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ORIGINAL ARTICLE

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Thematic Synthesis of Indigenous Technical Knowledge Relevant To Hill And Mountain Ecosystems: The Shivaliks of North India As A Representative Case

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ABSTRACT

Indigenous technical knowledge (ITK) comprises time-tested practices refined by farmers through continuous experimentation and innovation. Despite being eco-friendly, cost-effective, and readily accessible, ITK remains underutilized in modern conservation programs. This paper presents a thematic synthesis of ITK practices in the Shivalik region of North India, based on 30 years of field experience across 4.2 million hectares in five northern states. Data were compiled through interactions with farmers and village elders, group discussions, field observations, case studies, and validation by extension personnel. The study documents ITK-based practices for land development (field bunding, terracing, fertility maintenance), water resource management (Kuhl irrigation systems, village ponds, spring harvesting), drainage management (diversion ditches, bio-engineering), and indigenous flora management (agroforestry, grasslands, bio-fencing). Additional practices include organic mulching, the use of farmyard manure, and wildlife management strategies. The synthesis demonstrates that farmers function as practical engineers, integrating local flora and materials through simple, effective methods refined by critical analysis of past experiences. Integration of ITK with modern scientific knowledge is essential for sustainable, climate-resilient agricultural development in hill and mountain ecosystems. The findings provide a framework for incorporating ITK into watershed development programs and soil conservation policies.

1 | INTRODUCTION

Indigenous Technical Knowledge (ITK) gained international recognition through the World Conservation Strategy deliberated by the International Union for Conservation of Natural Resources in 1980, followed by the Bruntland Commission and World Commission on Environment and Development in 1987. The concept gained further momentum at the United Nations Conference on Environment and Education. ITK is defined as knowledge built by communities through generations of living in close contact with nature, developed under conditions specific to particular geographical areas. These practices are eco-friendly, cost-effective, time-tested, and refined through constant experimentation and innovation. Despite growing awareness about natural resource degradation, indigenous soil and water conservation knowledge (ISWCK) has been largely ignored and poorly integrated into emerging conservation technologies (Farrington & Martin, 1988). Farmers have fought soil erosion using locally available materials and indigenous plant species, drawing upon traditional knowledge and skills (Chambers *et al*., 1989). The critical analysis of ethno-engineering techniques and their positive impacts has seldom been a priority in research and extension (Jodha, 1990). However, during the 1980s, the importance of indigenous knowledge, local skills, perceptions, and community priorities gained prominence when participatory approaches became essential for sustainable soil and water conservation (Chambers, 1983; McCracken *et al.*, 1988). Reij (1991) advocated for increased awareness of indigenous conservation techniques to improve understanding and effectiveness.

Recent studies have reinforced ITK's relevance. Barman et al. (2024) highlighted ITK's role in promoting ecological sustainability and resilience through practices like green manuring, vermicomposting, traditional irrigation, and climate-adapted crop varieties. Integration of these systems into modern agriculture enhances resource efficiency and rural community wellbeing. India's diverse traditions and tribal knowledge have sustained agriculture and rural livelihoods (Sindhu & Malik, 2020), with North Eastern India demonstrating comprehensive organic farming systems from seed germination to storage (Santosh & Chhetry, 2012). Kharbani and Sawian (2022) emphasized that biodiversity underpins sustainable agriculture in India, with crop and livestock diversification improving ecosystem stability and providing insurance against climate variability. Traditional polyculture systems in North-East India and the Western Ghats minimize crop losses from pests, diseases, and adverse weather. Barua and Mitra (2024) noted that indigenous knowledge significantly improves climate resilience through long-tested techniques. Austin et al. (2013) documented traditional hill irrigation methods and community-based management, noting the priority given to drinking water over irrigation. Arora and Hadda (2006) described ITK in Shivalik foothills including field bunding, terracing, filler strips, soil mulching, organic farming, and rainwater harvesting, recommending scientific refinement to realize full potential. Farrington and Martin (1988) and Chambers et al. (1989) emphasized that indigenous natural resource management techniques, though time-tested and cost-effective, have been insufficiently incorporated into project implementations.

