Anwesha Borthakur
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Addressing the Climate Crisis in the Indian Himalayas

Can Traditional Ecological Knowledge Help?

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Climate Crisis in the Indian Himalayas: An Introduction

Ashima Sharma and Renu Masiwal

Abstract The Indian Himalayan Region (IHR), known for the stunning beauty and rich biodiversity, is facing an unprecedented climate crisis. The fragile ecosystem, which supports millions of people, is under threat due to human activities such as deforestation, overgrazing, urbanization and industrialization, compounded by the prevailing threat of climate crisis. Unparalleled variations witnessed in weather patterns, and ecological imbalances threatens the ecosystem. The region is exceedingly vulnerable to the implications posed by climate change, such as warming temperatures, melting glaciers, and erratic weather patterns. Moreover, climate-induced extreme weather events have become progressively common, resulting in property damages and life losses. The rising temperatures have resulted in accelerated melting of glaciers, which poses a significant threat to the region's water resources, biodiversity, and local communities' livelihoods. The situation in the Indian Himalayas is alarming, and urgent action is required to mitigate the effects, including sustainable and community-based practices, natural resource management, and concerted efforts to reduce greenhouse gas emissions, addressing both local and regional level pollutants. Failure to address this crisis threatens the future of the region and its inhabitants. In this context, this chapter will introduce the various factors contributing to the climate crisis in the Indian Himalayas and explore potential solutions to address the issue.

Keywords Indian Himalayan Region (IHR) · Climate crisis · Fragile ecosystem · Climate change · Extreme weather events · Indian Himalayas

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1 The Great Indian Himalayas

1.1 Introduction

Himalayas are the youngest mountains on the planet, spread across a length of 3000 km that covers an area of around 3.44 million km^2 (Kumar et al., 2018a). These mountains not only support the ecology and the economy, but their diverse geographical features, such as the towering peaks, deep valleys, glaciers, rivers, and alpine meadows, advance diverse cultural and ecological richness. They are also referred to as the "water tower of Asia". This denotes the potential of the complex orography of these mountain ranges and their interaction with the monsoon system that helps generate enormous precipitation leading to richness of water resources in this region (Bandyopadhyay & Modak, 2022). The range encompasses some of the highest peaks in the world, such as the Nanda Devi, Kanchenjunga, as well as the legendary Mount Everest.

The Indian Himalayas are both majestic and breathtaking, and act as a northern natural boundary line to the country. The Indian Himalayan Region (IHR) comprises 0.537 million km^2 area of the country, which translates to nearly 16.2% of the total geographical area (Kumar et al., 2018a). The IHR spreads between 21° 57′–37° 5′N and 72° 40′–97° 25′E, and covers a span of 13 Indian states and/Union Territories as shown in Fig. 1 (Babu et al. 2021; Kumar et al., 2018a). The salient characteristics of these Himalayan States and/Union Territories is given in Table 1.

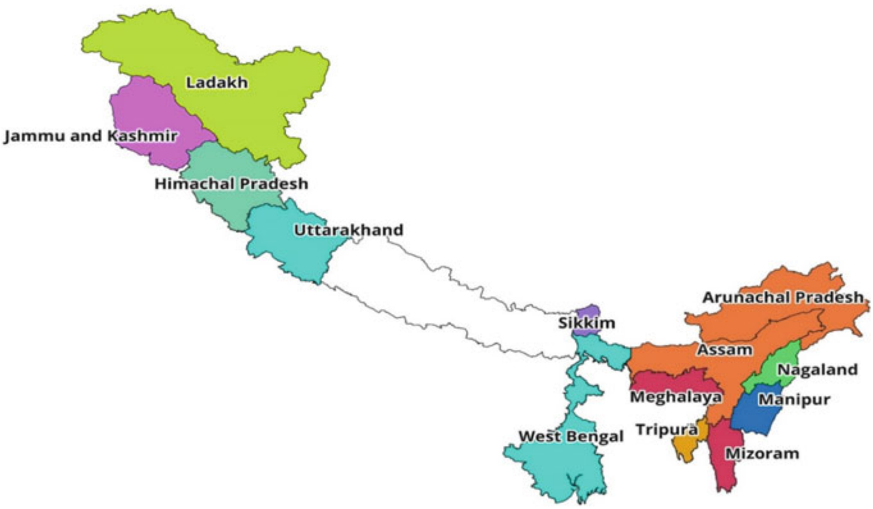

Fig. 1 The Indian Himalayan Region (IHR). *Source* Authors (Software used: QGIS)

Table 1 Salient Characteristics of the Indian Himalayan states

States	Geographical area (km^2)	Population (As of 31.12.2020)	Population growth % (2019–2011)	Forest cover 2021 Assessment (area in sq. km)	
				Total forest	% of geographical area
Arunachal Pradesh	83,743	15,70,458	13.49	66,431	79.33
Assam	78,438	3,56,07,039	14.10	28,312	36.09
Himachal Pradesh	55,673	74,51,955	8.56	15,443	27.73
Manipur	22,327	30,91,545	8.26	16,598	74.34
Meghalaya	22,429	33,66,710	13.48	17,046	76.00
Mizoram	21,081	12,39,244	12.95	17,820	84.53
Nagaland	16,579	22,49,695	13.71	12,251	73.90
Sikkim	7096	6,90,251	13.05	3341	47.08
Tripura	10,486	41,69,794	13.50	7722	73.64
Uttarakhand	53,483	1,12,50,858	11.55	24,305	45.44
Jammu & Kashmir	2,22,236	1,36,06,320	11.00	21,387	39.15
Ladakh		2,89,023	−0.51	2272	1.35

Sources Adapted and modified from: Kumar et al. (2018a); https://uidai.gov.in/images/state-wise-aadhaar-saturation.pdf; https://statisticstimes.com/demographics/india/indian-states-population.php; https://frienvis.nic.in/Database/Forest-Cover-in-India-2021_3550.aspx

1.2 *Climate and the Geology*

The Himalayas shows a great climatic variability, including the tropical humid climatic conditions to the cold Alpine tundra (Paudel et al., 2021). These ranges serve as a natural barrier for the summer monsoons, in addition to the winter westerlies (Chalise, 2001). There are evident disparities in rainfall with elevation, mainly due to the orographic nature of the monsoon rainfall (Eriksson et al., 2009). There is also a discernable prevalence of winter accumulation and summer ablation processes within the Himalayan glaciers, and this release of water due to melting eventually serves as a feedstock for numerous rivers downstream (Eriksson et al., 2009).

The Himalayas are broadly divided into: (1) The Greater Himalayas (or the Himadri), (2) the Lesser Himalayas (or the Himachal), and (3) the Outer Himalayas or the foothills (or the Shivalik hills) (Eriksson et al., 2009; Sorkhabi, 2010). Roy (2014) reports that the Himadri is made up of thick metamorphic rocks (schist and gneiss) and granites, the Himachal consists of metamorphosed sedimentary rocks (quartzite, marble, slate, etc.) and minor volcanic and granitic rocks while the Shivalik range is made up of sandstone and mudstone shed from the Himalayan mountains, and carried, deposited by the rivers.

The reason that the Himalayan mountains are considered geologically young is that they are still growing due to movement of tectonic plates and henceforth experiencing upliftment rates between 0.5–4 mm/year (Godard et al., 2014). This is also one of the reasons behind the vulnerability of this region to natural disasters.

1.3 Rivers, Forests and the Biodiversity

One of the defining features of the Indian Himalayas is its glacial landscape. Nearly 17% region of Indian Himalayas are under the permanent snow cover and glaciers (Kumar et al., 2018a, 2018b; Singh, 2006), including the Gangotri, Yamunotri, and Siachen glaciers etc. Several rivers also originate from these mountain ranges, including the mighty Ganges, the vast Yamuna, the massive Brahmaputra etc. Around 30–40% glaciers are under seasonal snow cover and feed these rivers (Kumar et al., 2018a, 2018b; Singh, 2006). Every year around 12,00,000 million m^3 water flow through Himalayan rivers (Kumar et al., 2018a, 2018b; Singh, 2006). These rivers not only provide water for irrigation and domestic use but also hold immense cultural and spiritual significance for millions of people who consider them sacred. These water bodies also support a great range of species diversity.

The one-third of India's undisturbed forests are located in the IHR. Around 41.5% land of IHR are under forest cover (Kumar et al., 2018a, 2018b; Singh, 2002). The IHR supports a number of diverse ecosystems including alpine meadows, temperate forests, and high-altitude wetlands. These serve to sustain a wide variety of endemic and endangered flora and fauna.

Based on ecological diversity, this region is divided into three ecological zones: (1) the subtropical foothill zone (altitude < 800 masl), (2) the temperate forest zone located between the foothill zone and timber line (altitude around 2800 masl) and, (3) the alpine and sub alpine zone, located above the timber line, rich in bushes, grasses and herbs (Negi et al., 2022). This region is one of the 36 global biodiversity hotspots, meaning areas that supports high degree of endemic species and are under high anthropogenic risks (Hamid et al., 2019).

Several studies have reported the abundant biodiversity that the IHR is enriched with. Butola et al., 2007 reports that the region is home to 21 forest types, 18,440 plant species; 816 tree species; 1748 species of medicinal plants; 675 species of wild edibles; 279 species of fodder; 155 species of sacred plants and 118 species of essential oil yielding medicinal plants. This region is also home to nearly 50% of the flowering plant population in India. Another interesting fact is that nearly 30% of these flowers are endemic to the region (Kumar et al., 2018a, 2018b; Negi et al., 2022). Table 2 reports the different categories of species and their numbers in the region.

Table 2 Species richness in Indian Himalayas. *Source* Adapted from the data of Kumar et al. (2018a)

Category	Number of species	Endemism (%)
Angiosperms	8000	40
Gymnosperms	44	16
Pteridophytes	1737	25
Lichens	1159	11
Fungi	6900	27

1.4 Ecosystem Services

The Indian Himalayas provides a range of goods and services (Fig. 2), which not only support the livelihood of the local communities but also contributes enormously to the nation's GDP (Bahuguna & Bisht, 2013; Badola et al., 2010; Negi et al., 2022;). A few ecosystem services associated with forests of the Indian Himalayas are climatic and hydrologic regulation, sequestration of carbon, formation of soil, decreasing soil erosion, improving water quality, filtering pollutants from water, recreational services etc. (Bahuguna & Bisht, 2013; Badola et al., 2010; Kumar et al., 2018a, 2018b; Negi et al., 2022).

The total financial value of these ecosystem services is too high and at present, we as consumers do not pay for these services. Many ecologists and economists have attempted to calculate this and the minimum estimated value is around $ 33 trillion/

Fig. 2 Ecosystem services provided by Indian Himalayan Region. *Source* "Authors"

year (Costanza et al., 1997). As per an article in Down to Earth by Mapahaptra (2019), the total estimated monetary value of the forest ecosystem services provided by the Indian Himalayan region is around Rs 94,300 crore/year, wherein the forests of the Uttarakhand alone provide services estimated at Rs 10,700 crore / year.

The IHR states are also recognized as India's water reservoir. The watershed services of Himachal Pradesh are assumed to be of nearly Rs 1.06 lakh crore per year (Mahapatra, 2019). Studies reported that the undisturbed forests of Sal, pine and oaks of Uttarakhand, sequester around 4–5 t C ha^{-1} yr^{-1} (Singh, 2007). Further estimations also suggest that the total forest biomass of Uttarakhand to be around 6.61 M t/year, which translates into a net worth of Rs. 3.82 billion (Singh, 2007). Another example is of a study where Badola et al. (2010) estimated the monetary value of forests of the Corbett National Park, observing carbon mitigation worth nearly $64 million/year, while the recreational value estimated at $167,000/year.

Besides timber, the forests also provide other plentiful forest products such as seeds, medicine, flowers, etc. These are further useful as edible products, used in cooking or lighting, providing employment to thousands of people, medicinal purposes, etc. (Negi et al., 2022; Pant, 2015; Singh, 2007).

1.5 Cultural and Spiritual Services

The Indian Himalayas are also a cultural and spiritual hub. It is one of the most commonly visited places as far as religious tourism is concerned, as it is the home to many religious shrines, sacred and naturally scenic places. Some famous destinations frequented by travelers across the world include the Badrinath, Kedarnath, Gangotri, Yamunotri, Hemkund Sahib, etc. in Uttarakhand, Manimahesh, Jwala Devi and Chintpurni in Himachal Pradesh, Vaishno Devi and Amarnath in Jammu and Kashmir, Khecheopalri and Gurudongmar lakes and the Buddhist monasteries in Sikkim, etc. (Kumar et al., 2018a, 2018b). The region is dotted with ancient temples, monasteries, and pilgrimage sites. The Himalayas have also inspired generations of poets, writers, and artists, who have depicted its grandeur and mystique in their works. Tourism here, is both in the form of pilgrimage trips to religious sites, or to the cooler hill stations such as Darjeeling, Nainital, Mussoorie, and Shimla, and the river sources located high up in the mountains (Kumar et al., 2018a, 2018b). The IHR receives both domestic and international tourists who play a vital role in its economy. Activities like trekking, mountaineering, river rafting, and wildlife exploration, contribute to the local economy and provide employment opportunities to the local communities. The tourism business is highly lucrative in the IHR, for the government as well as for the private investors, providing them with a source of income, business opportunity and work. According to Report of Working Group II Sustainable Tourism in the Indian Himalayan Region released by the NITI Aayog the tourism sector contributes around US$ 71.5 billion/year to the national GDP (Fig. 3).

However, the Indian Himalayas have been at the receiving end of the impacts of the climate crisis and human activities, that have posed significant challenges to

Fig. 3 The Chandak Hills, Pithoragarh, Uttarakhand. *Source* "Authors"

this fragile ecosystem, leading to habitat loss, species extinction, and disruptions in the delicate ecological balance (Kumar et al., 2018a, 2018b; Negi et al., 2022). The region is experiencing the consequences of global warming, leading to glacial retreat and altered precipitation patterns. The retreat of glaciers threatens the stability of the region's water supply, impacting agriculture, hydropower generation, and freshwater availability downstream. Changes in rainfall patterns have resulted in droughts, water scarcity in some areas, and devastating floods and landslides in others (Bandyopadhyay & Modak, 2022; Eriksson et al., 2009).

The Himalayas mean "home of snow" which given the climate crisis we are facing; one day might go obsolete (Bandyopadhyay & Modak, 2022; Eriksson et al., 2009; Masiwal et al., 2022a). The decrease in snow accumulation in the higher peaks would lead to acute water scarcity in near future. Studies report that owing to the changing climate, there might be formation of a large number of glacial lakes, with rapid increase in their water level due to the increased rate of snow and ice melting (Bandyopadhyay & Modak, 2022; Eriksson et al., 2009; Gantayat & Ramsankaran, 2023; Ives et al., 2010) As the Himalayan region fall under active seismic zone, a sudden jerk could lead to tsunami of water, mud and ice which could wash away all the infrastructure, field, livestock, and people (Kumar et al., 2018a, 2018b).

And if we talk about short term impact of climate impact, the melting of glaciers and unpredictable seasonal rainfall may lead to intense floods while the lack of rainfall can cause a drying spell over this region. Studies have predicted a fall in the water flow which would lead to catastrophic consequence as more than a billion people depend on its fresh water system for various purposes such as domestic, industrial, agricultural and power generation.

Henceforth, there is a need to restore balance between economic interests and environmental liabilities. This chapter will introduce the various factors contributing to the climate crisis in the Indian Himalayas and explore potential solutions to address the issue.

2 Climate Crisis: One of the Most Sensitive Issues of the Present World

The climate crisis is one of the most urgent and escalating global environmental challenge caused by human-induced climate change. It refers to the profound and wide-ranging impacts of the consequences of climate change (McCarthy, 2001). It poses an unprecedented threat to humanity and the planet as a whole. This crisis is driven by human activities, such as burning of fossil fuels, deforestation, unsustainable agricultural practices (McCarthy, 2001). The consequences are far-reaching, affecting ecosystems, water resources, food security, public health, and socio-economic stability (McCarthy, 2001).

It is evident in the form of rising global temperatures, that is a primary indicator of the climate crisis. Another indicator of climate crisis are the extreme weather events, that tend to occur more frequently and intensely as the climate warms. Heatwaves, droughts, hurricanes, cyclones, and heavy rainfall events are becoming more common, causing widespread damage, displacement of communities, and loss of life. These events also pose significant challenges to food production, water resources, and infrastructure. The warming climate is causing melting of glaciers, ice caps, etc., triggering a rise in the sea levels, and putting low-lying coastal areas and islands at risk of inundation and increased vulnerability to storm surges.

Rising temperatures, changing precipitation patterns, and habitat disruptions also pose significant challenges for species survival. Many ecosystems, including coral reefs, forests, and Arctic and alpine ecosystems, are experiencing rapid shifts, affecting the distribution and abundance of species. This further has far-reaching consequences for ecosystem services, food security, and human well-being, posing substantial risks to human health. Increased heatwaves contribute to heat-related illnesses and deaths, increased tendency of infectious and vector-borne diseases, etc. Air pollution, worsened by climate change, further exacerbates respiratory problems. Disruption of food systems and increased malnutrition are also concerns (Fig. 4).

Fig. 4 Enhanced Infrastructure development in the Himalayan regions. *Source* “Authors”

The climate crisis has wide-ranging socio-economic implications. Agricultural productivity is affected by changing weather patterns, leading to food insecurity and economic instability for farming communities. Disasters associated with extreme weather events result in significant economic losses and strain on resources for response and recovery. Displacement of communities happen due to sea-level rise and environmental degradation creates social and humanitarian challenges (McCarthy, 2001).

Urgent action is needed to restore ecosystems, and implement resilient adaptation measures. Addressing the climate crisis requires collective efforts from all stakeholders, to ensure a sustainable future.

3 Factors Contributing to the Climate Crisis Over the Indian Himalayan Region

The sensitive and fragile Himalayan ecosystem is facing a threat of unscientific development and consequential climate change. There are several factors contributing to the climate crisis, exacerbating the environmental challenges already present in the region. These factors include:

3.1 Deforestation

Agriculture, logging, and infrastructure development are the key reasons that contribute to deforestation, leading to climate crisis in the Indian Himalayas (Fig. 5). Between 1976 and 2014, Batar et al (2017) reported a decrease in forest cover area in the Rudraprayag district of Garhwal Himalaya due to an increase in agricultural land. Forests are of vital importance in capturing and storing carbon dioxide, functioning as carbon reservoirs. With deforestation happening, this carbon storage mechanism is disrupted, releasing previously stored carbon into the atmosphere and diminishing the region's capacity to counteract greenhouse gas emissions (Pant, 2015; Negi et al., 2022; Singh, 2007). According to the State of Forest Report, 2021, a loss of around 902 km^2 forest cover since 2019, has been observed, more evidently in the Himalayan states, wherein a cumulative forest area reduction in the 13 states, reducing down to 219,866 km^2 from 222,534 km^2.

3.2 Change in Land Use and Land Cover

The soil is a great sink of carbon; however, the rate of accumulation varies significantly from one ecosystem to another (Negi et al., 2022; Pant, 2015; Singh, 2007).

Fig. 5 City of Pithoragarh, Uttarakhand. *Source* "Authors"

Clearing of even a small patch of forest can cause a potential loss of soil carbon. Singh (2007), reports that forest degradation in the Lamgarha block of Uttarakhand's Almora District, could lead to an annual loss of ~ 3-ton carbon per hectare. Moreover, the alpine meadows possess a substantial soil carbon reservoir, owing to their significant root-to-shoot ratio, which enables greater carbon capture compared to grasslands. Due to climate change and enhanced warming, people are shifting towards higher altitude and this migration of people to these regions means more conversion into agricultural land, and consequent release of soil carbon into the atmosphere in the form of CO_2 (Pant, 2015; Negi et al., 2022; Singh, 2007).

3.3 Overexploitation for Timber and Non-timber Based Forest Products

Sal (*S. robusta*), teak (*Tectona grandis*) and deodar (*Cedrus deodara*) are considered as one of the best timber woods in India, costing around Rs. 13,000–51,000 per m^3 (Pant, 2015; Negi et al., 2022). Due to their high economical and commercial value, illegal logging is very common. Many times, forest mafias or timber smugglers start fires, to wipe away the evidence of tree felling and these practices pose a threat to the Indian Himalayan system.

Wild edible fruit plants have traditionally occupied an important position in the socio-cultural, spiritual and health care of rural and tribal lives, due to their nutritional efficiency, and also as a source of income (Joshi & Negi, 2011; Kapkoti et al., 2016).

Other non-timber-based forest products are also the reason behind the incessant logging and felling of trees. For instance, the Sal tree yields an oleoresin named Sal Dammar, used in incense and also in paints and varnishes, shoe polishes and as an astringent in diarrhoea and dysentery (Negi et al., 2022). Sal seeds are an important livelihood resource for poor people. A review of literature of a Central Himalayan state Himachal Pradesh (Masoodi & Sundriyal, 2020) screened 811 non-timber-based forest products (belonging to 495 genera) and found that maximum species were used for medicinal purpose (61.4%) followed by edibles (11.7%) and about 10% for fuel wood, fodder, essential oil, dyes, spices, tannins, resin, perfumes, religious purposes etc. High dependence on these products by the poor and marginal communities for domestic needs and excessive demand of these species creates an excessive pressure, resulting in an ecological disbalance.

3.4 Unsustainable Grazing

An increase in population and growing demand of milk-based products has resulted in an increase in the livestock population. A study published by Sati (2016) the main livestock reared in the Himalayan state Uttarakhand include cow, buffalo, oxen, hen, goat, sheep and lamb. Also, shifts in cultivation pattern from crops to vegetable has reduced the fodder production and to meet this demand of fodder, forests were exploited (Tiwari et al., 2020).

3.5 Agriculture

Agricultural practices (Fig. 6), including shifting cultivation, intensive farming, and livestock grazing, have a significant impact on the climate crisis in the Indian Himalayas. These agricultural practices result in soil erosion, loss of top soil and soil nutrients (Singh, 2007). Deforestation for agricultural expansion releases carbon stored in trees and contributes to greenhouse gas emissions. Furthermore, unsustainable agricultural practices, such as an incessant usage of chemical fertilizers, wasteful irrigation, can lead to soil degradation, reduction in carbon sequestration, and increased emissions of the greenhouse gases.

Apart from this, the Himalayas has smallholder farming and these farmers has experienced increasingly erratic rainfall, drought and floods, higher temperatures,

Fig. 6 Infrastructure development in Himalayas. *Source* "Authors"

and a rise in crop pests and diseases, leading to lower yields. In the central Himalayas, the drop in rainfall is thought to have exacerbated forest degradation, leading to more crops being devastated by wild animals, especially wild boars. As a result, income from and interest in farming have declined and many young people are moving to urban areas for work (Mukerjee et al., 2018).

3.6 Illegal Hunting

Over exploitation of natural resources and augmented developmental activities in this region has given rise to human-wildlife conflicts in the form of habitat loss or fragmentation or even degradation, triggered by activities like poaching, illegal trade, etc. These human activities have led to the continuous decrease in wildlife population and reduction in distribution range and also in some cases local extinction of species (Rana & Kumar, 2023). The endangered tiger (*Panthera tigris*) and vulnerable great one-horned rhinoceros (*Rhinoceros unicornis*) hunted for their body parts for their apparent usage in the traditional Chinese medicines, and the vulnerable snow leopard (*Panthera uncia*) and endangered red panda (*Ailurus fulgens*) that are sought for their beautiful pelts, while the Himalayan brown bear hunted for its gall bladder which is believed to be highly valuable for the traditional medicines whereas, bear skin claw and meat has commercial value. The poachers are quite active in this region and as per the forest department, they take advantage of forest fires to catch the animals. Sometimes they set intentional fires to bring out the wild animals from their hiding place. For instance, the state of Uttarakhand witnessed forest fires even during the month of winters under sub-zero temperature conditions (BSMS, 2023).

3.7 Mining

Himalayas are the store house of minerals. Essential minerals like talc, limestone, magnesite is found in Uttarakhand, whereas mining of limestone, silica boulder and barite is underway in Himachal Pradesh. There are important mineral deposits in Jammu and Kashmir, including that of limestone, gypsum, magnesite, sapphire or Paddar (DST, 2019). In February 2023, the Geological Survey of India discovered 5.9 million tonnes of lithium resources in Jammu & Kashmir. Mining not only damages the Himalayan ecosystem but also slow down its regeneration process.

3.8 Alien Species

These are the non-native species of a region. The Indian Himalayan region has abundance of nearly 190 alien species, falling under 112 genera and belonging to

Fig. 7 Bushes of Lantana and Parthenium recorded in a Himalayan city (Pithoragarh, Uttarakhand). *Source* Authors

47 families (Hussain et al., 2016). The most aggressive of them are *Parthenium hysterophorus, Lantana camara, Ageratina eupatoriaare* (Fig. 7). These species have encroached a large area of Indian Himalayas, and also, due to their invasive nature, replaced a number of native Himalayan species (Pathak et al., 2019). As per studies, these species have replaced the forest floor vegetation and led to reduction in growth of forest trees. The invasive plants hinder the regeneration of the tree saplings, and may lead to an enhanced frequency of fires.

The rise in temperature due to climate change in the Himalayan region is not only a threat to the local species but also help to thrive these kinds of invasive species, that can survive such changes, and eventually may cause significant species loss. For instance, *Lantana camara*, is native to the tropical region of Africa and America and was brought in India as an ornamental plant in 1807 and placed in Botanical Garden of Calcutta, but later spread across road side, railway track and even reached to Himalayas (Negi et al., 2019). *Lantana* is a noxious weed, that invades the pasture land as well as the forests. It is a threat to wildlife habitat leading to rise in wild life conflicts. In Himalayan foot hills, the *Lantana* bushland provide shelters to wild boars which not only damage the crops, but also harms the local communities. It has caused major ecological problem in Garhwal and Kumaon region of Uttarakhand (Negi et al., 2019). The natural or intentional fires favours the growth of Lantana, as after fire, it shows a more vigorous growth.

