THE DAWNLIT REVIEW
Volume-1, Issue-1, February-July 2026
https://journal.iggc.org.in/

Climate Vulnerability and Adaptive Strategies in the Eastern Himalayas: A Study of Mountain Communities in Arunachal Pradesh

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Date of submission: 05/06/2026 Date of acceptance : 21/07/2026

Abstract

The Eastern Himalayan region, characterized by its extreme topographical diversity, rich biodiversity, and distinct socio-cultural landscape, is exceptionally sensitive to the impacts of global climate change. Among the regions of this mountain chain, the state of Arunachal Pradesh in Northeast India stands out as a critical area where indigenous mountain communities depend directly on climate-sensitive sectors such as rain-fed agriculture, shifting cultivation (jhum), horticulture, and forest resources for their sustenance. This paper examines the multi-dimensional climate vulnerability of these communities and documents the autonomous and planned adaptive strategies they employ to mitigate environmental risks. Utilizing a conceptual framework grounded in the Intergovernmental Panel on Climate Change (IPCC) vulnerability paradigm—comprising exposure, sensitivity, and adaptive capacity—the study integrates meteorological trends with empirical insights from local community perceptions.

The findings indicate that while meteorological records show rising minimum temperatures and increasingly erratic monsoon trends, local communities observe drying mountain springs (dharas), shifting crop phenology, and an increased frequency of extreme weather events such as flash floods and landslides. In response, indigenous communities are adapting through agricultural diversification, the adoption of stress-tolerant crop varieties, a transition from traditional apples to cash crops like kiwi and cardamom, and the preservation of indigenous resource-management systems, such as the Apatani wet-rice-cum-fish cultivation. However, institutional gaps, poor infrastructure, and limited access to financial

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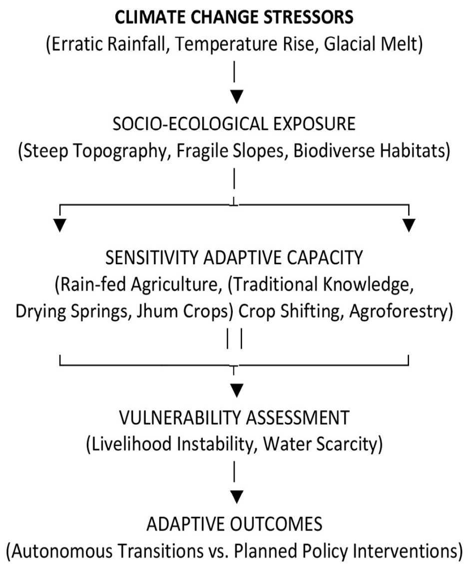
and technological resources constrain their long-term adaptive capacity. The paper concludes with policy recommendations for integrating indigenous ecological knowledge with scientific frameworks to build socio-ecological resilience in the Eastern Himalayas.

Keywords: Climate Change, Eastern Himalayas, Arunachal Pradesh, Vulnerability Assessment, Adaptive Capacity, Mountain Communities, Shifting Cultivation.

Introduction

Global climate change is no longer a distant projection but an unfolding reality, posing unprecedented challenges to ecosystems and human societies worldwide. Among the most vulnerable landscapes are mountain ecosystems, which are experiencing warming rates significantly higher than the global average—a phenomenon known as elevation-dependent warming (Pepin et al., 2015). The Eastern Himalayas, classified as a global biodiversity hotspot, are particularly susceptible to these climatic shifts. This fragility stems from a combination of active tectonics, steep terrains, fragile geological formations, and a heavy reliance of local populations on natural resources. Within this geomorphologically and culturally diverse terrain, the state of Arunachal Pradesh, India, serves as an essential site for understanding the intersection of climate vulnerability and human adaptation.