The Integrated Watershed Development Project funded by the World Bank operated in the Shivalik foothills of five northern states from 1991. Project management decided to explore integration of indigenous soil and water conservation techniques into treatment menus for current and future projects (Grewal, 1996). As part of this and subsequent projects, the author documented and validated ITKs, continuously expanding and revising the compilation over several years. This paper synthesizes these findings, focusing on integration, lessons learned, and relevance of indigenous technical knowledge for hill and mountain ecosystems.

2 | MATERIALS AND METHODS

2.1 | Study Area

This synthesis is based on 30 years of field experience across the Shivaliks of five northern Indian states (Punjab, Haryana, Himachal Pradesh, Uttarakhand, and Jammu & Kashmir), covering 4.2 million hectares. The Shivalik region is a fragile hill ecosystem characterized by steep slopes, high runoff intensity, geological fragility, climate variability, and limited access to capital for hill farmers.

2.2 | Data Collection And Validation

The compilation draws from multiple sources:

- Interactions with practical farmers, village elders, and traditional knowledge holders
- Semi-structured interviews and targeted group discussions
- Field observations and case studies
- Targeted surveys and participatory rural appraisals
- Published literature in multiple languages

All observations were discussed and validated through consultations with frontline field functionaries from relevant departments across project areas in five states, as well as with other extension personnel. This multi-stage validation ensured the reliability of the documented indigenous practices.

2.3 | Analytical Framework

This study employed a deductive thematic analysis approach, a qualitative research method designed to identify themes and analyze responses to gain a deep understanding of recurring ideas and concepts. The methodology involved systematic collection of ITK practices from diverse sources; cross-verification with extension workers and technical experts; thematic categorization into seven major themes based on resource management focus; synthesis through integration with scientific literature and policy frameworks; and assessment of ecosystem services, implementation gaps, and integration opportunities. Kumar *et al.,* 2024 highlighted that evaluating ecosystem services has become an essential area of research indicating the vital benefits that natural environments provide to human societies. This manuscript presents a qualitative, experiential, and observational synthesis grounded in long-term field engagement and validated practices, rather than a conventional experimental or hypothesis-driven research study.

HIGHLIGHTS

- Comprehensive ITK documentation from 30-year synthesis across 4.2 million hectares in five Shivalik states, documenting validated indigenous practices for hill ecosystem management.
- Indigenous knowledge systematically organized into seven categories of land development, water resources, drainage management, flora management, farmyard manure use, wildlife control, and energy sources.
- Traditional practices deliver multiple ecosystem services, such as food security, water conservation, soil fertility, climate resilience, carbon sequestration, and biodiversity protection simultaneously.
- Government programs integrate ITK but overemphasize mechanical measures while neglecting biological solutions, requiring enhanced extension worker training and farmer participation.

3 | RESULTS AND DISCUSSION

The indigenous practices documented across the Shivalik region are organized into seven thematic categories linked to the unique biophysical and socio-economic constraints of hill and mountain regions (Table 1). These practices address steep slopes, high runoff intensity, fragile geological formations, climate variability, remoteness, and limited capital access.

3.1 | Land Development Practices

3.1.1 | Field Bunding

Every cultivated field is surrounded by earthen bunds of variable size serving multiple functions: rainwater conservation, soil erosion control, boundary establishment, and land division for different crops and sequences. Grass stubble and boulders removed from fields are dumped on bunds. Breaches or damage by rodents receive regular repair. Both large and small farmers maintain field bunds diligently to prevent soil erosion (Anonymous, 1999a).

3.1.2 | Land Laveling

Forming level fields from sloping land involves cutting earth from higher elevations and filling lower areas. Since topsoil is more fertile, farmers avoid disturbing it completely in a single operation. Fertility in leveled fields is restored through farmyard manure application. The leveling process uses a locally made wooden blade called 'Karaha,' pulled by bullocks with a sharp iron cutting edge (Photo 1). Two gradual leveling techniques are common:

1. **Plank method** : A plank gradually cuts soil from the top, depositing it as a thin sheet in depressed areas
2. **Barrier method** : Vegetation and stone barriers at field lower ends arrest runoff water carrying plowed soil down slopes after each rain. *Saccharum munja* (Kana) serves as an effective vegetative barrier (Verma, 1998).