3.9 Infrastructure Development in the Eco-Sensitive Zone

Himalayas are geologically fragile, vulnerable to hazards and disasters (Sinha & Upadhyay, 1995). The unscientific development in this region linked with urbanization, growth of infrastructure, development of road networks, implementation of hydropower projects, etc. are the major anthropogenic threats that have intensified the vulnerability of the region (Fig. 8).

Fig. 8 Infrastructure development in the Indian Himalayan Region. *Source* Authors

The Himalayan states are quite eco-sensitive, and vulnerable to natural calamities especially the state of Uttarakhand and Himachal Pradesh. Majority of Himalayan states fall in zone IV and V of seismic zone classification, referring to the high-damage risk and very high-damage-risk areas, respectively.

Rapid infrastructure development are major factors contributing to the climate crisis in the Indian Himalayas (Grumbine & Pandit, 2013; Rao et al., 2016; Sabin et al., 2020). These activities often encompass deforestation, habitat destruction, and alteration of natural drainage patterns. Such changes exacerbate the impacts of climate change by intensifying water runoff, altering ecosystems, and increasing vulnerability to natural disasters. Activities like construction of multiple dams on a single river for optimum utilization of its energy potential has also been done. Grumbine and Pandit (2013) reported that the IH region will have the highest dam density in the world, with one dam in every 32 km of river channel. These dam constructions could lead to loss of direct submergence of forest land, and a consequent loss to the biodiversity. Studies hypothesize that the Joshimath disaster was caused by an ongoing hydroelectrical project. Bisht and Rautela (2010) reported that Joshimath is situated at an old landslide zone which is why, heavy construction is banned around it, however, the construction of hydroelectrical projects in these vulnerable regions cause havoc, including an increase in landslide incidents near the infrastructure development project sites (Fig. 8).

3.10 High Energy Demand

Due to the harsh topography and cold weather, majority of the households in the Indian Himalayan region depend upon traditional fuels such as wood, cow dung, agricultural residue for cooking and space heating (Fig. 9). The per household consumption of traditional fuel varies depending on size of the family, economical conditions, month of the year, and the region where household is located (Masiwal et al., 2021). Although, there has been a gradual shift towards cleaner fuels such as LPG, but with issues such as remote area accessibility, budget, etc., still a large population

Fig. 9 Traditional Chullah, wood is used as a dominant source of fuel. *Source* "Authors"

Fig. 10 Vehicular emissions and open-waste burning lead to air pollution over the Indian Himalayan Region. *Source* Authors

of rural households depend upon fuel wood for their daily requirements. These are mainly sourced from the forests, and on burning emits ample gaseous and particulate pollutants.

3.11 Tourism

The Indian Himalayas attract millions of tourists each year from across the world, who come to visit religious shrines, sacred places and beautiful scenic places, perform adventure activities, attain spiritual experiences, and to explore nature. Apart from this there are many thick forested and biodiversity rich regions which are used for commercial tourism. Unfortunately, these regions lack basic facilities of accommodation, transport, waste disposal and other amenities.

As per Niti Aayog report (2018), the tourism industry contributes significantly to the climate crisis through increased energy consumption, waste generation, and ecosystem degradation. Additionally, the infrastructure demands associated with tourism development has grave environmental impacts. The unregulated movement of tourists causes exploitation, disturbance and misuse of the fragile ecosystem of the Himalayas (Apollo et al., 2022). Inappropriate waste management in the ecologically sensitive areas of the IHR, adds to the growing impacts of climate change, that ultimately impacts human well-being (Aayog, 2018a, 2018b).

3.12 Air Pollution

The Indian Himalayas are affected by air pollution, primarily owing to industrial activities, vehicle emissions, open burning of biomass and waste, mining and infrastructure development activities (2022b; Masiwal et al., 2021) (Figs.10 and 11). Himalayas are prone to forest fires during the summer season, which earlier used to be either seasonal or natural processes, but in recent years have transformed into an intentionally induced event meant for illegal hunting and logging. This destroys the forest ecosystems and releases a large amount of air pollutants. Moreover, the air pollutants over the Himalayas have both local as well as regional and transboundary sources. Air pollutants, such as the black carbon and particulate matter, can settle on snow and ice surfaces, leading to accelerated melting. This exacerbates glacier retreat and contributes to the climate crisis in the region (Hassan et al., 2022; Saikawa et al., 2019; Sabin et al., 2020).

Fig. 11 Unsustainable waste management in Pithoragarh city, Uttarakhand. *Source* Authors

Fig. 12 Landslide prone route from Tanakpur to Pithoragarh, Uttarakhand. *Source* Authors

3.13 Lack of Solid Waste Management

A careless dumping of solid waste, including the municipal solid waste, e-waste, plastic waste etc., is happening due to anthropogenic activities, including tourism, urbanization, infrastructure development etc. in the IHR, (Aayog, 2018a, 2018b; Dame et al., 2019). The IHR receives around 100 million tourists yearly (Thakur et al., 2021), and this number is growing every year. Unmonitored activities and inconsiderate dumping resulted in unchecked solid waste generation Fig. 11 (Kumar et al., 2016). Estimates suggest an annual generation of around 8.3 million tonnes solid waste from the tourism activities like trekking and expedition, etc. (Thakur et al., 2021).

Key issues for waste management comprises of inconsistency in waste generation that normally varies with seasonal influx of tourists, which affects the solid waste collection, transportation and disposal processes, a harsh terrain, unregulated management, etc. (Kuniyal, 2005). The IHR generates around an annual solid waste of nearly 1.9 MT. Out of this, only 1.6 MT is collected, only 0.41 MT is processed and around 0.2 MT is dumped in the landfills (Aayog, 2018a, 2018b; CPCB, 2019). The untreated waste mostly ends up in water bodies and causes water pollution. Due to this inefficient collection, segregation and waste disposal system, locals prefer to burn their waste, which is a significant source of air pollutants such as dioxin, carbon monoxide, toluene, benzene, aerosols, oxides of nitrogen, etc. (Thakur et al., 2021).

3.14 Lack of Data

As per a report by the Intergovernmental Panel on Climate Change (IPCC), the entire Himalayan region, is described as a 'data deficient' area as far as climate monitoring is concerned (Solomon, 2007). It is evident that careful and regular monitoring is necessary to ascertain the changes occurring over time. Henceforth, long term weather, air and glacier monitoring is required across the Himalayan region (Tewari et al., 2017).

4 Consequences of the Climate Crisis in the Indian Himalayan Region

The Himalayas literally translate to mean a “home of snow”. However, this, might one day go obsolete, because the region is a sensitive hot spot to climate change. There are several consequences of the climate crisis in the Indian Himalayas. These are categorized into two broad categories, namely the environmental-ecological, and socio-economic impacts, which are discussed below:

4.1 Environmental-Ecological Impacts

4.1.1 Rising Temperature

Several studies have hinted that the mean temperature over Himalayas is rising rapidly, even faster than the global mean temperature. (Pepin et al., 2015). The western Himalayas has recorded a significant rise in temperature since 1975 (Sabin et al., 2020) and studied the alteration of the annual mean temperature over Hindu Kush Himalayas and Indian landmass, and observed that the Himalayan region is warmer compared to Indian landmass, but the warming rates were not same over the Himalayan ranges and alters with altitude (Liu et al., 2009; Ren et al., 2017). However, because of the extreme topography and complex reactions to the greenhouse effect, even high-resolution climatic models cannot give reliable projections of climate change in the Himalayas (Hasson et al., 2014; Sabin et al., 2020). As per the State of Forest Report, 2021 that Himalayan states and UTs like Ladakh, Jammu and Kashmir, Himachal Pradesh and Uttarakhand will record the maximum increase in temperature and also a possible decrease in rainfall (Mishra, 2022).

4.1.2 Glacier Retreat

The Indian Himalayas are home to numerous glaciers. There are around 9575 big or small glaciers in the IHR with an estimated ice cover of about 36,000 km^2 and overall ice volume of about 2000 km^3 (Singh et al., 2018). Most of the glaciers in the region are retreating at varying rates. It is estimated that since the 1960s, there has been 16% recession in the glaciers in IHR, which are experiencing rapid retreat due to global warming (DST, 2019).

Glacier retreat in the Himalayas results from precipitation decrease accompanied with an increase in temperature and studies suggest this glacier shrinkage will speed up if the climatic warming and drying continues (Ren et al., 2004). This also contributes to an increased water runoff, altered river systems, and the loss of freshwater storage. This has significant implications for water availability for millions of people, hydropower generation, and downstream communities that rely on these water sources (Hasnain, 2009). Excessive meltwaters, often in combination with liquid precipitation, may trigger flash floods or debris flows. It may also destabilise surrounding slopes and give rise to catastrophic landslides and sometimes floods (Eriksson et al., 2009; Kumar et al., 2018a, 2018b).

4.1.3 Changing Precipitation Patterns and Hydrological Patterns

Climate change is altering precipitation patterns in the Indian Himalayas, resulting in shifts in rainfall timing, intensity, and distribution. This has effects on agriculture, water availability, and ecosystem dynamics (Das & Meher, 2019; Saini et al., 2023; Tewari et al., 2017) and can lead to increased frequency and intensity of floods and droughts, causing extensive damage to infrastructure, agriculture, and human settlements (Eriksson et al., 2009).

4.1.4 Landslides and Avalanches

Increased extreme climatic/rainfall events, or more rainfall in areas which were otherwise dry, or an increased frequency of cloudbursts, contribute towards an increased occurrence of landslides in the Himalayan region (Dimri et al., 2017). Warmer temperatures destabilize slopes, leading to an increased risk of landslides and avalanches (Huggel et al., 2021). The frequency and severity of such events have already increased in recent years, endangering human lives and infrastructure (Chalise, 2001). These natural disasters pose significant challenges to transportation networks, communication systems, and mountain communities (Fig. 12).

Observations suggest that landslides are generally concentrated along the river valleys, mainly because of the high discharge in the rivers (Dikshit et al., 2020). This may also be correlated with the shift in rainfall pattern in IHR and the higher intensity of rainfall that has been noted particularly after 2010 (Kumar et al., 2018a, 2018b; Vardhan, 2019). There is now a higher occurrence of incidences of extreme

Fig. 13 Rāmgangā River, Village Masi, Uttarakhand. *Source* Authors

climatic events during recent past, like the one observed in 2013, causing havoc mainly in the Kedarnath Township, Mandakini valley and further downstream in the Alaknanda valley or in the year 2017, that witnessed high concentrated rainfall in many parts of the northwestern Himalayas causing numerous disastrous landslides in the Himalayan terrain (Eriksson et al., 2009).

4.1.5 Loss of Carbon

Deforestation leads to loss of soil carbon. This happening over the Himalayas is a distinct possibility, because of steep and immature slopes, which are subjected to heavy rainfall (Singh, 2007).

4.1.6 Biodiversity Loss

The Indian Himalayas are home to rich biodiversity, including many endemic species. The changing climate disrupts ecosystems, causing shifts in vegetation zones and altering habitats (Malhi et al., 2020). With increasing temperatures, numerous plant and animal species may encounter difficulties in adjusting or relocating to suitable habitats (Weiskopf et al., 2020). This could lead to the loss of habitats, decreased species populations, and heightened risks of extinction. In the regions of Uttarakhand and Himachal Pradesh, excess overburden and mining waste are disposed of in nearby agricultural or forested areas. This impedes prospect of any future agricultural and forestry activity there. Infrastructure projects such as dams tend to disrupt the natural flow patterns of the Himalayan rivers, causing detrimental impacts on their ecological functions and on the social, economic, cultural, and religious importance attributed to these waterways (Grumbine & Pandit, 2013; Rao et al., 2016; Sabin et al., 2020).

4.1.7 Human Wild-Life Conflicts

The frequency of human-wildlife conflicts rises as human population expands and land clearance augments (Sathyakumar et al., 2016). The clearing down of forest land into agricultural land and the exploitation of timber, fodder, and fuelwood pose significant threats to the biodiversity of the Indian Himalayan Region (IHR) (Singh, 2012). Other practices such as charcoal production in lower elevation areas, intensive grazing at higher elevations, demand for firewood, grazing domestic animals etc. put further strain on the forests, as well as on the local population, particularly women who often spend hours collecting firewood in the forest, increasing their chances of encountering wildlife conflicts. Likewise, forests can only support a limited number of grazers sustainably, as overgrazing frequently results in the consumption of saplings and the destruction of future forest regeneration.

4.2 Socio-economic Impacts

4.2.1 Water Security

Several Himalayan rivers and their tributaries feed the local and regional populace residing in the Himalayan region as well as downstream of this region (Fig. 13). Alterations in precipitation patterns, directly impact river runoff and have the potential to shift water availability away from meeting agricultural and dry season demands and toward the risk of monsoon-induced flash floods. Simultaneously, as the region's glaciers continue to melt, there is an elevated risk of encountering both short-term glacial lake outburst floods (GLOFs) and long-term water scarcity issues. GLOFs transpire when glacier meltwater accumulates in glacial lakes, breaching natural barriers and causing destructive floods downstream (Eriksson et al., 2009). All of this could worsen water scarcity concerns, impacting local communities, agriculture, and the generation of hydroelectric power.

At the same time, the degradation of vegetation cover and intensified land utilization can disrupt surface runoff, evapotranspiration, soil storage capacity, and infiltration processes, consequently perturbing the natural hydrological regime of the region (DST, 2019). In recent decades, urbanization and industrialization and the associated deforestation and landscape alterations have led to the deterioration of catchment areas, resulting in reduced seasonal flow and the drying up of rivers and springs (Ives et al., 2010).

4.2.2 Agriculture and Livelihoods

The Indian Himalayas are home to numerous agricultural communities that depend on the land for their livelihoods (Mukerjee et al., 2018). The IHR contributes to about 15–18% of agricultural production. However, owing to harsh climatic conditions and limited cultivable area overall yield is much less (1680.58 kg/ha) compared to the national average (2984 kg/ha) (DST, 2019). Overall health of soil in the region is on decline due to erosion and lack of management. Climate change in the Himalayan region poses new challenges to agriculture, animal husbandry and food security. The impacts, including altered precipitation patterns, increased temperature, and pests and diseases, can negatively affect crop productivity, livestock health, and overall agricultural systems, leading to reduced incomes, food insecurity, and migration from rural areas. This will eventually transform the future of indigenous people and their livelihoods more vulnerable and uncertain (Mukerjee et al., 2018).

4.2.3 Hazards

Infrastructure that has been built over the decades, including the hydropower plants, roads, bridges, and communication systems, is all the time more at risk due to climate change (Eriksson et al., 2009; Sinha & Upadhyay, 1995). Disastrous events like the earthquake of Sikkim (2011), Kedarnath tragedy and the aftermath (2013), Kashmir floods (2014), and snowballing incidents of cloudbursts are divulging examples of the area's active tectonics, intrinsic fragility and the likely risk to life and property possible. The impacts include both rapid hazards such as flash floods, or slow onset hazards such as melting of glaciers, drying of wetlands and springs, loss of biodiversity, etc. (Eriksson et al., 2009).

4.2.4 Permafrost

Ali et al., (2018) defines permafrost as the frozen ground that continues to remain at 0 °C or below for as a minimum of two successive years. Studies suggest that the Hindu Kush Himalaya has an extensive permafrost belt (Gruber et al., 2017). Allen et al., 2016 reports that in many regions, permafrost is warming due to global climate change, and the resulting thawing can have widespread impacts. These include destabilization of steep slopes, subsurface hydrology alterations, augmented sediment load in rivers, etc., all of which can disturb regional livelihoods, infrastructure and economies, and the hydropower sector (Yang et al., 2010).

4.2.5 Human Health

Impact of climate change on health can be direct (drought, heat waves, flash floods, etc.), indirect (economic disruptions, social conflicts, crop failure, associated malnutrition and hunger, spread of infectious diseases, etc.). Climate change is unfolding during a time when there are concurrent shifts in the global environment and human population dynamics, which have a subsequent potential, to interact and amplify the health effects (Thomas et al., 2014).

Case Study: Devastation of Himachal Pradesh: A Man-Made or a Natural Disaster?

The monsoon season of 2023 brought feelings of sorrow and despair among the inhabitants of the Himalayan region. Despite the susceptibility of Himalayan states to occurrences such as cloud bursts and landslides, this year witnessed an unprecedented level of havoc. Himachal Pradesh, a well-developed state within the Himalayas known for its sturdy mountains, advanced infrastructure, picturesque tea gardens, tourist attractions, mining activities, and more, experienced significant losses. Over 800 state roads, including major highways like Chandigarh-Shimla, Kiratpur-Manali, Pathankot-Mandi, and Dharamshala-Shimla, were lost. Tragedy struck with the loss of around 327 lives during the monsoon season (June–August 2023). Additionally, approximately 1762 houses were completely destroyed, while 8952 houses suffered partial damage.

The torrential rainfall and resulting landslides caused extensive devastation in various areas of Himachal Pradesh, including Summer Hill, Krishna Nagar, and Phagli. The region witnessed a staggering number of incidents, including over 113 landslides and 58 cloudbursts. These numbers could rise further if the rain continues unabated. Chief Minister Sukhwinder Singh Sukhu of Himachal Pradesh stated that the state incurred losses amounting to around Rs. 10,000 crores, primarily in terms of infrastructure (excluding potential losses to natural biodiversity). According to the Chief Minister, the state received an unusually high amount of rainfall compared to previous years, contributing significantly to the destruction. Climate experts have pointed out that the increased rainfall intensity, coupled with elevated temperatures, has led to landslides due to the loosening of strata in areas that have undergone cutting on the foothills downstream. Experts also contend that this disaster is primarily a result of human actions. The prominent causes identified include the expansion of four-lane roads, hydro-power projects, deforestation, cable car initiatives, and the construction of multi-storied buildings. The unregulated urbanization, especially driven by mass tourism, has led to activities such as deforestation, soil erosion, and slope destabilization beyond the environment's capacity to withstand. Himachal Pradesh, nestled amidst the Himalayan mountains, experiences the initial impact through forest clearing, leading to soil erosion. The construction of roads involves mountain excavation using heavy machinery and explosives, disturbing the mountain's equilibrium and contributing to sliding.

Experts also point out vertical cutting of mountains for road construction, often with inadequate retaining walls of just 5–10 feet, in Himachal. They highlight that several human-induced factors contribute to landslides in the region, including ecologically unsound constructions in the fragile Himalayas, diminishing forest cover, and structures obstructing water flow in streams. A report from the National Disaster Management Authority (NDMA) underscores poor urban planning in hilly areas and inadequate enforcement of existing regulations. Population pressures in specific hilly cities have also been identified as concerning. The Geological Survey of India in Himachal Pradesh has identified 17,120 zones prone to landslides, spanning districts like Sirmaur, Lahaul and Spiti, Mandi, Kinnaur, Kangra, Shimla, Solan, Bilaspur, Una, Chamba, Hamirpur, and others. Instances of land subsidence, similar to Joshimath in Uttarakhand, have emerged in various places within Himachal Pradesh.

Experts assert that this disaster is a consequence of policy decisions. Changes in land use for urbanization, inadequate planning, and similar factors have led to what can be described as a "policy induced disaster." Only a combination of technological intervention, effective governance, and sound policies can mitigate such devastating events in the future. Experts emphasize the need for tailored bylaws for different zones, taking into account the diverse topography of the state. In this regard, they propose that each panchayat should have distinct regulations to ensure responsible development and safeguard against such disasters.

5 Solutions to the Climate Crisis in the Indian Himalayan Region

The Indian Himalayas face significant challenges due to the climate crisis, and to address these challenges, several solutions can be considered:

1. **Mitigating greenhouse gas emissions**: Efforts to reduce emissions are crucial. India can adopt cleaner energy sources, such as solar, wind, and hydro power, and promote energy efficiency in industries, buildings, and transportation. The use of electric vehicles should be promoted whilst implementing stricter emission standards to reduce carbon emissions.
2. **Sustainable land and water management**: Efficient land use planning and watershed management practices is necessary. Implementing sustainable agricultural practices, by encouraging farmers to cultivate traditional varieties of crops to promote organic farming, agroforestry, and efficient irrigation techniques, can reduce land degradation, improve soil health, and conserve water resources, along with practices such as terracing, contour farming etc. to prevent soil erosion and enhance ground-water recharge.
3. **Climate-resilient infrastructure**: Developing and retrofitting infrastructure to be climate-resilient is essential, including energy efficient buildings. Infrastructure projects and their construction should incorporate the likely impacts of climate change, and be able to withstand them.
4. **Water resource management**: This comprises developing strategies to conserve water, such as rainwater harvesting and efficient irrigation systems. It is also essential to monitor and manage glacial melt. Programmes requiring a combination of interventions to decrease pollution, improve water-use efficiency, enhance flows during the dry periods, etc. are vital.
5. **Awareness of Local communities**: The local communities need to be prepared to cope the climate crisis to help them to build resilience. Strategies such as advising farmers about the crop diversification, best agricultural practices as per the altering climatic conditions, developing early warning systems, implementing standard operating procedures, knowledge of best practices, training in sustainable livelihood options, mock-drills etc. are required (Kumar et al., 2018a, 2018b).
6. **Green Energy**: Better alternatives to biomass burning and traditional fuels can be in the form of green energy sources such as solar, wind, biomass, hydro, and geothermal. This will help in mitigating environmental pollution and forest degradation.

7. **Biodiversity conservation**: Protecting the rich biodiversity of the Himalayas is crucial for ecosystem resilience. This can be done via establishing protected areas, promoting sustainable tourism practices, and regulating activities such as mining and logging that can help conserve fragile ecosystems.
8. **International cooperation**: Addressing the climate crisis in the Himalayas requires international collaboration. India can work with neighbouring countries and engage in regional initiatives to share knowledge, resources, and best practices.
9. **Sustainable tourism**: Creation of appropriate facilities and access to ecological resources, and multi-stakeholder partnerships to enable local communities to gain livelihoods, while leveraging financial, technical, and managerial capacities of investors, taking measures to regulate tourist inflows into mountain regions to ensure these remain within the carrying capacity of the mountain ecology, help drive responsible and sustainable tourism. Such measures help in curtailing the vehicular influx, traffic jams, and noise and air pollution in tourist areas.
10. **Sustainable waste management**: Door-to- Door garbage collection schemes, waste segregation at source, recycling of non-biodegradable waste, e-waste collection and recycling, promoting reuse and refurbishing of items discarded as waste, etc. are strategies that can cater to sustainable waste management in the Indian Himalayan region (Kumar et al., 2018a, 2018b).
11. **Powerful regulatory mechanism**: There is a dearth of regulatory mechanisms for infrastructure creation, management, and for controlling the tourist inflow in Himalayan regions (Kumar et al., 2018a, 2018b). This has resulted in excessive pressure on the sensitive ecosystems and cultural resources of these areas, far beyond their carrying capacities. It is henceforth necessary to develop and implement guidelines for the same, that should keep in view the livelihood interests and the long-term benefit of the local community.
12. **Community participation**: Creation of communicating networks and participatory research linkages between the public sector, NGOs and rural people is an effort to enhance successful implementation of environmental initiatives within the community, such as forest conservation, water conservation, etc. (Arce, 2019; Kumar et al., 2018a, 2018b; Poudyal et al., 2018; Singh, 2007).
13. **Strong monitoring system**: Environmental observation systems in Himalayan regions are very important for weather forecasts and warnings, mountain meteorological services, army operations, agriculture, tourism, power generation, water management, hydro-meteorological hazards preparedness, and risk reduction planning. The Government of India has initiated weather and glacier monitoring programmes such as the Himalayan Glaciology Programme (HGP) and Integrated Himalayan Meteorology Programme (IHMP), yet there is a need to establish more stations in this region (Kumar et al., 2018a, 2018b).
14. **Afforestation**: Forests help absorb atmospheric carbon, and comparatively are a cheaper and easier solution (Singh, 2007). It is always better however to avoid deforestation by conserving forests (Singh, 2007). Reforestation

programs should emphasize on planting indigenous tree species, and involve local communities for the implementation and management.

15. **Green Bonus**: Payments for Ecosystem Services refers to a range of agreements in which individuals or entities who benefit from environmental services, such as conservation of watersheds, forest preservation, capturing carbon, landscape management, etc. offer financial incentives or market-based compensation to those who maintain and provide these services on their lands. So, to incentivise the same, following may be practiced- for instance, farmers, practicing traditional farming including in Himalayan states, should be rewarded for their ecological services as it is considered climate-resistant and pro-environment. This is the green bonus and can serve as a fruitful spur for Himalayan states.

6 Conclusion

Undoubtedly, the climate crisis in the Indian Himalayas poses an immense and pressing challenge that demands immediate action and collaborative endeavors. This region, celebrated for its awe-inspiring landscapes, diverse ecosystems, and vibrant communities, now faces a stark reality of environmental deterioration and heightened vulnerability. The evidence of climate change is undeniable, manifesting in the rapid retreat of glaciers, unpredictable weather patterns, and an alarming increase in natural disasters. The repercussions extend beyond the Himalayas, affecting global ecosystems and climate dynamics. At the heart of this crisis lie delicate ecosystems, invaluable biodiversity, and the livelihoods of countless individuals. With rising temperatures and the escalating frequency of extreme weather events, the impact on local communities is profound, and the global implications are increasingly significant.

However, amidst these challenges, there exists an opportunity for building resilience and innovation. Addressing this crisis necessitates a comprehensive approach that encompasses adaptation strategies to bolster community resilience, mitigation efforts to curtail greenhouse gas emissions, and international collaboration to confront common challenges. It is only through sustained dedication, a profound appreciation for the delicate equilibrium of nature, and an unswerving commitment to safeguarding the well-being of present and future generations that we can hope to secure a sustainable future for the majestic Indian Himalayas and the planet as a whole.

By embracing sustainable practices, advocating for climate-conscious policies, and empowering local communities, we can strive towards a future in which the majestic Himalayas stand proudly, rejuvenated, and shielded from harm. It is a collective responsibility to protect this fragile ecosystem and ensure the prosperity of both current and future generations.

