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Reframing mountain agri-food systems and ecosystem services through a landscape approach

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Mountain agri-food systems are embedded in landscapes where farms, forests, rangelands, water resources, biodiversity, and communities function as interconnected social-ecological systems. Agricultural productivity and food security therefore depend not only on farm management but also on ecosystem services generated across the wider landscape. These include water regulation, soil fertility and nutrient cycling, pollination, erosion control, climate regulation, biomass production, and maintenance of agrobiodiversity. However, land-use transitions, biodiversity loss, water stress, socio-economic change, and climate change impacts are altering these ecological linkages. This article examines how a landscape approach can strengthen mountain agri-food system resilience, moving from global lessons to the Indian Himalayan Region. It argues for shifting from predominantly farm-centric interventions towards management that recognises ecological flows, landscape multifunctionality, and community stewardship. Diversified farming, agroforestry, watershed and spring-shed restoration, agrobiodiversity conservation, crop-livestock integration, habitat connectivity, and incentives for ecosystem stewardship provide practical pathways for aligning food and livelihood security with biodiversity conservation and climate resilience.

Keywords: Diversified farming, Indian Himalayan region, Landscape development, Resilience, Watershed

MOUNTAIN agriculture operates within exceptionally heterogeneous landscapes. Changes in elevation, slope, climate, soils, and vegetation create mosaics of croplands, forests, rangelands, freshwater systems, and settlements within relatively short distances. Consequently, a mountain farm's functioning depends on ecological processes that extend well beyond its physical boundary. Forests and grasslands influence water and biomass flows, natural and semi-natural habitats support biodiversity, livestock connect grazing lands with croplands through nutrient transfers, and local institutions govern access to many of these resources. Across the Hindu Kush Himalaya (HKH), biodiversity and ecosystem services are consequently closely linked with livelihoods and human well-being. This interdependence has important implications for food-system resilience. Mountain households frequently combine crops, livestock, forests, horticulture, and common-property resources rather than depending on a single production activity. Agricultural biodiversity further spreads risks across crops and varieties with different ecological characteristics, while contributing to food and nutritional security. Degradation of one landscape component can therefore propagate through the wider system: deteriorating watersheds can affect agricultural water, loss of vegetation can accelerate erosion, and simplified habitats can weaken beneficial ecological interactions. The appropriate unit for understanding mountain agri-food systems is therefore not simply the farm, but the landscape in which the farm is embedded.

Ecosystem services: The ecological infrastructure of mountain food systems

Agricultural performance is commonly measured through crop yields, livestock products, and farm income, yet these outputs depend on ecosystem processes operating across the wider landscape. Water regulation, soil formation, nutrient cycling, erosion control, pollination, biological regulation, carbon storage, and habitat provision form the ecological infrastructure underpinning mountain agri-food systems. Water security, for example, depends on soils, forests, vegetation, wetlands, and recharge zones that

regulate infiltration, runoff, water quality, and seasonal flows, linking upper reaches with farms and settlements through springs and streams. Similarly, vegetation, soil organisms, crop residues, and livestock manure maintain soil organic matter, nutrient cycling, moisture retention, and erosion control functions, particularly critical on steep Himalayan slopes. Agroforestry strengthens these processes while providing food, fodder, fuelwood, and other products. Biodiversity provides additional services through pollination, natural pest regulation, etc. Diverse crops and locally adapted varieties contribute to food and nutritional security while providing options for adaptation to environmental change. Forests, rangelands, and home gardens also provide provisioning and cultural services, while traditional knowledge supports crop selection, resource management, and adaptation. Ecosystem services should therefore not be viewed merely as environmental co-benefits; they are productive assets fundamental to the functioning and resilience of mountain agri-food systems.

From farm to landscape scaling

A landscape approach changes both the spatial scale and the logic of agri-food management. Instead of optimising individual fields independently, it considers how multiple land uses interact and how ecological flows connect them. Landscape approaches to sustainable land management emphasise such multifunctionality and the need to reconcile production, conservation, and livelihood objectives across land-use mosaics. If one considers four common mountain interactions: forest–spring–irrigation, natural habitat–pollinator–orchard, rangeland–livestock–manure–cropland, and tree cover–erosion control–soil productivity, none can be managed effectively within a single field. Each involves ecological processes moving between landscape components and, frequently, across ownership or administrative boundaries. A landscape perspective also exposes trade-offs. Commercial crop expansion may increase household income while increasing water demand or reducing crop diversity. Conversion of semi-natural habitats may expand cultivated area but diminish pollinator habitat and erosion regulation. Conversely, conservation measures that restrict access to forests or commons without considering livelihood dependence can transfer environmental costs to mountain communities. Landscape management therefore seeks negotiated multifunctionality, rather than maximising one service or land use at the expense of others. For mountain agri-food systems, the central question consequently shifts from how individual farms can become more productive to how landscapes can sustain food production, ecosystem functions, and livelihoods under environmental and socio-economic change.

From global mountain experience to the Himalaya

Experience across mountain and upland regions points to three broad principles.