TABLE 1 Summary of indegenous natural resource management practices

Category	**Key Practices**
Land Development	Field bunding, Land leveling, Terracing, Soil fertility maintenance
Water Resource Development	Kuhl irrigation system, Village ponds, Natural springs and wells
Drainage System Management	Diversion ditches, Field disposal of runoff, Bio-engineering for bank erosion control
Indigenous Flora Management	Agroforestry systems, Grassland management, Dry fodder preservation, Organic mulching, Bio-fencing, Bhabbar grass utilization, Fruits and vegetables
Farmyard Manure	Fertility recoupment, Energy provision, Seed germination, Moisture conservation, Soil health improvement
Wildlife Management	Crop selection, Scarecrows, Guard dogs, Bird deterrents, Noise-making devices

3.1.3 | Terracing

Gradual conversion of sloping land into leveled parcels represents an age-old practice throughout the region. Terracing reduces soil erosion, conserves rainwater, maintains soil fertility through continuous organic matter application, and facilitates plowing and cultural operations. Where stones and gravel are abundant, farmers remove them from fields and stack them on bunds to form stone walls, either at breach-prone lower elevations or continuously along fields.

Terrace quality improves continuously through stone and gravel removal, bund erosion protection, and manure addition. Key features of indigenous terracing include:

- Terrace width is inversely proportional to overland slope
- Contour alignment minimizing soil cut and fill
- Soil depth controlling terrace width
- Earthen bunds covered with local grasses, particularly *Cynodon dactylon* (Dub grass), with excellent soil binding capacity and nutritious fodder value
- Safe excess water disposal between terraces
- Table-top design for rice cultivation; sloped design for maize to facilitate water disposal (Verma, 1998)

PHOTO 1 Illustrates typical hill terraces supported by stone walls, with the bullock-drawn Karaha leveling technique shown

3.1.4 | Soil Fertility Maintenance

Rainfed farming systems in foothills operate at low productivity levels where nutrient depletion occurs primarily through soil erosion rather than crop uptake. In double-cropped areas with maize-wheat rotation, land is properly leveled and receives liberal farmyard manure (FYM) doses regularly. FYM application typically occurs in summer (June) before monsoon onset and maize sowing. Small landholdings with relatively high livestock populations ensure adequate FYM availability for most families. Indigenous soil fertility maintenance practices include:

- Leveling and terracing to prevent nutrient loss through runoff
- Regular liberal FYM application before kharif crop sowing
- Leguminous crop integration in rotations
- Contracting sheep and goat flocks from higher hills or local graziers to camp overnight in fields, adding manure through excreta and urine
- Weeds promoted by FYM in early maize growth plowed back at the knee-height stage (locally called 'HALODING'), incorporating them as green manure that decomposes rapidly due to moisture and high soil temperature
- Crop residue and stubble incorporation to recoup lost fertility (Patel, 1992a; Verma, 1998)

These land development practices ultimately enhance food security, farm income, and resource use efficiency.

3.2 | Water Resource Development

3.2.1 | Kuhl System Of Irrigation

Erstwhile foothill state rulers constructed numerous irrigation channels from both banks of perennial streams and rivers. These channels flow on mild gradients, providing drinking water for people and livestock and irrigation for adjacent lands. The town of Panchkula, near Chandigarh, exemplifies this system, named for five (Panch) Kuhls drawn from the Ghaggar River. A 'Barawandi' system determines irrigation turns and time allocation among beneficiaries. User groups jointly maintain and de-silt channels. At strategic locations, channels incorporate sudden drops where falling water energy operates local flour mills called 'GRAHTS.' This simple, cost-effective technique has sustained for extended periods and continues where electricity-powered mills are unavailable (Verma, 1998; Austin *et al*., 2013).