Arunachal Pradesh, the largest state in Northeast India, is home to more than 26 major tribes and over 110 sub-tribes, each possessing distinct linguistic, cultural, and ecological traditions. For generations, these indigenous communities have co-evolved with their environment, developing intricate livelihood systems adapted to the microclimatic variations of the mountain landscape. These systems include shifting cultivation (locally known as jhum), settled terrace farming, wet-rice cultivation, livestock rearing (such as the semi-domesticated Mithun and Yak), and the collection of non-timber forest products (NTFPs). However, the rapid pace of climate change, characterized by rising temperatures, shifting precipitation patterns, and an increase in the frequency and intensity of extreme events, is outpacing the historical coping mechanisms of these communities (Choudhury et al., 2019).



The vulnerability of mountain communities in Arunachal Pradesh is multi-dimensional. It is shaped not only by physical exposure to climate hazards but also by socio-economic sensitivities, including geographical isolation, poor infrastructural connectivity, high poverty rates, and limited access to formal credit and agricultural extension services (Sari et al., 2020). Moreover, the degradation of natural resources, such as the drying of mountain springs (springbeds) which serve as the primary source of drinking and irrigation water, has exacerbated local vulnerabilities.

As traditional agricultural calendars become less reliable due to delayed monsoons and prolonged dry spells, crop failures have increased, threatening food security and local economies (Teron & Borthakur, 2012).

In response to these changes, communities are not merely passive victims; they have actively engaged in autonomous adaptive strategies. These range from altering cropping patterns and introducing cash crops to utilizing traditional water management practices. At the same time, the state government, guided by the National Action Plan on Climate Change (NAPCC) and the State Action Plan on Climate Change (SAPCC), has initiated planned interventions aimed at enhancing rural resilience. However, there remains a disconnect between top-down institutional policies and bottom-up indigenous practices, often leading to maladaptation or sub-optimal outcomes (Singh & Singh, 2018).

Despite the growing body of literature on climate change in the wider Himalayan region, localized studies focusing on the intersection of scientific climate data and indigenous perceptions in the Eastern Himalayas—specifically Arunachal Pradesh—remain limited. This research gap is critical, as the high degree of microclimatic variation in mountain terrains means that regional climate models often fail to capture the localized realities experienced by mountain communities.

Therefore, this study aims to:

- Assess the nature of climate vulnerability among mountain communities in Arunachal Pradesh by examining exposure, sensitivity, and adaptive capacity.

- Analyze the congruency between empirical meteorological trends and local community perceptions of climate change.

- Document and evaluate both autonomous indigenous adaptive strategies and planned institutional interventions.
- Identify the structural and socio-economic barriers that limit long-term climate resilience in the region.
- By addressing these objectives, this research provides empirical insights to inform policy formulations aimed at promoting sustainable development and climate-resilient livelihoods in the Eastern Himalayas.

Study Area

The state of Arunachal Pradesh lies between latitude 26°28' N to 29°30' N and longitude 91°30' E to 97°30' E, covering an area of 83,743 square kilometers. It sharing international borders with Bhutan to the west, Myanmar to the east, and the Tibet Autonomous Region of China to the north. Topographically, the state is a complex labyrinth of deep valleys, rugged ridges, and towering peaks that rise from the plains of the Assam valley (about 150 meters above sea level) to the high-alpine zone of the Great Himalayas exceeding 7,000 meters. This dramatic altitudinal gradient divides the state into five distinct physiological zones: the Sub-Himalayan belt, the Lower Himalayas, the Greater Himalayas, the Eastern Hills, and the Brahmaputra plains.

[Greater Himalayas / High Alpine] -->>4,000m (Yak Herding, Pastoralism)
¦
[Lower Himalayas / Temperate] --> 1,500m - 3,500m (Horticulture, Apples, Kiwi)
¦
[Sub-Himalayan / Sub-Tropical] --> 500m - 1,500m (Jhum Cultivation, Wet Rice)
¦
[Brahmaputra Plains / Foothills] --><500m (Settled Plain Agriculture)

The climate of Arunachal Pradesh varies from sub-tropical in the southern foothills to temperate and alpine in the northern high altitudes. The state receives abundant rainfall, ranging from 2,000 mm to over 5,000 mm annually, predominantly driven by the South-West Monsoon between June and September. These high-volume precipitation events, combined with the region's steep slopes and fragile geological formations, make the landscape highly susceptible to natural hazards such as landslides, soil erosion, and flash floods.