- Diversity provides ecological and livelihood insurance. Diversified crops, agroforestry, mixed crop-livestock systems, and multiple income sources reduce dependence on a single ecological or market pathway.
- Connectivity among cultivated and natural habitats helps sustain movements of water, organisms, nutrients, and biomass.
- Many ecosystem services are collective goods; their maintenance requires institutions capable of coordinating management beyond individual holdings.

These principles are particularly relevant to the Himalaya because environmental gradients, small and fragmented holdings, forest dependence, and common-property resources create strong ecological interdependencies. The HKH experience shows that maintaining agrobiodiversity requires integrated approaches that link conservation with food security, economic incentives, and landscape management, rather than treating genetic resources separately from agricultural development. The landscape approach therefore provides a useful bridge between global sustainability principles and the distinctive ecological and social realities of the Himalayan region.

The Indian Himalayan agri-food landscape

The Indian Himalayan Region (IHR) encompasses



Terrace farming on mountain slopes for efficient land use



Protected cultivation using greenhouse structures for improved crop production

diverse agricultural environments, from cold-arid and temperate systems in the west to humid subtropical landscapes in the east. Despite this diversity, farming is characterised by close interactions among crops, livestock, forests, water resources, and communities. Traditional systems recycle biomass and nutrients: forests and common lands provide fodder, crop residues feed livestock, manure sustains soil fertility, and springs and streams connect drainage systems with farms and settlements. Agroforestry reinforces these linkages by combining food and livelihood products with soil protection, nutrient cycling, carbon storage, and habitat provision. Agrobiodiversity is another important asset. Traditional cereals, millets, pulses, vegetables, fruits, and locally adapted varieties support dietary diversity and provide nutritional security and options for adaptation to environmental change. Their continued value depends on maintaining cultivation, consumption, and market demand alongside seed conservation. Traditional knowledge related to mixed cropping, seed selection, livestock and resource management can further complement scientific and technological innovations. Community institutions governing forests, water, and grazing resources are equally important. Thus, IHR agri-food resilience ultimately depends on sustaining relationships among farms, forests, water, livestock, biodiversity, knowledge, and institutions.

Eroding the ecosystem service base

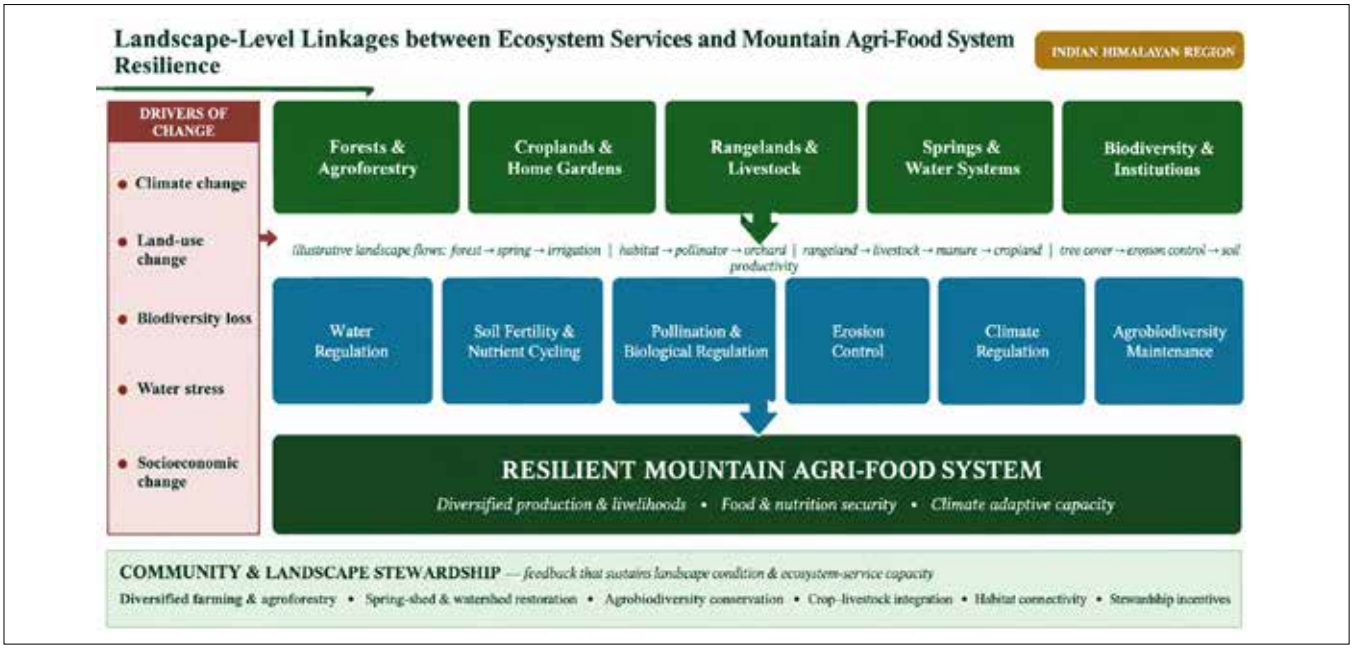
The ecological connections supporting Himalayan food systems are increasingly exposed to multiple pressures. Climate change impacts are altering temperature and precipitation regimes, influencing crop suitability, water availability, pests and diseases, and the distribution and functioning of biodiversity. These effects interact with land-use change and socio-economic transformation rather than occurring independently. Agricultural commercialisation presents both opportunities and trade-offs. High-value horticulture and specialised crops can raise farm incomes, but excessive specialisation may reduce agrobiodiversity or increase dependence on irrigation, external inputs, and volatile markets.