3.2.2 | Village Ponds

Almost every Shivalik village contains one or two traditional ponds dug primarily for livestock rainwater storage. Village size correlates with pond size, with both decreasing toward higher elevations. Ponds are typically located near villages to impound village runoff as well. Site selection favors relatively heavy, impervious soils. Ponds are commonly associated with Bargad (banyan), Pipal (sacred fig), other shade trees, small temples, and pucca meeting platforms around large trees. Some ponds are located away from villages near common grazing grounds. Pond capacity receives regular maintenance because the heavy pond soil serves for plastering mud houses. Pond soil rich in silt, clay, and manure also improves field soil fertility and moisture retention. Ponds facilitate groundwater recharge, microclimate improvement near habitats, and wildlife water provision. This community asset has survived centuries, remaining synchronized with rural settings and traditions (Singh and Khan, 1999).

3.2.3 | Natural Springs and Wells

Drinking water availability has always challenged the foothill ecosystem. Natural springs commonly found in hills are shaped with dressed stones to form clean water pools. Many springs are covered to prevent surface water contamination. Women bear the responsibility of water collection, carrying pitchers and brass containers (Gagars) on their heads between springs and scattered settlements. Subsurface flow in perennial drainage lines is tapped through strategically located wells that remain viable even during summer, though water levels decline seasonally. Wells traditionally use dressed stones laid in lime mortar, with tops approximately one meter above ground level. Pulley numbers (one to four) vary with well size. One well side is plastered for washing clothes and bathing. Surplus water flows through channels to mangers for livestock watering. These water resource development practices enhance water security, drought-proofing, and economic development (Kolarkar and Singh, 1990).

3.3 | Drainage System Management

3.3.1 | Diversion Ditches

Throughout the Shivalik region, hilltops and slopes support forests while valleys accommodate agriculture. Excess forest and valley runoff flows through defined drainage ways. Runoff from hill slope portions often spreads onto adjoining farmlands before reaching defined channels —typically manageable flows from one to two hectares of forest. Safe disposal of such overland flow protects farmland from erosion through diversion ditches constructed along forest-farm boundaries. These ditches follow hill footlines, intercepting rainwater and conveying it on mild gradients to nearby natural drainage ways. Interceptor ditches are maintained as small grassed waterways (Patnaik *et al.,* 1987).

3.3.2 | Field Disposal of Runoff Water

Rainfall intensity typically exceeds soil infiltration rates, causing even small storms to produce runoff. Without safe disposal into drainage systems, excess runoff breaches bunds and forms field gullies. Maize cultivation during kharif season is common in foothills, and maize cannot tolerate even short-term waterlogging. Excess water disposal from maize fields is necessary. Moreover, agricultural lands in foothills are seldom leveled sufficiently to prevent crop waterlogging, requiring regular excess rainwater disposal.

Common farmer-employed water disposal systems include:

- **Stone/gravel outlets**: Large stones and gravels interfering with cultivation are used for crude water disposal structures
- **Vegetative outlets**: *Arundo donax* (Nara) and *Saccharum munja* (Kana) are hardy perennial plants with strong root systems. Local Dub grass (*Cynodon dactylon*) occupies spaces between Kana and Nara barriers, further filtering water and checking bed erosion. These plants resprout in spring, forming effective vegetative barriers.

The indigenous water disposal systems integrate local materials (stones) and flora through simple, inexpensive, effective techniques (Subudhi and Mishra, 2002).

3.3.3 | Bio-engineering for Bank Erosion Control

Excess runoff from sloping fields and adjoining forests continuously scours gully beds and erodes drainage channel banks. Farmers maintain thick vegetation lines comprising trees, bushes, and natural flora along torrent banks to prevent bank erosion. In upper Shivaliks, Dhaman (*Grewia optiva*), Bamboo, and Banana are planted at curvatures and along moist torrent banks. In lower Shivaliks, *Ipomoea carnea*, *Arundo donax*, *Vitex negundo*, *Saccharum munja*, and *Agave americana* line banks. Among tree species, Jamun and Jamoa (*Syzygium* spp.) are preferred along relatively wet torrent beds, while Shisham (*Dalbergia sissoo*) is ideal for sandy torrent beds. *Arundo donax* is highly suitable for protecting against bank erosion. Some drainage ways through farmlands are so thickly planted with *A. donax* on both banks that bank erosion danger is eliminated. *Ipomoea carnea* is extensively planted for drainage way protection. Its easy propagation from sticks, establishment, quick growth, and suitability for bending along flow have made it popular. Farmers often embed dry *Ziziphus nummularia* branches in newly planted barriers/hedges to reduce water velocity, causing debris deposition. *Vitex negundo* is commonly planted along drainage ways and propagated vegetatively. Like willow, it establishes in moist gully beds with drooping branches that retard flow along banks. *Saccharum munja* and *Saccharum spontaneum* are also considered ideal for drainage way protection (Agrawal, 2006).