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Degradation of Water and Land Resources in the Himalayan Mountain Ecosystems

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Abstract Himalayan region is considered as the roof of the world. The nature of the Himalayan Mountain ecosystems is very complex. The climatic diversity of this region is significantly affected by the altitudinal diversity of Himalayan ecosystems. A large portion of area of this region is covered by glaciers as well as seasonal snow. The Himalayan Mountain ecosystems have great influence on the global climate, rainfall, atmospheric circulation, agricultural production, etc. The water resources from the Himalayan region drain through ten major rivers in Asia. The Himalayan Mountain ecosystem is very much vulnerable to climate change impacts. There is a significant knowledge gap of the long-term impact of climate change on water in the Himalayas, and their river basins in the downstream areas. Degradation of natural resources in the Himalayan region are found to be serious environmental issue. The water resources of entire Himalayan region are now facing high threats from various driving forces. Land degradation is also another serious problem in the Himalayan ecosystems. Various natural as well as man-made factors are responsible for the land degradation. Soil erosion is one of the major reasons of soil degradation of this region. Climate change in the Himalayan region induced various hazards like floods, landslides, and droughts which significantly affect the livelihoods of downstream population. Soil erosion may be of various types including mass erosion, sheet erosion, water erosion, terrace failure, and so on. Soil erosion decreases crop productivity and soil Fertility. This review article mainly focuses on the information regarding various factors of water and soil degradation in the Himalayan region and their probable remedial steps.

Keywords Himalayan Regions · Climate change · Soil erosion · Watershed · Water conservation

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1 Introduction

Water and Land, the primary natural resources available are currently under the potential menace of degradation (Alewell et al., 2019). Water erosion, the principal factor for the degradation of land signifies the declining quality and standard of soil, which in turn links to crop productivity, infrastructure upkeep, and natural resource quality (Lal et al., 2001). It might also involve biodiversity loss, alkalization of soil, depletion of nutrients, and minimization of organic matter present in soil (Acharya et al., 2009). Land degradation mostly depends on a variety of elements, including the slope's steepness, the climate, the use and cover of land, and natural calamities (Parveen et al., 2012). It is worth mentioning that around 60% of the land mass of the world is degraded by soil erosion (Pimentel, 2006). Soil degradation is a universal phenomenon which results in the loss of nutrients and acts as a significant barrier to the production and sustainable growth of agriculture (Guerra et al., 2017).

The primary reasons for soil degradation are both natural as well as man-made. Natural disasters viz., landslides earthquakes, floods, volcanic eruptions, tsunamis, droughts, wildfires and tornadoes are some of the natural factors of soil degradation. On the other hand, incorrect farming methods, industrial wastes, deforestation, surface mining, urban agglomeration, and industrial development activities are some of the important factors of man-made land degradation. Moreover, in addition to the factors mentioned above, various other factors such as lack of available land, loss in the amount of land available per person, poverty, land tenancy, population growth etc. are significant social reasons for soil degradation (ICIMOD, 2010).

In India, soil erosion is the most significant degradation issue causing loss of topsoil and terrain distortion. One of the most important environmental dangers i.e. soil erosion has negative effects both on the system and its surroundings and has a negative influence on the economy and its environment. The phenomenon of erosivity, proper management of land and erodibility are important factors in defining soil quality. Areas with a high percentage of vegetation are largely topographically controlled and have a decreased risk of soil erosion (ICIMOD, 2010).

Land degradation is considered a major factor in mountainous areas considering the steepness of the terrains. As a consequence of increased population pressure, factors such as clearing of forest cover, overgrazing, and intensive agriculture are frequently the causes of land erosion. In this chapter, we shall discuss the major causes of soil degradation in the Himalayan region with a focus on the Indian region of Himalayas, its potent environmental impact on the region and measures for its prevention and future scope for its remediation (ICIMOD, 2010).

2 Himalayan Mountain Ecosystems

An ecosystem signifies a biological community of living organisms consisting of microbes, plants and animals. Ecosystems perform a critical role in the health and sustainability of the environment and provide for a variable order of essential goods and services to people and civilizations. Mountain ecosystems are found all over the world and makeup around one-fifth of the planet's geographical area. Mountains serve as significant centres of biological diversity, in addition to their shared traits of great relative relief and steep slopes. The greatest benefit of mountains on a worldwide basis is that they are of source of origin of all the major rivers in the world. Mountain habitats depend heavily on climate, and creatures have developed climatic adaptations over time. It is found that nearly 50% of the global population depends on the commodities and services given by mountain ecosystems, which also preserve the integrity of the Earth's system by performing essential environmental management and rejuvenation tasks (ICIMOD, 2010).

The Eastern Himalayas span an area of 524,190 km^2. within the latitudes of 21.95° N and 29.45° N and longitudes of 82.70° E and 100.31° E, extending from eastern Nepal to Yunnan province in China. In India, it covers 52.03% of the total area covering the entire north-eastern region of India viz., Arunachal Pradesh, Assam, Meghalaya, Nagaland, Mizoram, Manipur, Tripura, Sikkim and Darjeeling Hills of West Bengal. It also covers 17.90% area of Myanmar, 16.08% area of Nepal, 7.60% of Bhutan (entire country) and 6.26% area of China. The western Himalayas spans 51,747 km^2 between latitudes 29º08′014″ N and 31º51′054″ N and longitudes 76º22′050″ E to 81º03′014″ E. It extends from Northern Pakistan to North Western India covering the entire hills Uttarakhand and a portion of Himachal Pradesh. The mountain contains 86% and 71% of the area of Himachal Pradesh and Uttarakhand (ICIMOD, 2010).

In India, the entire land mass of the country is classified into six physiographic divisions viz., (i) The Northern Mountains (ii) Northern Plains (iii) Thar Desert (iv) The peninsular Plateau (v) The Coastal Plains and (iv) Islands. In contrast to the other five physiographic divisions, the amount of water and land degradation is more pronounced in the case of the Northern Mountains. The Northern Mountains of India are further sub-divided into three parts viz., The Himalayas, The Trans-Himalayas and the Purvanchal Hills (ICIMOD, 2010).

The Himalayas are the youngest fold mountain range formed about 60–70 million years ago. It greatly influences the climate and environment of the region of Northern India and the Indo-Gangetic Plains. The range of the Himalayas extends from Indus to the Brahmaputra in the west–east direction across the country covering an approximate area of 2500 km. The width of the Himalayas varies from 400 km in the west to 150 km in the east. The Himalayas are further categorized into three parallel ranges (i) Greater Himalayas or Himadri (ii) Lesser Himalayas or Himachal and (iii) Outer Himalayas or Shivaliks (ICIMOD, 2010).

According to a recent study by the Ministry of Agriculture, in India, out of a total 107.4 million ha of degraded lands, 60 million ha are degraded by water erosion.

About 54 million ha of hill and mountain ecosystems are extremely vulnerable due to various factors viz., geological, topographical, climatic, and demographic factors (Biswas et al., 1994). Soils of mountain ecosystems are inadequate for cultivation due to issues such as increased acidity, limited exchange capacity, and aluminium toxicity. These ecosystems possess abundant biodiversity and potential production capacity, and govern the hydrology of river basins. Factors such as altitude, use of land etc. determine the variation of soils observed in these ecosystems (Walia et al., 1999). Moreover, various physiographic factors viz., slope, elevation and relief greatly influence the characteristics of the formation of soils in mountain ecosystems (Gupta et al., 1996).

Approximately 51 million people of the total population of the country reside in the Himalayan region, where the majority of them are involved in agriculture in the most difficult and varied ecosystems. The feeble Himalayan region ecosystems are particularly vulnerable to natural disasters, and possible climate change that may result in unusual floods, landslides, biodiversity loss, droughts, and concerns about food security (Xu et al., 2009). Mountain ecosystems have a pivotal role in the economic development of the region. They offer a potent scope of public services and goods, including clean potable water, food, life-saving medications, energy, biodiversity, and related traditional knowledge. However, though mountain ecosystems are of special importance for sustaining environmental and ecological balance, they are far from receiving priority in regional, national and international policies and strategies.

3 Soil Quality of Various Mountain Zones of the Himalayas

Soil is a critical component of for environment. Soil characteristics depend on various factors. In general soil fertility in a particular location is controlled by various factors like irrigation facilities, microorganisms living in the soil, climate, population pressure on land, topography, etc. Soil provides a medium for plant growth. A significant portion of land resources are gradually degraded due to various reasons. Soil quality can be evaluated by using various chemical or biological soil parameters. Soil quality may also be assessed through various parameters like pH, quantity of macro-elements, etc. (Sharma et al., 2006). Trace elements are considered a very crucial parameter in the assessment of soil quality. These elements are mixed with soil. Soils in the Eastern Himalayas are found to be of low macro and micronutrient contents. The quality of mountain soils is affected by condition of climate. Brown forest soils are found at heights ranging from 900 to 1800 m in the Himalaya Mountains (Kirmani et al., 2013). The brown forest soil of this zone is slightly acidic, rich in humus, fertile and suitable for vegetation. lime and potash content in this soil is relatively less. This soil is used for different varieties of crops.

In general, a large portion of soil in the Himalayan region is fertile, has very high plant growth potential, rich mineral content. The Himalayan plains are superabundant with alluvial soil. The mountain rivers of the Himalayan zone carry nutrients, pieces of rocks, and growth-friendly salts. The Himalayan soil contains large deposits of copper, zinc, nickel, antimony, gold etc. within the mountain range and rocks. The Himalayan soil is commonly acidic. The pH level of the Himalayan mountains is found to be slightly to moderately acidic. These soils give an ideal environment for different plants and various crops (Upadhyay et al., 2005). Soil is important for the existence of life on the planet. Soil consists of minerals, water, air, and various organic matter. Physico-chemical properties of soil of mountain areas of the Himalayas depends on various factors like topography, weathering process, vegetation on the surface areas, microbial activities, and different other biotic processes (Paudel et al., 2003). Soil quality significantly depends on soil depth as well as seasons.

The soil of Darjeeling and the northern territory of Sikkim is found to be brown and hilly. The soil of the North-Eastern Himalayan region including Karbi Anglong, Cachar Hills, Arunachal Pradesh, Nagaland and Meghalaya was found to be red sandy to laterite (Biswas & Mukherjee, 1994). A major portion of the land in Arunachal Pradesh is under dense forests. A very small portion of the land is only cultivated. The best part of the land of Arunachal Pradesh is mostly barren and uncultivated. About 45% of land in Meghalaya is cultivated and the rest part is forest (Majumdar et al., 2004). The North-Eastern Himalayan zone is characterized by rich vegetation, difficult terrain, large valleys, large variations in slopes and altitudes, complex geological structures, and land tenure systems. The North-Western Himalayas of India covers ten states. In India, approximately 16.2% area of the whole country is covered by Himalayan mountains (Patiram, 1994). These areas are occupied by dense forest and high peaks with snow covering. The North-Western Himalayan region is located between 28°43′ N to 37°05′ N Latitude and 72°02′ E to 81°02′ E Longitude. This Himalayan region has been broadly divided into three parts namely Greater Himalayas, Lesser Himalayas and Siwaliks (Rana et al., 2000).

The area covered by the Eastern Himalayas is 524,190 km^2. Starting from eastern Nepal to Yunnan in China, a large area was considered the Eastern Himalayas (Bajracharya et al., 2007). This region has ecologically rich diverse biodiversity with its mountains, plain and valley areas. This Himalayan Mountain system is also very significant from environmental, and ethnic perspectives as well as in terms of its ecosystems. The lowland areas are covered by different rivers emerging from deeply dissected foothills. There is a large diversity in this region in terms of topography, soil quality, and climatic conditions. This region contains many major ‘hotspots’ of biodiversity. The soil in the Eastern Himalayan region is brown and hilly and the climate is humid. The average rainfall is about 2700 mm per year. Canal irrigation in this region is relatively low (Mandal & Sharda, 2011).

Siwalik region is a part of the south-western Himalayas. Siwalik regions comprise Jammu, Himachal Pradesh, Uttrakhand, etc. The soil of the Siwalik region mainly consists of sedimentary rocks which comprise sandstone, clays, conglomerates, etc. (Gupta & Verma, 1992). The weather in this region is warm and humid. The soil qualities of the Siwalik sector were studied by various researchers. The soils of the Siwalik sector comprise podzolic soils. The plain area is mainly neutral, and some regions are found to be slightly alkaline (Sidhu et al., 1987). The moderately

Fig. 1 Representative photographs of northern leeward sides of Himalayan range & slope of Himalayan valley, Nepal (*Source* Moses et al. 2021 open access)

steep hills of Himachal Pradesh have medium-deep, loamy-skeletal, severely eroded soils (Sidhu et al., 2007). Soils of valleys are mainly sandy as well as coarse-loamy. Soils of gently sloping piedmont plains are well-drained, moderately alkaline, and coarse-loamy with moderate erosion (Sidhu et al., 1997).

Oak and pine forest is mainly found in the Western Himalayan region (Suri et al., 2013). Soil moisture in the oak forests significantly decreases with an increase in the soil depth during the winter season. The same thing applies to pine forests. Organic matter of soil is found to be a parameter, and its deposition significantly affects carbon storage (Jina et al., 2011). The geographical area of the Northeastern Indian Himalayan Region is about 26.3 million ha. About 50% land of this Himalayan Region is prone to degradation due to various factors (Mohapatra & Ngachan, 2016). Soil fertility in this region is gradually decreasing due to excessive agricultural work. Soil organic carbon as well as nitrogen content is generally high in this region. Soils of this region are categorized into various zones like inceptisols, alfisols, mollisols, etc. In Arunachal Pradesh, soil organic carbon concentration ranges between 14 and 59 g/kg (Saha et al., 2015). Soil organic carbon concentration in Manipur is found to be within the range of 1–36.6 g/kg in Bishnupur and Imphal Valley (Ramesh et al., 2013). Agricultural soils may be considered as great potential for Soil organic carbon stock (Fig. 1).

4 Water Resources of Himalayan Eco-system

The Himalayan region extends up to 3500 km from Afghanistan in the west to Myanmar in the east and is often referred to as the Hindu Kush Himalayan (HKH) region (Eriksson et al., 2009) (Fig. 2).

The Himalayas play a prime role in maintaining the availability of freshwater for almost a billion people living in the Indus, Ganga and Brahmaputra River basins. The Himalayas are said to be the third pole since they comprise of enormous amount of frozen water besides the outside the North and South poles. Along with the Indian monsoons, the frozen water ensures that the rivers initiated from the Himalayas

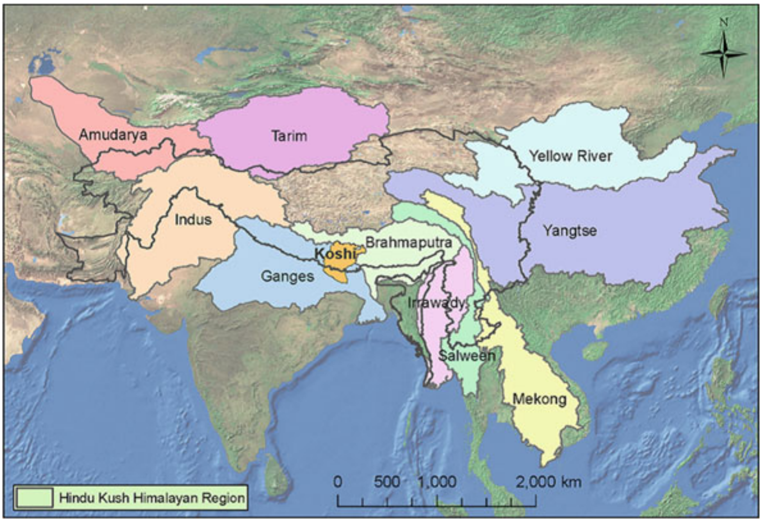

Fig. 2 The Hindu Kush-Himalayan (HKH) region and position of the Koshi river basin (*Source* International Centre for Integrated Mountain Development; the boundary of the Koshi basin is taken from ICIMOD's Koshi Basin Programme)

probably never face a shortage of water (Immerzeel et al., 2020). The most vital water resources comprise snow, glaciers, rivers, groundwater, springs, lakes, and wetlands. Indian Himalayan Region (IHR) is considered to be the water reservoir of Asia. Snow and ice-covered mountains play a critical role in safeguarding water, food, energy and environmental issues of the inhabitants.

4.1 Snow and Ice Reservoirs

In the higher Himalayas, snowfall has been building for many years, which results in the formation of glaciers. These glaciers serve as reservoirs of water. The higher Himalayas and Asian ranges constitute the second biggest glaciated areas (Dyurgerore & Mejer, 2005). Glacial melt results in for majority of typical river flow across the Himalayan rivers. In total, the HKH region has a total of 54,252 glaciers with an assessed ice reserve of 6127 km^3 (Bajracharya et al., 2015). However, there exists a considerable difference between river basins and the major glaciated areas are found in the Indus, Brahmaputra and Ganges Basins. More than 60% of the total glacier area of this region is located between 5000 and 6000 m above sea level. The presence of fewer meteorological observation stations has been creating challenges for enduring monitoring of ice and snow (Shea et al., 2015) in the HKH.

4.2 Lake Systems

The Himalayan mountain region is comprised of a good number of lakes, each having its unique appeal. They are not only adding to the unique beauty of the Himalayan region but also act as a water reservoir (Singh, 2021). From the fascinating colours of Pangong Tso Lake to the sacred waters of Manasarovar Lake, all of them can be considered to be natural wonders surrounding these high-altitude gems. Pangong Tso Lake, situated at an altitude of 4350 m is considered to be one of the most spectacular lakes in the Himalayas. This lake is approximately 134 km long and ranges from India to Tibet. Yamdrok Lake, considered to be one of the three largest sacred lakes in Tibet is located at an altitude of 4441 m. This beautiful lake is nearly 72 km long and ranges over an area of 638 km^2 The name "Yamdrok" means "turquoise" in the Tibetan language, an appropriate explanation for the lake's brilliant turquoise waters. The Gokyo Lakes, a series of six remarkable lakes in the Himalayas, are located in Nepal's Sagarmatha National Park. Situated at altitudes ranging from 4700 to 5000 m above sea level, these lakes constitute the world's highest freshwater lake system. Situated in the northern part of the Indian state of Sikkim, Gurudongmar Lake is one of the highest in the world and covers an area of approximately 290 acres. Situated amidst the scenic Langtang National Park in Nepal, Gosaikunda Lake is another freshwater lake that covers an area of about 34 acres. The lake is surrounded by a spectacular landscape of snow-capped mountains and verdant valleys which makes it a popular destination for both trekkers and pilgrims. Tso Moriri Lake, located in the Changthang Plateau of the Indian region of Ladakh situated at an elevation of 4522 m above sea level ranges approximately 19 km in length and 7 km in width. With its crystal-clear waters surrounded by barren hills and snow-capped peaks, Tso Moriri is creating a peaceful and awe-inspiring landscape. Situated at an altitude of 4300 m, Chandra Taal Lake known as the "Lake of the Moon," is a fascinating high-altitude lake located in the Spiti Valley of Himachal Pradesh, India. The crescent-shaped lake is formed by the melting of glaciers. The generation of most of the lakes in the IHR region can be related to glacier melting (Khanal et al., 2015).

4.3 River System

The HKH region is the source of ten large Asian river systems (Eriksson et al., 2009). The Himalayan Mountain is the basis of Asia's 10 largest rivers including Brahmaputra, Ganges, Indus, Mekong, Yangtze, and Yellow Rivers. These rivers along with their various tributaries act as the prime sources of freshwater in South Asia. Nearly 50% population of India and Bangladesh and almost 100% population of Nepal depend on the Ganges River system for fresh water supply. The Ganges and Yamuna canal systems supply irrigation for vast areas of India through the use of surface and groundwater originating from the Himalayas. The Brahmaputra River is also a prime river in this region that supports irrigation, hydropower, fisheries and other important activities for a majority part of Bangladesh, Bhutan, and India (Cathcart et al., 1998).

5 Development of Water Resources in the Himalayan Region

Snow-melt water from glaciers is generally commonly used in irrigation for cultivation in the valley of the Himalayan region. About 60% of people in the Himalayas mainly depend on natural resources basis for their livelihood (Dabral et al., 2008). In addition to supplying groundwater, the Himalayan eco-system provides major inputs to agricultural water to fulfill their regular water needs for drinking, irrigation etc. In foothill areas of Himalaya groundwater is generally abundant. However, due to the sloppy surface major portion of water flows out. Major rivers in the Himalayas provide the main sources for surface as well as groundwater irrigation. Irrigated agriculture is considered one of the most important systems through regulating and controlling micro-climates as well as monsoon circulation. Himalayan rivers have a major contribution to the irrigation system of the fertile, agricultural plains in its watershed. Groundwater in the Himalayas also has an equal contribution to irrigation in the agricultural landscape of a major portion of South Asia.

All countries like Pakistan, India, Nepal, etc. have constructed dams in the mountains of the Himalayas. These dams are built for the generation of hydropower and to store water for irrigation as well as other purposes. Hydropower is the major source of power for all these countries. Rivers of the Himalayan Mountain zone have a capacity of approximately 75% of the total hydropower resources of India (Basistha et al., 2009). Himalayan rivers have great potential to produce hydroelectric power. Some of the largest hydropower generation stations are already constructed in the Indian subcontinent in the Himalayan rivers. Various small, medium and major hydropower generation stations are constructed in the Himalayan mountains. Almost 133 hydropower projects are constructed in the Indian Himalayas (Agrawal et al., 2010). Himachal Pradesh have 15 and Uttarakhand have 33 power stations in the Himalayan zone. Uttarakhand government has planned to generate power through hydroelectric projects in an environment-friendly way. Himachal Pradesh can be considered a power state of India. Himachal Pradesh has a capacity for hydropower production of about 27,463 MW. A major portion of these hydro powers is contributed mainly from Himalayan Mountain zones (Kumar & Katoch, 2015).

6 Various Factors Responsible for the Degradation of Land and Water Resources in the Himalayan Mountain Ecosystems

The HKH region is full of cultural diversity, encouraging climatic conditions and gorgeous scenic beauty. These instrumental qualities have made this region a substantial hotspot for tourism activities which increased road infrastructure and growth of the region. Simultaneously these results in an increase in urbanization, modification of land use patterns, increased deforestation and damage to biodiversity. Urban areas have been extended and replaced with concrete structures resulting in decreased groundwater recharge. The mismanaged land use, soil erosion and deforestation are prime environmental issues in Himalayan regions. Rapidly increasing population and urban centres in have put incredible pressure on available natural resources.

As this region is the youngest, the constant movement of the Indian plate northward results in frequent high-scale earthquakes. This results in undeveloped topography of the Himalayas, which makes it susceptible to erosion and denudation. On top of this, the risk posed by human-induced climate changes, especially global warming is having a surging effect on the Himalayan eco-system. Due to the sensitivity of the mountain ecosystem to small changes in temperature and precipitation, the effect of temperature rise and climate change is more prominent (Whiteman, 2000). The unplanned urbanization which results in the exponential increase in the inflow of tourists and vehicles, construction of buildings has led to the worsening of environmental conditions. The prime topic on climate change in the Himalayas is focused on glacier melt that will affect the natural ecosystems and agricultural patterns. The high concentration of sediments generated from the Himalayas has been creating serious problems for the hydropower and irrigation projects in the Indian subcontinent. The high speed of exploitation of natural resources is the prime reason for the increase in sediment flux. Climate change modifies the regular annual precipitations of various regions, thereby causing radical changes in precipitation behaviour (Holeman et al., 1968).

Gradually, it has been observed that per capita water availability has been decreasing. Per capita water availability in Pakistan dropped to 1100 m^3 per annum in 2006 from 5000 m^3 per annum in 1951. India is also facing the same scenario where with increasing population and unplanned urbanization, the per capita water availability decreased to 1731 m^3 in 2005 compared to 1986 m^3 in 1998 (Gupta & Deshpande, 2004). Climate change, especially global warming has been leading to drought-like situations in a lot of areas of the Indian Himalayan region. Water scarcity has been affecting food production and the adverse effect will be more serious unless proper control measures are taken (Aggarwal et al., 2004). Increased extraction of groundwater has resulted in lowering the level of groundwater in most parts of the Indian Himalayan region. This leads to serious concern for the deficiency of water and energy that has affected both agricultural output and economic growth. The energy shortage situation has become challenging situation in all over the region that depends on precipitation from Himalayas, i.e., India, Bangladesh, Pakistan and Nepal.

Burning of biomass has adversely affected the food, water and energy balance in South Asia. A majority of the population in South Asia practices biomass as the prime source of energy for cooking. Incomplete combustion of biomass in the traditional process contributes to air pollution too by emission of carbon monoxide gas and black carbon aerosol particles (Venkataraman et al., 2005). The black carbon aerosol particle also absorbs heat radiation and releases it back which increases the atmospheric temperature. Also, the black carbon depositing on ice and snow decreases the albedo of these surfaces which in turn leads to an increase in the absorption of heat. This process increases the speed of melting of Himalayan glaciers (Ramanathan et al., 2005), thereby leading to the generation of flash floods in higher Himalayan regions.

7 Land Degradation, Overland Flow, Soil Erosion, and Nutrient Loss in the Himalayan Ecosystems

Land degradation is a global phenomenon that causes nutrient loss and is a key barrier to agricultural productivity and sustainable agricultural growth. It affects around 25% of the world's land mass and signifies a detrimental impact on people's livelihood (Pimentel et al., 1995; Mishra & Rai, 2013). The main sources of soil erosion and nutrient loss are rainfall and overland flow, which lead to soil sterility, loss of productivity, and ecological deterioration (Adimassu et al., 2016; Ma et al., 2016). Different types of soil erosion exist, including sheet erosion, water erosion, mass erosion, landslides, terrace failure, and more. Land degradation is not only natural, however various human-induced factors also intensify land sliding such as clearing of vegetation, the construction of roads and buildings, mining, and hydropower projects (Bhattacharyya et al., 2015). Soil erosion and nutrient loss are interconnected and act as a primary factor affecting sustainable agriculture. Around the world, in addition to human-induced factors excessive deforestation, overgrazing, wildfires, and inappropriate land use practices have all been linked to soil erosion (UNEP/ISRIC, 1990; Stefanidis, 2011; Efthimiou, 2020).