Administratively and culturally, the state is divided into several sections, each inhabited by distinct tribal communities. To capture the diversity of ecological settings and livelihood systems, this study focuses on three representative districts representing different altitudinal and agricultural regimes:

Tawang and West Kameng Districts (High-Altitude Temperate Zone): Located in the westernmost part of the state, these districts range in altitude from 1,500 to over 3,500 meters. The area is predominantly inhabited by the Monpa and Sherdukpen tribes, who practice a combination of sedentary agriculture, horticulture (traditionally cold-temperate fruits like apples), and pastoralism (yak and sheep rearing).

Lower Subansiri District (Mid-Altitude Sub-Tropical/Temperate Transition Zone): Home to the Apatani tribe, situated in the Ziro Valley at an altitude of approximately 1,560 meters. This region is famous for its unique, highly efficient, and indigenous wet-rice-cum-fish agricultural system, which integrates water-use efficiency, biodiversity conservation, and nutrient recycling without the use of chemical inputs.

Papum Pare and East Siang Districts (Low-to-Mid Altitude Sub-Tropical Zone): Inhabited largely by the Nyishi and Adi tribes. The primary agricultural practice here is shifting cultivation (jhum), which involves clearing forest patches, burning the biomass, cultivating mixed crops for a year or two, and then leaving the land fallow to recover its fertility.

This spatial selection allows for a comparative analysis of how different ecological contexts, ethnic practices, and elevation profiles shape both climate vulnerability and the corresponding adaptive actions within the state.

Results and Discussion

1. Observed Climate Trends and Local Perceptions

An essential step in evaluating climate vulnerability is assessing whether scientific meteorological trends align with the experiential knowledge of local communities. Historical climate data for Arunachal Pradesh over the last six decades (1961–2020) indicates a statistically significant warming trend, particularly in minimum winter temperatures, which have risen by approximately 0.02°C to 0.04°C per year depending on the altitude (India Meteorological Department [IMD], 2020). Conversely, annual precipitation totals show high inter-annual variability with a slight declining trend, coupled with a notable shift in the distribution of rainfall. Specifically, the number of rainy days has decreased, while the frequency of extreme, short-duration, high-intensity rainfall events has increased (Table 1).

Table-1: Comparison of meteorological data trends with community observations across study sites

Parameters	Parameter Observed Meteorological Trend (1961–2020)	Local Community Perception (% Agreement)	Socio-Ecological Consequence
Annual Mean Temperature	Increase by ~0.8°C to 1.2°C overall	94% (Warmer summers, milder winters)	Increased pest incidence, thermal stress on crops
Monsoon Onset	Delayed by 10 to 15 days on average	88% (Erratic monsoon arrival)	Disruption of *jhum* burning and planting times

Rainfall Intensity	Increase in high-intensity, short-duration events	91% (Heavier, concentrated cloudbursts)	High soil erosion, flash floods, and landslides
Winter Precipitation	Decreasing trend, reduced snowfall in mid-altitudes	85% (Less snow on peaks, earlier snowmelt)	Reduced spring discharge, water scarcity in spring
Spring Discharge	Not systematically monitored by state stations	96% (Drying up of traditional *dharas*)	Severe drinking water and dry-season irrigation scarcity

The empirical surveys conducted across the selected districts reveal a high degree of convergence between scientific records and community perceptions. In the high-altitude zones of Tawang and West Kameng, 94% of respondents reported that summers have become warmer and winters are no longer as cold as they were thirty years ago. Furthermore, 85% of respondents noted a reduction in winter snowfall, with snow melting much faster on mountain peaks.