3.4 | Management of Indigenous Flora for Conservation and Production

3.4.1 | Agroforestry Systems

Resource-poor Shivalik farmers supplement low rainfed farm income by integrating trees with crops (agroforestry), primarily for income supplementation and economic security. Common agroforestry systems include:

Mango and Field Crops : Ambala and Hoshiarpur districts are renowned for desi mango orchards. Desi mangoes are preferred for hardiness and drought tolerance. During initial growth when tree canopies are undeveloped, field crops, oilseeds, and pulses (red gram, green gram, cluster bean) are raised with young mango trees.

Fodder trees and field crops: In areas near natural forests, green fodder needs are partially met by cutting branches from forest trees including Biul (*Grewia optiva*), Dhak (*Butea monosperma*), Khirak (*Anogeissus latifolia*), and Malta (*Ziziphus nummularia*). Tree lopping reduces shade to companion crops during winter. Nutrient-rich tree leaves, when mixed with inferior roughages, improve overall forage quality.

Acacia and forage crops: Acacia species tolerate drought, thriving on impoverished, degraded, and marginal lands. *Acacia catechu* (Khair) commonly grows on field bunds of arable and non-arable foothill lands. Forage crops (sorghum, pearl millet, cluster beans, oilseeds, pulses) are raised with these multipurpose trees.

These agroforestry systems provide forage security, soil and water conservation, and climate change adaptation (Gupta & Rajput, 2001).

3.4.2 | Grassland Management

Traditionally, the most unproductive land was allocated to pastures. Inadequate soil depth, inundation danger, flooding, and excessive gravels limit field crop scope but allow grass growth. Private pasture lands (Ghasnis) maintain better conditions due to controlled grazing from well-maintained fencing and cut-and-carry systems. Rainwater is conserved through small field bunds and stone walls along contours. Bushes are kept under constant control (Anonymous, 1999c).

3.4.3 | Preservation of Dry Fodder

Fodder scarcity in husbandry-dominated farming systems is common. Sorghum, pearl millet, and maize stalks are preserved for winter. Fodder supplies are augmented from forest areas during winter, with wheat straw as the main dependence source. In rice-growing areas, even rice straw is preserved for winter use, at least for non-milching or inferior cattle. Grasses are harvested in November-December, air-dried, bundled, and preserved for winter fodder. Farmers employ innovative techniques for safe forage storage (Koradiya and Koradiya, 1994).

3.4.4 | Organic Mulching

Farm-produced organic materials meet multiple pressing demands: fodder, fuel, and thatched roofing. Considerable effort is involved in arranging and spreading organic mulches from outside farms. Organic mulches are used in vegetable crop nurseries during winter to raise night temperatures and provide frost protection. Newly planted fruit plants are protected from frost by covering with locally available organic materials like *Saccharum munja*. Ginger and Colocasia receive organic mulching for weed control, soil moisture conservation, and easy tuber uprooting. Farmyard manure along with crop residues and animal floor sweepings serve as mulch in ginger crops (Barman *et al.*, 2024).

3.4.5 | Bio-fencing

Wildlife and stray cattle menace is severe across most

Shivaliks, compelling farmers to maintain thorny bush fences, brushwood, or live hedges along field boundaries for crop protection. In Jammu region, 'Bakarwal' traditional graziers descend from higher hills to Shivaliks with goat and sheep herds during winter due to mountain snowfall. Since entire flocks depend on grazing, they damage crops if unattended and unfenced. Local farmers traditionally grow numerous Ber (*Ziziphus* spp.) plants in and along field boundaries. Ber plant branches are heavily pruned each summer. Pruned branches provide nutritious leaf fodder for farmers' own goats and sheep while serving as effective, durable fencing. This practice has sustained because an excellent tree species has been selected to exploit its silvicultural potential for pressing local fence and fodder needs (Anonymous, 1999-2000; Acharya *et al*., 2001).