The steep slopes, reduced forest cover, and strong seismicity of the Himalayas are important contributors to river flow soil erosion and sedimentation (Jain et al., 2001). In the eastern Himalayas, landslides, mudslides, terrace failure, and soil loss from steep slopes are the primary drivers of land degradation. Much research has been carried out to evaluate soil erosion in the middle Mountain region of the central Himalayas, but only a few studies have concentrated on the Greater Himalayas (ICIMOD, 1994; Kayastha et al., 2013; Ghimire et al., 2013; Paudel & Andersen, 2010).

In the region of the eastern Himalayas, it is found from detailed research that water erosion has resulted in 601 Mt of soil loss and 685.8, 99.8, 511.1, 22.6, 14.0, 57.1, and 43.0 thousand tonnes of nitrogen, phosphorus, potassium, manganese, zinc, calcium, and magnesium nutrient loss.

8 Potential Impacts of Climate Change on Soil and Water of Himalayan Mountain

It is crucial for the development and implementation of efficient policies and management plans for mitigation and adaptation to comprehend and foresee the effects of climate change on the ecosystems of the Himalayan forest and the services they provide to humans. Long-term monitoring and modelling of forest structure and dynamics are essential to foresee the potential effects of climate change on the structure and functions of these distinct ecosystems and to assess their socio-ecological sustainability. In terms of observations of the effects of climate change on ecosystems and biodiversity, the Himalayan region is severely data-deficient. Concerning the impacts of climate change on individual species in the Himalayas, comprehensive research and empirical observations are woefully lacking. The Indian Council of Forest Research and Education conducts applied research on potential impacts of climate change focused on particular issues relating to forest ecosystems, such as possible effects of climate change, biodiversity preservation, halting desertification, and sustainable management of forest resources (ICIMOD, 2010).

9 Consequences for Livelihoods on the Soil and Water Resources of Himalaya

The Himalayan region is home to large varieties of plant and animal species. It is a region of rich biodiversity. Soil erosion is a major problem in this area. Soil erosion at a rate of 30–40 tone ha^{-1} was reported in Asia and Africa (Barrow, 1991). The average soil erosion rate in the Asian zone is approximately 138 tone ha^{-1} $year^{-1}$ (Sfeir-Younis, 1986). In most cases, this farming system is done traditionally. There is an increased food demand in this area due to high population growth (Sharma et al., 1998). In the last few years, agricultural areas are increasing considerably which may be one of the reasons for deforestation in this region (Rai et al., 1994). Many forest areas are newly converted into agricultural land which ultimately accelerates the process of nutrient losses. Agricultural activities may lead to a reduction in soil fertility. Nutrient losses are generally high in agricultural fields. The magnitude of soil erosion is increasing gradually significantly.

Milliman and Meade reported that average soil degradation from the watershed in the Himalayas was approximately 500–1000 $Mg/km^2/year$ (Milliman & Meade, 1983). Reports from various studies indicated that there was lower phosphorus loss compared to organic carbon. It has been observed that agroforestry and stabilized cultivation are relatively much better than shifting cultivation in terms of reducing soil losses. As per the study it has been found that approximately 80% of all agricultural land is severely affected by erosion problems (Bala et al., 2007). Nutrient losses in forest areas are much less than in croplands.

Approximately 70% of the population in the mountain areas of Uttarakhand state mainly do agricultural activities for their livelihood. The annual rainfall range in the mid and high hills of the Himalayas is 1000–2500 mm (Negi & Joshi, 2002). The majority of water flows down the steep slopes and is not available in mountain areas for agricultural use. A large portion of the inhabitants of the Himalayan region have to struggle for sustainable livelihoods due to different topographical constraints (Rai & Sharma, 1998). Approximately 10% of agricultural lands in the hill areas of Uttarakhand are irrigated. Agriculture in this Himalayan region of Uttarakhand is mostly rainfed. Soil loss was found to be the least in the agroforestry followed by terrace cultivation. The roots of plants can bind the soil tightly which also stabilizes the soil. Maximum soil loss is reported mainly from barren land. Soil loss is significantly less under terrace cultivation. Erosion depends on various factors like slope length, rainfall quality, moisture content of soil, etc.

It has been observed that upland agricultural activities undertaken by local people are one of the main factors of large-scale soil erosion in the Himalayas. The steep slopes of mountains in the Himalayan region and depleted forest covers are the major reasons for soil erosion. Himalayan agriculture is mainly based on marginal rainfed as well as limited irrigated land covering upon which the livelihood of the majority of the rural population depends. Various research data have indicated the declination of soil fertility (Mandal & Sharda, 2013). The Indian Himalayan Region has clear ecological variations concerning their various factors like demography, topography, etc. The mountain areas of the North-western Himalayan Zone have very diverse climatic as well as topographical features (Shaheen et al., 2013). The majority of the people in this zone are agro-pastoral. About 5% area of this zone is covered by vegetation (Sharma et al., 2009). Over the last few years, it has been observed that land fragmentation has led to higher land-to-man ratio. The degradation of forest areas in the Himalayan region has a very bad impact on the ecosystem. A decrease in overall rainfall and a decrease in moisture retention capacity is observed in the Himalayan region. A decrease in rainfall as well as a decrease in moisture retention capacity are observed in the Himalayan region. Environmental health is directly related to the carbon content of soil. There are various challenges and issues related to water resources like increasing demands of consumable water, increasing waste, increasing agricultural uses of water, expanding urbanization, etc. (Kumar et al., 2008).

10 Environmental Constraints and Natural Disasters Affecting Soil and Water Resources of the Himalayas

Climate change can directly affect the soil and water resources of the Himalayan region. The mountains in the Himalayan zones are very vulnerable and sensitive to climate change. Average surface temperatures of the Himalayan region are day by day increasing and snow cover is gradually decreasing. Glaciers have a significant contribution to river flow. Climate change has a direct impact on glacier which ultimately affect directly on water availability as well as ecosystem balance (Raina et al., 2009). Gangotri Glacier retreated considerably in the last few years. The same situation is reported for many other glaciers like Bhagirath, Kharak, Zemu, etc. Due to global warming, Himalayan glaciers are retreating abnormally. The hydrological characteristics of the Himalayan watersheds are gradually changing due to various reasons like extensive land use, extensive agricultural activities, hydrological disasters, enhanced reservoir sedimentation, changing patterns of rainfall, etc. Global warming has a very bad impact on the hydrological cycle of the Indian Himalayan region (Mall et al., 2006).

Glaciers have a major role in controlling the hydrological cycle as well as ecosystem stability. They mainly control the water supply in the mountain rivers. Total Himalayan glaciers are found to be approximately 70% of total world non-polar glaciers (Nandy et al., 2006). An area of approximately 32,000 km^2 of the Himalayan region is permanently covered with ice and snow (Negi, 1991). Mountain rivers of the Himalayan region are associated with different hydrological risks like glacier dams, glacier outburst floods, and huge landslides. Some disastrous phenomena such as glacial mud flows, outbursts of glacier-dammed lakes, floods, etc. very frequently occur by glacier meltwater in the mountains of the Himalayas (Mishra et al., 2021). Glacier Lakes Outbursts floods are found to be a very common problem of Himalayan mountains which are mainly due to bursts of water from glacier-dammed lakes. Dangerous flood waves of very high amplitude are recorded in the Himalayan mountains.

Gangotri is an important glacier in the Himalayan region. The length of the Gangotri glacier has been reduced from 25 to 20 km within the last few years with an average rate of recession of approximately 23 m per year (Hasnain, 2002). Gangotri glacier retreated at a slow rate of 11.8 m per year from 2005 to 2007 (Kumar et al., 2008; Raina et al., 2009). Dokriani Bamak Glacier was found to be retreated by 20 m in the year of 1998. Global warming significantly affects the process of melting of glaciers and, the pattern of rainfall river flow in the Himalayan region. The patterns of winter rainfall are becoming very much unpredictable.

Severe storms and Cloudbursts affect the soil and water resources in the Himalayan ecosystem. Considerable loss of soil is observed by severe storms in the Himalayas due to high waves of winds and intense rainfall. Severe freeze–thaw cycles in the mountain climate of the Himalayas may be considered as one of the reasons for the greater erosion of soil as well as rock formation. Snowmelt is found to have a significant role in the Indus basin as well as the Brahmaputra basin (Immerzeel et al., 2010). From the research data, it has been estimated that the present rate of erosion is 100 cm/1000 years (Borrelli et al., 2017). High-temperature oscillations may be considered as one of the factors of this high rate of erosion. Landslides and soil creeps are very frequently observed due to heavy squalls. Sediment yield produced from the Himalayan rivers is approximately estimated to be around 16 Ha-m/100 km^2/year (Choudhury et al., 2022). Mass wasting is considered another major problem of the Himalayan ecosystem. Mass wasting is a process through which a large portion of masses of earth moves downhill through either slow creeping or landslides. Intense rainfall, floods, cloud bursts, seismicity, landslips, ground water flow, etc. are some of the factors of mass wasting in the Himalaya.

11 Soil and Water Conservation in the Himalayan Mountain Ecosystems

The mountain ecosystems are reported to provide livelihood to approximately 10% of total world's population. These people directly depend on the natural resources of the mountain like water, forest, soil, agricultural products, etc. Soil erosion reduces the soil quality in different ways. Conservation of Soil and water is very urgent and essential to protect agricultural land in Himalayan regions (Panday & Srivastav, 2013).

Various methods are there. Some of these methods include systematic land use, control of mining activities, utilization of denuded lands as fuel, proper management of grazing lands, plantation, effective implementation of proper erosion control and land stabilization methods, crop rotation processes, using appropriate cultivation techniques, water harvesting, improvement of soil fertility, cut-off drains, etc. (Kumar & Shukla, 2021). The integrated watershed management process is very important to protect the soil. Steep slopes of Himalayan mountains with shallow soils should be covered with trees. Agroforestry may be helpful as windbreaks across the slope area of the mountain. The plant cover of the soil can be increased by intercropping method. The intercropping method increases the soil quality (Gairola et al., 2012). Protection of the soil surface is very important. A cover above the ground can effectively protect the soil surface from erosion.

Organic matter helps in the stabilization of soil structure. Due to the various organic matter water can enter the pores of soil which will ultimately help to absorb water into the soil. Pores created within the rotten organic material in the soil help the water to enter the deeper part of the soil. A cover of dead organic matter near the surface area of the soil can protect the topsoil (Singh & Singh, 1997). Decaying organic materials can also help in the formation of fungal hyphae and sticky liquids. Rainwater harvesting may be a very useful technique for the conservation of natural water. It is one of the most promising techniques of management of natural resources for the people of the Himalayan eco-system.

Mulching is very helpful in maintaining the moisture content of soil in the low-rainfall regions. Mulched soil surfaces generally absorb water much faster. Conservation tillage is one kind of conservation practice which may be very helpful for reducing soil erosion (Rees & Collins, 2004). The physical properties of soil can be significantly modified by zero tillage practices. These technologies are helpful for low-cost cultivation, high water productivity, and high-quality soil production in the Himalayan mountains (Panday et al., 2008). The zero tillage practices increase the organic carbon content of soil by about 300 kg C/ha/year in the Indian Himalayan region.

The Himalayan region is a major ecotourism destination centre rather than a commercial tourist destination. Contour bunding is one of the effective methods of soil conservation. It is made up of narrow parabolic-shaped bunds on mild slopes and generally useful for low-rainfall areas. The bunds are open-ended to slowly drain off excess water which may be recommended in high rainfall areas. Bench terracing is another frequently used conservation method for mountainous areas of Himalayan zones. Bench terracing can reduce the degree of slope (Andraski et al., 1992).

In-situ rainwater harvesting is a process through which the water content of the soil is increased by directly trapping the rainwater locally (Stott et al., 2001). In this method, there is negligible movement or wastage of rainwater as surface runoff. In-situ rainwater harvesting can prevent the net runoff of surface water in a cropped area. The plantation method is very effective for the conservation of the land in the Himalayan mountains. *Acacia catechu* is highly recommended for plantation in high-sloping areas. In the sub-tropical hills, various fruit trees are recommended. Some of the fruit trees are apples, almonds, peaches, and plums. Fuel fodder plantations are also an effective measure of soil conservation in hill areas. Grewia optiva (Bhimal), Melia azadirach (Bakain), *Albizzia* sp. (Siris), Oak, etc. are some of the important plants for this purpose. Fast-growing species of eucalyptus planted in a denuded watershed can reduce total runoff by 28% (Mathur et al., 1976). The plantation of eucalyptus can effectively reduce peak discharge and soil loss by about 50% (Vishwanatham et al., 1984).

The geographical area of the Northeastern Indian Himalayan Region is about 26.3 million ha. About 50% land of in this Himalayan Region is prone to degradation by various factors like soil erosion, acidity, etc. (Saha et al., 2012). Soil fertility in this region is gradually decreasing due to excessive agricultural work. Soils of this region are categorized into various zones like inceptisols, alfisols, mollisols, etc. In Arunachal Pradesh, soil organic carbon concentration ranges are within 14–59 g/kg (Singh et al., 2006). Soil organic carbon concentration in Manipur is found to be within the range of 1–36.6 g/kg in Bishnupur and Imphal Valley (Sharma et al., 2006). Agricultural soils may be considered as great potential for soil organic carbon stock.

12 Future Prospects

The increase in Greenhouse gases, deforestation etc. has a adverse effect on climate. Given the climatic change, land degradation occurs which increases the possibility of heavy storms, extensive dry spells, and reduction of forest cover. Minimizing land degradation and investing in soil conservation measures is a key issue that requires the promotion of sustainable development and the conservation of nature. Maximum consideration should be given to an integrated watershed approach to tackle land degradation and environmental issues, especially in vulnerable areas. The combination of conservation agriculture with other technologies, such as micro-irrigation and management of degraded soils using essential and particular technologies, holds enormous promise for improving crop and fruit productivity and also in reversing soil degradation. Other means to stop land degradation include better grazing techniques, irrigation management, reducing urban sprawl, and controlling and managing mining activities. Enhancing water and nutrient use efficiency and reducing pesticide use should be the main topics of future study.

Human-induced ecological degradation should be rectified through land development activities like land shaping, terracing, bunding, and re-vegetation, among others in the lower foothills of the Himalayas. Research on micro watershed development, groundwater, surface hydrology, and other topics should be strengthened to conserve water degradation. Moreover, tracking the effect of climate change on soil quality and the soil's carbon content needs to be focused.

13 Conclusions

Land degradation is projected to worsen as the climate changes, owing to high-intensity storms, prolonged dry spells, and forest denudation. A significant problem involving the promotion of sustainable development and nature conservation is preventing future land degradation and investing in soil conservation. To tackle land degradation and environmental challenges, particularly in vulnerable areas, an integrated watershed approach should be prioritised. By securing SOC, as well as by enhancing soil quality, sustainable agricultural intensification holds great promise for raising productivity and protecting natural resources. Local communities must be included at all stages of the application of resource-saving technology, prudent irrigation water management, wasteland reclamation, watershed development, and afforestation. In order to implement scientifically supported sustainable management of land and forests, it is vitally necessary to develop an integrated land use strategy that includes rural fuelwood and fodder grazing. Controlling the fragmentation of land ownership is still another major concern. This could be done by guaranteeing the stability of land rights and tenure and promoting the effective utilization of marginal lands.

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Traditional Ecological Knowledge in Sustainable Conservation of Seeds and Food Grains in the Himalayas

P. Kiran Babu and Rampal

Abstract Himalayan region is one of the oldest agricultural civilization areas and treasure for the food and agricultural crops such as rice, wheat, maize, millets, pulses, oilseeds, fibers, and other economically potential crop species. This region considered for centre of origin for few crops and bestows trait specific valuable genetic resources include the cold tolerance, disease, pest resistant genotypes, plant populations and traditional crop varieties of inter and intra-specific, racial diversity in for future needs. These indigenous crops consists great dietary value and plays a vital role in the sustainable development of aboriginal people nutritional security. Indigenous people management the local crop varieties/landraces which take account of socio-cultural practices of seed selection, production, and traditional storage techniques with their ancestral knowledge systems. Farmer's have developed many unique structures (made of bamboos, canes, mud, wood, etc.) which are relatively cheap, eco-friendly, climate resistant and impart lofty self-life for safe storage of food grains and seeds from pests/insects and rodents. The seeds are exchanged as gifts, bartered, and purchased from local markets. Conservation of these trait specific traditional landraces at a very low cost using in situ/*on farm* can be successfully achieved by providing special incentives to farmers/indigenous people, village communities may get the benefits through to identify collection priority areas, explored and unexplored areas with the establishment of community seed/gene banks, field genebanks etc. and also protect human and soil health need to be strengthened to tackle of climate change with the help of this natural wealth.

Keywords Seeds · Storage · Conservation · Traditional knowledge · Himalayas

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1 Introduction

Currently, three billion people worldwide cannot afford a healthy diet because of high food costs, widespread poverty, and income unfairness (FAO, IFAD, UNICEF, WFP, WHO, 2021). The primary concern with food production in recent years has been the reform of food systems for greater nutrition, food security, and accessibility to wholesome diets. Researchers are looking into other food sources that may be able to provide human nourishment as a result of the growing population, rising hunger, limited food supply, pervasive malnutrition, and climate change (Soni et al., 2023). The traditional agricultural system in Himalaya evolved through trial and error methods over the centuries (Bisht et al., 2007). The Indian Himalayas is divided into four main areas from west to east: the eastern and north-eastern Himalaya, which includes Sikkim, Arunachal Pradesh, and Darjeeling; the eastern flank, which includes Meghalaya, Assam, Tripura, Manipur, Nagaland, and Mizoram. The north-west Himalaya, which includes Jammu and Kashmir, Himachal Pradesh, and Uttarakhand. The Himalayas are the source of the rarest crop biodiversity and have the highest agro-ecosystem on the planet (Lata et al. 2023). The Himalayas, which are a global biodiversity "hotspot" and home to ~2500 of India's <6000 indigenous plant species and constitute 6.5% of total endemic genera, play a significant role in the country's reputation as a "mega-biodiversity" country (Rana et al., 2023; Rao & Pant, 2001).

Biocultural diversity, or the study of the relationship between culture and biodiversity in a particular socio-ecological area, also finds considerable shelter in mountain habitats (Pieroni & Soukand, 2018). Since the biological world is always changing and evolving on both a spatial and temporal scale, each culture has its own distinct viewpoint on it. As a result, cultures have developed a corpus of traditional knowledge about this natural wealth (Gómez-Baggethun et al., 2010; Turner et al., 2011). Foraging is an essential human ecological reaction in times of famine or food shortages because people who live in these places are constantly at risk of food insecurity (Sulaiman et al., 2022). There are more crops and related biodiversity in the rainfed agricultural system, which is common in mountainous regions than in the irrigated system. A wide variety of traditional agro-ecosystems, ethnic groups, and wild flora, including 273 cultivated crop species, 898 wild relatives and related cultivable plant kinds, 744 wild edible plants, and 591 plants with industrial potential, can be found in this region (Rana et al., 2023). Through crop rotation in space and time, as well as the utilization of both mono and mixed farming techniques, local farmers maintain high levels of crop diversification practices (Mehta et al., 2010).

The Himalayan region is home to indigenous tribal populations with Mongolian characteristics, as well as Buddhist religion and culture. Extreme climatic conditions such as extreme diurnal temperature fluctuation, scant and heavy rainfall, strong afternoon winds, heavy influx of infrared and ultraviolet radiations, and reduction in oxygen levels at higher elevations, low atmospheric carbon dioxide concentration, and low relative humidity characterize the region (Rana et al., 2012a). In addition to cultivated indigenous landraces, the Indian Himalayas are home to a variety of wild, underutilized crops. Local cultures have traditionally used these for food, fibre, animal fodder, oil, or medicine, but they still have unexplored potential uses. They are extremely adaptable to agro-ecological niches and play an important role in local consumption and production systems. Landraces/ecotypes have precedence, and these crops have received minimal attention in research and creation of national agricultural and biodiversity conservation programmes (Padulosi et al., 2002; Williams & Haq, 2002).

2 Agricultural Practices in the Himalayan Region

Cropping activities begin with the arrival of summer when melting snow offers adequate moisture for seed germination and sucker sprouting. Crops achieve full bloom in June-July and then begin to fade as maturity progresses in September–October (Rana et al., 2012a). Locally farmed landraces typically have lesser production capacity than high-yielding types. However, other more desirable traits, such as excellent nutritional content, good cooking attributes including enjoyable aroma, and sufficient cooked meal volume with less raw food, make up for the difference. Furthermore, diets prepared from these landraces have a significantly longer shelf life than other cultivars. As a result, these landraces have a larger market demand and command a higher price. Furthermore, regionally adapted landraces serve as an essential repository of trait-specific genes, which is crucial for crop improvement (Malik et al., 1994). It may be argued that farmers in general have a wide range of traditional knowledge on the best ways to dry and safeguard their crop harvests using affordable techniques and technology that reduce pest infestation and work well within the predominant system of small-scale family production. However, relatively little is known about how farmers in this area use their understanding of storage techniques in the selection and upkeep of the diversity of traditional crop landraces in their fields (Morino et al., 2006).

Traditional farming methods are used for everything from sowing to threshing. The broadcasting method is used to sow seeds. The field is ploughed with either a single horse or a pair of yaks/bullocks/cows. The fertility of the soil is maintained by locally accessible high-quality manure and night soil. Local wooden tools are used in the field to level and create ridges. Rainwater is the primary source of irrigation, which is channeled into the fields. Harvesting is done by hand with a sickle or by uprooting.

Harvested crops are crushed using a stick and under the weight of animals during threshing. To winnow, one uses the wind. The chosen plants are left in the field until they are fully developed, ripe or until their roots and branches have completely dried out. Throughout the process, farmers defend these mother plants from pests, grazing animals, poachers, and wild animal crop assaults. The seeds are harvested, sun-dried for a few days, and then stored in wood, mud, metal, or plastic containers with a variety of conventional pest control measures (Rahim, 1998). In general, men or the head of the household play a significant role in exchanging grain crops within and outside of villages. Women are primarily responsible for sharing vegetable and pulse seeds within the family.

3 Sustainable Storage Methods of the Locally Cultivated Crops

Traditional seed conservation and seed storage methods rely on regulated environmental conditions to preserve long-term viability of seeds and genetic variety, which can assure agricultural viability in the event of natural fiascos. The storage of the seeds after harvest between growing seasons is an essential footstep linking crop generations (Kays & Paull, 2004; Snowden, 2010). An efficient method of storage after the harvest season can help the socioeconomic situation in India, particularly in the Himalayan region. These storage buildings are environmentally beneficial, inexpensive, and give a long shelf life for the commodities held. Farmers' expertise in storing commodities using traditional techniques is more secure and protects commodities from infestation for a longer period of time. Though chemical treatments conserve commodities, they also leave hazardous residues behind. Grain, legumes, and cereals must be stored all year to meet demand in the off-season. Adequate storage and processing facilities will bridge the demand–supply mismatch. It has been discovered that different parts of India have their own storing strategies. This also relies on whether the storage facilities are outdoor or indoor, large or little, permanent or temporary, and, last but not least, if the storage is for communal or individual use. Structures for storage could be semi-open, open, or closed. Certain approaches are traditional and exclusive to a culture. These are fully based on the wisdom of locals who are aware of the environment in their native land.

Except for seeds and tubers, wild edible plants have a short duration and a short shelf life, therefore they must be consumed right away or conserved (sun/shade dried) for use in winters when little fresh food is available, either wild or produced (Mishra et al., 2008; Sundriyal & Sundriyal, 2003). Leafy and other vegetables are commonly dried in the region. When the leaves of a few cultivated crops, such as tomato, cabbage, and capsicum, ripen, they are cut and dried on roof tops throughout the months of August and September, when they are plentiful. Others, such as radish, turnip, cabbage, and potato, are kept fresh by burying them in pits dug in basements that keep chilly (10_C) all year (Rana et al., 2012a). Minor cereal grains are often kept for use during scarcity since they retain longer. While collecting data on wild edible plants, Rana et al. (2012a) discovered up to 50-year-old grains of amaranth and finger millet saved by some families in their traditional seed storage bins. Insects, rodents, and microbes destroy over 30% of the seeds during storage. The storage period begins when the seeds reach physiological maturity in the field and ends when they are sown the following season (Fig. 3). The seeds' germination capacity, viability, and vitality should be preserved. Environmental elements such as storage structure, seed internal factors like moisture content of the seeds, kind and variety of the seeds, seed health and quality, whereas the external factors like origin of the seed, interaction of microbes and pest, climatic conditions like temperature, pH, relative humidity etc., have a significant impact on natural contamination of food grains.

4 Internal Factors

4.1 Moisture Content of the Seeds

The moisture content of the seeds is the most critical factor impacting viability during storage. If the seed has high moisture content, it is prone to mould formation and pest infestation. Seeds with more than 14% moisture content decay quickly, whereas seeds with very low moisture content deteriorate slowly. Harrington's thumb rule states that a 1% decrease in seed moisture content doubles the seed's potential. This guideline is only relevant at moisture levels ranging from 5 to 14%, because moisture levels below 5% trigger physiochemical changes in the seeds, and moisture levels beyond 14% are susceptible to insect and mould assault. Another criterion suggests that every 5 °C fall in storage temperature doubles seed life. It is valid for temperatures ranging from 0 to 50 °C. The safe moisture content is determined by the storage period, storage structure, seed variety, and packaging materials utilized. For example, if cereals are to be stored openly, a moisture content of 10% is appropriate; if they are to be stored in sealed containers, the seeds must be dried to a moisture content of 4 - 8%. This region mainstreamed with cool climatic conditions which preserves the seeds from the deterioration.