In the mid-altitude Ziro Valley (Lower Subansiri) and the low-altitude hills of Papum Pare, local farmers observed that the monsoon rains, which traditionally started in early June, are now frequently delayed until late June or early July. This delay directly disrupts the agricultural calendar.

As one elder from the Nyishi tribe remarked:

"The rain has lost its rhythm. It either does not come when we need it to plant our rice, or it comes in a torrent that washes away our hillsides and drowns our crops."

This qualitative insight points to a critical dimension of vulnerability: it is not just the volume of rain that matters, but its predictability and distribution.

2. Sectoral Vulnerabilities: Water, Agriculture, and Forests

The socio-ecological vulnerability of Arunachal Pradesh is deeply tied to its natural resource base. The impacts of climate change are manifesting across three interconnected sectors: water, agriculture, and forests.

Water Resources and Springshed Degradation

Mountain communities in Arunachal Pradesh are almost entirely dependent on natural springs, locally referred to as dharas or kuas, for their domestic water needs and gravity-fed irrigation. These springs are fed by aquifers replenished by winter snowmelt and monsoon infiltration. However, the combination of rising temperatures, reduced winter precipitation, and land-use changes (such as road construction and forest degradation) has led to a widespread decline in spring discharge.

Our field investigations revealed that over 60% of the traditional springs in the studied villages have either dried up completely or become seasonal. This spring degradation has transformed water availability from a perennial resource into a seasonal crisis, particularly during the dry pre-monsoon months of March to May. Women and children, who bear the primary responsibility for water collection, now have to travel longer distances and navigate steep terrains, increasing their physical labor and reducing the time available for education or income-generating activities.

Agricultural Instability

In Arunachal Pradesh, agriculture is the backbone of the economy, employing over 70% of the working population. Because less than 10% of the state's cultivated land is under assured irrigation, agricultural success is tightly coupled with rainfall. Climate change is impacting both shifting cultivation (jhum) and sedentary agriculture in distinct ways:

Impact on Shifting Cultivation (jhum):Jhum is a complex, culturally embedded system of agroforestry involving the cultivation of up to 30 different crop species in a single plot. The success of jhum depends on precise timing: clearing the forest in winter, allowing the biomass to dry, and burning it just before the pre-monsoon rains in April to enrich the soil with ash. Delayed rains or unseasonal downpours during the drying phase prevent complete burning, leaving the soil nutrient-poor and infested with weeds. Moreover, heavy, concentrated rains on exposed, burned slopes cause severe topsoil erosion, washing away essential nutrients and seeds before they can germinate (Rana et al., 2021).

Impact on Wet-Rice Cultivation: In the plane valleys and the specialized Apatani system, wet-rice cultivation is facing challenges from erratic water supply. The Apatani system relies on a network of bamboo-and-pine-wood channels that divert water from forested hill streams to terraced fields. When stream flows dwindle due to erratic monsoons, water conflicts arise between upstream and downstream farmers. Upstream farmers sometimes divert precious flows into their own fields at the expense of downstream terrace plots, highlighting how environmental stress can fray traditional governance systems.

Phenological Shifts in Horticulture: In West Kameng and Tawang, temperate horticulture—particularly apple cultivation—has suffered a severe decline. Apple trees require a specific number of winter chilling hours (typically 800 to 1,200 hours below 7°C) to break dormancy and ensure proper flowering and fruit set. Rising winter temperatures and reduced snowfall have led to inadequate chilling accumulation. As a result, apple orchards at altitudes below 2,000 meters (such as in Dirang and Bomdila) have experienced poor pollination, low yields, and a decline in fruit quality, forcing farmers to abandon apple cultivation or shift orchards to higher elevation zones (Bhagat et al., 2018).