For example, in large-cardamom systems of the eastern Himalaya, climate variability, pest incidence and anthropogenic pressures have been associated with declining productivity, illustrating the vulnerability of economically important mountain production systems. Labour availability, migration, changing aspirations, and transitions in traditional land-use practices can further alter relationships among farming, livestock, and forests. Changes in shifting cultivation in the Indian Himalaya, for example, have implications beyond crop production, affecting ecosystem services, cultural relationships, and human well-being. The concern is therefore not agricultural change itself. Mountain farming must evolve. The critical question is whether transformation maintains or erodes the ecosystem-service base needed for future production and adaptation.

Reframing resilience at landscape scale

Strengthening IHR agri-food systems requires interventions that boost productivity while maintaining the ecological functions that support it. Because the region is heterogeneous, no single model is appropriate. Landscape strategies must be adapted to local ecological and socio-economic conditions.

- First, diversified farming and agroforestry can reconnect production with ecological functions. Integrating trees, crops, livestock, home gardens, and semi-natural habitats can generate food and market products while supporting soil functions, carbon storage, and biodiversity. Existing Himalayan agroforestry systems provide a strong foundation for such context-specific diversification.
- Second, water management should connect farms with drainage systems. Irrigation efficiency needs to be complemented by spring-shed and watershed restoration, protection of recharge areas, soil and water conservation, and appropriate vegetation management. This reframes water from an on-farm input to a landscape service.
- Third, agrobiodiversity conservation must generate livelihood value. Community seed systems, local processing, procurement, culinary promotion, geographical identity, and premium markets can



Landscape-level linkages between ecosystem services and mountain agri-food system resilience (Generated using Claude Sonnet 5)

help keep traditional crops in production. This is important because conservation disconnected from consumption and markets may not provide sufficient incentives for farmers to maintain diversity.

- Fourth, ecological connectivity should become an agricultural objective. Field margins, agroforestry patches, forests and semi-natural habitats can support pollinators and other beneficial organisms while linking otherwise fragmented habitats. Landscape restoration should therefore focus not simply on increasing vegetation cover but on restoring ecological functions and flows.
- Finally, community stewardship needs institutional and economic support. Communities maintaining forests, watersheds, rangelands, and agrobiodiversity generate benefits that extend beyond individual households. Incentives for ecosystem stewardship, collective governance, value addition to sustainable mountain products, and locally appropriate nature-based enterprises can help align conservation with livelihoods.

Recommendations and way forward

Reframing agri-food systems in the IHR requires planning beyond individual farms to landscape and watershed scales, integrating croplands, forests, rangelands, water and biodiversity. Ecosystem services such as water regulation, soil conservation, pollination, nutrient cycling, and agrobiodiversity should be recognised as ecological infrastructure supporting agriculture. Priority should be given to diversified farming, agroforestry, crop-livestock integration, watershed and spring-shed restoration, and habitat conservation. Traditional crops should be sustained through cultivation, value addition, and market opportunities, while farmers and communities should be incentivised for ecosystem stewardship. Integrating traditional knowledge with science, climate information and coordinated institutional planning can align viable livelihoods with ecological conservation and strengthen the long-term resilience of Himalayan agri-food systems.

SUMMARY

Mountain agri-food systems are inseparable from the landscapes in which they occur. In the IHR, farms depend on forests, rangelands, water systems, biodiversity, and community institutions for ecosystem services, including water regulation, soil fertility, nutrient cycling, pollination, erosion control, biomass, and genetic resources. These relationships mean that interventions confined to individual farms may overlook ecological processes essential to long-term productivity. A landscape approach reframes farms as components of interconnected social-ecological systems. It emphasises multifunctionality, ecological connectivity, and managing trade-offs among food production, conservation, and livelihoods. This is important as climate change, agricultural specialisation, land use transitions, and socio-economic change reshape Himalayan food systems. Resilience can be strengthened through diversified farming, agroforestry, watershed and spring-shed restoration, integrated crop-livestock systems, conservation and use of agrobiodiversity, habitat maintenance, and stronger community stewardship. Economic incentives, markets for diverse mountain products, and coordinated institutions are needed to make ecological stewardship compatible with viable livelihoods. Ultimately, resilient mountain agri-food systems require moving beyond farm-centric productivity toward managing the ecological connections linking food, landscapes, and people.

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