 700 to 3800 meters above sea level, to generate robust, reliable data on forest structure, species composition, and key ecological indicators that support adaptive management strategies. Meanwhile, alpine ecosystems, characterized by their rich endemic plant diversity, remain particularly sensitive to climate change due to extreme temperature variations and short growing seasons. To better understand these high-altitude environments, the institute has also set up six GLORIA observation sites above 3200 meters, systematically monitoring vegetation dynamics, soil temperature, and precipitation patterns, thereby providing an ecosystem-level understanding that aligns with national biodiversity conservation priorities.

The Long-Term Ecological Monitoring (LTEM) and GLORIA initiatives provide critical insights into the impacts of climate change on Himalayan forests and alpine ecosystems. By generating robust, long-term ecological data and integrating field observations with remote sensing and modeling, these programs enable adaptive management and informed conservation strategies. Strengthening and expanding such monitoring networks is essential to safeguard biodiversity, enhance ecosystem resilience, and ensure the sustainable management of the Indian Himalayan Region amid accelerating environmental change.

Long-Term Ecological Monitoring (LTEM) in Himalaya

Understanding Ecological responses of Himalayan vegetation to Environmental Changes

Situational Analysis & Rationale

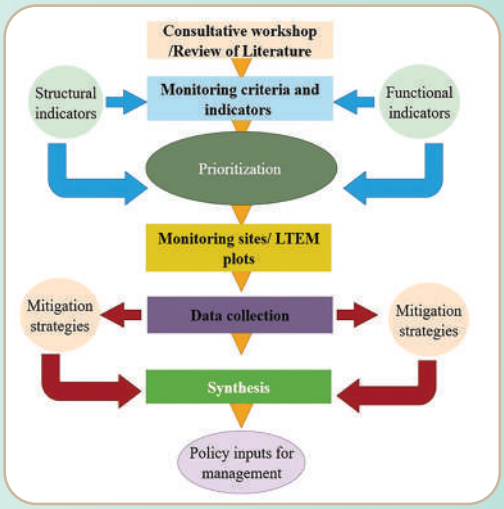
- The Himalayan region, a global biodiversity hotspot, is warming at twice the global average.
- The warming effect and anthropogenic pressure has significant ecological disruptions including, species range shifts, change in forest structure, and greater ecosystem vulnerability in the region.
- A critical data deficiency in systematic, long-term ecological observations, hinders accurate predictions of ecosystem dynamics and informed decision-making.
- This scenario calls for an urgent need for a robust ecological monitoring network to track the changes in real time and support policy making in conservation planning .

Activities & Innovations

- The LTEM - a pioneering effort to monitor forest ecosystem dynamics over time.
- A network of 10 permanent monitoring plots established in Western Himalaya (700–3800 m asl)
- Generating reliable, long-term data on forest structure, composition, and ecological indicators for adaptive forest management & conservation planning.

Key Steps & Processes

- Establishment of LTEM plots in major forest types: tropical (Sal), subtropical (Pine), temperate (Oak, Cedar, mixed broadleaf), and sub-alpine forests.
- Long term data collection on tree density, basal area, and soil nutrients to assess forest health.
- Monitoring of key species such as *Shorea robusta, Pinus roxburghii, Quercus leucotrichophora, Cedrus deodara, Rhododendron arboreum,* and *Betula utilis*.
- Phase-wise analysis to identify ecological trends and changes over time.



Outcomes

- Reliable data on forest structure, composition, and dynamics.
- Evidence-based forest management and sustainable land-use planning.
- Identification of high-pressure sites for targeted restoration.
- Integrates local knowledge with science for adaptive strategies.
- In-built citizen – science approach for monitoring forest resources.

Key Highlights

- Established multiple long-term ecological monitoring (LTEM) sites across Himalayan region.
- Assessed vegetation dynamics, carbon fluxes, and biodiversity changes under varying climatic conditions.
- Monitored trends in temperature, precipitation, soil moisture, phenology, and ecological responses.
- Generated dataset on the forest carbon sequestration, hydrological cycles, and vulnerability of mountain ecosystems to anthropogenic pressures.
- Identified climate-resilient species, ecosystem thresholds, and adaptive management frameworks to ensure ecosystem stability in the Himalaya.

Impacts & Policy Relevance

- Strengthened traditional knowledge of Himalayan region by integrating indigenous ecological knowledge with monitoring of forest ecosystem of the Himalayan region.
- Response based policies, including State Action Plan on Climate Change serve as the primary policy document at sub-national (state) level to address vulnerabilities and increase resilience to CC impacts.
- LTEM studies directly supports the SDG goals specially SDG-15 (Life on Land) and SDG- 13 (Climate Action), this strengthening India's position as a global leader in mountain ecosystem research.

Linkages with National Priorities & International Goals

- Aligns with National Mission for Sustaining the Himalayan Ecosystem (NMSHE) under National Action Plant on Climate Change.
- Contributes to International commitments including Kunming-Montreal Global Biodiversity Framework and UNFCC targets.
- Strengthens forest governance through Long term data monitoring of forest ecosystem in western Himalaya.
- Guides sustainable tourism and eco developments policies in fragile Himalayan ecosystem.
- Contribution to State Action Plan on Climate Change (SAPCC) of all the Indian Himalayan states with forest monitoring data.

Way Forward & Scoping for Up-scaling

- Expansion of LTEM networks across underrepresented forest types and elevation ranges.
- Integration of advanced technologies such as RS and AI for effective monitoring.
- Capacity building of stakeholders to sustain and utilize LTEM data.
- Development of policy briefs and knowledge-sharing platforms for wider replication.
- Scaling across the Indian Himalayan region and other similar mountain ecosystems accross the word.

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Global Observation Research Initiative in Alpine Environments (GLORIA)

Building Globally Applicable Indicators for Monitoring Change in Alpine Vegetation in Himalaya

Situational Analysis & Rationale

- Alpine ecosystems in the Himalaya harbor a high level of endemic plant diversity and demonstrate high sensitivity to increase in global temperatures.
- Extreme low temperatures and abbreviated growing seasons further increases the vulnerability of these ecosystems to climate change.
- The absence of systematic, long-term datasets tracking vegetation dynamics and environmental variables under changing climate highlights urgent need for continuous ecological monitoring in the alpine region of Himalaya.

Activities & Innovations

- The Institute established six GLORIA observation sites in alpine zones above 3200 meters in the western Himalaya.
- Integrated vegetation, soil temperature, and precipitation monitoring for ecosystem-level understanding.
- Policy-linked monitoring framework aligned with national biodiversity conservation priorities.

Key Steps & Processes

- Summit Selection
- Marking Highest Summit Point and Summit Area Sections
- Demarcate & geo-referencing 3m x 3m & 1m x 1m quadrats in four directions (N,S,E,W)

- Activation & installation of soil temperature data loggers
- Plant sampling, phyto-sociological assessment & soil sampling to analysis baseline vegetation data
- Reconnaissance survey of monitoring site after five-year to collect vegetation and temperature datasets

Site	Location (Summit code)	Altitude	Geographical location
Chaudans	Bhairav Ghati (BHT)	3773 m	30°02.782' N; 80°39.122'
	Kharangdhang (KHA)	3881 m	30°02.927'N; 80°39.320'E
	Ganglakhan (GAN)	4060 m	30°03.113'N; 80°39.575'E
	Sekhuakhan (SKN)	4260 m	30°03.783'N; 80°39.927'E
Byans	Shyang (SHY)	3999 m	30°02.782' N; 80°39.122'E
	Kuti (KUT)	4038 m	30°02.927'N; 80°39.320'E
	Chaga (CHA)	4072 m	30°03.113'N; 80°39.575'E
	Eurong (EUR)	4154 m	30°03.783'N; 80°39.927'E

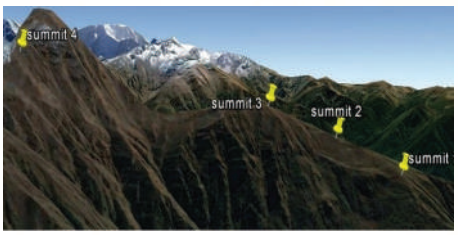
Key Highlights

- The initiative focused on the importance of long-term ecological monitoring of alpine ecosystems in the Himalaya in the face of climate change.
- Emphasize vulnerability of alpine regions due to extreme low temperatures, short growing seasons, and accelerated impacts of climate change.

Outcomes

- Robust datasets on species richness, distribution, and ecosystem cover generated and resurveyed at regular five-year intervals, enabling effective long-term monitoring of alpine biodiversity and climatic trends.
- Continuous ecological surveillance to detect and quantify climate-induced changes in Himalayan alpine ecosystems and supported a standardized protocol for international comparison.
- Strengthened research networks, collaborative data sharing, and adaptive management strategies for mountain ecosystems across the region.

Species	Number of plots occupied		p-value	Change in cover (%)	p-value
	Baseline	Resurvey			
Gentiana venusta	1	10	↑	0.38	↑
Leontopodium jaconitum	1	7	↑↑	0.21	↑
Anemonastrum polyanthes	3	8	↑↑	0.31	↑↑
Bistorta affinis	35	36	ns	1.1	↑↑
Bupleurum falcatum	24	26	ns	1.21	↑↑↑
Cyananthus microphyllus	18	28	↑↑↑	1.21	↑↑
Euphorbia stracheyi	26	37	↑↑	0.61	↑↑↑
Phlomis bracteosa	3	10	↑	0.05	ns
Poa alpina	21	31	↑↑	1.07	↑↑↑
Polygonum filicaule	11	18	↑↑	1.86	↑↑↑
Viola biflora	45	44	ns	0.7	↑↑
Anaphalis contorta	37	31	ns	0.84	↑↑
Anemone rivularis	3	13	↑↑↑	1.64	↑↑↑
Carex setosa	22	23	ns	3.16	↑↑
Tenexia cachemyriana	62	63	ns	4.41	↑↑↑
Trigonella emodi	1	10	↑↑↑	0.52	↑↑
Juniperus communis	16	18	ns	1.72	↑↑



Impacts & Policy Relevance

- **Early Warning Signals:** Provides the first evidence of thermophilization (shift to warm-adapted species) in Uttarakhand Himalaya — a critical alert for biodiversity conservation.
- **Biodiversity Conservation:** Identifies vulnerable alpine and threatened species at risk of local extinction, supporting prioritization in the National Biodiversity Action Plan (NBAP).
- **Evidence-Based Policy Input:** Generates robust, long-term ecological monitoring data to support the National Mission on Sustaining Himalayan Ecosystem (NMSHE) under NAPCC.
- **Climate Adaptation Planning:** State Action Plans on Climate Change (SAPCCs) for Uttarakhand and the broader IHR, helping policymakers design site-specific adaptation measures.