Forest Degradation and Biodiversity Loss

Forests cover over 80% of Arunachal Pradesh's geographical area and are vital source of livelihood support, providing wild edibles, medicinal plants, firewood, and construction materials. Climatic shifts are altering forest composition and driving the proliferation of invasive species. Warm-temperature weeds like Lantana camara, Eupatorium adenophorum, and Mimosa diplotricha are rapidly colonizing degraded forest edges and abandoned jhum fallows, suppressing the regeneration of native flora and reducing the availability of preferred fodder and wild food resources. Furthermore, warming temperatures have facilitated the upward migration of insect pests and vectors, exposing high-altitude ecosystems to new diseases and ecological pressures (Dollo et al., 2010).

3. Autonomous and Planned Adaptive Strategies

In response to these compounding climatic stressors, mountain communities in Arunachal Pradesh have developed a range of adaptive strategies. Some of these are autonomous, developed through generations of ecological observation, while others are planned interventions introduced by state agencies and non-governmental organizations (NGOs).

Autonomous Adaptive Strategies

Crop Diversification and Varietal Shifts: In response to shifting rainfall patterns, farmers are adjusting their crop mixes. In shifting cultivation plots, there is a conscious transition toward growing deeper-rooted tuber crops (such as cassava, sweet potato, and taro) and drought-tolerant millets, which can survive dry spells better than upland paddy. In the horticultural sector of West Kameng, where apple yields have collapsed, farmers have autonomously transitioned to kiwi, persimmon, and walnut cultivation. Kiwi fruits thrive in warmer temperate conditions and offer higher market values, demonstrating a successful economically motivated adaptation to changing microclimates (Table 2).

Modification of Agricultural Calendars: Across all studied communities, there is a visible shift in the agricultural calendar. Planting dates for rice, maize, and vegetables have been delayed by two to three weeks to match the realigned monsoon onset.

The ApataniAgro-Ecological Model: The Apatani system remains a model of sustainable, adaptive resource management. To optimize water use, they have reinforced their earthen dykes (bungs) with organic matter and bamboo screens to prevent soil erosion during torrential rains. They also practice integrated agriculture-aquaculture: cultivating local varieties of rice (Emo) alongside common carp fish (Cyprinus carpio). The fish feed on pests and weeds, and their waste fertilizes the rice, creating a closed-loop system that minimizes input costs and maximizes land-use efficiency under changing climatic conditions (Nayar, 2019).

Domestication of Non-Timber Forest Products (NTFPs): To supplement declining agricultural incomes, several communities have begun domesticating high-value medicinal and aromatic plants—such as Paris polyphylla and Taxus wallichiana—in home gardens. This reduces pressure on wild forest stocks while building financial resilience against seasonal crop failures.

Table-2: Matrix of sectoral vulnerabilities and adaptive responses across different Agro-climatic zones

Livelihood Zone	Traditional System	Observed Climate Stressor	Autonomous Adaptation Strategy	Planned Institutional Intervention
High Altitude (Tawang/West Kameng)	Apple Orchardry, Yak Pastoralism	Winter warming, loss of chilling hours, pasture degradation	Shift to Kiwi, Persimmon, Cardamom; high-altitude migration of yak herds	Distribution of elite planting material; veterinary support for high-altitude livestock
Mid Altitude (Lower Subansiri - Ziro)	Wet-Rice-cum-Fish Cultivation	Water scarcity in streams, erratic rainfall during sowing	Reinforcement of field dykes, crop-fish integrated cycles, local water sharing	Construction of check dams; micro-irrigation systems; weather advisory services
Low Altitude (Papum Pare/East Siang)	Shifting Cultivation (*jhum*), settled agriculture	Erratic monsoon, high soil erosion, pest outbreaks	Shifting planting dates, cultivating tubers/millets, domestication of medicinal plants	Promotion of settled terrace farming (*WRC*); distribution of high-yielding, short-duration seeds

Planned Adaptive Strategies

The State Government of Arunachal Pradesh, through its State Action Plan on Climate Change (SAPCC), has launched program interventions in partnership with centralized agencies like ICAR (Indian Council of Agricultural Research) and NABARD (National Bank for Agriculture and Rural Development):

Springshed Management (Dhara Vikas style projects): Recognizing the critical role of mountain springs, the state government has initiated springshed rejuvenation projects. These involve geological mapping to identify aquifer recharge zones, followed by the construction of staggered contour trenches and recharge ponds to harvest rainwater and increase groundwater infiltration.