4.2 Kind and Variety of Seeds

The kind and variety of seeds have a large impact on seed storage. Some seeds, such as oil seeds such as groundnut, mustard, and soyabean, have a short storage life, while others, such as wheat and cotton, have a medium storage life, and rice and legumes can be stored for a longer amount of time. Starchy seeds, in general, can be stored for a longer amount of time than oil or proteinaceous seeds due to their hygroscopic nature.

4.3 Seed Health and Quality

Seeds must be healthy and are free from pests and diseases. From the period of physiological maturity till harvest, numerous environmental factors can have a significant impact on seed quality. Soil health, nutrient availability to the plant, nutrient deficit during plant growth, and pest and disease damage may all have an impact on seed quality before harvesting. Seeds exposed to the weathering process may lose their germination viability due to mechanical damage. When compared to damaged and degraded seeds, healthy, plump, and undamaged seeds can be stored for a longer amount of time.

5 External Factors

5.1 Origin of the Seed

The viability of seeds gathered from different climatic locations and at different seasons varies. Seeds obtained from a high RH and temperature area at the time of seed maturity or harvest can be preserved for a shorter period of time than seeds harvested from a low RH and moderate temperature area.

5.2 Interaction of Microbes and Pests

Bacteria, fungi, mites, insects, rodents, and birds can all harm seeds while they are in storage. Bacteria have no discernible influence on the stored seeds because they require water to reproduce. Storage fungus such as Aspergillus and Penicillium infect seeds and produce mycotoxins that degrade seed quality. Insects and mites do significant harm, particularly in warm and humid circumstances. Birds and rodents cause significant seed loss during the storage period.

5.3 Climatic Conditions: Relative Humidity (RH) and Temperature

Seeds are naturally hygroscopic. As a result, when exposed to a specific quantity of air humidity at a specific temperature, they achieve precise moisture content. This is referred to as moisture equilibrium content. The moisture equilibrium content of seeds varies. Even at the same relative humidity and temperature, it is generally lower in oily seeds than in starchy seeds. Seeds should be stored in dry and cool settings to maintain their quality during storage. The ICAR, DRDO, and Indian School of Mines recognized a hill location (500 diameters and 100 m height) in Leh and Chang-La in Ladakh as a suitable place for establishing a National Permafrost Facility for keeping plant germplasm as a safety repository, similar to Svalbard in the North Pole. The National Bureau of Plant Genetic Resources in New Delhi has a germplasm collection of approximately four lakh accessions in its Gene Bank. A permafrost facility in Ladakh was planned to provide long-term storage and a safety net in the event of a disaster.

5.4 Storage Structures/ Materials Used

There was no additional storage expense, the resources required were easily available, the storage structure was built as part of the house, so there was no additional space problem, and no further technical knowledge was required. Farmers in India mostly use two major sorts of storage structures, depending on their resources: old or indigenous structures and new or modern storage structures (Lamichaney et al., 2019). Mud constructions to modern containers are used as storage. The containers are created of locally accessible materials and vary in style, shape, size, and purpose. Wood, bamboo, reeds, clay, bricks, paddy straw, wheat straw, cow manure, and other materials are used. Grains can be stored indoors, outside, or underground (Channal et al., 2004). Traditional storage structures encompass a variety of structures created and mastered by ancient and/or local farming cultures throughout the country. Their design and application vary according to agroclimatic conditions, and they are constructed from a range of locally available materials. Storage facilities produced and constructed by various research and development organisations and commercial suppliers around the country are included in the modern storage structures (Naveenaa et al., 2017). Farmers store their grains in traditional constructions such as polypropylene bags, jute sacks, granaries built of wood and mud, and plastic containers. While typical storage facilities are inexpensive and easy to use for farmers, they are not always efficient in preserving grains from storage pests, resulting in substantial losses (Kotu et al., 2019). Different storage structures are available based on the duration of the seed storage. Storage structures can be classified into indigenous structures and modern structures.

6 Indigenous Traditional Storage Structures in the Himalayan Region

Storage and maintenance of agricultural products are critical post-harvest tasks. A significant amount of food grains perish after harvest due to a lack of adequate storage and processing facilities (Singh & Satapathy, 2003). Small or large storehouses, indoor or outdoor, temporary or permanent, and individual or community storage structures exist. The interior storage is primarily used to obtain seed, whilst grains for consumption are stored in separate structures built away from the dwelling (Jain et al., 2004). The indigenous peoples of the tropics and subtropics primarily store food grains in traditional ways. Traditional methods have been utilized for many years with little or no alteration and have been successful due to the use of scientific concepts, which are often overlooked. The choice of a traditional storage system by an ethnic group is often influenced by climate, but local natural resources and customs also plays a major role (Hall, 1970). Seeds stored in unsuitable circumstances are very vulnerable to fungal assault and/or insect infestation. Insect pests that attack stored seeds multiply rapidly and can destroy an entire seed lot in a single season, making them unsuitable for crop cultivation. In recent years, there has been a growing interest in understanding the traditional seed storage system, not only because it is more environmentally friendly than alternative chemical storage techniques, but also because it is simple, dependable, and readily available to farmers all over the world (Kumar et al., 2009).

6.1 Gunny Bags

Gunny bags, which are both resilient and affordable, are used to store seeds. Capacity of the bag varies from 10 to 100 kgs. They are lightweight and allow air to circulate, keeping the seeds cold. They can be stacked within the household. There is no need for a separate storage location for gunny bags. Gunny bags should be treated with a 10% neem kernel solution before to storage. Before using, soak the gunny bags in neem kernel extract for 15 min and let them dry in the shade. New gunny bags should soak for 30 min before use. The seeds are stored in dried bags. Pests can be kept away from seeds for up to four months. After four months, the seeds will be dried and again the bags will be treated with neem kernel extract.

6.2 Mud Pots/Earthen Pots

Cereals are stored by farmers in tall mud pots or bins. These are composed of clay soil and plant fibres. Cereal crop husks can sometimes be blended with clay to strengthen the storage structure. The mud pot is around 1–3 m tall, with a narrow entrance at the top and a tight lid. The pots' walls are coated with clay, and the mouth is sealed with stiff cow dung paste strengthened with fabric. Depending on the size of the pot, pots are stacked vertically one on top of the other. The capacity of the pot varies according to its size. It can store seeds and grains and can only be accessed through the top aperture.

6.3 Paddy Straw Bin

The ethnic groups live in hilly areas where the rainfall is high and the humidity, excessive using straw bins. The straw bins protect the grains from the moisture and preserves it as seed grain for the next season. Dried paddy plants are used for making temporary structures which after filling the grains are further reinforced from outside by winding paddy straw ropes around the whole structure. These structures generally store up to 5quintals of paddy grains. It is a common practice in eastern humid regions in India. Whereas, in Southern parts of India, palm leaves are also incorporated in these structures to provide them extra strength and safety from heavy rains which are prevalent in these regions. Puri is the name of one of the indigenous storage facilities. It is built with paddy straw over a hard surface of the ground, with a layer of loose straw provided at the bottom. This is done to prevent moisture from absorbing from the ground. After the seeds have been loaded, the structure must be covered with straw to make a conical roof. Because it is easily damaged by rodents, the side wall can be built with brick/cement concrete. One of the indigenous storage is called Puri. It is built with paddy straw over a hard surface of the ground, with a layer of loose straw provided at the bottom. This is done to prevent moisture from absorbing from the ground. After the seeds have been loaded, the structure must be covered with straw to make a conical roof. Because it is easily damaged by rodents, the side wall can be built with brick/cement concrete. The storage container's capacity ranges from 5 to 15 tonnes (Karthikeyan et al., 2009).

6.4 Bamboo Containers

Bamboo grain storage container, Kanaja, is another name for it. The bamboo bin is a popular storage construction that can be built in any open place for a very low cost. The base is typically circular with a large hole at the top. The height differs. To avoid grain spillage and pilferage, it is plastered with a mud and cow dung combination. Straw or gunny bags are also glued over the top. The clay creates an impenetrable layer that prevents even small insect pests from entering. The insect repellent effect of the ginger grass used in the top cover prevents insects from settling on the structure.

6.5 Wooden Boxes

Wooden boxes are also called as Sanduka, are used to store pulses, seeds, and tiny amounts of grains. These bins may hold between 3 and 12 quintals. In some circumstances, a barrier is built inside the box to hold two to three different types of grains. A large lid on top with a little gap allows the grains to be removed. The box is raised 12 in. above ground level by stands/legs to protect the grains from dampness. The box must be polished on a regular basis to ensure its longevity (Fig. 1).

Fig. 1 (1) Vegetable seeds storage in bottle gourd; (2) Maize cobs hanging on roof; (3) Storage of potato seeds in wooden boxes; 4. Various indigenous seeds storage in bottle gourds

6.6 Use of Wooden Bin (Kothar/Kothari)

Wooden bins built of the *kali* tree, known locally as *Kothar* and *Kothari*, for storing grains, particularly maize and wheat. Kothar and Kothari have the same structure but differ only in size. In terms of the structure, farmers revealed their traditional knowledge that both Kothar and Kothari are entirely made of locally available Kail and Deodar tree wood. The corner of Kothar's four legs is made of *Deodar* tree (*Cedrus deodara*), and the main body is constructed of *Kail* tree. Farmers believed that the insect resistance of Deodar and Kail wood aids in the long-term preservation of grains. These constructions are extremely long-lasting, and farmers have used them for storage for more than 50 years (Sharma et al., 2022).

6.7 Underground Storage

Underground structure is also called as Hagevu and used for grain storage. It is a simple pit coated with straw ropes to minimize moisture damage. Hagevu is sometimes built as an inside construction (with stones). This is an age-old storage system that is built in agro-ecological zones when the water table is low. It can hold up to 20 tonnes of grains such as millet, cowpea, sorghum, and others. It is either bell-shaped or cylindrical. Insulated with straw mats or corn husk mats with 3–9 feet deep and diameter, and it's made of hardwood planks and polythene/iron sheets. After completely filling the structure, a thick layer of paddy straw is laid on top and the structure is sealed with mud plaster. It is crucial to note, however, that these indigenous storage structures are not suited for storing grains for extended periods of time. For a range of indoor and outdoor storage containers and structures, regular mud plastering is essential to extend their life and ensure safe grain storage.

6.8 Rectangular Wooden Bins

This rectangular wooden construction is intended to protect seeds and grains from insects, dampness, mould growth, and bird and rodent attack. The bin wall is constructed with wooden boards to a height of 1.5–2 m, is 80 cm above ground level, and is supported by four wooden poles. The entire unit is divided into four equal pieces, each of which serves as a drawer for storage. As a roofing material, a tight hardwood board is placed on top. A little outlet at the base is utilized to remove seeds from the storage structure. One tonne is the capacity of such a storage container.

6.9 The Crib

This is fully built of bamboo, wood, metal wires, and thatch straws roofed in such a way that air may pass through them perpendicularly. It has a rectangular shape and is elevated above ground by 0.5–1 m. To keep rats from damaging the product, the legs are fitted with a rat-proof mechanism. Its form facilitates grain drying while allowing natural airflow to continue.

6.10 Hapur Tekka

It is a cylindrical rubberized cloth structure supported by bamboo poles on a metal tube base, with a small hole in the bottom for grain removal. This structure has a storage capacity of 1–3 metric tonnes. The construction is made up of a metal basis with 22 gauge sheets built on it, a rubberized cloth container, and bamboo pillars for lateral support. The structure stands 2 m tall.

6.11 On the Rooftop Floor

Buikal is another name for it. This method is used to store crops such as maize and potatoes. The seeds are collected here and stored on the roof. The grains are processed prior to settling, and while storing, they are treated in numerous homemade and traditional procedures that are most common because to readily available ingredients.

6.12 Storage Bins on Elevated Floor

It is an interior building built of cement and burned bricks. It is constructed on a raised level, and when the polythene sheet is imbedded, the walls should be plastered to create an airtight seal. The structure's inlet is at the top and its outflow is at the bottom. To reinforce the walls, the inner layer should be reinforced with iron bars. This construction is employed to keep the moisture level of the stored product the same as it was when it was stored. The capacity of rural dwellings varies according on the available space.

6.13 Separate House for Storage

A commonly used approach in which a small house is built and the entire harvest is housed, in addition to the previously described methods for repelling insects and vermin. The Romans were especially fond of any dried fruit that could be produced. In the Middle Ages, "still houses" were built specifically to dry fruits, vegetables, and herbs in locations without enough direct sunlight. The heat needed to dry and, in some cases, smoke food was produced by a fire.

6.14 Reinforced Cement Concrete Ring Bin

It is built with cement concrete rings, which are widely distributed throughout. On the cement concrete roof with a steel inlet opening, the rings are placed one atop the other. An outlet is supplied at either the base or the bottom ring. Cement mortar is used to bind the rings together. The capacity of each bin is determined by the diameter of each ring and the number of rings utilized in each bin.

6.15 CAP Storage (Cover and Plinth)

It entails the erection of 14-inch-high masonry pillars with grooves into which wooden crates for stacking bags of food grains are fastened. The construction may be built in less than three weeks. It is a cost-effective method of large-scale storage.

6.16 Open Fireplace

Traditionally, the majority of farmers have stored their grains near where they cook in order for the heat and smoke to keep pests at bay. Barns with slow-burning fires are used to keep grains dry when keeping a large quantity.

6.17 Gourd Casing

The outer casing of gourd vegetables is traditionally used for seed storage. Seeds for vegetable crops are kept in these. Some people use dried empty bottle gourds (Fig. 1), clay jars shaped like gourds, or gourd-shaped baskets as storage. If it's a basket, it needs to be tightly mud-plastered.

6.18 Bhukari/Bhakari

Bukhari storage buildings are cylindrical and are used to store paddy, maize, wheat, sorghum, minor pulses, and other grains. This can be created entirely of mud or mud & bamboo. A wooden or masonry platform raises the cylindrical storage structures above ground. The bin's floor is built of either timber planks or bamboo splits, which are plastered with mud mixed with excrement and paddy straw. The structure's walls are built of timber or bamboo framework and bamboo matting. On both sides of the walls, mud-straw plaster is put. The cylindrical construction has an overhanging cone-style roof. The roof is typically constructed of bamboo structure and straw. These structures are built near the farmers' homes. At the floor's base, large stones are arranged in a concentric pattern. Wooden sticks are placed on top of the stones to build a platform. The construction has a circular form. Mud or cement and bricks are used to construct 1 m-high side walls. Over the top of the cylindrical structure is a conical roof made of bamboo sticks or coconut fronds. A wooden plank is used to create an opening in the roof so that someone can enter and get the seeds as needed. Ladders are used by farmers to harvest seeds from the roof. An inverted pot is placed over the conical point of the roof to stop rainwater from entering the storage structure.

6.19 Improved Bhukhari

Although the structure's basic form has not altered, it has changed to material and building techniques to improve its durability and safety. The circular floor of the building is made of either a double layer of bamboo splits arranged closely and at right angles to one another or hardwood planks connected by lap joints. Over the floor is a mud plastering that is 5 cm thick. The walls of the building are made of two sets of sturdy bamboo framework. The interstellar space is covered in mud. The walls on both sides are plastered with mud. Conical in shape, the roof is supported by a bamboo frame that is thatched with paddy straw or another material. The top of the conical roof is covered with a 4–5 cm thick layer of mud to provide further weather protection. The building is 1.5 m above the ground and is supported by masonry or wood. To keep rats out of the storage building, rat-proofing cones have been put on each of the four pillars.

7 Modern Storage Structures

7.1 Pusa Bin

This is a mud or brick storage structure with a polythene film implanted into the walls. Indian Agricultural Research Institute (IARI), New Delhi, invented the Pusa Bin. It is constructed using unburned brick. To make it airtight, a polyethylene sheet is inserted between two brick walls. The entrance is at the top of the bin for loading and unloading, while the outflow is at the bottom. To prevent rat damage, bins are built with a few layers of burnt bricks plastered with cement at the bottom. It is a sandwiched LDPE (Low density polythene sheet) bin. This bin can safely store approximately 10 MT of grain. Warehousing is the business of storing items for profit. The warehouse is a physical site that gathers commodities and products for ultimate distribution to consumers or other businesses.

7.2 Silo

A silo is a robust and cylindrical building that is mostly used to store rice, a staple food grain. Bulk grains are unloaded into these structures and transported to the storage structure using conveyor belts and mechanical processes. It is placed on an embankment made of coarse gravel and insulated from moisture. It is pest resistant and is made of various materials like metal, concrete, plastic, and mud. In a Silo, you can store grains for 6 months to some years. Metallic silos and super grain sacks are extremely good in preventing maize weevils and larger grain borers. Nonetheless, technical soundness is a necessary but not sufficient prerequisite for farmers to accept market commodities or technology (Chigoverah & Mvumi, 2016).

7.3 Storage in Metal Drums

Farmers store sorghum, maize, millets, and groundnuts in metal drums. The half-ton capacity drum needs to be clean and dry before being stored. The drum is filled with seeds using the funnel, and the drum is then tightly closed with a cap. Seeds can be shielded from rodent damage, and pests can easily be kept at bay by fumigating the drums.

7.4 Storage in Metal Bins

Metal bins can be used for small-scale storage. Bins are positioned on a raised platform or cement base to prevent water seepage from the outer floor into the bin. Bins are light in weight and easy to transport. The storage container has a capacity of one ton.

8 Homemade and Traditional Ways of Storage Using Natural Products

When resources are low, storing seeds for more than a year becomes a significant problem, but it has the potential to dramatically extend planting options, improve food security, and raise resilience for the farmers in the developing-world countries. Seed production, handling, and storage are critical agricultural practises for achieving food security by ensuring seed availability at the correct time. In the early stages of crop growth, proper seed treatment improves healthy germination, seedling and plant establishment, and crop protection. Indigenous technical knowledge is distinct, traditional, local knowledge that exists within and is created around the specific conditions of indigenous women and men in a certain geographical location that is unique among the people and community (Costa, 2000). This historic expertise is employed in the management of various animals and diseases in fields, as well as the development of unique storage structures and methods of long-term storage in home yards (Deka et al., 2006). There are few Homemade and traditional ways of storage are using natural Products are listed below:

8.1 Sun Drying

Food grains drying techniques have long been applied since ancient times in conventional ways, such as drying in the sun. Evidence suggests that the Middle East and oriental societies deliberately dried foods in the scorching sun as early as 12,000 B.C. Later societies left more evidence, and each had ways and materials that reflected their food supply. To prevent post-harvest losses, farmers use procedures such as drying the grain before storing it, as well as adopting storage facilities that are adequately aired and moisture-proof. Sun drying is the process of exposing grains to sunlight at temperatures over 20 degrees. The duration of sun drying varies with each grain and is best known to the farmer. The best way to determine if they have dried enough for storage is by chewing them and farmers are well versed with it (Fig. 2). Optimal seed moisture of 10–12% is essential for appropriate storage of seeds. During the sun drying, it will reduce the moisture in the seeds and most of the insect pests are died due to exposure of the direct sunlight and to be stored (Kumar & Singh, 2013) (Fig. 3).

8.2 Using Camphor

Camphor is one of the protective measures used by farmers from the damage caused by insects for short-term storage. It is acts as repellent, fumigant, and antifeedant pungent smell prevents insects from attacking the grains. Biotic and abiotic stresses have a substantial impact on seed quality. A variety of storage bugs infest cereal and pulse seeds. Farmers used a simple method of seed storage to overcome this challenge. In this practice, around 1 g of camphor piece was placed in the jute gunny bags for every 5 kg of seeds, and fresh camphor is changed with sun drying of seeds every 3–4 months. Because of the strong fragrance emitted by camphor, the camphor employed within the seed storage bag repelled storage pests (Karthikeyan et al., 2009).

8.3 Use of Deodar Oil and Salt

Utilizing deodar tree (*Cedrus deodara*) oil and common salt for secure storage of pulses seed, such as blackgram (*Vigna mungo*), lentil (*Lens culinaris*), and kulth (*Macrotyloma uniflorum*), assists in protecting their pulses seed against assault by storage insect-pest. In accordance with science, salt has an insecticidal and hygroscopic quality (Chander et al., 1991; Sharma et al., 2022).

Fig. 2 Sun drying on roof top: (1) Finger millets; (2) Large cardamom; (3 and 4) Indigenous garlic

8.4 Neem Oil in Seed Storage

Agriculture is the backbone of a rural subsistence economy. Farmers have adopted varied agricultural practises based on topography, agro-ecology, and cultural backgrounds, using time-tested indigenous knowledge and technologies. One such practise is the application of neem oil to uniformly cover the seeds prior to storage for seed treatment. Neem oil was found to repel a variety of storage insects, including weevils, red flour beetles, long headed flour beetles, and fig moths.

Fig. 3 Local traditional crop panicles/cobs hanging and saving for next season; (1) Fox tail millets and maize; (2) Little millet; (3) Sorghum; (4) All types of indigenous crops

8.5 Neem Leaves in Seed Storage

Farmers take neem leaves from trees, dry them in the shade, mix them with seeds, and store them in gunny bags or containers. Neem leaves contain bitter compounds known as meliacins, such as nimbin, salannin, and meliantriol, which work as anti-feedants against storage pests. Azadirachtin, an active chemical found in neem leaves, functions as an insect repellant, insect feeding inhibitor, and sterilant with antifungal and nontoxic properties (Mishra & Pandey, 2014). These leaves' strong fragrance repels storage pests such as smaller grain borers; saw toothed beetles, and flat grain beetles (Karthikeyan et al., 2009).

8.6 Use of Salt and Chilli Powder

Pulse seeds are preserved in a plastic bag or bin with a mixture of 200 g salt and 200 g dry chilli powder for 15 kg seeds. Chilli's spicy flavour repels insects, and salt has hygroscopic and insecticidal properties, resulting in superior storage insect control (Madhumathy et al., 2007).

8.7 Use of Neem Leaves Powder in Seed Storage

A variety of seed storage pests, such as pulse beetles, smaller grain borers, and others, caused considerable losses in terms of seed quality and economic returns in crops such as pulses and oilseeds. Farmers used indigenous post-harvest seed management techniques that do not necessitate a high level of technical expertise or a large investment. The use of neem leaves in the storage of beans and other crops was one such strategy. Farmers have known about the insecticidal benefits of neem from time immemorial. The bitter taste of neem protects seeds from pests and pathogens due to its various qualities such as repellence, feeding and ovipositional discouragement, and growth inhabitation (Kwasi Opoku et al., 2011).

8.8 Seed Storage with Ash

One of the most effective traditional seed preservation methods is storing seeds with ash. Burned ash from plant woods and other biological materials, like as cow dung, and has long been thought to be a vital agent in preventing fungal and insect growth in seed storage (Kiruba et al., 2006, 2008).When compared to untreated controls, seeds of various species, including cowpea, maize, melon, and beans, survived better or were less impacted by pests after being treated with ash (Murdock et al., 1997; Oguntade & Adekunle, 2010; Wambugu et al., 2009; Wolfson et al., 1991). Farmers have been using wood/cow dung ash to store seeds for centuries. Farmers traditionally stored pulse in earthen mud pots, with seeds filled to 3/4th volume and the remaining top 1/4th top covered with wood/cow dung ash to control various storage pests such as pulse beetles. After a few months of storage, the seeds were left open to the light, and the ash was dispersed above the seeds' surface and maintained for storage. Rekha and Padmakar (2014) reported that the *Jowar* (Sorghum) seeds were combined with ash in a 4:1 ratio, and the seeds were sealed in jute gunny bags before storage. The beneficial effect of ash seed treatment is attributed to the presence of silica in ash, which interferes with insect feeding while simultaneously inhibiting fungal pathogen multiplication. Ash is a pest management solution that is both safe and effective. To keep beetles and other storage pests at bay, combine equal parts seed and wood ash. Lantana camara leaf ash is highly good against pests that attack stored potato seedlings. Seed storage is a crucial procedure for preserving the viability and vigour of seeds throughout storage. Ash dust reduces the relative humidity of the storage environment while also drying the seed surface. Because ash dust covers the seeds, egg laying and larval development of storage pests may be hampered. It also obscures insect movement in search of mating partners, and friction between dust particles and the insect's cuticle causes desiccation and hinders pest development.

8.9 Sand-Seed Layer Method of Storage

A thick layer of sand is maintained at the base of the mud pot in this form of sand-seed layer storage, and sundried seeds are distributed over this sand. Sand is sprinkled over the seeds once more. This method of layering the sand-seed mixture is repeated until it reaches the brim of the pot. The jar has a lid and has been made airtight by smearing with cow dung paste. Sand particles operate as an abrasive agent on the cuticle of insects, killing them. It also works as a barrier between the seeds and the insects, while cow dung spread on the top of the pot acts as a repellant, protecting the seeds from pests during storage (Prakash et al., 2016).

8.10 Use of Lime Powder (Calcium Carbonate)

Farmers use this approach to keep pulse seeds by dusting them with calcium carbonate (lime). Lime powder is blended evenly with seeds and stored in gunny bags in a dry place. For 1 kg of grains, 10–15 g of lime is often used. Calcium carbonate acts as repellent and anti-feedant properties reduce storage bug infestation and insect reproduction (Rekha & Padmakar, 2014).

8.11 Storage of Seeds with Sweet Flag

This is an indigenous method of seed storage in which seeds are blended with sweet flag (*Acorus calamus*) powder (10 g per kg of seeds) to protect seeds against insect attack in the storage of pulses, cereals, and oil seeds. The strong fragrance emitted by sweet flag functions as a repellent to all storage pests.

8.12 Seed Storage with Common Salt

Farmers used common salt in the storing of red gram seeds. In this practice, around 200 g of salt was manually blended for a kg of red gram seeds and stored in jute gunny bags that were sewn. This practice aids in keeping insects away from the stored seeds. Because salt has an abrasive effect on insect skin, it restricts movement within storage containers. Farmers said this practice was moderately effective and reasonably priced (Karthikeyan et al., 2009).