Linkages with National Priorities & International Goals

- National Action Plan on Climate Change (NAPCC) – supports the National Mission for Sustaining the Himalayan Ecosystem (NMSHE) by generating long-term biodiversity and climate data.
- National Biodiversity Action Plan (NBAP)/ State Action Plans on Climate Change (SAPCCs) –conservation of alpine and threatened species by providing baseline data on diversity trends.
- MoEF & CC vision on Long-Term Ecological Monitoring (LTEM) – fulill critical data gaps in high-altitude ecosystems
- UNFCCC & Paris Agreement –commitments to track CC impacts on ecosystems and biodiversity.
- IPBES Global Assessments –standardized biodiversity monitoring feeding to global biodiversity outlooks.
- Sustainable Development Goals (SDGs)

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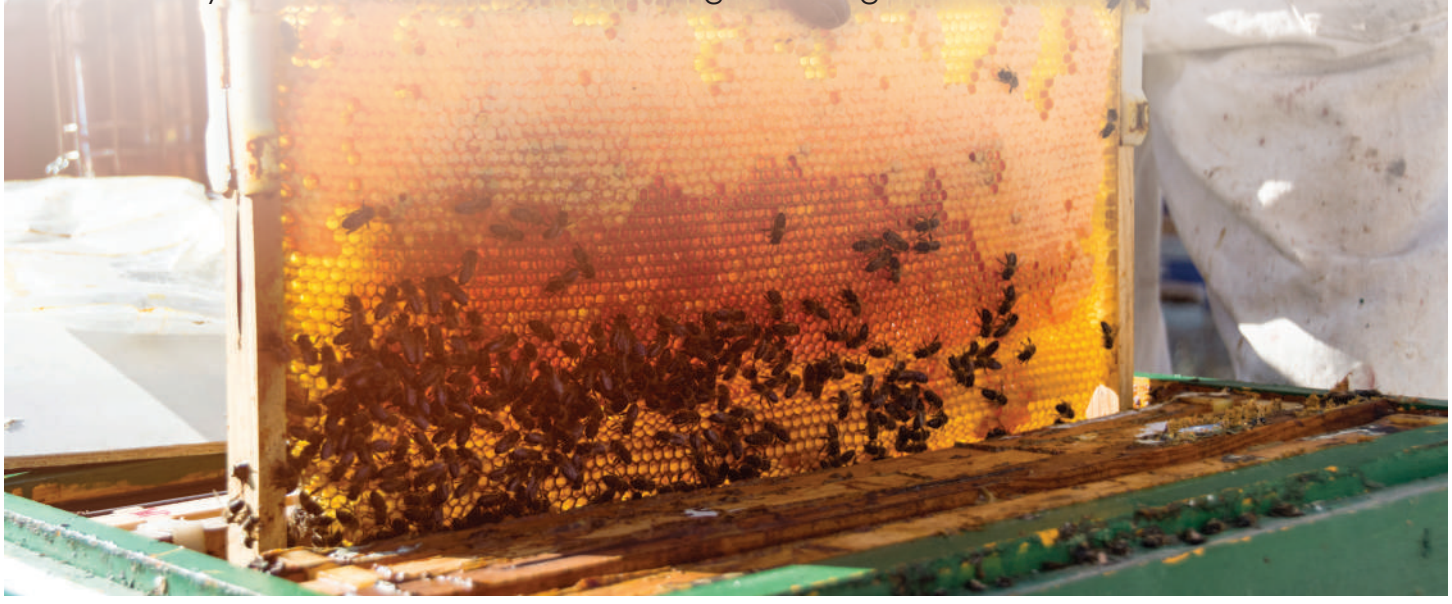
Chapter 3

Innovative Livelihood Models for Sustainable Development in the Himalayan Region

The Himalayan region faces increasing livelihood challenges due to its fragile ecosystem, climate change, and socioeconomic transitions. Traditional subsistence agriculture can no longer sustain the growing population, resulting in poverty, migration, and food insecurity. Innovative and sustainable livelihood strategies are crucial to enhance resilience, diversify incomes, and ensure ecological balance.

In the Sikkim Himalaya, where tribal communities traditionally practice beekeeping, income from large cardamom has dropped sharply due to reduced pollination and pests. Integrating indigenous honeybees (*Apis cerana*) with large cardamom and medicinal plant cultivation offers a sustainable solution—enhancing pollination, productivity, and community resilience while conserving biodiversity. Successful models from Himachal Pradesh show that combining indigenous practices with modern beekeeping can strengthen eco-friendly livelihoods. In high-altitude regions like Ladakh, long winters, short growing seasons, and water scarcity limit farming and lead to dependence on costly imported vegetables. A solar-powered, low-cost hydroponic system using the Nutrient Film Technique (NFT) inside polycarbonate greenhouses enables year-round vegetable cultivation with minimal water and renewable energy, ensuring food security and improved nutrition in extreme environments.

Innovative, eco-friendly livelihood models are vital for sustaining communities in the fragile Himalayan ecosystem. Integrating traditional knowledge with modern technologies, such as indigenous beekeeping for crop pollination and solar-powered hydroponics for year-round cultivation, can significantly enhance income, food security, and ecological resilience. These community-based approaches not only revive local biodiversity and traditional practices but also promote sustainable, self-reliant rural economies. Strengthening such integrated models across Himalayan states is key to ensuring long-term environmental sustainability and socio-economic well-being in the region.



Integrated Beekeeping Model in Sikkim

Environmental Sustainability and Climate Resilience Among Rural Communities

Situational Analysis & Rationale

- Sikkim Himalaya's ecology supports rich floral diversity, ideal for beekeeping.
- Traditional beekeeping is practiced by the tribal communities (Lepcha, Bhutia, Limboo, Tamang) of Sikkim.
- Large Cardamom (LC) based income declined over the years from ~50% to 29% due to reduced pollination, increase in pests, and diseases.
- Decline in productivity of LC severely impacted livelihood of local communities and ecosystem services.
- Integrating indigenous honeybee (*Apis cerana*) with cardamom & medicinal plants offers a alternate sustainable solution.

Activities & Innovations

- This integrated model combines beekeeping with large cardamom and medicinal plant cultivation.
- It leverages indigenous species, traditional practices, and scientific observations to improve pollination, crop productivity, rural income, leading to enhancing community resilience and sustainable ecosystem services.

Key Steps & Processes

- Baseline assessment of farmers, floral resources, and traditional practices.
- Pollination and pollinator density studies in cardamom & medicinal plants.
- Community mobilization through awareness, trainings and sensitization workshops.
- Capacity building on hive management, colony division, pest control, seasonal migration of honey bee.
- Integration of beekeeping with agroforestry & floriculture system.
- Convergence with local organizations and departments.

Key Highlights

- Indigenous honeybee (*Apis cerana*) central to the model.
- Combines traditional knowledge with scientific hive management.
- Strengthen pollination, diversifies income, enhances agro-biodiversity.

Outcomes

- Increased pollinator density in large cardamom fields.
- Adoption of the integrated beekeeping model by the farmers (8 Nos.).
- Honey production increased between 20 to 40%.
- Improved fruit/seed set in cardamom crop.
- Over 40% women beneficiaries earned > ₹ 75,000/year.
- 105 farmers, researchers & skilled trainers developed.

Impacts & Policy Relevance

- Supports National Beekeeping and Honey Mission (NBHM).
- Aligns with National Biodiversity Action Plan & pollinator strategies.
- Strengthens Aatmanirbhar Bharat via entrepreneurship & women empowerment.
- Promotes climate-resilient rural technologies for replication and scaling.
- Income diversification and sustainable rural enterprise.

Linkages with National Priorities & International Goals

- **SDG 13: Climate Action –** community resilience & adaptation.
- **SDG 15: Life on Land –** pollinator conservation.
- **SDG 2: Zero Hunger –** improved pollination boosts yields.
- **SDG 5: Gender Equality –** 40% women beneficiaries.
- **SDG 8: Decent Work & Economic Growth –** income diversification.
- **SDG 12: Responsible Consumption & Production –** sustainable rural enterprise.

Way Forward & Scope for Up-scaling

- Developing convergence with key departments (e.g., horticulture) and organizations for value chain linkages for honeybee products.
- Promoting integration with other pollinator-dependent crops.
- Policy support for training, subsidies, and market access
- Replication of the model and adoption among marginal farmers.

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Indigenous Beekeeping Practice in Himachal Pradesh

Promoting Community-based Sustainable Development Approach

Situational Analysis & Rationale

- Traditional beekeeping practices are challenged by habitat loss, climate change, declining indigenous knowledge.
- Introduction of non-native species, modern housing architecture, monoculture, pesticide use further threaten local bee populations.
- Limited access to training and market reduces viability of these practices; call for integrated, sustainable solutions.
- Over 40 pollination-dependent cash crops in Himachal Pradesh; Indian honeybee plays a vital role in pollination and production of these crops.
- Development of an integrated beekeeping model is required to sustain the bee population.

Activities & Innovations

- A community-based Indian honeybee (*Apis cerana*) practices developed in Himachal Pradesh.
- Indigenous practices combined with modern sustainable techniques aimed to strengthen livelihoods, biodiversity, and eco-friendly agriculture.

Key Steps & Processes

- Surveys carried out in Kullu, Kinnaur, Mandi, and Kangra districts covering upper, mid, and lower hill regions.
- Data gathered from 450–550 randomly selected beekeepers per district using structured questionnaires.
- Promoted *Apis cerana*-specific foraging resources.
- Trained over 10,000 stakeholders and developed 250 master trainers.
- Established a farmer led state-of-the-art beekeeping Centre in Kullu.

Key Highlights

- Community-based practices emphasizing harmony with local ecosystems.
- Integration of indigenous practices with sustainable techniques.
- Use of native bee species (*Apis cerana*).
- Hive construction with locally available materials.
- Enhances rural livelihoods and supports biodiversity.
- Promotes eco-friendly and sustainable agriculture.

Outcomes

- Empowered local communities through income generation from honey and allied bee products, leading to improved economic resilience.
- Supported pollination of native flora, enhancing local biodiversity and ecological balance in forest and agricultural ecosystems.
- Revived & integrated traditional beekeeping practices with modern techniques, preserving cultural heritage and ensuring sustainability.
- Strengthened community adaptation to climate change through eco-friendly, low-cost beekeeping practices with minimal inputs.
- Encouraged participation of women and rural youth in beekeeping enterprises, fostering inclusive development and skill-building.

Details of Bee Related Income	Year Wise Net Income (Rs.) from Beekeeping M/s. Deen Dyal Bee Farm, Karadshu, Kullu, HP			
	2021	2022	2023	2024
Sale of honey only	100,000/-	1,40,000/-	1,75,000/-	2,00,000/-
Bee Wax only	10,000/-	6,000/-	5,000/-	20,000/-
Active Bee Hives	6,00,000/-	6,50,000	8,50,000/-	16,00,000/-
Active Bee Frames	10,000/-	20,000/-	40,000/-	50,000/-
Beekeeping Items	1,00,000/-	105,000/	1,10,000/	100,000/-
Bee Hive Rent	25,000/-	35,000/-	50,000/-	50,000/-
Training & Other supporting Services	30,000/-	25,000/*	35,000/-	40,000/-
Total Net Yearly Income	8,75,000/-	9,81,000/-	12,65,000/-	20,80,000/-

Impacts & Policy Relevance

- Supported biodiversity conservation by protecting native bee species and enhancing local pollination networks, crucial for regional agriculture.
- Empowered indigenous communities through sustainable livelihoods and value-added honey production.
- Revived traditional knowledge systems rooted in environmental stewardship.
- Aligned with climate resilience, rural development, and biodiversity goals, offering a scalable, community-led approach to sustainable development.

Linkages with National Priorities & International Goals

National Priorities

- Food security and pollination management
- Sustainable livelihoods and income generation
- Biodiversity conservation and environmental health
- Strengthening traditional knowledge systems

SDG Goals

- **SDG 1 – No Poverty:** Enhances rural incomes through beekeeping.
- **SDG 2 – Zero Hunger:** Ensures pollination services for food and crops.
- **SDG 12 – Responsible Consumption & Production:** Promotes sustainable beekeeping practices.
- **SDG 13 – Climate Action:** Builds resilience by conserving indigenous bees.
- **SDG 15 – Life on Land:** Conserves biodiversity and supports ecosystem health.

Way Forward & Scope for Up-scaling

- Integrating the Indigenous sustainable beekeeping model into government rural development schemes and providing technical training to local communities to upscale and replicate and strengthen its impact.
- Out- scaling across similar agro-ecological zones in the Himalaya, enhancing both livelihoods and regional biodiversity conservation.

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Custom-Made Hydroponics Systems in Ladakh

Strengthening Climate-Resilient Soilless Agriculture in Cold Desert Region of Himalaya

Situational Analysis & Rationale

- Open-field farming is nearly impossible during severe winters lasting for 4–5 months in Ladakh and other trans-Himalayan region.
- Short growing seasons (2–3 months) and low agricultural productivity limit local food production.
- Water scarcity, with reliance on seasonal glacial meltwater poorly aligned with cropping cycles.
- Heavy dependence on imported vegetables leads to high costs and low freshness.
- Nutritional deficiencies among vulnerable groups, especially children and the elderly, during winter months.

Activities & Innovations

- A solar-powered, low-cost hydroponic model was developed.
- Nutrient Film Technique (NFT) housed within polycarbonate greenhouses.
- Custom made hydroponics system, using renewable energy & minimal water.
- Enabling round-the-year vegetable cultivation in extreme cold environments.