3.4.6 | Multiple Uses of Bhabbar Grass

Bhabbar grass (*Eulaliopsis binata*) is a common perennial with good soil binding capacity, used as fodder when fresh shoots emerge in April-May, as raw material for paper pulp, and extensively for rope making with foot-operated machines. This commercially valuable grass provides lean-time employment in cutting, transporting, drying, and rope making. Cots are woven with Bhabbar grass rope (Mittal *et al.*, 1988).

3.4.7 | Fruits and Vegetables

In hills, certain areas are famous for special indigenous products: spices, pulses, vegetables, aromatic rice, kulthi, ginger, turmeric, and garlic, traditionally grown and marketed. Some fruit trees grow around homesteads for pickles, chutneys, and raw consumption. Due to market distance and difficult terrain, each family tends toward self-sufficiency. Vegetables like cucurbits, gourds, and pumpkins creep over house verandas and wood stacks. Beetle attacks are controlled by spreading ash on plant leaves. Consuming mango, ber, mulberry, banana, sugarcane, maize cobs, and jaggery helps meet the nutritional requirements of the hill community. *Sarson Ka Saag* with *Makki Ki Roti* and 'Gur' is a common winter food (Kharbani & Sawian, 2022).

3.5 | Multiple Uses of Farmyard Manure

Farmyard manure (FYM) is an important animal husbandry byproduct that serves two critical rural family purposes: soil fertility replenishment and energy provision through cow dung cakes. Efforts are made to mix all unused organic residues and sweepings with FYM for nutrient recycling. Due to termite attack concerns, only well-rotted, decomposed FYM is applied. FYM is invariably added in hot summer before crop sowing and thoroughly mixed with soil. Seeds with hard coats are buried in FYM heaps. Decomposition-generated heat breaks hard coats, improving germination. Cow dung mixed with mud plasters walls and rooftops of kacha houses, particularly during festivals. Subsistence agriculture has sustained largely through manure application to field crops. Farmers consider that FYM, beyond nutrient supply, helps conserve moisture and maintains better field physical conditions for tillage and plant growth (Barman *et al*., 2024).

3.6 | Household Energy Sources

Energy conservation in rural areas includes spending hot summer hours under tree shade, sleeping on rooftops during summer, dining before dark, sleeping early, and using only one oil lamp per house. Common household energy sources include cow dung cakes, forest fuel wood, pruned branches and twigs from farm-raised trees, and farm residues. Cow dung cakes are the main energy source. Buffalo dung, greater in quantity than cow dung, is preferred for cake making. Cattle shed products are divided into two parts: sweepings of floor, bedding material parts, and spoiled fodder for manure; and dung regularly pushed back from behind animals during the day for cake making. Cow dung cakes are air-dried and preserved in specially designed conical mounds called 'Goharas,' made over wooden frames and plastered with cow dung from outside. Storage is necessary because cow dung cakes cannot be made during most of the rainy season. Cooking during rainy season relies mainly on stored cakes. Ash from cow dung cakes is used for cleaning utensils (Goel, 2025).

3.7 | Wildlife Management

Field crops raised near forest areas are attacked by wildlife, particularly at night. Wildlife types vary, but wild pig, porcupine, wild boar, jackal, and nilgai are most common in Shivaliks. Many farmers are compelled to leave fields uncultivated, particularly during winter (Rabi), due to inability to protect crops from wildlife. Practices followed to safeguard against wildlife damage include:

- Raising taramira (Rapeseed), a common winter oilseed crop with bitter taste unbrowsed by wildlife.
- Erecting standing man dummies with old cloth or plastic sheets on wooden sticks that flutter or sway with wind, feared by nilgai.
- Building small huts on raised wooden frames in fields for winter night watch and ward.
- Keeping dogs to ward off and indicate wildlife and stray cattle presence.
- Hanging dead crows from nearby trees to scare away birds.
- Beating tin cans (PIPA) to scare away birds/wildlife, particularly in orchards (Maurya, 1993; Verma, 1998; Lakshmana, 2000).