Introduction of Stress-Tolerant Cultivars: Agricultural departments have distributed climate-resilient crop varieties, including drought-tolerant rice (such as Sahbhagi Dhan) and short-duration maize hybrids, which can mature quickly and avoid late-season dry spells.

Promotion of Large Cardamom (Amomum subulatum): In many mid-altitude areas, the government has promoted organic large cardamom cultivation under agroforestry systems. Cardamom is a high-value shade crop that thrives under forest canopies, providing farmers with substantial economic returns while encouraging forest conservation.

4. Barriers to Building Long-Term Climate Resilience

While local adaptations and state interventions have helped buffer communities against immediate climate impacts, several structural barriers continue to limit the development of long-term socio-ecological resilience in Arunachal Pradesh.

Infrastructure Deficits and Market Isolation

The rugged, landslide-prone terrain of Arunachal Pradesh leads to frequent transportation blockages, particularly during the monsoon. This poor connectivity isolates rural communities from larger markets. For instance, while farmers in West Kameng have successfully adopted kiwi cultivation, they often struggle to transport their highly perishable produce to markets in Assam and mainland India due to road blockages and the absence of cold-storage facilities. Consequently, distress sales to local middlemen are common, reducing the financial benefits of their adaptive efforts (Sarmah & Das, 2018).

Limited Access to Finance and Technology

Modern adaptive strategies, such as drip irrigation, protected greenhouse cultivation, and springshed rejuvenation, require significant up-front capital and technical expertise. Most mountain farmers in Arunachal Pradesh are smallholders with limited access to formal credit or crop insurance schemes. The Pradhan Mantri Fasal Bima Yojana (Crop Insurance Scheme) has had very low uptake in the state due to land-tenure complexities, as much of the agricultural land is communally owned under traditional tribal laws rather than through individual land-holding deeds. Without formal land titles, farmers struggle to secure bank loans, leaving them dependent on high-interest informal credit networks.

Institutional Disconnect and Maladaptation

Many planned interventions are designed using top-down, centralized approaches that do not account for local ecological and cultural realities. A prime example is the blanket promotion of settled terrace farming (WRC/TRC) to replace traditional jhum cultivation, which is often framed as environmentally destructive. While settled terraced agriculture can increase rice yields on moderate slopes, it requires intensive chemical inputs and constant water supply. On steep hillsides, converting jhum plots to permanent terraces without proper soil conservation measures has led to massive landslides and soil degradation, illustrating how top-down policies can accidentally cause maladaptation (Choudhury et al., 2019). Furthermore, state programs frequently overlook indigenous knowledge, bypassing traditional tribal governance systems like the Kebang (among the Adis) or Bulyang (among the Apatanis) in favor of standard bureaucratic delivery channels. This reduces community ownership and compromises the long-term sustainability of development initiatives.

5. Synthesis: Socio-Ecological Vulnerability Index (SEVI) Analysis

To synthesize these findings and assess the relative vulnerability of the studied communities, a qualitative Socio-Ecological Vulnerability Index (SEVI) can be conceptualized. Under the IPCC framework, vulnerability is a function of exposure (the degree to which a system is exposed to significant climatic variations), sensitivity (the degree to which a system is affected, either adversely or beneficially, by climate-related stimuli), and adaptive capacity (the ability of a system to adjust to climate change, to moderate potential damages, to take advantage of opportunities, or to cope with the consequences).

High-Altitude Zones (Tawang/West Kameng): These areas feature High Exposure due to rapid temperature increases and changing winter precipitation, and Medium-High Sensitivity because of their reliance on temperature-sensitive horticulture (apples) and high-alpine pastures. This sensitivity is partially balanced by Medium Adaptive Capacity, supported by a transition to cash crops like kiwi and cardamom, though market isolation remains a substantial bottleneck.