Key Steps & Processes

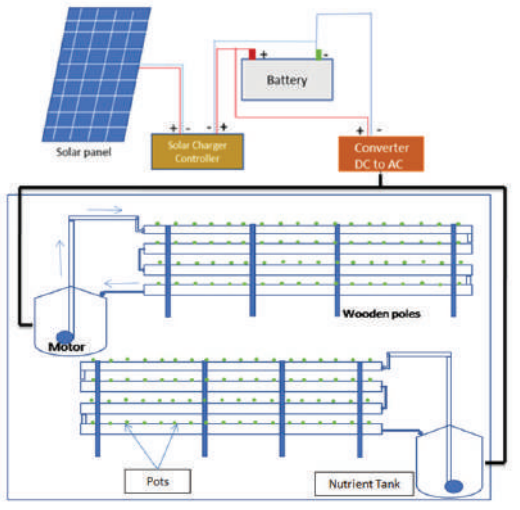
- **Solar Energy Setup and NFT Unit:** The solar-powered hydroponic prototype comprises two key components: a nutrient reservoir (10 L plastic bucket and 90 mm U-PVC pipe) and a solar-driven system (solar panel, battery, water pump, and aerator) for nutrient circulation and oxygenation.
- **Polycarbonate Greenhouse:** Three-layered 16 mm polycarbonate sheets were used to protect crops from harsh wind and sub-zero temperatures. The polyhouse having an approx. dimension of 18 x 32 ft with approx. 100 pots was set up in 20 ft u-PVC pipes.
- **Conducted Crop Trials:** Focused on leafy greens like lettuce, spinach, and mint, high value medicinal plants suitable for hydroponic systems.
- **Closed-loop Irrigation:** Ensured efficient nutrient and water recycling with minimal wastage.

Key Highlights

- A solar-powered hydroponic system efficiently utilizes treated wastewater for nutrient circulation and crop cultivation.
- Polycarbonate greenhouse ensures year-round vegetable production under extreme cold and windy Himalayan conditions.
- Closed-loop hydroponics enhances yield and income potential for high-value crops in resource-scarce Ladakh.

Outcomes

- The low-cost hydroponic system was developed to produce Tomato, Cucumber, Lettuce and Mint.
- Higher number of fruits (Tomato and Cucumber) produced per plant per month than the soil grown plants.
- Higher weight of Lettuce and Mint produced per plant per month than the soil grown plants.
- The low-cost hydroponic system based Lettuce cultivation system lead to additional income of Rs. 8000 in every winter season.



Impacts & Policy Relevance

Impacts

- Successful winter cultivation of leafy vegetables with consistent yields inside protected polycarbonate greenhouses.
- Up to 90% water savings compared to traditional soil-based farming; fully solar-powered operated.
- High-quality, fresh produce was available locally even in extreme cold.
- Easy replication and scalability for household-level or community-level farming in cold arid regions.
- Empowering marginal farmers in remote regions with resilient agricultural practices.

Policy Relevance

- Promotes decentralized food systems, reducing dependency on long-distance food supply chains.
- Supports local employment and micro-enterprises through protected cultivation and renewable energy integration.

Way Forward & Scope for Up-scaling

- Sustainable model for water conservation, clean energy use, and local innovation.
- Serves as a nationally relevant pilot for protected hydroponics in other high-altitude and water-stressed regions.
- Out-scaling of the model may boosts income opportunities through round-the-year vegetable production in cold deserts.
- Potential for strengthening food and nutritional security for border populations.
- Promotion of private-public partnership for large-scale decentralized set up for protected hydroponic vegetable cultivation.

Linkages with National Priorities & International Goals

- Aligns with climate-resilient agriculture strategies under National Mission on Sustainable Agriculture (NMSA), MoAFW, GoI.
- Addresses the SDG goals, especially SDG-2 (Zero Hunger), SDG-6 (Clean Water), and SDG-13 (Climate Action).
- Integration into State Action Plans for Climate Change (SAPCCs) in Himalayan states.

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Chapter 4

Eco-Friendly Greywater and Wastewater Solutions for the Himalayan Region

The fragile Himalayan environment faces serious threats from improper disposal of greywater and faecal sludge, which causes soil erosion, landslides, and water contamination. Rapid urbanization and tourism have intensified wastewater generation, overwhelming inadequate sanitation systems. To address this, an innovative, low-cost greywater treatment system was developed using *Pinus roxburghii* (pine needle) litter to create activated and bacterial activated carbon adsorbents. Combined with ecosystem-based purification using *Mentha spicata* and *Brassica juncea*, the system provides an eco-friendly, self-regenerating solution for sustainable greywater reuse and waste valorisation in Uttarakhand. In Ladakh's cold, arid trans-Himalayan region, where water scarcity is acute, a pilot project integrating Faecal Sludge Treatment with protected cultivation demonstrated the reuse of treated wastewater for hydroponics and crop production. Implemented with local partners, the initiative exemplifies circular economy practices and sustainable water management suited to fragile mountain ecosystems

Effective management of greywater and faecal sludge is crucial for safeguarding the fragile Himalayan ecosystem. The innovative use of locally available *Pinus roxburghii* needles for developing low-cost, ecosystem-based treatment systems demonstrates a sustainable solution for wastewater reuse and environmental conservation. By integrating biological purification and circular economy principles, such approaches not only reduce freshwater dependency but also convert waste into valuable resources. The successful pilot initiatives in Ladakh highlight the potential for scaling up these models to enhance water security, support sustainable livelihoods, and promote resilient sanitation systems across the Himalayan region.

Greywater Treatment using Pine needles

Ecosystem based Solution for Wastewater Treatment and Management in Himalaya

Situational Analysis & Rationale

- Greywater (GW), originated from sinks, showers, and washing machines (excluding toilets), forms a large part of household wastewater.
- GW treatment saves freshwater, ensures reliable supply, lowers treatment costs, and protects ecosystems.
- Using abundant Himalayan pine needles as a base material for making adsorbent, the waste valorisation, low-cost treatment, and environmental conservation is possible.
- There is need for design and upscaling GW treatment system for water conservation and protecting environment.

Activities & Innovations

- Innovative system developed at pilot scale using pine-needle-based activated carbon & bacterial activated carbon.
- Ecosystem-based treatment with plants like Mentha spicata and Brassica juncea for final purification.
- Low-cost, eco-friendly solution for treatment and reuse of greywater in Himalayan environment.

Key Steps & Processes

- Greywater collected from Institute's researchers hostel.
- Pre-filtration & sand/silt removal for initial screening to remove suspended solids and large particles.
- Coagulation process for the removal of fine particles.
- Removal of contaminants using fixed bed adsorbent column of activated and bacterial activated carbon.
- Phytoremediation stage for further polishing of waste water along with the direct testing of GW treatment.
- Continuous monitoring and assessment of original and treated greywater quality parameters to assess efficiency and sustainability.

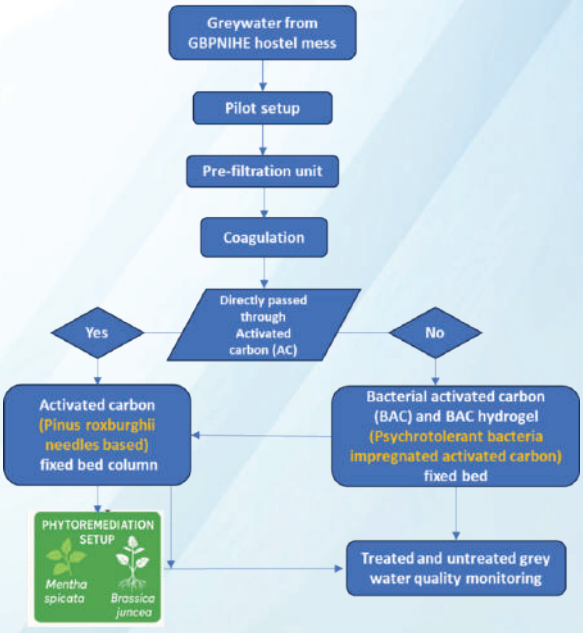
Key Highlights

- *Pinus roxburghii* needle litter, an abundant Himalayan biomass, utilized for activated and bacterial activated carbon (AC and BAC) preparation.
- Developed Integrated GW Treatment System
- Self-regenerating BAC adsorbent for sustained treatment.
- Water conservation by enabling safe greywater reuse, waste valorisation by converting underutilized pine needle litter into a high-value product for environmental management.

Outcomes

- Efficient grey water treatment model suitable for non-potable purposes.
- Low cost & sustainable solution and greywater treatment model for households and organizations.
- Pine needle valorisation and GW treatment process designed
- Addressed environmental protection and waste management.



Impacts & Policy Relevance

- Eco-friendly greywater management: Low-cost, sustainable treatment combining physical, chemical, biological processes.
- Forest waste valorization: Transformed fire-prone pine needle litter into activated and bacterial carbon, linking forest management with greywater treatment and its reuse.
- Efficiency & resilience: BAC with self-regeneration and phytoremediation (*Mentha spicata, Brassica juncea*) enhanced treatment.
- Scalable model: Provides a decentralized greywater reuse template for institutions and residential complexes.
- Green campus policies: Promotes eco-campuses and aligns with national goals on water reuse, resource efficiency, and conservation.

Way Forward & Scope for Up-scaling

- Technology Optimization – Refining the pilot setup with varied contaminant loads to enhance treatment efficiency.
- Scalability– Replicating the model for households, hostels, and community housing, both in urban and rural settings, through industrial partnership.
- Policy Integration – Aligning with state and national water and waste management policies for wider adoption.
- Community Engagement – Training local communities in decentralized greywater management and system maintenance.
- Entrepreneurship & Livelihoods – Promoting pine needle-based activated carbon as a green enterprise opportunity.

Linkages with National Priorities & International Goals

National Priorities

- Jal Shakti Abhiyan – Supports water conservation and sustainable use through decentralized greywater management.
- Swachh Bharat Mission – Addresses decentralized wastewater treatment & reuse.
- National Action Plan on Climate Change (NAPCC) – Promotes resource efficiency and eco-friendly technologies.
- National Mission on Himalayan Studies (NMHS) – Demonstrates innovative solutions for eco-sensitive Himalayan ecosystems.

International Goals

- SDG 6: Clean Water & Sanitation
- SDG 8: Decent Work and Economic Growth
- SDG 11: Sustainable Cities and CommunitiesSDG 13: Climate Action
- SDG 15: Life on Land

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Faecal Sludge Treatment Model in Ladakh

A Circular Approach to Climate-Resilient Protected Cultivation in Trans-Himalayan Region