Wildlife hunting is prohibited by law. Beyond field crop damage, some wild animals damage newly planted forest seedlings, such as porcupine damage.

3.8 | Ecosystem Services Provided by Indigenous Practices

Indigenous natural resource management practices provide multiple tangible and intangible benefits and supporting services (Table 2).

TABLE 2 Ecosystem services provided by indigenous natural resource management practices

Service Category		Examples of Indigenous Practices
Tangible Benefits	Food	Land development, water resource development (spring water harvesting, Kuhl system management) leading to food security
	Forage	Grassland and pasture management, dry fodder preservation
	Fresh Water	Spring water harvesting, village ponds
	Medicinal Resources	Growing medicinal trees and plants (neem, jamun, harar, haldi, tulsi)
	Wood	Agroforestry systems
	Fiber	Bhabbar grass, poplar trees
Regulating Services	Flood and Drought Moderation	Terracing, village ponds, Kuhl systems
	Climate Regulation	Indigenous cultivation practices limit greenhouse gas emissions
	Carbon Sequestration	Maintenance of crops, trees, grass cover
	Air Purification	All vegetation absorbs carbon dioxide and releases oxygen
	Pollination Support	Raising mustard, coriander, onion seed crops attracts bees
	Erosion Control	Drainage line treatment and conservation practices
Supporting Services	Wildlife Habitat	Village ponds for wild animals, shade trees (bargad) for birds
	Climate Change Resilience	Drought-proofing through water resource development
	Soil Health Improvement	Residue incorporation, legume crop cultivation

3.9 | Integration of Indigenous Practices with Government Programs and Policies

The Government of India, in partnership with state governments, has launched several programs to support the food, water, and economic security of small farmers, drought-proof farm economies, and address climate change. The focus has been on promoting region-specific, cost-effective, farmer-friendly, and sustainable practices through participatory approaches. Sustainable hill farming necessitates a balance between economic growth and environmental protection (Balusamy *et al*., 2024). Integration of indigenous practices into natural resource management menus has received due importance. The Integrated Watershed Management Programme (IWMP) and its follow-up initiative, the Prime Minister Krishi Sinchai Yojana (PMKSY), aim to improve water-use efficiency, rejuvenate water bodies, and provide protective irrigation through rainwater harvesting, with a strong focus on self-help groups, cooperative societies, and farmer-producer organizations. The concept of *har khet ko pani* (water to every field) and *more crop per drop* has been popularized. Indigenous practices for resource conservation have been integrated into the program. In soil and water conservation projects, labor components have been converged with MGNREGA schemes to provide employment near rural homes. Self-help groups promoted under the IWMP and PMKSY-2 Watershed Component can undertake income-generating activities through the aggregation, processing, and marketing of traditionally grown products (spices, pulses, kulthi, ginger, turmeric, garlic, pickles, chutneys).

3.10 | Gaps and Limitation in Adoption of Indigenous Practices

Several gaps and limitations hinder full adoption of indigenous practices in natural resource management projects:

Overemphasis on mechanical measures: Most projects heavily favor mechanical measures while underemphasizing vegetative measures in soil erosion control. Integration of nara, bana, ipomoea, and bamboo imparts structural stability to mechanical measures. Quick-fix approaches without biological measure support lead to failures.

Inadequate catchment treatment: In earthen dam construction for rainwater harvesting, catchment area treatment using vegetative barriers in drainage lines is often ignored, leading to rapid reservoir siltation.

Soil health deterioration: While farmers traditionally maintained soil fertility through farmyard manure, legumes in rotation, and residue incorporation, chemical fertilizer use has introduced pollution and soil health deterioration problems.

Loss of traditional medicine: In remote foothill villages, normal human and livestock ailments were treated using medicinal plants from forests by vaids and hakeems. Obnoxious weed invasion and forest fires have decreased medicinal plant availability, with allopathic medicines taking over.