8.13 Use of Garlic Cloves

Farmers have a practise of stacking garlic cloves in storage bins filled with seeds like pulses. Several pests are repulsed by the garlic cloves. The primary chemicals included in garlic are diallyl di-sulphide, diallyl tri-sulphide, and diallyl sulphide, which are anti-feedant, bactericidal, nematicidal, insecticidal, fungicidal, and function as a repellant for certain storage pests (Prowse et al., 2006).

8.14 Storage Bins Soiled with Cow Dung

Farmers cover bamboo bins with clay and cow dung before storing seeds like pulses to prevent insect attack from the outside. Soil particles absorb any remaining moisture in the seeds, keeping them from spoiling. Soil and cow dung paste act as a obstacle between seeds and storage insects, as well as a repellent to storage insect pests (Prakash et al., 2016).

8.15 Storage for Specific Crops

Integration of science and traditional knowledge would aid in the development of technologies that are need-based, better problem solvers, locally available, easily acceptable, cost effective, compelling, and believable to rural clients. Indigenous practises emerge from the people's cultural contact with unique environmental conditions and are based on traditional societies' intimate knowledge of their surroundings. These criteria suggest that indigenous knowledge is environmentally beneficial and safe for both man and the environment (Karthikeyan et al., 2009). Crop wise storage methods are listed below:

8.16 Storage of Pumpkin and Pomelo

By putting mustard oil to the surface of the fully developed pumpkin or pomelo, the pumpkin or pomelo can be preserved for a longer period of time. The fruit is then sun-dried for two days and stored over a smoked chullah. This extends the shelf life of both fruits.

8.17 Oilseeds and Pulses Storage

If cereals/oilseeds/pulses are not stored properly, they are easily damaged by pests and illnesses. The seeds are preserved in earthen pots with a layer of sand 10–12 cm thick above the grains. Tin pots can be used in place of clay pots, however a thin layer of sand of about 5 cm should be added before storing the grains in the tin pots.

8.18 Storage of Onions, Garlic, Potato

After harvesting, onions, garlic, and potatoes can be preserved for a longer period of time. The harvested uncleaned onions and potatoes are collected in a bamboo sieve, which is then placed at least 8 feet above a fuel chulah. This aids in storage for up to 7 months.

8.19 Pulses Storage Structure

Pulses storage is the most difficult issue for farmers since the seeds retain more moisture due to their size. The structure is made of bamboo or wood, known locally as Bhoral, and is commonly used for rice storage. The structure is filled with rice or wheat husk and pulse seed bags, which are then wrapped in jute bags and stored inside the structure. This protects the seeds from various rodents and pests. Furthermore, the husk absorbs moisture from the seeds, which aids in the preservation of the seeds against disease concerns.

There are few advantages are associated with these traditional storage practices such as not much more storage cost, the resources required were easily available, the storage structure were made as the part of house so not more problem of space, not more technical knowledge is needed. However, few disadvantages are associated with these indigenous technologies like the seeds no longer have a lengthy storage life, the amount of seed that can be stored is limited, and disease and insect incidence is considerable in comparison to modern procedures.

9 Socio-cultural System and Exchange of Seeds

9.1 Bio-cultural Heritage

Traditional knowledge, biodiversity, landscapes, cultural and spiritual values, and customary laws are all intertwined in bio-cultural heritage. Although the holistic worldview of Quechua people in the Andes (Peru) inspired the concept, it is also visible in Himalayan communities in India. The communities see culture as an essential component of nature. All customs involve nature, whether it is a religious ritual, a family event, or a communal festival. Hindu religious rituals include the adoration of trees, water sources, and cows, as well as a variety of rituals and practices to appease deities in order to protect crops and animals. They are inextricably linked to biodiversity conservation, and environment is revered in their traditional cultures. Indigenous mountain communities have a profound relationship with their landscape characteristics such as rocks, mountains, and lakes, which has been passed down via hereditary practices anchored in trust and reverence and expressed through numerous rituals, as well as with their ancestors. Traditional knowledge, rituals, and practices reflect the rich bio-cultural past as well as cultural values such as reciprocity, solidarity, balance, and collectivity. In the Eastern Himalayan region, Bungthing (Lepcha priests) and Phedangbha (Limbu priests) have conserving several endangered plant species in their domestic gardens for religious purposes (Mukerjee et al., 2018).

9.2 Conservation Through Management of Home Gardens/ Backyard Farms

Maintenance of the home gardens/ backyard farms are the best conservation activity of nutri-rich food crops which is having more diverse in a particular small place. The most important species in home gardens are linked to diversity and livelihoods. They are typically traditional crops with significant ties to local culinary culture and uses. In home gardens, they have a greater variety of varietals. Most essential species are managed by all farming households, regardless of socioeconomic status. The abundance of major home garden species is evenly divided among richer and poorer farmer groups. The biggest contributors to household nutrition are key home garden plants. These important species are diverse and may be grown at various periods of the year, ensuring a year-round supply of diverse diets for home use. Farmers must keep a variety of spices and vegetables in their gardens to ensure a consistent supply of herbs, spices, and vegetables. The aforementioned cultural needs give incentives to conserve critical home garden species and varietal diversity that are not usually present in bigger agro-ecosystems. This argues that government policies and research agendas should reconsider the significance of home gardens to family well-being and society in general. Leafy vegetables, legumes, spices, fruits, and fodder species are the most important home garden species, providing food diversity to homes either directly or indirectly through improved animal output. Household dietary diversity can be used as a proxy measure of family nutrition. Some of the essential perennial species like tomato, eggplant, garlic, ginger, coriander, fenugreek, palak, amaranth, onion, chillies, etc. require relatively little management effort, are easy to maintain, and might provide a consistent household supply of spices and vegetables. Farmers must keep a variety of spices and vegetables in their gardens to ensure a consistent supply of herbs, spices, and vegetables (Johns & Sthapit, 2004).

9.3 Seed Exchange

Seed exchange is a frequent practice among farmers in the hilly regions. It is either between farmers within a farming community, between farmers in different ecological zones, or between farmers who live quite far apart. Seeds for planting can also be obtained from the market or preserved from past plantings. Farmers in the community rely on their social connections and familial ties to obtain additional seeds for planting. Farmers evaluate the seeds in small trial plots over two or three cropping seasons, making performance comparisons between the farmer's own variety and the variety acquired from neighbors, relatives, and friends, demonstrating good adaptation to the physical environment, being equally as tolerant to pests and diseases as the farmer's original cultivars, and yield (Sannegowda & Garkoti, 2022; Uguru, 1998).

Farmers contemplate exchanging seeds in a variety of scenarios, although it is most commonly done when seed quality deteriorates. Farmers also swap seeds if: seeds become diseased during storage, seeds are utilized for food owing to a lack of food grains, crop failure happens as a result of drought, and seeds are sold at high prices (Niekerk & Wynberg, 2017). Farmers' access to seeds of local landraces and neglected crops maintains local food and economic sources while also preserving genetic variety. Unfortunately, even big and well-established seed banks confront difficulties in keeping seeds for lengthy periods of time. Small-scale farmers' seed storage structures and granaries continue to rely significantly on ancient technologies, and are generally not designed or fitted for storing grain for extended periods of time, typically 1–2 years, the latter in the case of a bumper harvest. However, in resource-constrained tropical settings, there is also a need for low-cost, accessible methods of preventing dried seeds from rehydrating and degrading when placed in structures with high ambient humidity and in containers that may not be completely sealed. Accessible and affordable storage solutions can improve the quality of seeds transferred through informal seed systems. Despite successful seed preservation for many generations, there are still large rates of seed quality loss in traditionally conserved seeds, as well as losses that can be mitigated with technologies that combat seed decay in storage conditions (Croft et al., 2012).

9.4 Traditional Seed System

Traditional farming methods are still widely used in the Himalayan region, however many regions are changing. These changes include site loss, management changes, farm structure changes, and subsidy-driven crop type changes, such as switching from farm bred fodder seed stocks to commercial cultivars. Genetic loss of semi-natural and wild forage grass and legume populations will result from these alterations. On-farm seed selection entails identifying and harvesting healthier, taller, bigger, plumper, and heavier cobs, panicles, fruits, and vegetables for seed. Documenting and preserving historic methods of seed selection, production, storage, and exchange has become increasingly vital as many landraces and traditional crop cultivars are being eroded. Weakening of the traditional seed system has ramifications for seed sovereignty, conservation of in situ germplasm for future use, and nutraceutical security of Indian Himalayan farmers (Vernooy et al., 2014). Thus, the decrease of traditional knowledge is as important as genetic erosion itself, because the loss of information about the use and management of variety may result in the abandonment or loss of variations in the medium and long term (Pilling et al., 2020).

Farmers prioritize grain quality, crop byproducts, longevity, and predicted output in the traditional seed system. Furthermore, they choose seeds from single crop fields rather than mixed crop fields due to the risk of contamination and reduced yield. Traditional seed systems internalize minor environmental and meteorological fluctuations, maintain soil health, control market pricing, and assure minimal output and income security (Asiedu-Darko, 2014). Farmers switch seeds when the production begins to decline, which typically occurs after 7–8 years of continuous cultivation. Farmers examine the production, by-products, and longevity of the crop with the crop owner before exchanging or purchasing it, and then decide whether or not to take it. If the crop owners are relatives or friends, they mutually agree to exchange seeds in exchange for the same amount or twenty percent more soon after the crop harvest. Farmers collect an additional $1/4^{th}$ than expected during seed exchange or buy due to storage losses and keeping wastages during sowing (Samberg et al., 2013).

A traditional seed system administered by local farmers is essential for long-term food production, balanced nutrition, and the preservation of genetic variety in marginal milieu (Jarvis et al., 2000; Poudel et al., 2015). At the local community level, the informal seed system is generally popular, with the formal seed system playing a limited role except in river valleys and plain areas where improved farming is undertaken under assured irrigation. Hill farming seed systems rely on free seed exchange among farmer households, which can be performed by seed selection, production, storage and exchanges as small gifts, barter exchange, purchased from nearby markets or, to a lesser extent, trade (Bisht et al., 2018; Jensen et al., 2013; Nabuuma et al., 2022). It has been discovered that storing seeds in-house promotes the traditional seed system and increases the genetic diversity of local landraces (Coomes et al., 2015; Pandey et al., 2011).

9.5 Community Seed Banking

Community-based conservation activities encourage and support objectives of economic and social development, conservation, and sustainability (Dutta & Dutta, 2023). Community seed banks, in particular, have great potential for improving access to diverse seeds and building the resilience of smallholder farmers and communities (Vernooy et al., 2017). The community-led effort aiming at promoting, selling, and boosting the production and quality of indigenous crop types via a "farmer-trader interface" was a huge success in India's southern states. Adopting such a community-driven on-farm landrace conservation concept could breathe new life into the Himalayan region's custodian farmers. The value of maintaining genetic resources has grown in importance over the last few decades. Traditional farmers' roles in protecting and maintaining agrodiversity are critical in this environment (Aswani et al., 2018; Ebert & Engels, 2020; Mburu et al., 2016).

10 Conservation

Crop variety has been limited to one or a few genetically homogeneous species in recently developed intensive cropping systems. Crop genetic resource management ensures crop diversity, both in trust collections or gene banks (ex-situ) and on farms (in-situ) (Bezabih, 2008; Smale, 2006). Crop diversification is critical for farmers to combat production risks associated with changing conditions. Understanding farmers' crop attribute preferences and incentives to plant varied varieties is crucial to the success of on-farm conservation (di Falco et al., 2010). Effective genetic resource management and conservation occurs when genetic resources are recognized and exploited to satisfy the needs of local populations (Nurgi et al., 2023). Moreover, these landraces demand more conservation and research attention, and increased production can improve nutritional security by providing a balanced diet, combating micronutrient deficiencies, and preventing hunger (Singh et al., 2022). The gradual loss of traditional crop diversity is as a result of agricultural commercialization and increasing farmer access to contemporary crop varieties (Shrestha et al., 2004).

Agro-biodiversity conservation and management is a critical issue in the effort to attain food security for the world's rising population in the face of global change (Fatima et al., 2020).. In recent decades, the substantial changes in agricultural systems caused by industrialization and the introduction of contemporary cultivars have diminished the desire for quality products based on landrace cultivars, increasing the risk of genetic loss (Canella et al., 2022). Farmers' expertise of landraces is a priceless asset in germplasm conservation. Farmers use a purposeful approach to selection. Individual plants that are characteristic of a specific group or are useful for a specific purpose are chosen. Pre-harvest selection plants are typically excellent in terms of pod yield, pest and disease incidence, and overall plant performance (Jana, 1988). Plant breeders may be able to exploit the potential of these genetic resources adapted to the world's most hostile conditions by applying modern molecular breeding technologies.

The ethnic tactics have been tried and tested and have proven to be quite effective in pest-free storage of numerous goods. Some of the structures are rarely used due to altering agricultural practices of ethnic groups, which are mostly influenced by climatic circumstances. Even though the ethnic groups do not have established scientific knowledge, only traditional wisdom, the scientific underpinning for these structures is remarkable. Most of their practices are worth replicating because they are environmentally friendly and sustainable. Land use intensification, agricultural structural changes, climate change, and urbanization are all continual risks to the preservation of traditional landraces. These processes and their interactions reduce variety at the species and landscape levels, diminishing crop communities and related ecosystem services as a result of the loss of species-specific traditional knowledge. For the management of agro-biodiversity, local knowledge is crucial. Landrace seed varieties are consequently disappearing, along with part of the acquired traditional knowledge (Andualem et al., 2022; Lustosa-Silva et al., 2022; Wang, 2020, Zimmerer & de Haan, 2019).

11 Traditional Crop Landraces Diversity in the Himalayan Region

The term "traditionally cultivated landraces" refers to historical varieties with a certain degree of genetic heterogeneity that are not only essential sources of desirable traits for crop breeding but also serve as markers of local identity due to their association with traditional foods and enhanced sensory qualities (Casañas et al., 2017; Khoury et al., 2022; Ramirez-Villegas et al., 2022). Plant breeders may be able to exploit the potential of these genetic resources adapted to the world's most hostile conditions by applying modern molecular breeding technologies. A landrace is a "balanced populations variable in equilibrium with both environment and diseases and genetically dynamic" population (Harlan, 1992). Plant landraces are varied local adaptations of domesticated species that provide genetic resources for cultivation in harsh situations (Dwivedi et al., 2016). Plant breeders are required to incorporate good sources of new diversity into their breeding programmes, either through the use of landraces that are reasonably acclimated to the desired habitat or through wild relatives that require long pre-adaptation or pre-breeding. Landraces are a superior alternative since they are thought to be the most important repository of genetic variety that can be easily utilized (Nazco et al., 2012; Newton et al., 2010; Sharma et al., 2013). Farmers have long been responsible for preserving and improving agro-ecologically appropriate landraces. It was found that all family farmers collaborated with a variety of crops to diversify their production. These ancient landraces may include genetic resources that breeders and farmers might utilise to choose crops and modify them to meet changing climatic circumstances or the needs of a growing human population. Maxted et al. (2009) conducted an inventory of landraces documents the current landraces and associated knowledge in a specific geographic region and can be used to design effective conservation initiatives. The accompanying knowledge should include eco-geographic information on the site where it is grown, information about the farm and the farmer who grows them, nomenclature, cultivation and habits, and distinguishing characteristics. In the Himalayan region, the occurrence of distinct crop-wise landraces conserving in their specific region are given below:

11.1 Rice

Rich traditional knowledge of agriculture and allied activities in India aided in the development of a variety of crop landraces that are highly adapted to region-specific resource bases while also matching quality preferences. India has around 70,000 naturalized landraces spread across varied ecosystems, with the biggest diversity of fragrant rice found anywhere in the world (Kumari et al., 2023; Siddiq, 1992; Singh & Singh, 2003). Large numbers of rice landraces such as *Jattoo, Begumi, Ramjwain, Kalijhini, Chuhartu, Qudirbeigh, Mushkbudji, Mehwan, Thapachini, Tilkakchandan, Bakulia, Mirikrak, Gnoba, Batlong, Ryllobed, Tongla,Maiku Tsuk Buidhan, Lama, Krishma Bhog, Phulpattas, Allang amo,Pyapi, Aino ari, GovindBhog, Kolakhara, Sadakhara, Koliajiri, malbhong, Chakoa, bora, Amo hasso and Rarre amo, Phorel* are still occupying sizable acreage because of their special attributes like aroma, fine grains and medicinal properties (Rana et al., 2008, 2012a, 2012b). *Namfafzu, Dhanase, Takmaru, Dharmali, Juari Dhan, Red Zomu, Sirkey* are grown in high altitudes. *Sano* Attey is identified for lodging resistance. Rare localized cultivars viz., Red Zomu, Zokub, Nepal Dhan, Zomu, Takmaru, Pahelo dale, Tauli, Brihmphool, Dudhey Juari, Bael Buty, Sijali and Bhangeri needs immediate security due to their tiny population size in the state of Sikkim (Kapoor et al., 2017).

Aromatic landraces Mushk budji and Kamad have traditionally been served on special occasions like as weddings and celebrations. During the Maharaja's reign, these kinds were marketed as 'food for the royal families' in Srinagar's local markets, and could only be afforded by affluent and rich households due to its 4–5 times higher market price. Even today, these landraces are highly prized and offered to prominent visitors and dignitaries. Some red rice types named 'Zag' are utilized for the manufacture of snacks like 'Vazul bate' for pregnant ladies owing to their increased nutritious value, while some are favoured for preparation of munchies like 'Bate laaye', 'Mur-murei' and 'Chewrei'. The varieties' names in the regional verbal communication often reflect the rice's appearance (Kaw kreer, Laer beoul, Nika katwor, Shala kew), smell (Mushk budji, Mushkandi), colour (Zag, Safed Khuch, Bari safed, Kaw kreer, Khuch, Sig safed, Safeed braz, Safed cheena), cultivator's name (Aziz beoul, Begum, Qadir baig, Rehman bhatti, Noormiree), etc. Many species have a distinct flavour, and their seeds are traded among neighbors/relatives or given as gifts in the form of roasted rice, known locally as 'Bayel tamul'. The long-grained basmati type types are cooked as 'Kashmiri pulao' and served along with dry fruit and raisins in the famed Kashmiri dish locally dubbed as 'Wazwan'. As a result, the loss of biodiversity would imply a disappearing rural tradition (Husaini and Sofi (2018).

11.2 Wheat

The hilly tracts of western Himalaya (Kinnaur, Lahul Spiti, Pangi valley in Himachal Pradesh, Laddakh, Baramula, Gurez valley in Jammu & Kashmir), eastern region (North Bengal, Sikkim, Arunachal Pradesh) of India have a rich diversity of landraces and primitive cultivars. These are popular by numerous names such as Sharbati, Kankoo, Dharmaouri, Kathi, Kharchia, Lakha, Dhavati, Hansy, Donya, Safed mundri, Jhusia, Kishva, Churi Bhuri mundiya, Lal Kanak, White and Red pisi etc. in T. aestivum (Mehta et al., 2019) Samba poopattia, Gothumai, Goduma Vadlu, Kathia, Jhalia, Khandwa, Malawi, Wadanak, Gangajali in T. durum and Samba poopattia, Gothumai, Goduma Vadlu in T. Dicoccum (Phogat et al., 2021). When markets for their derived goods are extended through improved consumer access to knowledge on recipes, nutritive and cultural qualities, the likelihood of wheat landraces being conserved on-farm increases (Jaradat, 2013). Mehta et al. (2019) reported 36 unique wheat landraces on-farm conservation from Uttarakhand state, among that *Bhotia, Chanosi, Dapati, Daulatkhani, Dudh gehun, Lakha, Lal mundia, Mundia* and *Thanga* were very unique with their distinctive characters. The wheat dwarfing gene Norin 10, which emerged from an artificial crossing between the USA-introduced variety Turkey Red and the Japanese landrace Shiro-Daruma, is a typical example of landrace use. During the green revolution, a large increase in wheat output was obtained by developing high-yielding semi-dwarf varieties for ideal environmental circumstances using genes from this landrace (Adhikari et al., 2022).

11.3 Maize

The Himalayan region is home to many morphologically distinct maize landraces that are currently protected and used by farmers for a variety of uses. *Banchareymakai* (high altitude maize with yellow, flint kernel), *Badamtopo* (popcorn), *Chakhouchujak* (aromatic, soft, sticky), *Chapthimakai* (white, dent type kernels), *Chujak* (aromatic, popcorn), *Darikincho* (small yellow hard kernels), *Fingdong* (aromatic popcorn), *Gadbademakai* (white kernels with some purple flint kernels), *Kaalimakai* (dark purplish black), muri (good taste), Bhambla, Chitkanoo (popping), Gadda, Sathoo, Rohdu, Temta,Bhakadu, Misiri makai, Bhogad challi, Sweti, Poorvi Botapa, Khasi Riewhadem, *Kholakitthi* (sticky), *Kuchungdari* (orange colored popcorn, flint), *Kuchungtakmar* (mix yellow, white, purple and red kernels, flint), *Kukharey* (dwarf, high altitude), *Kukidolong* (flint), *Lachung maize* (multi coloured, tolerant to cold), *Nepali Sappa* (3 cobs/plant), *Pahelimakai* (yellow/orange flint), *Pahenli* (light dent), *Phensong* (cob up to 30 cm long), *Putalimakai* (multi-coloured), *Raathimakai* (dark red), *Sathiyamakai* (early-duration), *Setimakai* (white and soft), *Tanee* (popcorn) and *Tistamehdi* (flint), multi-cob bearing maize *puakzo* from Mizoram (Singh et al., 2016), Oghum, Oyusum, Fengtang, Ashum, Top puli, Tapio, Tami, Puiritchi, Topp (Arunachal Pradesh) Chitknoo, Salhu, Bhogad, Temta, Gadda, Rohdu (Himachal Pradesh), Chiti Makka, Lal Makka, Sathi (J&K), Poorvi Botapa, Khasi Riewhadem, Tsungrhu (Meghalaya), Pilli makki, Murali makka,Timasia, Gorakha makka, Anguli ghogha, Safed makka (Uttarakhand), *Kukkuri, Sweti, Sweti-Chapti*, *murli makai, paheli* (yellow) is considered good in terms of taste, as a substitute for rice, tolerant of many pests and diseases, and easy to store and *seti* (white) good taste, and *thapleykuchey* (smashed head), *birmakai* (cliff maize), a semi-wild type, has become extinct in the region (Sikkim), are some of the fascinating trait-specific unique local types/ landraces documented from this region (Babu & Rai, 2022; Prasanna, 2012; Rana et al., 2012b; Singode & Prasanna, 2010).

11.4 Soybean

Bhat, Bhatmash, Kala Bhat, Safed Bhat, Soria Bhat, Bhangrail Bhat, Thangri Bhat.

11.5 Barley

Owa jau, Jau, Va, Chama, Rena (a short awned variety), Gojai, Bijra, Thang Jau (awnless), Jhusi Jau (awned).

11.6 Finger Millet

It is locally called as Maduwa. The available landraces are: Nangchuniya, Tokaria, Putkya, Garhwalo, Jhankaria, Bhuwakhetia (round head inflorescence), Lumariyaw, Dhuniyaw, Lal madu (red grains), Safed Madu (whitish grain), Garau, Putki, Dwit, Ganoli, Gol Madu (fingers closed): (1) Timasi (matured in three months), (2) Chhaimari (matured in six months), (3) Chaumasi (fingers smaller as matured during rainy season), Chhitalu (fingers open and drooping), Nangchuni (The ears can be removed with the help of nail after maturation), Katuriya Mandua (big. Or long fingers and closed) (Bhat & Chauhan, 1999; Pandey et al., 2016).

11.7 *Allium Species*

Allium stracheyi Baker, *A. wallichii* Kunth, and *A. humile* Kunth have vernacular names such as 'jambu,' 'jamboo,' 'dhungar' (by 'Bhotias' of Johar and Dharma valleys, Pithoragarh, Kumaon region) and 'pharan,' 'faran,' 'koch,' 'ladum,' 'la Similarly, A. przewaliskianum Regel, A. stracheyi, and A. roylei Stern are renowned for their regional value as seasoning spices in Kashmir (J&K), and A. przewaliskianum and A. hypsystum Stearn are known for their regional value as seasoning spices in Nepal Himalaya (Fig. 2). In their study, Kuniyal and Negi (2018) mentioned the cultivation of 'pharan' (A. stracheyi) in Tolma village, Uttarakhand. Among the numerous famous edible Allium species in the Indian subcontinent, A. stracheyi is widely known for its high cultural and traditional value, and it has a high market demand in Uttarakhand Himalaya (Bisht et al., 2017; Pandey et al., 2021; Sundriyal & Sharma, 2016).

12 On-Farm Conservation of Landraces

Conservation should attempt to conserve all genetic variation available in a population, which is best ensured via seed rejuvenation in a setting as comparable to the population's native habitat. On the contrary, evaluation should try to identify and isolate obviously beneficial genotypes, involving selection and purification. Splitting original stocks into pure lines, as well as recurring seed increase cycles, are evaluation and utilization aids. Conservation protects germplasm inputs, while evaluation and utilization make conservation viable. Traditionally cultivated landraces were discovered in Himalayan hill agricultural contexts to be planted and kept on-farm. It allows farmers enough time to sow, select, and grow landrace populations for increased climatic resilience and tolerance/resistance to a variety of biotic and abiotic problems. The majority of traditional hill farming landrace populations are well adapted to certain agro-ecologies. Before beginning any on-farm conservation and utilization project, the dynamics of each crop must be understood. So long, the typical approach has been to transfer innovations developed elsewhere to farmers. However, such an approach has not only resulted in less efficient adoption of technologies by farmers, but has also resulted in the replacement or loss of local genetic resources. Several researchers documented on-farm conservation of these rare Himalayan landraces.