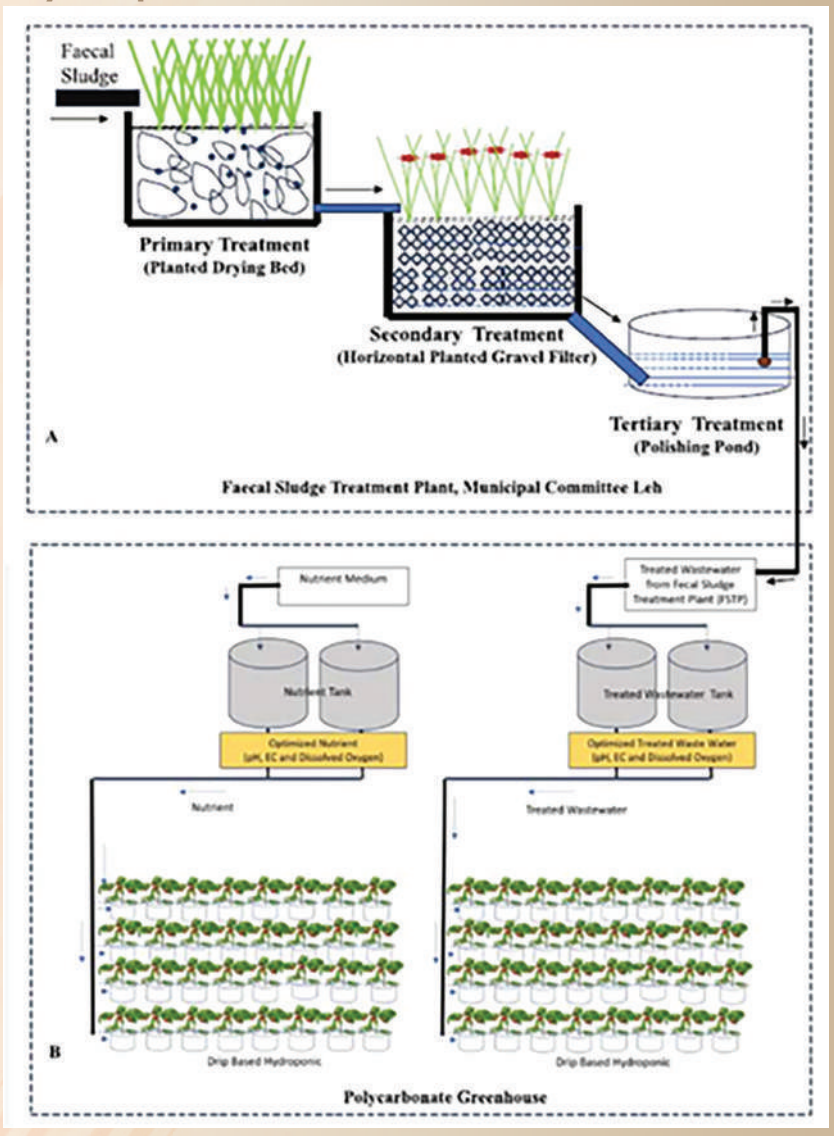
Situational Analysis & Rationale

- Ladakh, with harsh, cold, and dry trans-Himalayan region facing water scarcity challenges.
- Expansion of urbanization and increasing tourism leading to an increase in wastewater generation and excessive groundwater extractions for agricultural expansion activities.
- Treated wastewater uses through Hydroponics can be harnessed as option to mitigate water scarcity in the region.
- Wastewater treatment in Ladakh can be addressed through a Faecal Sludge Treatment Plant (FSTP), which treats wastewater for agricultural and other uses.

Activities & Innovations

- A pilot project to explore the integrated Faecal Sludge Treatment and protected cultivation was initiated in collaboration with the Municipal Committee Leh (MCL) and the Ladakh Ecological Development Group (LEDeG).
- The treated wastewater was used in a polycarbonate chamber for the cultivation of crops for the circular economy in the Trans-Himalayan Regions.

Key Steps & Processes



Simplified flowchart: (A) Faecal Sludge Treatment Plant and its process for treating faecal sludge, and (B) growing tomatoes under a polycarbonate green house using treated wastewater and nutrient-based drip hydroponics.

Key Highlights

- Solar-powered hydroponic system reused 15,000 Lt./month treated wastewater for sustainable vegetable cultivation in Leh.
- Treated wastewater enhanced tomato and cucumber growth and yield, showing potential for resource-efficient farming.
- This innovation is has been granted a patent "A System for Hydroponic Cultivation Using Treated Wastewater from FSTPs".

Outcomes

- Scientific study demonstrated that tomatoes grown using treated wastewater significantly outperformed those cultivated in conventional soil in terms of biomass production as well as chlorophyll and b-carotene content.
- Heavy metal analysis of the fruits revealed no harmful residues, confirming the produce was safe for consumption.
- The system proved highly viable under the cold-arid environmental conditions of Ladakh and showed strong potential for enabling year-round vegetable cultivation in the region.

Performance of Treated Wastewater for Growing Vegetables

Parameters	Soil	Nutrient	Wastewater
Carbohydrate (mg/g)	39.48±0.07c	80.42±0.26a	**55.91±1.19b**
Fat (mg/g)	15.32±1.79c	31.04±2.03a	**24.38±0.77b**
Crude fiber (mg/g)	29.17±2.15a	27.10±1.01a	**24.99±1.93a**
Protein (mg/g)	18.52±0.10c	24.44±0.28a	**21.34±0.31b**
Ash (mg/g)	21.86±2.95c	34.80±1.44b	**40.45±2.08a**
Total energy (kcal/100g)	36.98±1.57c	69.88±1.87a	**54.06±0.93b**

Proximate composition of tomato harvested from different growing conditions

* Different letters in the same column indicate statistical significance, by Duncan's multiple range tests ($p<0.05$).

Parameters	Soil	Nutrient	Wastewater
(N) (%dm)	2.62±0.07b	3.50±0.04a	2.66±0.01b
Mg (% ppm)	132.17±12.06b	284.50±11.68a	153.33±9.18b
K (%dm)	2.56±0.03a	2.35±0.00b	2.14±0.05c
P (% dm)	0.18±0.00b	0.20±0.00a	0.16±0.00c
Fe (mg/kg dm)	49.00±6.27c	158.33±5.56a	151.00±8.29b
Heavy metals			
Mn (mg/kg dm)	34.83±1.49a	23.50±4.14b	10.50±2.24c
Zn (mg/kg dm)	18.67±1.19b	50.67±1.19a	10.67±1.19c
Cu	0	0	0
Pb	0	0	0
Cd	0	0	0
Cr	0	0	0

Mineral and heavy metal analysis of tomato fruit harvested from different growing conditions

Linkages with National Priorities & International Goals

National policies and relevant SDGs

- Doubling farmers' income
- Climate-resilient agriculture
- Urban-rural sustainability linkages
- Offers replicable model for other Indian Himalayan Region (IHR) states

Supports wastewater reuse in agriculture, as envisioned in:

- Jal Shakti Abhiyan
- GOBARdhan Scheme
- Namami Gange

Way Forward & Scoping for Up-scaling

- Establish long-term monitoring and safety standards for treated wastewater reuse in high-altitude agriculture.
- Scale-up solar powered community hydroponic clusters integrated with livelihood and horticulture missions.
- Promote public–private partnerships for decentralized wastewater reuse and circular resource management in Ladakh and Trans Himalaya.

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Chapter 5

Empowering Himalayan Livelihoods through Sustainable Rural Technologies

The Himalayan region faces challenges such as low agricultural productivity, limited income opportunities, and climate change impacts, creating a need for low-cost, eco-friendly rural technologies. These technologies improve livelihoods through sustainable agriculture, water and energy management, and local product processing. To address this, the G.B. Pant National Institute of Himalayan Environment (GBP-NIHE) has established six Rural Technology Centres (RTCs) across Himalayan states, operating on a Hub-and-Spoke model. RTCs serve as hubs for research-based demonstrations, training, and technology dissemination, bridging the gap between scientific research and rural communities. These centres promote entrepreneurship, self-reliance, and sustainable employment by adapting region-specific technologies in agriculture, energy, water, and livelihood sectors.

Key achievements:

- Over 750 training programs conducted, benefiting more than 35,000 people accross IHR.
- Demonstration of over 30 low-cost technologies (protected cultivation, integrated farming, hydroponics, mushroom cultivation, bio-compost).
- Development of pine needle-based products (paper, bio-briquettes) to reduce forest fire risks and generate income.
- Promotion of more than 10 small-scale natural resource-based enterprises, including ecotourism, beekeeping, and local food products.
- Strengthening rural livelihood diversification, especially among women.

A notable initiative is the Pine Needle Processing Unit at the RTC, converting inflammable Chir-pine needles (Pirul) into value-added products through a Public-Private Partnership (PPP) model. This mitigates forest fire risks, provides sustainable livelihoods, and supports environmental conservation.

GBP-NIHE's Rural Technology Centres are empowering Himalayan communities through low-cost, sustainable technologies. By linking research with local needs, promoting entrepreneurship, and creating innovative solutions like pine needle products, they boost livelihoods, reduce environmental risks, and foster self-reliance, demonstrating a model for sustainable rural development in the Himalaya.

Rural Technology Centre

Transforming Rural Livelihoods through Low-cost Technologies in the IHR

Situational Analysis & Rationale

- The fragile ecosystems of the IHR facing shrinking resources, forest degradation, declining soil fertility, and climate change issues.
- Limited market access and livelihood opportunities, combined with dependence on costlier, un-sustainable agricultural inputs, leads significant pressure on mountain communities.
- There is need to bridge gap between rural communities and technological advancements, helping to boost the local economy by increasing productivity, creating employment, and improving livelihoods.

Activities & Innovations

- Technology demonstrations: Hydroponics, polyhouses, rainwater harvesting, bio-briquettes, eco-bricks, bamboo-based crafts, floriculture, medicinal plant cultivation, etc.
- Livelihood based skill development program to different stakeholders.
- Knowledge Products: Technical manuals, articles, and exhibitions.
- Feedback Mechanism: Problem identification → Option development → Demonstration → Dissemination.

Key Steps & Processes

- The RTCs function in a Hub-and-Spoke model, with a focus on region specific rural technologies through HQs and five regional centres of the institute.
- Serves as a hub for R&D-based demonstrations, training, and technology dissemination across the IHR.
- Identifying, adapting, and disseminating appropriate technologies to address specific rural challenges in agriculture, water management, livelihood, and energy.
- The RTCs are providing training and capacity building for promoting local entrepreneurship.
- Act as hubs for innovation, promoting self-reliance and empowering rural populations in Himalaya through sustainable solutions.

Key Highlights

- Improving entrepreneurial business for small and medium enterprises.
- Transfer of technologies to rural areas for generating sustainable employment.
- Helping rural entrepreneurs with capacity building and training programs.
- Serving as a bridge between research and the last-mile user.
- Connecting scientific research with practical needs of rural communities.

Outcomes

- Six RTCs established in five states of IHR (Ladakh, Himachal Pradesh, Uttarakahnd, Sikkim, Arunachal Pradesh).
- Conducted over 750 training programs, directly benefiting more than 35,000 people across the IHR.
- Demonstrated more than 30 low cost technologies for livelihood improvement (e.g., protected cultivation, bio-compost, integrated farming, hydroponic, mushroom, etc.).
- Developed pine needle-based products (e.g., paper, bio-briquettes) to mitigate forest fires and generate livelihoods.
- Promoted over 10 small-scale natural resource-based enterprises including ecotourism, beekeeping, local foods & beverages, etc.
- Strengthened livelihood diversification of rural communities, particularly women.





Impacts & Policy Relevance

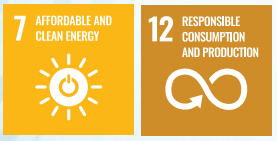
- Demonstrated scalable, low-cost, climate-resilient technologies for mountain farming and rural livelihoods.
- Supported national policies on Atma-Nirbhar Bharat, Swachh Bharat Mission, and Doubling Farmers' Income.
- Provided actionable models for forest fire mitigation, waste-to-wealth, and sustainable agriculture.
- Informed development planning at state and district-level in the Himalayan region.

Linkages with National Priorities & International Goals

- Atmanirbhar Bharat – Rural Innovation
- Doubling Farmers' Income (DFI)
- National Mission for Sustainable Agriculture (NMSA)
- National Rural Livelihood Mission (NRLM)
- Startup India

Women & Youth Empowerment

Climate Resilient Agriculture



Green & Circular Economy

Way Forward & Scope for Up-scaling

- Promote women- and youth-led enterprises through capacity building and incubation.
- Developing public –private partnership for sustainability of the interventions.
- Process documentation of success stories of the transformative interventions for replication.
- Scaling RTC Hub–Spoke model for region-specific, climate-resilient technologies.
- Dovetailing with schemes and programme of state line agencies for replication of the successful models.

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Pine Needles for Green Economy

Waste-to-Wealth Model for Sustainable Livelihood and Forest Fire Mitigation

Situational Analysis & Rationale

- Chir pine *(Pinus roxburghii)* sheds vast quantity of dry needles (Pirul) every summer in Uttarakhand and Himachal Pradesh.
- Pirul is highly inflammable, making it a major driver of forest fires, which cause biodiversity loss, habitat destruction, and hinder forest regeneration.
- The abundant Pirul remains underutilized, providing minimal benefits to communities.
- Despite ongoing fire-control efforts, the rising frequency and intensity of fires highlight the urgent need for innovative, community-driven solution
- Conventional paper production leads to deforestation and pollution. So, sustainable Pirul utilization for making paper can create livelihoods, reduce fire risks, and support environmental conservation.