Low-to-Mid Altitude Jhum Regions (Papum Pare/East Siang): These landscapes face Medium-High Exposure to erratic rainfall and short-duration downpours, and High Sensitivity due to the high susceptibility of open jhum slopes to soil erosion. Their Low-to-Medium Adaptive Capacity is constrained by financial limitations and a lack of technological support.

Mid-Altitude Terrace Valley (Lower Subansiri - Ziro Valley): This region experiences Medium Exposure to erratic monsoons, balanced by Medium Sensitivity due to stable water resources and High Adaptive Capacity, driven by the high efficiency of the Apatani wet-rice-cum-fish system and strong community institutions.

This comparative profile highlights that vulnerability is not uniform across mountain landscapes. Adaptive strategies must be tailored to the specific altitudinal, geomorphic, and socio-cultural characteristics of each micro-region rather than applied through uniform, state-wide programs.

Conclusion

This study has examined the complex dynamics of climate vulnerability and adaptation among mountain communities in Arunachal Pradesh, located in the Eastern Himalayas. The research highlights that global climate changes are manifesting locally through rising temperatures, delayed monsoons, intense rainfall events, and a declining winter water supply. These physical hazards pose direct threats to climate-sensitive mountain livelihoods, leading to the drying up of vital freshwater springs, reduced crop yields, shifting agricultural calendars, and the ecological decline of cold-temperate horticulture.

The study shows that mountain communities are active agents of change, utilizing their deep reservoirs of traditional ecological knowledge to adapt autonomously. These adaptations include adjusting cropping calendars, diversifying crops, making transition to resilient cash crops like kiwi and cardamom, and maintaining integrated agro-ecological systems like the Apatani wet-rice-cum-fish culture.

However, these autonomous efforts are frequently constrained by structural barriers, including geographic isolation, poor transport infrastructure, limited access to formal credit, lack of agricultural extension services, and a disconnect between top-down state policies and bottom-up indigenous practices.

Based on these findings, we propose the following policy interventions to foster long-term climate resilience in the Eastern Himalayas:

Mainstream Indigenous Knowledge into Climate Policy : Rather than attempting to replace traditional agricultural practices like jhum, developmental programs should focus on improving them. This could involve introducing leguminous fallow crops to accelerate soil-fertility recovery or promoting contour hedgerow systems (SALT - Sloping Agricultural Land Technology) to minimize erosion. Traditional tribal institutions, such as the Kebang and Bulyang, should be formally integrated into climate planning and resource-management programs.

Implement Spring-Rejuvenation Programs: Given the critical reliance of mountain communities on natural springs, the state government should scale up decentralized springshed management initiatives. Utilizing hydrogeological mapping to identify recharge zones, local youth can be trained as "barefoot hydrologists" (Para-hydrologists) to monitor spring health and lead community-driven conservation efforts.

Build Post-Harvest Infrastructure and Market Connections: To ensure that agricultural adaptation translates into financial security, the state must invest in rural infrastructure. This includes developing landslide-resilient roads, establishing solar-powered cold-storage facilities at local trade centers, and supporting the formation of Farmer Producer Organizations (FPOs) to help smallholders negotiate fairer prices for value-added organic crops.

Develop Decentralized Weather Advisory Systems: Given the high degree of microclimatic variation in mountain terrains, regional weather forecasts are often of limited use to rural farmers. Establishing automatic weather stations at the block level, combined with transmitting localized weather-crop advisories in local dialects via mobile applications, would provide farmers with actionable information to manage climate risks.

By integrating the ecological wisdom of indigenous communities with modern scientific discoveries and supportive state policies, the vulnerable communities of the Eastern Himalayas can build robust socio-ecological resilience, securing both their livelihoods and this fragile mountain environment for future generations.

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