Smallholder farmers in underdeveloped countries can benefit from on-farm storage. It can improve household food security by allowing farmers to have a consistent source of their own food. It has the potential to boost farmers' income by allowing them to engage in temporal arbitrage in the face of significant seasonal price changes (Tesfaye & Tirivayi, 2018). Grain losses linked with traditional storage structures (without chemical treatment) approach 30% if grains are held for six months or more, according to on-farm research. Such a significant level of loss suggests that existing storage technologies must be improved (Chigoverah & Mvumi, 2016). Ex situ preservation in gene banks ought to ideally be complemented by in situ preservation on farms, which enables landraces to develop in their original areas of distribution under selection by farmers and environmental factors. In addition, the genetic diversity of populations on farms is significantly higher than in gene bank accessions (Conversa et al., 2020). Farmers in traditional agricultural systems manage genetic resources in farm conservation in a sustainable manner. On-farm conservation is a major strategy for ensuring future generations' access to landrace germplasms and agricultural diversification, both of which contribute to sustainability. This strategy has significant advantages and can help the functioning, resilience, and, to some extent, productivity of agroecosystems that grow conventional landraces (Thomas et al., 2011).

13 Shift and Threats

Crop diversification is essential to develop a varied range of nutrient-rich foods and provide food and nutritional security. Indigenous food systems are a storehouse of underutilized food crops with significant biodiversity, ensuring that a diverse diet benefits human health. These nutrient-dense, climate-resilient, adaptable crops are used medicinally and play an important role in local rituals and traditions (Mabhaudhi et al., 2019; Mustafa et al., 2019; Singh et al., 2022). In recent years, the government's particular initiatives to strengthen the road and communication network, increase tourist traffic, and intensify agricultural production have created more jobs and business opportunities, improving the socioeconomic standing of people throughout the tribal region. As a result, there has been a shift in lifestyle and eating habits. Traditional techniques of harvesting and consuming traditional food crops are becoming increasingly obsolete.

The richness of indigenous crop species in Himalayan villages has been preserved over time because to traditional farming practises. Farmers have consistently demonstrated an unwillingness to depart from the established pattern of crop production and crop germplasm conservation (Bisht et al., 2007. However, with increasing population pressure on land and the modernisation of various agricultural practises, the art of food production based on indigenous knowledge and local inputs is deteriorating (Uguru, 1998). To meet the current need for food crops, new crop varieties, crop conservation, and agricultural production practises have been developed. As a result of these factors, traditional farmers' previously conservative posture is changing, and scientific advances are being integrated into traditional germplasm conservation and farming practises. As more farmers embrace improved crop types, knowledge of indigenous agricultural diversity is sure to dwindle (Laghetti et al., 1990). Crop landraces are not immune to the natural process of extinction of developed variation. Its accelerated pace, which originally impacted fast-expanding high producing cultivars, is frightening over the world, including in India, particularly in the Himalayan foothills and Northeast India (Das et al., 2013; Rana et al., 2009; Roy et al., 2015). Many local communities have witnessed cultural transformations in recent history, prompting them to reconfigure their relationships with natural resources and rearticulate the local knowledge associated with plants (Khalid et al., 2023). People in multicultural settings tend to share knowledge and information, but the dominant culture frequently influences and imposes its viewpoint on minority groups, forcing the latter to conform to the conventional way of belief and behaving (Quave & Pieroni, 2015).

14 Legal Status

Landrace integration into the industrial chain: current state and future prospects In Kerala, India, the process of mainstreaming superior landraces into the legal framework of the production chain, notably the Protection of Plant Varieties and Farmers' Rights Act, 2001 (PPVFR Act) and the Geographical Indications of Goods (Registration and Protection) Act, 1999, proven encouraging (Blakeney et al., 2020). The former sought to secure legal rights, instill pride, attract breeders to access scientifically certified varieties, and benefit the custodian agricultural community. The latter assures premium price realization of landraces in a globally competitive market, as well as financial sustainability through the preservation of social capital (Radhika et al., 2018). The impact of genetically modified organisms (GI) on the fate of Kala Namak rice from Uttar Pradesh, India, and Jeera Phool rice from Chhattisgarh, India, is extensively established (Blakeney et al., 2020; Kumari et al., 2023). However, distinct agricultural products/ crops are recognized based on their geographical origin and received as Geographical Indication Tag with respect to their state are; Arunachal Orange (Arunachal Pradesh), Assam Karbi Anglong Ginger, Boka Chaul, Boka Chaul, Boka Chaul, Judima, Tezpur litchi, Joha Rice of Assam (Assam), Basmati (Himachal Pradesh), Ladakh Raktsey Karpo apricot (Ladakh), Chak – Hao (Manipuri black rice), Tamenglong Orange, Kachai Lemon, Hathei Chilli (Manipur), Khasi mandarin, Memong narang (Meghalaya), Mizo ginger, Mizo chilli (Mizoram), Naga cucumber, Nagar mircha, Naga tree tomato (Nagaland), Dalle khursani (Sikkim), Tripura queen pineapple (Tripura), Kumaon Chyura Oil, Mansyari Razma (Uttarakhand), Tulai panji rice, Gobindbhog rice, Fazil mango, Khirsapati (Himsagar) mango, Laxman bhog mango (West Bengal). These crops demand more conservation and research attention, and increased production can improve nutritional security by providing a balanced diet, combating micronutrient deficiencies, and preventing hunger.

15 Conclusion

Food grains are the primary source of nutrition for a big population, so spoiling should be prevented. The traditional methods of storage outlined above can be improved further with new technologies. This will assist us in meeting the demand for food grains and putting an end to global hunger. The identification of indigenous food crops that merit consideration for national plant germplasm conservation and usage to improve rural poor livelihoods and offer food security insurance is an urgent demand. To accomplish this, it is vital to assess landraces' local, regional, and worldwide relevance in terms of their contribution to food security, ecosystem sustainability, and potential for domestication and commercialization. Other areas that require immediate attention include a threat assessment due to continuous use, genetic degradation, and the relevance of complementing conservation efforts. The only option is to use local genetic resources to generate new crops. In this regard, policy makers, researchers need to build a network of traditional seed systems in which farmers' knowledge of their traditional food system is recognized and represented in the participatory nature of farming activities. There is also a considerable need for capacity-building programmes to be based on the farming community's existing indigenous knowledge. Small farmers' on-farm seed saving is critical for preserving Himalayan agricultural biodiversity. It is critical to network and connect institutions active in agro-biodiversity research, management, and education in this region. A fruitful research outcome on such a line would improve chances for the conservation of traditionally cultivated landraces and the food security of this hilly region.

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Traditional Knowledge-Based Sustainable Agriculture in the Eastern Himalayas in India

Dharitri Borah, Jayashree Rout, and Thajuddin Nooruddin

Abstract The Himalayan region occupies 18% of the Indian subcontinent. In Indian Himalayas, the Eastern Himalayas is represented by North-East India covering more than 50% of the total area. In this region, terrace farming (TF) together with shifting cultivation (SC)/jhum/swidden are the most important livelihood sources of local tribes since early days. In India, more than 80% of the land under SC lies in the North-East region. The species cultivated in SC present the cultural significance of the respective tribes, while many endemic species together with genetic resources are conserved. Hence, the eradication of SC is not a viable approach to agrobiodiversity and forest conservation. Rapid industrial development and demographic changes have reduced SC and TF. However, uncontrolled deforestation in many regions for SC with a reduced fallow period has caused a reduction in the carbon sink, nutrients, soil fertility, forest cover, productivity, topsoil erosion, loss of biodiversity including microbiota, and climate change. Contours in TF conserve soil, retain moisture/nutrients, and soil productivity. However, TFs have been abandoned pertaining to rugged terrains, steep topography, poorly designed agriculture tools, irrigation difficulties, transport networks, demographic changes etc. Ecosystem restoration and conservation with economic objectives are often not effective and limit fallow regeneration. Therefore, it is worthwhile to study traditional agricultural practices and their challenges in productivity for the conservation of the agroecosystems in the Indian Eastern Himalayas. The policies for livelihood security as per the sustainable development goals (SDGs) and agroecological elements [Food and Agricultural Organization (FAO)] for agricultural management are also addressed.

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Keywords Agroecosystem · Conservation · Shifting cultivation · Terrace farming · Eastern Himalaya

1 Introduction

The Eastern Himalayan region (EHR) presents various traditional agricultural techniques based on indigenous knowledge. The North-Eastern Himalayas is rich in agriculture pertaining to the rich organic matter, diverse geographical/climatic conditions, and abundant natural resources (Das et al., 2009; Lama et al., 2017). The Himalayan region (HR) presents five countries viz. India, China, Nepal, Bhutan, and Pakistan. The Indian HR presents nearly 4% of the domicile of the country's total population. The region is rich in biodiversity with diverse species of flowering plants (~8000 species), trees (816), edible plant species (675) and medicinal plants (1740). Approximately 40% of the species found in the region are endemic to India. This region separates Indo-Gangetic Plain (IGP) from Tibetan Plateau, and ecologically important pertaining to energy security, food, and water (Lama et al., 2017). The HR includes the states of Jammu and Kashmir, Uttaranchal, West Bengal, Himachal Pradesh and North-Eastern states of India with a total geographical area of approximately 533,604 km^2 (Pramanik & Bhaduri, 2016). Shifting cultivation (SC) or jhumming (JH) is a traditional farming, prevalent in tropical countries. Millions of people are dependent on for their livelihood across the world within the forested land area of about 280Mha (Heinimann et al., 2017; Mylona et al., 2020). SCs are integrated with the uplands, leading to secondary forest production (Fig. 1). Terrace cultivation involves graduated terraces alongside the hill slopes, mostly practiced in tropical hilly countries of the world. HR presents diverse cultures and faces climatic uncertainties with hard geographic conditions (Lama et al., 2017). The traditional ecological knowledge of tribal communities is well presented in their soil and forest conservation techniques. Forests are conserved as per their customs, e.g. Meitei community in Manipur conserves forest by umanglai, sacred groves are preserved in Arunachal Pradesh/ Meghalaya, Apatani people practice SC with paddy-cum-fish farming. Reportedly, more than 90% of the forest of Nagaland and Meghalaya are under the maintenance of traditional village institutions, communities, together with private individuals.

1.1 Eastern Himalayan Region

The North-Eastern Himalayas present a total 52% area of the EHR (Giri et al., 2020). The region places in between 21°57′–29°30′ N and 89°46′–97°30′ E, and presents an international border of 4500 km. The region is represented by mountains (63%), plains (29%) and plateau of 8% (Dikshit & Dikshit, 2014; Pandey et al., 2022). EHR presents diverse cultural heritage and customs. JH, settled agriculture in plains and

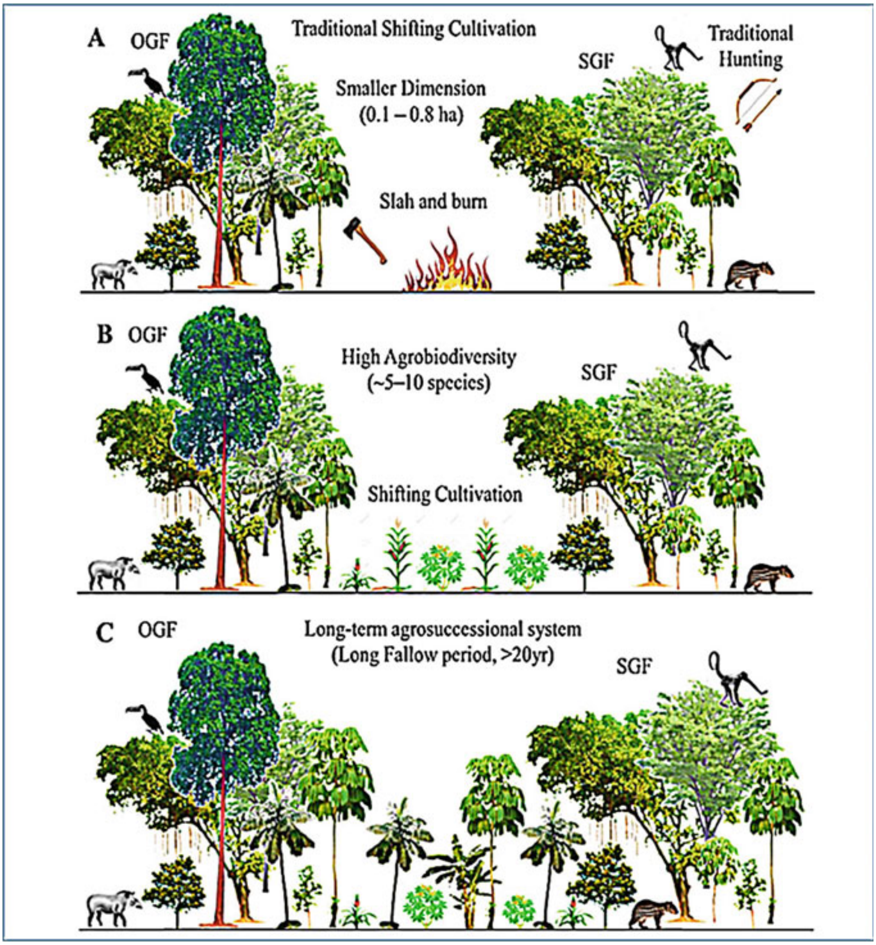

Fig. 1 The traditional process of shifting cultivation (OGF: Old-growth forest; SGF: Secondary growth forest). Re-printed by permission from Copyright. © 2021 Elsevier Ltd

terraces, forestry, and livestock are mainstays for livelihood, and rice is a common food. Out of the total geographic area of the North-Eastern region, 28% of the area is at or above 1200 m, 18% is between 600 and 1200 m, and 11% is between 300 and 600 m above sea level. Approximately, 72% of the geographical area of this region is hilly (Kumar & Meena, 2016). Considering the entire geographical area, N.E. India presents the maximum forest cover (84.53%) in the country. Arunachal Pradesh (79.33%), Manipur (74.34%), Meghalaya (76%), and Nagaland (73.90%) are the next-highest states after the state. Of the total forest resources of the country, the N.E. states present 23.75% of the total forest cover. Most of the Eastern Himalayan states present negative changes in forest cover. SC, short rotation, biotic pressure, encroached area clearance/deforestation, natural disasters, developmental activities, etc. are the detrimental factors for the reduction in forest cover. However, some of the interpretations require in-depth collateral remote sensing data analysis with high-resolution images and intensified ground truthing. Major losses are estimated for Arunachal Pradesh (257 km^2), Nagaland (235 km^2), Manipur (249 km^2), Mizoram (186 km^2), Meghalaya (73 km^2), Assam (15 km^2), Tripura (4 km^2) and Sikkim (1 km^2). This accounts for a total change of 1020 km^2 of the area (India State of Forest Report, 2021).

1.2 Demography of Eastern Himalaya

The North-Eastern HR includes more than 200 dominant tribes/subtribes of 635 ethnic groups of India with diverse ethnicity, sociocultural structure and language (Dikshit and Dikshit, 2014; Lama et al., 2017). The different tribes in this region include Bodo/ Kachari, Mishing, Mishmi, Rabha, Galong, Nishi, Wancho, Adi, Thadou, Tangkhul, Kabui, Inpui, Khamti, Khasi etc. According to the Unique Identification Authority of India (UIDAI), the total projected population (2022) of Assam was 35,378,000 followed by Tripura (4,109,000), Meghalaya (3,318,000), Manipur (3,194,000), Nagaland (2,213,000), Arunachal Pradesh (1,548,000), Mizoram (1,227,000) and Sikkim (683,000). According to the census (2011), the total population of Assam is 312.06 lakhs, followed by Tripura (36.74 lakhs), Meghalaya (29.67 lakhs), Manipur (28.56 lakhs), Nagaland (19.79 lakhs), Arunachal Pradesh (13.84 lakhs), Mizoram (10.97 lakhs) and Sikkim (6.11 lakhs). The percentage of ST populations in the states covering the country in Assam (3.7%), Meghalaya (2.4%), Nagaland (1.6%), Manipur (1.1%), Tripura (1.1%), Mizoram (1%), Arunachal Pradesh (0.9%) and Sikkim (0.2%). The tribal communities mostly reside on the hills. North-East India presents a mixture of different races of Mongoloids (Indo-Aryans/Austric/Australoids) and Dravidians (small immigrants). The Indian HR faces the challenges like air/water pollution, population pressure, soil erosion, reduction in forest cover, mass tourism (unplanned) etc. It cause detrimental effects on biodiversity status, ecosystem health, agricultural and forest productivity (Baland et al., 2010; Lama et al., 2017).

1.3 Hill Agriculture in Eastern Himalaya

Only 8% of the earth's surface is covered by tropical forests, which are also a carbon sink and home to biodiversity. The ecosystem services provided by the forests are soil fertility, pollination/seed dispersal, water regulation, carbon stock affecting carbon cycle and global climate (Villa et al., 2021). As they are more adapted to the local environment, traditional agricultural practises involve traditional skill in cultivation with locally available resources (Upadhaya et al., 2020). In North-East India, rice is the main cereal followed by maize. In Himalayas, agriculture is practiced in limited arable land (> 90%) irrigated, rainfed areas (< 1 ha) of approximately 16%, whereas a greater proportion of population (80%) is dependent upon it for their livelihood (Lama et al., 2017; Partap, 1999, 2011). Agriculture in the HR is diversely integrated, and includes agroforestry, animal husbandry with little commercial agriculture (Pramanik & Bhaduri, 2016). Terraces on the hill slopes with steep topography help in retaining moisture and soil conservation (Bhardwaj et al., 1996; Lama et al., 2017). An intensive cropping system involves diverse cropping (17–30) in both monsoon and winter. A total of 16% of the cropland area is covered by apples, citrus fruits, walnuts, plums, peaches, bananas, mangoes, pineapples, vegetables like tomatoes, radish, potatoes, cabbage, and cauliflower (Partap, 2011). Also, other crops include ginger, chillies, pulses, maize, cardamom, saffron, flowers such as orchids, gladioli, marigolds and chrysanthemums. SC and rice cultivation in terraces (80%)/ bun cultivation are widespread agricultural practices in the hills. Rice cultivation includes monocropping, while SC involves rainfed mixed cropping. In many locations, economically significant agroforestry plants like cardamom and mandarin have helped to rehabilitate SCs. The leaf litters/fine roots act as nutrients to the soil. Also, major land area under SCs have been replaced by horticulture. Unchecked SCs have caused an ecological imbalance, with reduced JH cycle and forests being replaced (Nandy et al., 2006; Pramanik & Bhaduri, 2016). Areca nuts are a traditionally grown, unorganised tree crop. In North-East India, 80% of the primary cropped land is dedicated to the production of rice. Multiple cropping is very less (< 20%), and the plantations like tea (> 90% of area in Assam), rubber, pulses, maize, and several horticultural species are available in the area. With regard to the region's challenging terrain, there are indigenous cultivation techniques that have not been diffused to other regions (Dikshit and Dikshit, 2014). The Zabo (Dzüdü/ Ruza) system (water impoundment) of cultivation is a slope management system, practiced in Nagaland. The top of the hill is the forest, followed by the tanks for siltation at the middle, water harvesting tank at the lower concavity, and the paddy field (3.0–3.5 ton/ha rice) at the lowest slope above the river. The 'Apatanis' practice Paddy-Cum-Fish Culture (4.0–4.5 t /ha rice) with finger millets on the bunds, Ziro, Arunachal Pradesh. In order to cultivate the intermontane basin, well-designed channels are used to irrigate it with stream water. Interestingly, the farmers also include red algae as a source of nitrogen and fish feed. For drip irrigation, bamboo networks are used, which is beneficial for growing areca and betel nut trees. The variety of rice cultivated is indigenous like Mipya (maturing early in July) and Empo (maturing late in October) varieties. The fish varieties are *Cyprinus carpo* (Common carp), *Cyprinus carpio* var. *communis* (Scale carp), *Cyprinus carpio* var. *specularis* (Mirror carp) and *Cyperinus carpio* var. *nudus* (Leather carp). The plantations include *Terminalis myrinalia*, *Ailanthes excelsa*, *Michelia* sp., *Mangolia* sp. and bamboos. The Angami Nagas practice settled agriculture (terraces) at low hill slopes in Khonoma village of Nagaland. It is cultivated for maize, millets, potatoes, chillies, pumpkins, and other crops. It is known locally as panikheti. In this cultivation practice, green manure is developed from the alder trees at the slopes with elevations 1000 and 2000 MASL. The stubbles or agricultural residues are burnt in the terraces. In the panikheti, the agricultural activities start from the months of winter (December-January). Soil submergence, maintenance of standing water (5–8 cm), rice seedling transplant is continued in the month of June (2.5–3-ton rice/ha). Rice is grown in the seasons viz. autumn, winter and summer. A large part of the rice grown in hills is cultivated in JH cultivation. With the highest yield, summer rice is cultivated in low valley lands of Assam, Manipur and Tripura (Dikshit & Dikshit, 2014). Alder with large cardamom system of cultivation is found in high altitude of Sikkim. Alder fixes nitrogen maintaining soil fertility. In Sikkim, temporary cattle shed is also maintained in the field. It provides urine, cow dung and organic litters for production of ginger/cole crops. Raised bed/bun method of cultivation (modified shifting cultivation) is practiced in Meghalaya, where dry method of vegetation/biomass/legumes are used as manure with the productivity of 18–20 ton of potato/ha. Dry vegetations are used as raised beds(buns), burnt and cultivated by mixed cropping (1–3 years). A fallow period exists for 3–5 years (Upadhaya et al., 2020). In Arunachal Pradesh, springs are protected from livestock encroachment and flooding. Cow dung slurry and urine are used for pests repellents like aphids, thrips, mites, caterpillars etc. (De, 2021). Different rituals practiced at different stages of crop growth, viz. Irriiwhwn (Adis in Pashighat) at just grown paddies, Ampu-yolu (Galo-Adi) for crop protection from pests/diseases etc. The agroclimatic and topographical conditions are conducive for the cultivation of horticultural crops (half-moon terraces/contour) and vegetables like Mandarin, Acidlime, Assam Lemon, Aonla, Pineapple, Jackfruit, Papaya, Beans, cucurbits, potato. Peach, Plum, Apricot, Pear, Pomegranate, Grapes, Low chilling Apple, Persimmon, Kiwi etc. Agrihorti, Agri-horti-silvi pastoral, mixed horti, pure horti, and horti-silvi-patoral are adopted for increased productivity. The study therefore considers the importance of various traditional knowledge-based agricultural practises in the EHR and their productivity constraints. Also, socioeconomic aspects, policies to achieve the sustainable development goals (SDGs) and agroecological elements [Food and Agricultural Organization (FAO)] for agricultural management are also addressed herein.

2 Shifting Cultivation in Eastern Himalayas

For SCs, the forest has burned completely at lower elevations, around 1500 m asl. At higher elevation big trees are retained, which is a comparatively unfertile area (Borah et al., 2022a; Mishra & Ramakrishnan, 1983). Different regions of the world have different names for SC, including Milpa (Mexico/Central America), Roca (Brazil), Caingin (Philippines), Masole (Congo and Central Africa), Ladcmg (Indonesia) etc. (Longkumer et al., 2019). In India SC is referred to as Kumari (Western Ghats), Bringa (Orissa), Watra (Rajasthan), jhum (N. E. India) etc. Most of the crops raised in JH are mixed crops (8–35 species), including small-scale rice varieties (De, 2021). Crops include cereals (rice, millets maize), legumes (beans, soybean, pigeon pea, cow pea rice bean), oilseeds (mustard/ground nut), root crops (cassava, potato, Colocasia, yam, sweet potato), cucurbits (bottle gourd, pumpkin, snake gourd, cucumber, melons, bitter gourd etc.), seeded vegetables (chilli, okra, tomato, brinjal), fruits (papaya, banana, citrus etc.) etc.