Activities & Innovations

- A Pine Needle Processing Unit was setup at RTC of GBPNIHE supported by NMHS.
- Sustainable use of dry Chir-pine needles by converting the biomass into value-added products.
- The unit is developed as a Public-Private Partnership (PPP) model.

Key Steps & Processes

- Collection: SHGs and youth collect Pirul during fire-prone months, earning incentives while reducing fire risk.
- Pulping: Needles are cleaned, chopped, and processed with eco-friendly chemicals; cotton waste added for fiber quality.
- Sheet Formation: Pulp is made into 60x80 cm sheets using deckle frames and solar drying.
- Product Development: Sheets converted into eco-products like folders, bags, and visiting cards.
- Capacity Building: Women and youth trained in collection, processing, and design for enterprise development.
- Other value-added products like bio-briquettes and decorative items also developed.

Key Highlights

- Trained over 35,000 people, including women and marginalized groups.
- Introduced low-cost, eco-friendly technologies for briquette and paper production.
- Developed a Pine Processing Unit.
- Pine fiber based biodegradable handmade paper developed.
- Enabled product distribution to government offices and exhibitions to boost demand.

Outcomes

- Handmade paper produced (200–500 GSM) with verified lab parameters, suitable for eco-friendly stationery and packaging.
- 100% biodegradable and environment-friendly product.
- Unit processes more than 6,000 kg of pine needles annually.
- Over 10,000 products (file covers, folders, bags) supplied to government, private, and NGO sectors.
- SOP developed for replicating pine-based green industries in other Himalayan districts.
- Under the PPP model, local communities actively participate in collection, processing, and production, earning sustainable incomes.






Cost Efficiency (Rs. per unit)

Product	Material cost (Rs.)	Labour Material cost (Rs.)	Total Cost Material cost (Rs.)
File Cover	17	8	25
Folder	20	5	25
Carry Bag	20	5	25

Parameter	Pure Pine Sheet	Cotton-Mixed Sheet
Tear Index (mN.m²/g)	13.35	5.45
Burst Index (kPa.m²/g)	0.65	0.71
pH	7.2	7.5
Moisture (%)	7.65	6.52
Ash Content (%)	7.62	5.61

Impacts & Policy Relevance

- **Ecological Impact:** Pine needle removal from fire-prone forests reduced dry biomass and fire risk.
- **Eco-Restoration:** Helped in forest regeneration by reducing fire damage.
- **Waste to Wealth:** Converted biomass waste into useful products.
- **Income Generation:** Women's groups earned up to Rs. 16,000 annually from bio-briquette sales, with Rs. 450 profit per 100-unit batch.
- **Women's Empowerment:** Enabled home-based income and strengthened women's role in forest management.
- **PPP Success:** Demonstrated scalable public-private-community collaboration.

Linkages with National Priorities & International Goals

- Atmanirbhar Bharat Abhiyan
- Green Economy & Circular Economy Initiatives
- National Rural Livelihood Mission (NRLM / Aajeevika)
- Startup India (Eco-Enterprise Development)

- **SDG 1: No Poverty-**Income opportunities for local communities
- **SDG 5: Gender Equality-**Women & Youth Empowerment
- **SDG 12: Responsible Consumption & Production-** Promoting biodegradable, eco-friendly paper
- **SDG 13: Climate Action-** Mitigating forest fire risk

Way Forward & Scope for Up-scaling

- Establish additional pine needle processing units across the IHR.
- Build capacity of SHGs and youth to manage production, marketing, and supply chains.
- Promote pine-based eco-products under national schemes like ODOP, Make in India, and Vocal for Local.
- Strengthen consumer awareness about eco-products to drive demand and adoption.

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Chapter 6

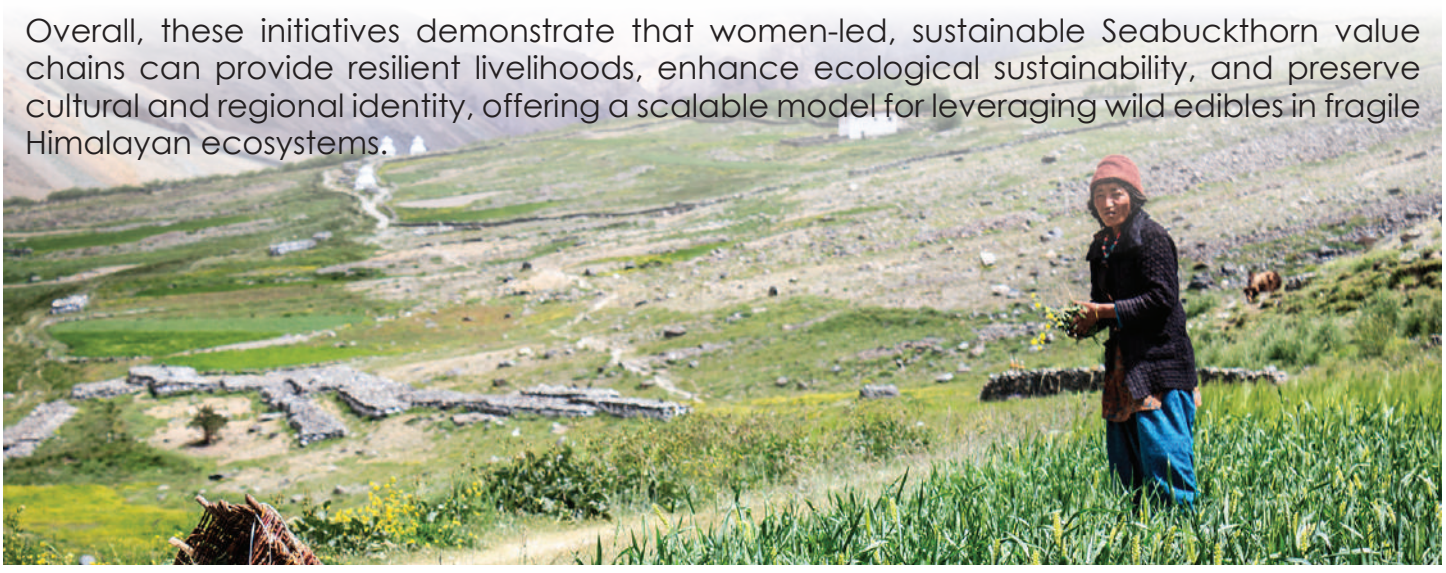
Harnessing Seabuckthorn for Sustainable Livelihoods and Ecological Resilience

Promoting wild edibles, particularly Seabuckthorn (*Hippophae spp.*), is vital for enhancing livelihoods, food security, and women's empowerment in rural Himalayan communities. Harsh climates, fragile ecosystems, and limited agricultural land make wild edibles a sustainable alternative to conventional farming. However, declining traditional knowledge and unsustainable harvesting practices have limited their full potential.

In Lahaul & Spiti (Himachal Pradesh) persistent poverty, remoteness, and ecological fragility restrict livelihood options. Seabuckthorn, a nutrient-rich shrub thriving at 2,500–4,200 meters, remains underutilized due to weak value chains, lack of processing infrastructure, and limited market access. Women, central to natural resource management, have had minimal economic engagement. To address this, a women-led Seabuckthorn value chain was established. A technology and processing Centre was set up for product development, and 150 tribal women were trained in sustainable harvesting, value addition, and marketing. Several value-added products were developed and marketed, and the women's group "Palden Lamo" was registered for branding and certification. Efforts were initiated for GI certification of Lahaul Seabuckthorn. This integrated approach combining technology, skills, product innovation, and market linkages enhanced incomes, strengthened ecological sustainability, and promoted regional identity.

In the Siachen valley, Ladakh, extreme cold, poor infrastructure, and limited storage reduce the shelf life and market potential of Seabuckthorn produce. To unlock its economic and ecological potential, interventions included mapping 7,184 ha of Hippophae, documenting traditional medicinal knowledge, and establishing community-run processing units for juice, oil, and herbal products. Trainings improved harvesting efficiency by 30–40%, while market linkage strategies ensured sustainable income opportunities.

Overall, these initiatives demonstrate that women-led, sustainable Seabuckthorn value chains can provide resilient livelihoods, enhance ecological sustainability, and preserve cultural and regional identity, offering a scalable model for leveraging wild edibles in fragile Himalayan ecosystems.



Seabuckthorn Enterprise in Lahaul & Spiti Valley, Himachal Pradesh

Empowering Rural Women through the Seabuckthorn Value Chain

Situational Analysis & Rationale

- Lahaul and Spiti, a tribal district in Himachal Pradesh, faces persistent poverty despite national economic growth.
- The region's harsh climatic conditions, ecological fragility, and remoteness limit livelihood options.
- Seabuckthorn (*Hippophae spp.*), a nutrient-rich shrub thriving at 2500–4200 m, is underutilized due to weak value chains, lack of processing infrastructure, and low market access.
- Women of the region, central to natural resource management, have limited economic engagement activities.
- Seabuckthorn offers a climate-resilient, high-value livelihood option for cold desert ecosystems.
- Promoting women-led processing, value addition, and market integration can enhance incomes, support ecological sustainability, and strengthen community resilience.

Activities & Innovations

- Established a women-led Seabuckthorn value chain in Lahaul & Spiti.
- A women led technology centre for processing and product development was setup.
- Trained women in sustainable harvesting and value-addition techniques.
- Registered women's group "Palden Lamo" for branding and certification.
- Initiated GI certification for Lahaul Seabuckthorn.

Key Steps & Processes

- Empowered tribal women in sustainable harvesting and post-harvest processing of Seabuckthorn.
- Established a technology Centre in the region as a core facility for timely and quality processing of Seabuckthorn berries.
- Development, certification, branding, and marketing of a range of Seabuckthorn products.
- Institutionalized the initiative through registration of the society 'Palden Lamo'.
- Initiated the GI Certification process to enhance product value and identity.

Key Highlights

- "Palden Lamo" - a women's society, formalized a tribal Seabuckthorn value chain, empowering 150 members through collective action and market leadership.
- Combined modern technology, skill development, product innovation, and market linkages - stands out as the core achievement of this initiative.
- Generated income (₹6 lakh/ yr) and laid a foundation for long-term economic and ecological sustainability.
- Regional identity through branding and GI certification efforts.

Outcomes

- Women Entrepreneurship: Established "Palden Lamo," a registered women-led society, to formalize entrepreneurial efforts, enabling collective action, branding, and leadership.
- Infrastructure & Capacity Building: A modern Technology Centre with latest technologies deployed for high-quality, decentralized processing, complemented by targeted skill-building and exposure training for women.
- Diverse Product Portfolio: Created and tested a range of Seabuckthorn products (pulp, tea, juice, jam, etc.) with verified nutritional benefits to enhance consumer acceptability and marketability.
- Market Linkages: Successfully showcased products at major fairs, connecting to broader markets and generating ₹6 lakh in revenue from initial product processing.
- Long-Term Sustainability: Initiated the GI certification process and undertook new sapling plantations to secure resource supply, enhance brand value, and ensure future growth




Impacts & Policy Relevance

Impacts

- Empowered tribal women through a sustainable Seabuckthorn value chain.
- Generated significant income and improved livelihoods.
- Developed eco-friendly processing and diverse nutritious products.
- Initiated GI certification for product authenticity.

Policy Relevance

- Supports tribal empowerment and livelihood diversification.
- Promotes sustainable resource management and climate resilience.
- Demonstrates effective NTFP value chain development.
- Highlights importance of technology, training, and market access.
- Encourages GI certification for regional economic growth.

Way Forward & Scope for Up-scaling

- Build market linkages by securing GI certification, developing a premium brand, and expanding onto digital/national level marketplaces.
- Scaling up through collaboration with departments like MSME, NRLM, etc. to increase production and introduce high-value products such as Seabuckthorn oil and nutraceuticals.
- Ensure long-term enterprise sustainability by replicating the successful model in other regions and promoting widespread Seabuckthorn cultivation.