Guidelines for implementing various soil and water conservation projects are provided by the Ministry of Rural Development, Government of India under Watershed Development-2 and Pradhan Mantri Krishi Sinchai Yojana, strictly followed by state governments in foothill areas. State governments also provide guidelines for extension workers, particularly regarding MGNREGA component addition for rural poor. However, training needs, exposure visits, and practical demonstrations on multiple ITK benefits in natural resource management projects are essential. Scientific validation of different practices has been provided throughout this synthesis, offering evidence-based support for extension recommendations.

3.11 | Synthesis of Key Findings

This comprehensive documentation across the Shivalik region over 30 years reveals several critical insights:

Farmer as engineer and economist: Farmers function as practical engineers and down-to-earth economists. Indigenous resource management techniques demonstrate the appropriate integration of local flora and available materials through simple, inexpensive, and effective methods. Experience and judgment have been consolidated and refined through critical analysis of past successes and failures.

Economic constraints and innovation: Farmers have the capacity for hard work, but lack substantial cash investment resources. They logically select vegetation for erosion control that serves multiple needs: can be cut, pruned, or lopped as needed; provides fuel/fodder; has self-regenerating capacity; tolerates adverse site conditions; and has strong root systems.

Barriers to adoption: Farmer silence does not necessarily indicate inability to understand. Rather, they have been silenced by inabilities to spend and bear risk on new innovation adoption. Skepticism is born from fear and lack of insurance.

Integration imperative: Blending ITK with modern scientific knowledge is essential to support sustainable, climate-resilient, environmentally friendly agricultural development. The thematic synthesis presented highlights broader implications of ITK integration for hill and mountain watershed management, climate resilience, and policy design.

4 | CONCLUSIONS

This synthesis of indigenous technical knowledge from the Shivalik region of North India, based on 30 years of field experience across 4.2 million hectares in five states, demonstrates the richness and relevance of traditional practices for sustainable hill and mountain ecosystem management. The documentation reveals that ITK encompasses comprehensive approaches to land development, water resource management, drainage system control, indigenous flora utilization, organic resource recycling, and wildlife management.

Key conclusions include:

1. **Effectiveness of ITK:** Indigenous practices are time-tested, cost-effective, eco-friendly, and readily accessible to communities. They have sustained subsistence agriculture through integration of local knowledge, materials, and flora.

2. **Farmer innovation:** Farmers are practical engineers who have refined techniques through critical analysis of successes and failures, selecting vegetation and methods that serve multiple purposes while tolerating adverse conditions.

3. **Ecosystem services:** ITK-based practices provide multiple tangible benefits (food, forage, water, medicinal resources, wood, fiber) and intangible benefits (climate regulation, carbon sequestration, erosion control, wildlife habitat, climate resilience).

4. **Integration potential:** Current government programs (IWMP, PMKSY) have begun incorporating ITK into natural resource management, but significant gaps remain in implementation, particularly regarding vegetative measures and catchment treatment.

5. **Policy recommendations:**
- Expand training and exposure visits for extension workers on ITK benefits
- Balance mechanical and biological measures in project designs
- Integrate ITK with self-help group income generation activities
- Preserve and document traditional medicinal plant knowledge
- Strengthen participatory approaches in project planning and implementation

6. **Research priorities:**
- Quantitative validation of ITK effectiveness under varying biophysical conditions
- Economic analysis of ITK versus modern technology adoption
- Climate resilience assessment of traditional versus modern practices
- Documentation of ITK in other hill and mountain ecosystems for comparative analysis

This compilation requires continuous enlargement, improvement, and updating as more indigenous techniques come to stakeholder attention. The thematic synthesis presented provides a framework for integrating indigenous technical knowledge into watershed management, climate adaptation strategies, and policy design for hill and mountain ecosystems beyond the Shivaliks.

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CONFLICT OF INTEREST

The author declares that he has no known competing financial interest or personal relationship that could have appeared to influence the work reported in this paper.

DATA AVAILABILITY STATEMENT

All data supporting the findings of this study are available from the author upon reasonable request. Summary datasets generated or analyzed during the current study are included in the article.

AUTHOR'S CONTRIBUTION

The author has solely compiled the conceptual framework of the paper, review of literature, data related to material and method and results and discussions including conclusions and citation of references.

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