Linkages with National Priorities & International Goals

- SDG 1: No Poverty
- SDG 8: Decent Work and Economic Growth
- SDG 12: Responsible Consumption and Production
- SDG 15: Life on Land

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Innovative Seabuckthorn Processing in Siachen Valley

Empowering Livelihoods of High-Altitude Communities in Cold desert of Ladakh

Situational Analysis & Rationale

- The Siachen valley of Ladakh faces extreme cold weather, poor accessibility, and weak infrastructure.
- Lack of cold storage and erratic power reduces the shelf life of Seabuckthorn produce.
- Limited technical skills, weak market linkages, and unsustainable harvesting practices reduce livelihood opportunities.
- Coordinated efforts are required to tap the ecological and economic potential of Seabuckthorn in the Siachen valley.

Activities & Innovations

- Ecological assessment of Seabuckthorn in the Siachen Valley is conducted.
- A low-cost Seabuckthorn Processing Unit (SPU) is established with seasonal capacity of producing approx. 2000 lt. pulp.
- Other than pulp, Seabuckthorn products such as soaps, balms, crème, etc. are being prepared.

Key Steps & Processes

- **Ecological Mapping:** Approx. 7,2 ha of *Hippophae sp.* identified through satellite data & field surveys.
- **Resource Estimation:** Out of the total annual production of Seabuckthorn in Ladakh, less than 5% (~500 MT/year) is used.
- **Processing Setup:** A community-run Seabuckthorn Processing Unit (SPU) established at Chamsen, Nubra for extracting oil and preparing pulp, juice & herbal products.
- **Skill Building and Market Linkages:** Trainings to a 40-member Women Self-help Group (WSHG) at Nubra are organized to improve collection and product diversification. Effective market linkages are established at Himachal Pradesh for trading of pulp.

Key Highlights

- Antioxidant and phytochemical profiles of Seabuckthorn (*H. rhamnoides*) indicate unripe berries having higher medicinal values.
- The seasonal economic potential of Seabuckthorn in Siachen Valley is computed to be approx. Rs. 25.0 lakh/ha.
- The low cost SPU at Chamsen, Nubra generated a revenue of approx. Rs. 1,80,000 during 2024 - 25.

Outcomes

- Phytochemical and antioxidant properties of Seabuckthorn berries at different ripening phases are quantified.
- Income potential of Seabuckthorn berries, juice and pulp is quantified for the Siachen Valley.
- During 2024-25, approximately 1500 lt of Subuckthorn pulp is produced by the WSHG of Chamsen, Nubra and traded in Himachal Pradesh.
- Organized training and FGDs lead to more than 100 locals participating in the collection and processing of berries enhancing harvest efficiency by 30–40%.

Moisture content of the berry at different ripening stages (g/50 berries)

Sample	FW (g)	DW (g)	Moisture content (%)
Green	4.20 ± 0.08	2.53± 0.05	39.64± 2.41
Yellow	4.83 ± 0.05	2.68± 0.03	44.48 ±0.27
Orange	5.27± 0.13	2.55± 0.05	51.50±1.17
Reddish Orange	5.70± 0.08	2.19± 0.04	61.57±0.92
Red	8.40± 0.08	2.32± 0.11	72.41±1.54

Evaluation of Phytochemical analysis (mg/g FW) of seabuckthorn berry at different ripening stages

Sample	Total Flavonoids	Total Phenol
Green	0.99 ± 0.02	1.08 ± 0.00
Yellow	0.27 ± 0.01	1.01 ± 0.01
Orange	0.16 ± 0.01	0.98 ± 0.00
Reddish Orange	0.17 ± 0.01	0.92 ± 0.0
Red	0.06 ± 0.03	0.87 ± 0.05

Evaluation of lycopene and β-carotene content at different ripening stages (mg/100ml)

Sample	lycopene	β carotene
Green	0.003 ± 0.00	0.006± 0.00
Yellow	0.005± 0.00	0.040± 0.00
Orange	0.023± 0.00	0.051± 0.00
Reddish orange	0.060± 0.00	0.029± 0.00
Red	0.061± 0.00	0.033± 0.00

Impacts & Policy Relevance

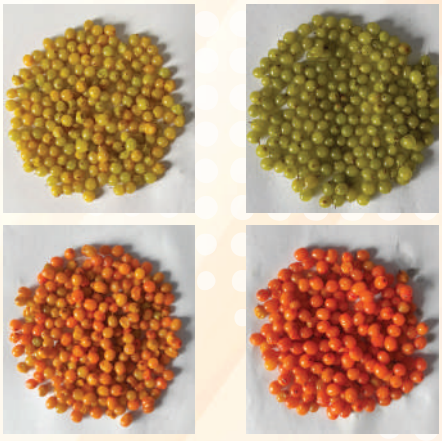
- Strengthened local entrepreneurship in underserved, high-altitude regions.
- Promoted *Atmanirbhar Bharat* through self-reliance specially among the rural women.
- Aligns with climate-resilient livelihoods and ecological safeguarding.

Linkages with National Priorities & International Goals

- SDG 1: No Poverty
- SDG 8: Decent Work and Economic Growth
- SDG 12: Responsible Consumption and Production
- SDG 15: Life on Land

Way Forward & Scope for Up-scaling

- Expand community-based processing across other valleys.
- Strengthen cold-chain infrastructure and renewable energy solutions.
- Build long-term partnerships for sustainable market access.
- Foster research on phytochemical and medicinal properties for nutraceutical markets.



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Chapter 7

Germplasm Conservation in the Himalaya: Safeguarding Biodiversity, Food Security, and Livelihoods

Germplasm conservation in the Himalaya is vital for preserving the region's genetic diversity, enhancing crop resilience, ensuring food security, and supporting fragile mountain ecosystems. The Himalayan region harbor numerous landraces and wild relatives with traits such as resistance to pests, diseases, and harsh climatic conditions, forming the foundation for developing high-yielding and climate-resilient crop varieties. Traditional crops like millets, buckwheat, and amaranth thrive in marginal soils, while wild fruit species serve as hardy rootstocks, boosting productivity. Conserved germplasm enables year-round cultivation of regular and off-season vegetables, increasing farm income and food availability. By maintaining plant diversity, these programs stabilize agro-ecosystems, prevent soil erosion, reduce pest losses, and support native pollinators, including Himalayan honeybees. As a biodiversity hotspot, the Himalaya host thousands of endemic plant species, many with medicinal and nutritional value, which are safeguarded through conservation. Additionally, germplasm programs preserve cultural heritage, traditional knowledge, and provide opportunities for value-added products, promoting resilient livelihoods and sustainable agriculture.

Millet Seed Bank for Food Security

Preserving Genetic Diversity and Empowering Communities in Himachal Pradesh

Situational Analysis & Rationale

- Millet cultivation in Himalayan region is facing geographic, climatic, and socio-economic challenges.
- Over the last two decades, a shift from traditional millet farming to cash crop cultivation is observed.
- This led to loss of biodiversity at local level and decreases community resilience to climate change.
- Small landholding, steep slopes, less productive agricultural methods further exacerbated these challenges.
- This highlights need for interventions to restore and sustain millet cultivation for food and nutritional security.

Activities & Innovations

- A community-led Millet Seed Bank initiative in Kharihar Panchayat, Kullu (HP).
- The initiative aimed to: (i) revive & conserve traditional millet varieties; (ii) empower local farmers & women through sustainable practices; (iii) enhance climate resilience, food & livelihood security by reintroducing resilient millet crops.

Key Steps & Processes

- Collection of millet seeds from five experienced village practitioners.
- Safe storage of seeds in airtight glass jars for maintaining viability.
- Distribution of seeds to 20 farmers, along with training on sustainable and eco-friendly cultivation techniques.
- Support for farmers with organic manure and technical inputs to enhance productivity.

Key Highlights

- Promoted climate-resilient farming practices in ecologically fragile Himalaya.
- Increased awareness and skill-building among farmers, particularly women.
- Community-driven model ensured local ownership and knowledge exchange.
- Development of a scalable model for millet revival in other mountain regions.

Outcomes

- Successful revival of local millet biodiversity through seed banks.
- Enhanced availability and conservation of traditional millet seeds.
- 20 farmers benefitted from quality seed access and capacity-building sessions.
- Strengthened local food security and nutritional diversity.

Impacts & Policy Relevance

- Support India's National Food Security Act (NFSA) goals by guaranteeing steady millet supplies.
- Supports India's National Action Plan on Climate Change (NAPCC), particularly the National Mission on Sustainable Agriculture (NMSA).
- Contributes to India's NDCs (Nationally Determined Contributions) under the Paris Agreement, particularly in climate resilient agriculture.
- Policy relevance for investing in climate-resilient seed storage infrastructure like solar powered cold store unit.

Linkages with National Priorities & International Goals

National priorities addressed:

- National Food Security Mission
- National Mission for Sustainable Agriculture
- Rastriya Krishi Vikas Yojana
- Pradhan Mantri Krishi Sinchayee Yojana
- Production-Linked Incentive Scheme for Millets

Way Forward & Scope for Up-scaling

- Synergy with government schemes, NGOs, and research institutions for enhancing technical support.
- Establishing community seed committees for quality and equitable distribution.
- Promotion of value-chain development for millet-based products to ensure market linkages and economic sustainability.
- Promoting public–private partnerships (PPP) for seed processing, branding, and market linkage.
- Building capacity of farmer producer organizations (FPOs), self-help groups (SHGs), and local cooperatives in seed selection, storage, and certification.

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Germplasm Conservation Centres

Conservation Model for Species Genetic Resources in Himalaya

Situational Analysis & Rationale

- The Himalayan region, a global biodiversity hotspot, harbors over 1200 endemic plant species with unique genetic traits. However, factors like habitat fragmentation and anthropogenic pressures causing loss of rare alleles and local genotypes which can lead to a loss of genetic variation within populations, local extinction of species, reducing their long-term viability.
- Establishing germplasm conservation centre is essential to safeguard and conserve these genetic resources for future breeding programs. Such centres preserve region-specific genetic diversity, which is vital for plant breeding and crop improvement, while providing a secure ex-situ backup against inevitable environmental changes.
- These models addresses depletion of genetic diversity caused by factors, such as habitat loss & climate change.

Activities & Innovations

- Germplasm Conservation Centre stablished at different locations of Uttarakhand, Himachal Pradesh, Sikkim, and Ladakh.
- These centres are aimed to (i) conserve germplasm of threatened, endemic and other high value species of diverse origin, (ii) knowledge generation, (iii) planting material for large scale cultivation, and (iv) training and demonstration purposes.
- Replicability of demonstration model in similar parts of Himalaya and exchange of germplasm among diverse stakeholders.

Key Steps & Processes

- Enrichment and accessioning of germplasm of diverse medicinal and high value plants across the Himalaya.
- Multilocational trials and growth performance analysis for developing cultivation practices.
- Development and up-scalability of propagation protocol for mass cultivation.
- Genetic and chemical characterization for standardising agronomic traits.
- Data/material exchange and synergy building with collaborative partner organisations.
- Training, demonstration and knowledge dissemination as model of conservation.

Key Highlights

Conserving different threatened, endemic and high value species at diverse locations of Himalayan region:

- 150 orchids, 55 medicinal plants, 12 Rhododendrons, 28 Zingiberaceae species along with more than 200 accessions of *Hedychium spicatum* and 60 accessions of *Amomum subulatum* in Sikkim.
- Cold desert medicinal plant species (25 No.) in Leh.
- Threatened and endemic plant species (30 spp.), medicinal plants (100 spp.), multipurpose spp (120 No.) in Uttarakhand.
- Medicinal and multipurpose species (40 No.) in Himachal Pradesh.

Outcomes

- Established ex-situ gene banks for threatened MAPs and high value species at diverse locations (1000-3500 m asl) including farmers field.
- Created source of planting material to different plantation programme and medicinal plants cultivators.
- Provided material for detailed phytochemicals and molecular profiling for identifying elite accessions.
- Standardized propagation packages (tissue culture, vegetative propagation, seed germination) for 78 MAPs.
- Promoted cluster-based farming in different locations in Uttarakhand.
- Integrated medicinal plants cultivation with different Govt. schemes for market linkages.
- Capacity building of diverse stakeholders (farmers, officials, students) for conservation and sustainable utilization of Himalayan biodiversity.

Impacts & Policy Relevance

- **Biodiversity conservation:** These Centres have conserved genetic diversity for threatened, endemic and high value multipurpose species, with success rates of 52–62% for native plant survival in different locations.
- **Knowledge generation:** Over 50 publications (2020–2025) cover population assessments, habitat suitability modeling, phytochemical variability, and climate impacts.
- **Socio-economic benefits:** Programs engage ~500 farmer families in cluster-based cultivation with certification under the Quality Council of India's VCSMPP scheme and buyback arrangements for better pricing.
- **Capacity building:** Training in on nursery development and medicinal plants cultivation has uplifted livelihood of rural women and communities in Uttarakhand, Himachal Pradesh, Ladakh and Sikkim.

- Conserving intra- and Inter-specific genetic variability of medicinal and high value Himalayan taxa.
- Himalayan Genetic Resource Database supported data-driven prioritization and predictive modeling of genetic erosion.
- Serving as reservoirs of functional genes and traits for crop improvement and cultivation.
- Serving as a live demonstration for skill development and capacity building.
- Fulfilling requirement of regional community and industries with improved availability of bio-resources.

Linkages with National Priorities & International Goals

- Supports **Sustainable Development Goal 15** (Life on Land), **FAO's Global Plan** of Action for Plant Genetic Resources for Food and Agriculture and **Aichi Target 13** on maintaining genetic diversity of wild species.
- National Biodiversity Action Plan **(NBAP)**, National Action Plan on Climate Change **(NAPCC)** and **Bioeconomy Policy 2022**.
- Policy linkage with the **Biological Diversity Act (2002)** and People's Biodiversity Registers **(PBRs)**.
- Fulfilling requirement of regional community and industries with improved availability of bio-resources.

Way Forward & Scope for Up-scaling

- Develop multi-institutional network linking, Indian Botanical gardens, Institutions, universities, and ICAR-NBPGR for coordinated germplasm collection and sharing.
- Develop SOPs for passport data collection to ensure data uniformity and scalability across the Himalaya.
- Strengthen community knowledge on regional biodiversity.
- Training in participatory biodiversity documentation.
- Encourage bioprospecting and bio-enterprise incubation based on conserved germplasm, ensuring benefit-sharing and economic sustainability.

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Chapter 8

Monitoring Atmospheric and Forest Ecosystem Responses to Climate Change

The Himalayan region, a critical regulator of climate over South Asia and a source of major river basins, is experiencing rapid environmental change driven by warming, increasing human activities, and rising pollution. Growing tourism, urbanization, and biomass burning have intensified aerosol loads, yet long-term, systematic aerosol observations remain sparse. This limits understanding of aerosol- monsoon interactions, radiative forcing, and air-quality impacts.

Simultaneously, Himalayan forests, situated within two global biodiversity hotspots, are highly sensitive to climate-driven shifts in temperature, precipitation, and seasonality. Yet, ecosystem-scale, continuous flux measurements essential for quantifying carbon, water, and energy exchange and budget remain largely absent. This lack of long-term eddy-covariance observations severely limits our ability to evaluate ecosystem functioning, characterize climate–ecosystem feedbacks, and quantify the regional carbon balance with confidence.

Strengthening atmospheric and ecosystem monitoring through aerosol climatology development and eddy covariance based flux observations is, therefore, essential for improving climate modelling, guiding conservation strategies, and informing policies for climate-resilient Himalayan region.

To address these research gaps, GBP-NIHE has developed long-term aerosol monitoring stations in Himachal Pradesh and Uttarakhand using advanced instruments, satellite data, low-cost sensors, and AI/ML tools to track seasonal trends, sources, and regional transport of aerosols. Additionally, in collaboration with CSIR–4PI, the Institute has established eddy covariance sites in pine- and oak-dominated forests of Uttarakhand to monitor carbon fluxes and improve understanding of ecosystem–climate interactions in the Himalayan region.

Aerosol Monitoring Over North-Western Himalaya

Long-Term Aerosol Climatology across Himachal Pradesh and Uttarakhand

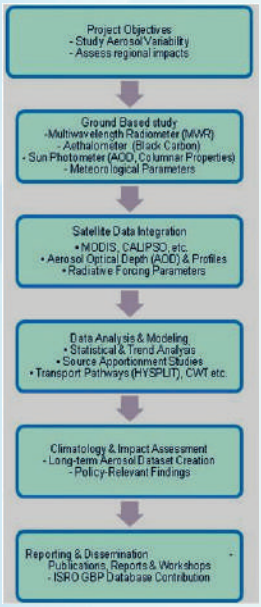
Situational Analysis & Rationale

- The Himalayan region is crucial for climate regulation, monsoon dynamics, and water resources.
- However, human activities, tourism, and pollution have introduced aerosol loads, affecting air quality, visibility, and climate.
- Lack of systematic aerosol climatological data and long-term observations is a major concern.
- Developing an aerosol monitoring network over Himalayan region can address the existing research gaps, support climate dynamics studies, and policy recommendations as part of several national initiatives.

Activities & Innovations

- Established long-term aerosol monitoring stations in Himachal Pradesh and Uttarakhand using advanced instruments and satellite integration.
- Analyzed seasonal and annual aerosol trends, identify sources, and regional transport.
- Low cost sensors, real-time monitoring, application of AI & ML tools, and vertical profiling.
- Capacity building and climate impact assessment involving training to researchers and community engagement.

Key Steps & Processes



Specification	MWR	MTOPS
Measurement	Direct	Direct
Operation	Automatic, sun tracking	Handheld, sun pointed
No. of channels	10	5
Wavelengths, µm	0.38, 0.4, 0.45, 0.5, 0.6, 0.65, 0.75, 0.85, 0.935, and 1.025	0.38, 0.50, 0.675, 0.936 and 1.02
Bandwidth FWHM	5 nm	10 nm
Field of view	2°	2.5°

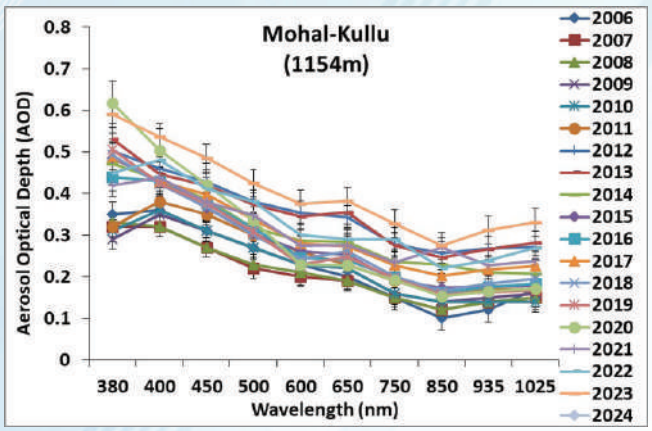
Key Highlights

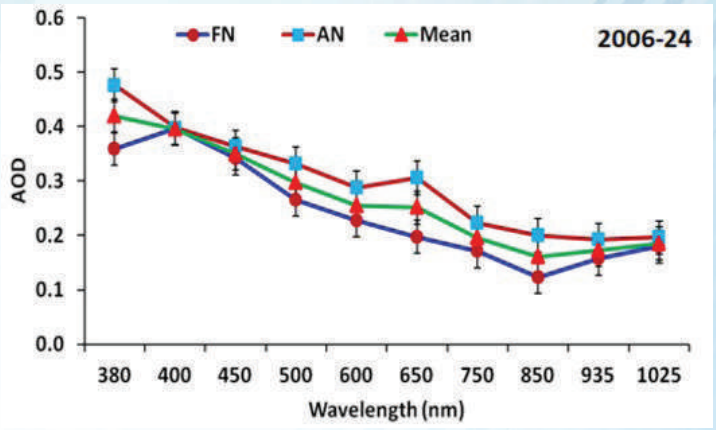
- Created a spatially and temporally resolved database of aerosols and trace gases over the Indian Himachal region.
- Integrated aerosol and trace gas data with regional climate models to assess their effects on the climate.

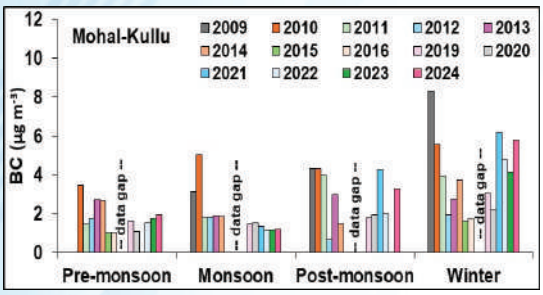
Outcomes

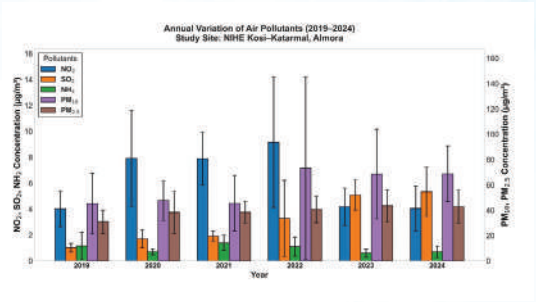
- Established network of aerosol observatories (ARFINET) collaborately with ISRO for continuous measurements of AOD.
- ISRO GBP-ARFI network project - a national project with more than 42 observatories in India.
- Accurately characterized aerosol using an in-house built Multi Wavelength Solar Radiometer (MWR) using common protocols across all the observatories in India.
- Improved scientific skills, networking with other research institutions, and opened up new research avenues.
- The research outcomes and results have been cited in the IPCC's fifth assessment report for highlighting the current situation in Asia and to evaluating the effects.

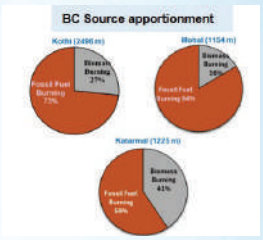
Aerosol optical depth, Black carbon, Particulate matter and gaseous pollutants variation at Mohal-Kullu and Kosi-Katarmal











Impacts & Policy Relevance

- Understanding aerosol-climate interactions in the North-western Himalayan region, revealing their impact on radiative forcing, temperature, and cloud formation.
- Highlighting effects of black carbon and dust deposition on glacial melting and identifies seasonal and anthropogenic sources affecting air quality.
- Assessment of impacts on water resources, agricultural productivity, health, ecosystem balance, and biodiversity.
- Providing scientific input for air quality management, strengthens climate adaptation and mitigation strategies, and enhances disaster preparedness for glacier lake outburst floods.
- Building a long-term aerosol climatology database through collaboration between ISRO, universities, and environmental agencies, and supporting global climate datasets.

Linkages with National Priorities & International Goals

- **National Alignment:** Supports NAPCC, NMSHE, and NCAP by generating data on aerosols, climate, and air quality.
- **Global Commitments:** Contributes to UN SDGs (13: Climate Action, 15: Life on Land, 3: Good Health) and Paris Agreement objectives.
- **Collaborative Integration:** Connects with ISRO-ARFINET, IMD, and NASA-AERONET for national and global data sharing and research.
- **Policy & Scientific Impact:** Strengthens India's role in climate research and IPCC assessments through reliable long-term aerosol datasets.

Way Forward & Scope for Up-scaling

- Use of advanced data and modeling approaches, collaborating with ISRO Centres and Universities, and transforming research into policy actions.
- Outscale studies to the entire Indian Himalayan Region, incorporating results into future ISRO missions and national climate plans.

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Eddy Covariance for Himalayan Ecosystems

Long Term Monitoring of Carbon and Water Fluxes for Mountain Ecosystems

Situational Analysis & Rationale

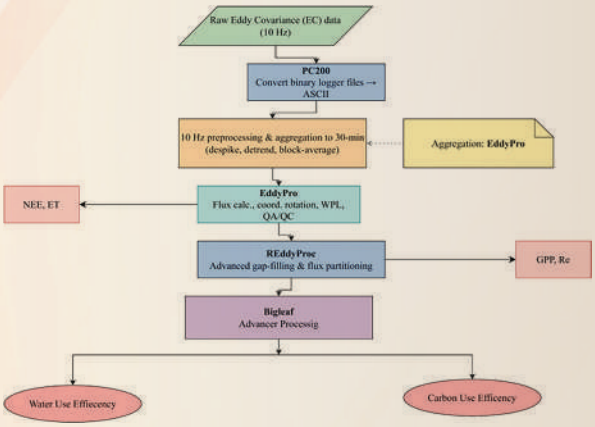
- The Himalaya contains two global biodiversity hotspots, yet ecosystem-level observations remain limited, restricting our ability to understand how accelerated warming is altering forest functioning and climate–ecosystem feedbacks.
- Eddy covariance (EC) systems provide continuous, high-resolution measurements of carbon, water, and energy fluxes, offering a robust framework to quantify land–atmosphere interactions and generate science-based, targeted forest management and climate policies.
- GBP-NIHE has initiated long-term EC-based monitoring across representative Himalayan forest ecosystems to fill critical data gaps, strengthen ecosystem assessments, and support adaptive conservation and climate-resilient planning.

Activities & Innovations

- The EC system estimates the fluxes by concurrent measurement of vertical wind speed, CO2 and H2O concentrations with other micro-meteorological variables at a certain height above the land surface.
- The GBP-NIHE in collaboration with CSIR–4PI, Bangalore, established its first eddy covariance site at Kosi-Katarmal, Almora, Uttarakhand over a Pine-dominated (*Pinus roxburghii*) ecosystem. A second EC site for an Oak-dominated (*Quercus leucotrichophora*) forest was set up in 2016 at Gangolihat, Pithoragarh, Uttarakhand under the NMSHE Task-Force-3 (DTS, Govt. of India) initiative.

Key Steps & Processes

- The EC systems at Almora and Gangolihat were working at 10 Hz frequency. The flow diagram shows basic data processing framework:



Ecosystem Characteristics

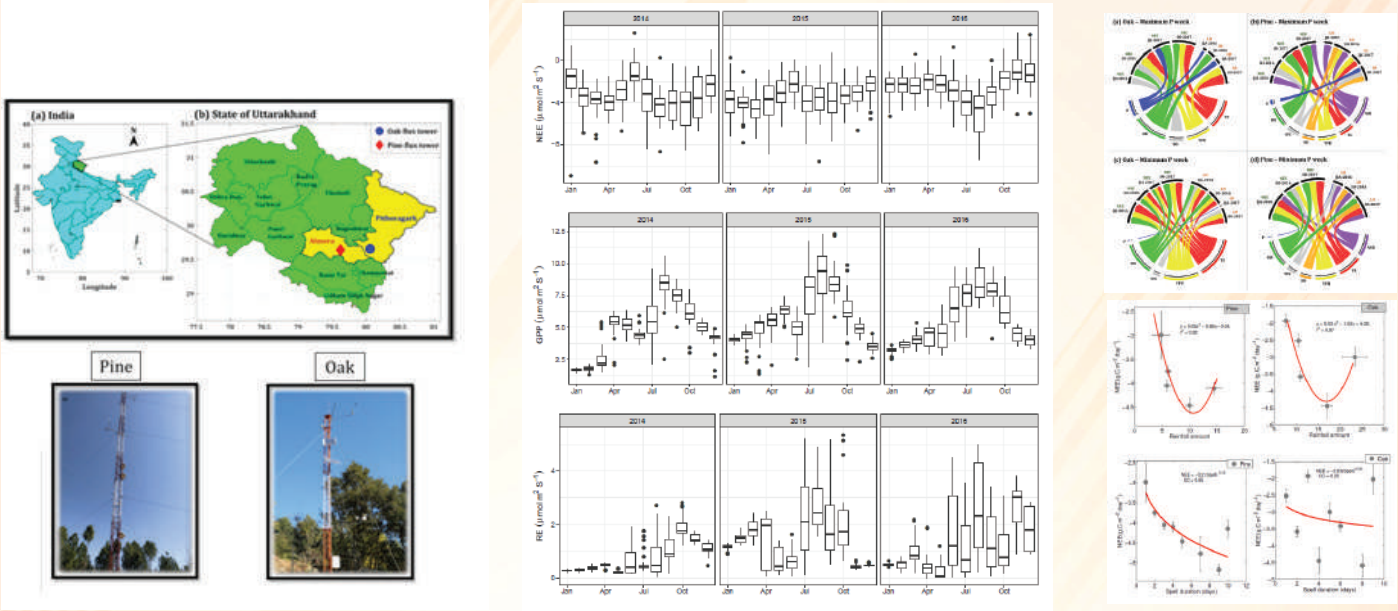
	Pine	Oak
Elevation	1217 masl	1650 masl
Lat	29°38'N, 79°37'E	29°39'N, 80°03'E
EC measurement height	30 m	10 m
Canopy height	12-15 m	8 m
Dominant	*Pinus roxburghii*	*Quercus leucotrichophora*
Co-dominant	*Quercus leucotrichophora*	Cedrus Deodara
Diversity	0.95	0.33
Richness	11	3

Outcomes

- Atmospheric surface layer processes: EC data quantified turbulence, energy exchange, and near-surface stability over Himalayan forests.
- Ecosystem functioning: Continuous EC fluxes revealed seasonal patterns of carbon uptake, respiration, and water use in pine and oak systems.
- Drivers of ecosystem growth: EC observations identified temperature, soil moisture, and radiation as key regulators of productivity.
- Ecosystem–atmosphere interactions: EC measurements captured real-time carbon–water–energy coupling shaping forest–climate feedbacks.
- Regional-scale data: GBPNIHE EC sites provided rare long-term flux datasets supporting Himalayan carbon budgeting and climate assessments.

Key Highlights

- The average annual carbon sequestration of the Pine ecosystem (~1000 gC.m-2) is much higher than the global average (~183 gC.m-2). The soil moisture□induced drought at the Pine ecosystem promoted the drought stress condition.
- Pine ecosystem sequesters around 1.8 times higher carbon than the Oak. Both Pine and Oak ecosystems were sequestering highest amount of carbon (-4.65 and -4.91 g.C.m−2. day−1, respectively) just after the day having maximum monsoon rainfall.
- The mutual information-based TIPNet model showed Pine ecosystem is heat dominated, whereas, Oak is moisture dominated at a 06-hourly scale.



Source: Mukherjee et al. (2018, Biogeosci Diss), Khadke et al. (2024, J. Hydrol), and Lohani et al. (2023, Env. Mont. Assess).

Impacts & Policy Relevance

- EC observations enabled a new atmospheric surface-layer parameterisation, improving understanding of turbulence and land–air exchange in Himalayan forests.
- Collaboration with ISRO and IITM used GBPNIHE EC fluxes to generate national-scale gridded NEE datasets, filling a major gap in India's carbon budgeting.
- International collaboration produced Asian continental NEE estimates, with GBPNIHE sites contributing key high-altitude ecosystem flux information.
- An information-theory-based diagnostic model was developed using EC data to assess land–atmosphere coupling in pine and oak ecosystems of the Himalaya.
- The pine EC site is among India's longest-running carbon and water flux stations, offering rare long-term datasets crucial for climate and ecosystem research.

Linkages with National Priorities & International Goals

- Aligns with National Mission for Sustaining the Himalayan Ecosystem (NMSHE) under National Action Plant on Climate Change.
- Thematic Area-III (Forest Ecosystem and Biodiversity) of National Adaptation plan for climate change (NAP)
- Strengthens forest governance through Long term data monitoring of forest ecosystem in Central Himalaya.
- The activities are aligned with the cross-cutting climate change theme of NMHS, MoEFCC, GoI and MetFLUX programme of MoES, GoI.

Way Forward & Scope for Up-scaling

- Expansion of eddy covariance networks across different forest and grassland ecosystems of IHR in needed.
- Ecosystem specific carbon budget assessment needs convergence with large-scale process-based carbon cycle model.
- Targeted policy directives for plantation or selective loping of Himalayan trees, based on the long-term assessment of land-atmosphere interactions using EC-based systems, need mainstreaming.

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Epilogue

The Indian Himalayan region (IHR), rich in biodiversity and cultural heritage, is facing unprecedented environmental and socio-economic pressures. The integrated and transformative initiatives by G. B. Pant National Institute of Himalayan Environment (GBP-NIHE) - from ecological monitoring and conservation to sustainable livelihoods, water management, and waste valorization, provide a replicable approach for sustainable development. Collectively, these integrated efforts provide replicable models for holistic ecosystem management, balancing environmental stewardship with socio-economic growth, and building climate resilient communities in the fragile Himalayan ecosystem.

By harmonizing scientific research, technological innovation, and community led solutions, NIHE demonstrated pathways for thriving ecosystems and human communities together. The impactful initiatives and transformative approach of the Institute strengthen ecological resilience and foster sustainable livelihood options ensuring IHR as a vibrant, productive, and ecologically balanced region. These initiatives of NIHE offer not only the protection of the Himalaya's natural wealth, but also the creation of resilient, empowered communities capable of coping the challenges of climate change, environmental degradation, and socioeconomic changes. The continued efforts of NIHE provide a blueprint for sustainable growth, ensuring that the IHR remains a vibrant and ecologically balanced region for generations to come.

The G. B. Pant National Institute of Himalayan Environment aims to scale-up and deepen its integrated approaches to ensure sustainable development across the Indian Himalayan Region. Key action priorities include:

1. **Enhanced Community Engagement:** Strengthening participatory models that empower women, marginalized groups, and local communities to actively manage natural resources and generate sustainable livelihoods.

2. **Scaling Eco-innovations:** Expanding waste-to-wealth solutions, renewable energy-supported agriculture, and water reuse technologies to wider regions, fostering replicable, low-cost, and eco-friendly interventions.

3. **Climate Resilience and Biodiversity Conservation:** Broadening ecological monitoring networks (LTEM, GLORIA) and conservation programs to safeguard high-altitude ecosystems, endemic species, and agro-biodiversity under changing climatic conditions.

4. **Value Chain Development:** Supporting local enterprises, wild edible products, and biodiversity-based businesses through technology, skill development, and market linkages to strengthen 'Vocal for Local' initiatives.

5. **Long-term environmental monitoring:** systematic, sustained observation of environmental conditions over long time periods to track changes, understand trends, and assess impacts on ecosystems, biodiversity, and human health; thereby evaluating the effectiveness of conservation efforts, developing policy, and informing decisions for sustainable management.

6. **Policy and Knowledge Integration:** Leveraging scientific research and field-based evidence to guide regional policy, contribute to national missions, and align with international biodiversity and sustainable development frameworks.

The Himalayan ecosystem is facing severe threats from climate change and unsustainable development, demanding transformative solutions. Past conservation and development efforts and fragmented policies have under achieved in reducing environmental vulnerability marked by ecological degradation, livelihood decline, and rising out-migration. Rapid urbanization and poorly managed tourism have further strained the region's fragile ecosystem. To enhance resilience of the Himalayan communities and ecosystems towards the changing scenarios, a transformative approach is essential- one that redefines governance, social systems, and economic models toward long-term sustainability.

By combining science, innovation, and community participation, NIHE aims to foster resilient ecosystems, self-reliant communities, and sustainable development that balance environmental stewardship with socioeconomic growth.

About the Institute

Govind Ballabh Pant National Institute of Himalayan Environment (GBP-NIHE) was established at Kosi-Katarmal, Almora, Uttarakhand in 1988 as an autonomous institute of the Ministry of Environment, Forest and Climate Change (MoEF&CC), Government of India. The institute is identified as a focal agency to advance scientific knowledge, evolve integrated management strategies, demonstrate their efficacy for conservation of natural resources, and ensure environmentally sound development in the entire Indian Himalayan Region (IHR). The institute follows a multidisciplinary and holistic approach in all its Research and Development programmes, with emphasis on interlinking natural and social sciences, and particular attention is given to the conservation of fragile mountain ecosystems, indigenous knowledge systems, and sustainable use of natural resources. Training, environmental education, and awareness to different stakeholders are essential components of all the R&D programmes of the institute. GBPNIHE functions in a decentralized manner, with its headquarters located in Kosi-Kaarmal, Almora, Uttarakhand, and six regional centres. Ladakh Regional Centre (Leh), Garhwal Regional Centre (Srinagar-Garhwal), Himachal Pradesh Regional Centre (Mohal Kullu), Sikkim Regional Centre (Pangthang, Gangtok), North-East Regional Centre (Itanagar), and Mountain Division (MoEF&CC, New Delhi).

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