2.1 Conservation of Crop Genetic Resources

Along with ensuring food security, SC supports livelihoods, tropical countries' ecosystems, encourages the preservation of indigenous cultures, and is environmentally sustainable (Pandey et al., 2022). SC significantly contributes to biodiversity protection, climate change mitigation, and soil/water conservation (Bani et al., 2022). Interestingly, crop varieties, cropping patterns, fallow cycle, and management practices vary within the tribes of N.E. India (Bhuyan, 2019; Borah et al., 2022a). In Northeast India, the cropping cycle is frequently one year; however, the fallow period ranges from six to twenty-seven years (Borah et al., 2018, 2022a). The N. E. India is mostly hilly, undulating and ecologically fragile terrain. Being a traditional ecosystem, SC is highly connected with a high level of agro-biodiversity (Wangpan et al., 2017). Often intercropping is performed in new fields for important and subsidiary cereals viz. foxtail millet (*Setaria italica* L.), proso millet (*Panicum miliaceum* L.), finger millet (*Eleusine coracana* L.) and pearl millet (*Pennisetum glaucum* (L.) R.Br.), maize (*Zea mays* L.), tapioca (*Manihot esculenta* Crantz.), *Dioscorea* sp., *Colocasia esculenta* L., sweet potato (*Ipomoea batatas* (L.) Lam.), ginger (*Zingiber officinale* L.), etc. Indigenous rice varieties are also cultivated in the old fields. A total of 140 species of crops were observed to be intercropped in JH of Tirap/Longding District (Arunachal Pradesh), India (Wangpan & Tangjang, 2015). Various plants collected from the jhumplots are cereals (*Oryza sativa*, maize), oil seeds (*Sesamum indicum* L., *Perilla frutescense* Var); grain legumes (*Phaseolus vulgaris* L., *Vigna umbellata*, *Lablab purpureus* (L.) Sweet.); vegetables (*Momordica charantia* L., *Solanum lycopersicum* L., *S. torvum* Sw., *S. indicum* L., *S. nigrum* L., *Plantago major* L., *Spilanthes paniculata* Wall.); tuber/root crops (*Colocasia esculenta* L., *Dioscorea allata* L.), spices and sugarcane etc. In JH, kitchen, and homestead garden, it is known to grow more than 50 indigenous rice varieties (Wangpan et al., 2017). Arunachal Pradesh's Nocte and Wancho community reported 36 different indigenous upland rice varieties. Among 24 villages, at least 4 rice varieties were present with the maximum of 16. The turning of SCs into monocropping has become a threat to the endemic species of the region (Pandey et al., 2022). SCs are also rich in bird diversity (Borah et al., 2022a). Three vulnerable bird species viz. *Paradoxornis flavirostris*, *Tragopan blythii* and *Sitta formosa* were identified in SC. *Garrulax nuchalis*, *Spelaeornis chocolatinus*, *Psittacula finschii*, *Luscinia pectardens*, *Spelaeornis caudatus* were the near threatened species. The bird diversity was influenced by the retained large trees in the SCs and fallows with young regeneration. The fallow period is also associated with tree species richness (Hauchhum & Singson, 2020). A 47% increase in tree species was observed from the fallow of F5 (2–5 years) to F10 (6–10 years), however diversity increased in F10 and F-30 (21–30 years). The dominance of the species also varied with fallow period F5 (*Castanopsis tribuloides*), F10 (*Rhus chinensis*), F20 (11–20 years) (*Macaranga denticulata*) and F30 (*Albizia chinensis*). A total of 39 crops with 4 indigenous livestock breeds were categorized in West Garo Hills, N. E. India (Pandey et al., 2022). Crop density varied from 3.1 (*Daucas carota*, *Camellia sinensis*) to 97.9% (*Zea* *mays*). There were 5 wild edible plants recorded in the traditional food diet. The edible bamboo species recorded were *Dendrocalamus hamiltonii*, *Bambusa tulda*, *B. pallida*, and *D. gigantea*. The commonly consumed vegetables by Garo people are *Zanthoxylum armatum*, *Z. rhetsa*, *Clerodendrum glandulosum*, *Solanum violaceum*, *Dillenia scabrella*, *Lasia spinosa*, etc. The SC-agrobiodiversity recorded in Meghalaya plateau (Jhum I) recorded as cereals (3), tubers (6), vegetables, (11), leafy vegetables (6), spices/oilseed (6) and one pulses (Behera et al., 2016). The major crops cultivated in Alder based JH cultivation are millets, Job's tear, maize, tomato, potato, chilli, cauliflower, cabbage, squash, cucumber, French bean, ginger, pea and soybean (Mylliemngap, 2021). In Mizoram, recent abandoned SCs were rich in weeds, reeds, herbs and surviving crop plants (Lianzela, 1997). *Eupatorium* spp., *Mikania scandens*, *Melocann bambusoides* are among them. The cash crops like ginger, chili, turmeric, cucumber (jum marfa), kozu/kochu (arum/aroides) etc. have great demand in local market (Panda et al., 2017). The crops in SC are generally resistant to pests and diseases, requiring no chemical control. Diverse crops are grown without the use of additional fertiliser, conserving biodiversity more than low-lying areas.

2.2 Productivity Constraints

The constraints related to SCs are infrastructural (market access, products transport subsidy, proper road, absence of small-scale enterprise), resource together with economic (savings, good market price, credit unavailability, water resources during winter) constraints (Punitha et al., 2018). According to the farmers, rice productivity in the SCs was lower than it had been in earlier periods. Therefore, the identification, prioritization, and dissemination of high-yielding rice varieties including horticultural crops must be emphasized. Crop yield is also affected by the soil/nutrient loss and short fallow period (Bani et al., 2022). For crop productivity improvement, the development of new plant varieties, and utilization of traditional knowledge for crop diversity conservation (growth/maintenance) with weightage at the family and community levels is important (Pandey et al., 2019). Although, traditional crops contribute to sustainable crop rotation in agriculture, are less profitable as 'orphan crops', lagging behind the major crops. Reportedly, it varies in quality, productivity, and consumer preference. The other major constraints could be (a) remoteness or inaccessibility; (b) jurisdiction of various line departments; (c) prevailing land tenure system; and (d) transitory land use (NAAS, 2016). Intense and prolonged cropping with short fallow degrade the soil environment. A variable land tenancy system restricts the improvement of abandoned JH lands in several places. It requires scientific management with effective local institutional support. In India, the constraints for the SC improvement belong to economic (labor intensive and costly technology), social (off-farm employment), institutional (land tenure system, unavailability of proper training/research institutes with extension), distant location of land and involvement of local organizations (NAAS, 2016; Tripura & Mandal, 2016).

2.3 *Effects of Shifting Cultivation*

Impact of SC on biodiversity is dependent upon disturbance attributes, niche, dietary, habitat, and other requirements (Namgyel et al., 2008). The soil properties vary with the fallow period and the soil depth (Table 1). SC is sustainable with a long fallow period, however, population pressure has decreased to 3–5 years. Intense SC combined with a short-term fallow period has reduced soil fertility. Burning practices cause air pollution, secondary forest generation, loss of soil nutrients, organic matter, and soil/gully erosion with loss of fauna and microbes (Panda et al., 2017). Fallow period was found to enhance soil organic carbon, conductivity, available phosphorus, available nitrogen, exchangeable potassium, moisture, cation exchange capacity and clay (Temjen et al., 2022). SCs had the highest weighted soil quality index (SQI), followed by FL3, FL12, and FL7. Intensification of SCs also causes ecosystem service/biodiversity losses (Fig. 2), fragmentation of forests, excess greenhouse gas emissions, and even extinction (Villa et al., 2021). As SC is prevailed in tropical countries, in the long term it affects climate change. Defaunation causes limiting the dispersal of zoochoric/larger tree species and the dominance of smaller, light-demanding, non-zoochoric tree species (Peres et al., 2016; Villa et al., 2021). Accompanied by an excessive reduction in habitat area, SC is more common in the tropics within the ranges of threatened forest species. (Kadoya et al., 2022). The size, type, duration, intensity, frequency together with return interval affect the flora and fauna (Namgyel et al., 2008). It has been noted that monocropping in SC causes soil health deterioration and pest attacks, local crop diversity losses, increase pollution, and climate change (Upadhaya et al., 2020). SC also causes wild animal shelter depletion, flooding in plains on siltation, perish of microbial population, and survival of heat resistant microbes (NAAS, 2016). It can threat native forest conservation, wild plant diversity, insectivorous birds (terrestrial/understory) and organisms living on the secondary generation during long fallows, soil physical and hydraulic properties (Chappell et al., 2009; Mukul & Herbohn, 2016). Interestingly, increase in monoculture like rubber, oil palm etc. has enhanced deforestation/biodiversity losses more than the traditional SCs (Mukul & Herbohn, 2016). In a study on the dynamics of earthworm populations in Meghalaya, it was found that fallows between the ages of 0 and 15 years old contained only one species of earthworm. In contrast to the other species found in the two fallows, a different species was seen in a 5-year-old fallow (Mishra & Ramakrishnan, 1988). Bird abundance was significantly positively correlated with fallow age (Raman, 2001). It's interesting to note that three of the Himalayan bird species that is considered to be endangered were negatively correlated with the habitat change brought on by JH. Hence, all organisms along the food chain are impacted. Except a few adaptive organisms, porcupines, reptiles, barking deer and goral, red-vented bulbul, sparrow, crow, munia, doves and swallow are adversely affected. Wild population was found to be dwindling in the state of Mizoram, N. E. India (Lianzela, 1997). In the state, frugivorous birds like hornbills, barbers, pigeons etc. are worst affected by SCs. Ecology of the area changes pertaining to the frequent changes of land causing exotic weed invasion and threatening native species (Deka & Sharmah, 2010). It is worth mentioning that biodiversity conservation in SC is dependent upon the recovery of biodiversity as the secondary forest ages (Borah et al., 2022a). It takes a secondary forest 48 years to achieve 80 percent of an old growth forest's species richness. SC provides a mosaic of heterogenous habitats and a refuge for biodiversity. However, many argue that SCs should only be partially blamed for deforestation, and are vital for the preservation and maintenance of forests (Mishra et al., 2021). According to FAO, clearing forests for SCs is forest modification.

3 Terrace Cultivation of Eastern Himalayas

Common agricultural practices in the EHR include rice terraces on the sides of hills (Table 2). The earthen embankments are built with cross-slope channels, and the slope length is reduced. Terraces improve farmability by reducing soil erosion, runoff and by retaining water for plants (Bocco & Napoletano, 2017; Valdivia, 2002). Valley agriculture is practiced both at low and high elevations. Wet rice is cultivated wherever the terrain allows, even on small terraces around flat valley, a saucer-like structure with organized rice plots. In North-East India, the Apatanis of Arunachal Pradesh is dependent upon the nutrient washout from hill slopes. In sustainable practice, the Apatanis use organic wastes, recycle residues of the crops and maintain soil fertility. In Sikkim, rice terraces are known as Pakho khet, where slopy lands are converted into sustainable terraces (Mishra et al., 2020). There were three primary rice terraces observed viz. sloping (51%), levelled (33%) and reversed (14%). Levelled terraces are used to stabilize irrigation water required for rice cultivation. Here Maize is the primary crop followed by paddy. In the watershed, the levelled terraces are dominant in the lower and middle zone. Lower terraces receive water from the terraces above. In the watershed, outward sloping was the most common type of terrace. These terraces are at the base of the steep slopes with large retaining walls used for collecting slope wash. Reverse slope (>40°) terraces are built at the upper zone. Terraces are constructed by soil and locally available stones of different sizes and grades. The terraces are generally built at a slope angle of 20–40°.

3.1 Terrace Cultivation and Climate Change Mitigation

Climate change has a significant impact on agricultural production, reducing yield due to high temperatures and extreme weather. Owing to marginal and fragile lands, peasants (commercial, subsistence, and mixed) are highly affected by climate change

Table 1 Physico-chemical parameters in soils of shifting cultivation in Eastern Himalayas

Site	Depth (cm)	pH	EC (dSm^{-1})	MC (%)	BD (g/cm^3)	Sand (%)	Silt (%)	Clay (%)	SOC (%)	N_{av} (kg/ha)	K_{ex} (kg/ha)	P_{av} (kg/ha)	References
Nagaland (Mokokchung)	0–10	5.60	0.094	33.67	1.62			23.82	1.86	320.71	117.51	20.44	Temjen et al. (2022)
	10–20	5.60	0.110	33.97	2.27			21.70	1.33	267.99	96.31	18.69	
	20–30	5.57	0.108	33.20	2.29			20.25	1.18	235.16	104.07	18.18	
	Fallow 3 0–10	5.22	0.404	37.27	1.45			26.60	2.18	353.08	129.31	26.92	
	Fallow 7 0–10	5.17	0.586	44.97	1.04			32.25	3.10	534.90	200.70	34.94	
	Fallow 12 0–10	4.88	0.736	46.52	1.01			34.70	3.94	542.99	214.75	36.32	
Nagaland (Changki, Mokokchung)	Fallow 5 0–15	4.28	0.47		1.62				1.63	251	182	6.82	Saplalrinliana et al. (2016)
	Fallow 10 0–15	4.53	0.49		1.60				1.88	278	240	7.42	
	Fallow 20 0–15	4.68	0.54		1.57				2.16	288	270	7.89	
Nagaland (Kohima)	0–70/83	5.93			1.06	46.3	31.7	21.8	1.0	359.40	221.62	27.96	Mishra et al. (2021
Nagaland (Satsukpa)	0–20	4.14			1.36			58.9	1.05				Ray et al. (2021)
	20–40	4.37			1.53			69.2	0.58				

(continued)

Table 1 (continued)

Site	Depth (cm)	pH	EC (dSm^{-1})	MC (%)	BD (g/cm^3)	Sand (%)	Silt (%)	Clay (%)	SOC (%)	N_{av} (kg/ha)	K_{ex} (kg/ha)	P_{av} (kg/ha)	References
Nagaland (Mangmatong)	0–20	4.22			1.34			52.3	1.50				
	20–40	4.25			1.44			58.9	0.77				
Nagaland (Longjang)	0–20	4.00			1.26			33.7	1.18				
	20–40	4.28			1.34			35.8	0.63				
Nagaland (Moulingyimsen)	0–20	4.57			1.39			27.2	0.96				
	20–40	4.63			1.51			27.5	0.85				
Nagaland (Dimapur)	0–20	5.30				611 g/kg	110.6 g/kg	277.7 g/kg	12.1 g/kg	127.9 mg/kg	141.2 mg/kg	8.2 mg/kg	Singh et al. (2014)
Nagaland (Khonoma)	Fallow 2 0–15	4.31	0.24						1.39	67.9 mg/kg	111.3 mg/kg	4.87 Mg/kg	
	Fallow 4 0–15	4.33	0.22						1.45	82.2 mg/kg	118.4 mg/kg	5.67 mg/kg	
	Fallow-8 0–15	5.38	0.40						2.18	100.5 mg/kg	138.3 mg/kg	6.56 mg/kg	Kalidas-Singh et al. (2021)
Mizoram (Muallungthu)	Fallow 5 0–15	4.88	0.31		1.61				1.22	222	257	7.88	Saplalrinliana et al. (2016)
	Fallow 10 0–15	5.12	0.39		1.57				1.42	281	259	8.06	

(continued)

Table 1 (continued)

Site	Depth (cm)	pH	EC (dSm^{-1})	MC (%)	BD (g/cm^3)	Sand (%)	Silt (%)	Clay (%)	SOC (%)	N_{av} (kg/ha)	K_{ex} (kg/ha)	P_{av} (kg/ha)	References
	Fallow 20 0–15	5.36	0.41		1.45				1.82	293	272	9.32	
Mizoram (Lengpui)	Fallow 10 0–10	6.54							2.14			10.44	Wapongnungsang et al. (2021)
	Fallow 15 0–10	6.98							2.49			14.78	
Arunachal Pradesh (West Siang)	0–20	5.40		32.46					1.99	477	327	8.6	Kumar et al. (2017)
	20–40	4.01		33.58					1.24	41.8	210	9.9	
Assam (Dima Hasao)	Short jhum (1-3y) 0–15	4.45				54.92	17.81	23.24	0.98				Nunisa et al. (2023)
	Medium jhum (4 to 6 y) 0–15	4.64				50.19	21.63	28.17	1.34				
Assam (Hapjan)	0–6	6.55	0.113						1.20		560	13	Dey & Kalita (2008)
NHR region	y 0–15	4.49				56.9	17.8	25.3	1.73				Choudhury et al. (2020)

EC Electrical conductivity; *MC* Moisture content; *BD* Bulk density; *SOC* Soil organic carbon; N*av* Available nitrogen; K_{ex} Exchangeable potassium; P*av* Available phosphorus

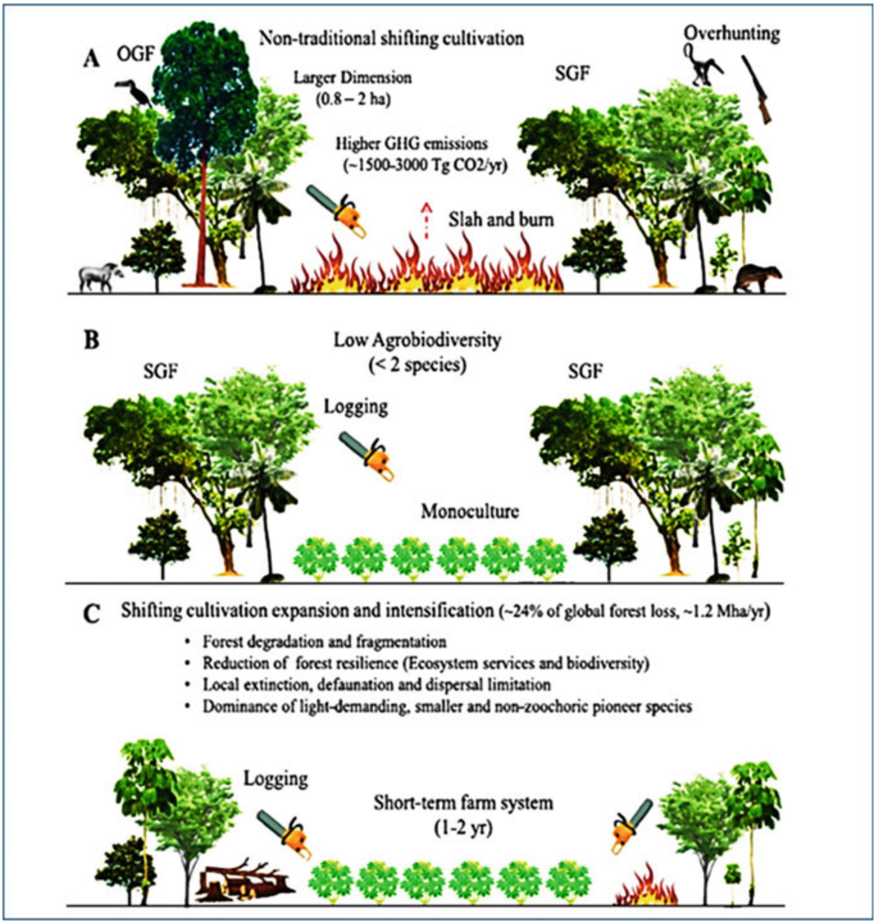

Fig. 2 The non-traditional process of shifting cultivation (OGF: Old-growth forest; SGF: Secondary growth forest). Re-printed by permission from Copyright © 2021 Elsevier Ltd

(Bocco & Napoletano, 2017). Also, peasant agriculture is difficult to model pertaining to extreme locational specificity and complexity. In Eastern Himalayan landscape, Apatanis are experiencing warmer climate with an increase of 0.2 °C temperature. A decrease in rainy day and rainfall amount have been projected by 2030 (Aich et al., 2022). Cloudburst, flash floods, landslides, pathogen attack are affecting the agro-forest landscape sustainability of Apatanis in Arunachal Pradesh. Pollen viability, seedling mortality and crop productivity decline due to plant physiological changes due to high temperature. Drought and flood are also responsible for the decline in soil fertility, water holding capacity, seed/crop production and increased runoff (Aich et al., 2022). Three approaches viz. organic; soil/water conservation/community farming; and keeping the local agro-biodiversity alive were classified as environmentally friendly and climate-resilient. The cumulative effects are weather changes

Table 2 Soil properties of upland agroecosystems in Eastern Himalayas

Site	Elevation (m)	Depth	pH	OC	N_{av} kg/ha	P_{av} Kg/ha	K_{av} Kg/ha	BD (g/cm^3)	PO (%)	EC (µS/cm)	WHC (%)	Sand (%)	Silt (%)	Clay (%)	References
Arunachal Pradesh (Ruksin)	< 150	0–15						0.78	70.57		68.50	72	24	4	Yumnam et al. (2013)
Arunachal Pradesh (Pasighat)	150–300	0–15						0.71	73.08		54.55	80	18	2	
Arunachal Pradesh (Mebo)	300 – 450	0–15						0.68	74.21		82.94	52	40	8	
Arunachal Pradesh Pangin	> 450	0–15						0.69	73.96		78.52	48	44	8	
Sikkim Conservation tillage	1350	0–10	5.76	15.26 g/kg	331.3	15.5	329.5								Singh et al. (2021)
Sikkim Reduced till	1350	0–10	5.78	15.75 g/kg	335.5	15.9	331.2								
Sikkim No till	1350	0–10	5.79	16.49 g/kg	354.5	16.4	336.7								
Meghalaya Bun cultivation	1961	0–15	5.32	2.36%	390	19.60	320.80	1.54	41.88	21.2					Hinge et al. (2019)
Nagaland (Dimapur) Upland terrace	260–690	0–20	4.6	10.7 g/kg	113.7 mg/kg	7.1	89.8					682.2 g/kg	92.8	225.1	Singh et al. (2014)

(continued)

Table 2 (continued)

Site	Elevation (m)	Depth	pH	OC	N_{av} kg/ha	P_{av} Kg/ha	K_{av} Kg/ha	BD (g/cm^3)	PO (%)	EC (µS/cm)	WHC (%)	Sand (%)	Silt (%)	Clay (%)	References
North Sikkim Dzongu	1200–1400	0–15	5.61	40.99 mg C/ha				0.75				42.80	30.62	26.58	Lepcha and Devi (2020)
Darjeeling Peshok catchment	220–1930	0–10	5.24									47	29	24	Kijowska-Strugała et al. (2022)
Assam Dima Hasao Rice terrace	433.5–1100	0–10	5.21–6.42	1.02–1.42%				0.78–1.11	58.11–70.57	534–756	42.71–53.43				Borah et al. (2022b)

OC Organic carbon; N_{av} Available nitrogen; P_{av} Available phosphorus; K_{av} Available potassium; *BD* Bulk density; *PO* Porosity; *EC* Electrical conductivity; *WHC* Water holding capacity (extreme/unpredictable), longer summer season, drying up of aquatic bodies, and wetland disappearance. This impact on agricultural productivity including staple crops, livelihood, food security and biodiversity loss (Mukerjee et al., 2018). The key reasons for the changes were noted as deforestation and humidity increase. Irregular rainfall pattern, drying-up of aquatic bodies (springs/streams), migration of species towards higher elevations, and increased diseases/pests occurred in Sikkim Himalaya. Paddy, maize, wheat, oil seeds, cardamom, ginger, drinking water sources were highly impacted by the climate change (Sharma & Rai, 2012). Among cereals and pulses, many traditional varieties (Punaro, Kanchi, Attey, Thulo Marshi etc.) were disappeared. Large cardamom production was declined by 60% pertaining to viral and fungal diseases. Abandoning terraces also amplify climate change, which requires climate-smart agriculture for socio-economic benefit and reducing climate change impact (Mylona et al., 2020). The climate-smart practices include soil–water management techniques, which increase productivity and resilience while lowering GHG emissions (Kosmowski, 2018; Zougmoré et al., 2014). Eastern Himalaya is also affected by overland flow, soil loss, land degradation, and nutrient loss. Soil loss was found to be maximum in barren lands (7.73 Mg/ha/year), followed by mixed cropping (4.32 Mg/ha/year), terraces (3.75 Mg/ha/year) and cardamom-based agroforestry (3.23 Mg/ha/year). The lowest N loss (4.49 kg/ha/year) was estimated in terraces, while P loss (8.19 kg/ha/year) was the lowest in mixed farming (Mishra et al., 2022). The state presents 5 agroclimatic zones viz. alpine zone, temperate zone, sub-tropical hill zone, mid-tropical hill zone and mid-tropical plain zone. The agriculture is greatly vulnerable due to fragile/poorly accessible landscapes, sparse settlement, poor infrastructure, changes in the hydrological cycle and river run-off change in Arunachal Pradesh. Also, a rise in temperature of 0.1–0.4 °C/year is observed in Eastern Himalaya. Climate change's impact on agriculture is both direct (temperature, precipitation or carbon dioxide concentrations) and indirect effects (soil moisture and the distribution and frequency of infestation by pests and disease). The rise in the state's minimum temperature has slowed the growth of temperate fruits like the kiwi and caused them to move to higher elevations (Bhagawati et al., 2017; Gautam et al., 2014).

3.2 Food Security and Sustainable Agriculture in Terraces

Sustainable agriculture is encouraged by climate-smart agriculture. However, a climate change-resilient agricultural practice under a single framework is difficult to develop pertaining to different production landscapes (Aich et al., 2022). Indian agriculture is primarily rain-fed irrigation, and the production is greatly affected by the anomalous rainfall, extreme climatic events, pests etc. Apatanis in Arunachal Pradesh follow an effective, sustainable way of irrigation by planting early and late varieties of rice. Early varieties are grown away from the village where poor irrigation, grazing, and nutrient availability are the main obstacles. Late varieties are preferred near village with well-synchronized fish farming. The indigenous sustainable cultivation practice 'Zabo' (Phek district, Nagaland) is similar to integrated farming system. However, whole families in the village involve management/off-farm activities in farming and share rainwater harvesting during cropping. Zabo is the integration of forestry, fishery, animal husbandry and agriculture by utilizing harvested rainwater (Amenla & Shuya, 2021). Among cereals, rice covered about 81% of total area, followed by maize (12.8%). Oilseeds occupy 5.6%, while wheat occupies a very small fraction of North-East India. Pineapple and citrous are largely cultivated. In North-Western Arunachal Pradesh, highland traditional farming systems are crop (cereals, wheat, maize or rice with multiple cropping and intercropping) /horticulture (horticultural species), livestock (pasture management and livestock grazing), and mixed farming (combination of all the systems) dominated (Saha & Bisht, 2007). The productivity in wet paddy cultivation is high pertaining to optimum drainage, use of organic manure, irrigation, and terrace riser/bund utilization. Production fishes was 80–100 kg/ha/year. With consistent productivity, a stream provided irrigation and nutrients, and bio-terracing maintained soil fertility. However, crop varieties with low cropping intensity were more vulnerable to fungal attacks. Climate-driven crop-failure is reduced by cropping indigenous drought-tolerant varieties, agroforestry, polyculture, soil conservation, and water harvesting (Aich et al., 2022). Arunachal Pradesh's food grain production increased from 242.4 thousand tonnes to 495.6 thousand tonnes between 2003–2004 and 2019–2020, with a compound annual growth rate of 9.35% (Lobsang, 2022).

3.3 Terrace Cultivation in Biodiversity Conservation

Traditional agroecosystems are drawing much attention for biodiversity conservation and sustainable food production pertaining to changing climate (Aich et al., 2022). High crop/tree diversities increase carbon sequestration and reduce global warming. Mixed cropping reduces the risks of crop failure. Apatanis in Arunachal Pradesh grow pyaping (*Oryza sativa*) in zebi aji (soft fields). In the paddy-fish cultivation system, various indigenous varieties of rice, including, mipya, empu emo, layi, and missang emo, are grown in aller aji (hard fields) (Kacha, 2016). The naturally available fishes are *Puntius* spp. (papi ngiyi) and *Channa* spp. (tali ngiyi). The fishes available in kiley (river) are *Schizothorax* spp. (ngilyang ngiyi), Eels (tabu ngiyi), *Nemaucheilus* (ribu ngiyi), dorikona or weed fish (ngiyi papi). For economic sustainability, cropping of less perishable black pepper, cinnamon, cashew nut and coconut are essential (Alam, 2014). In Sikkim, North-East India, the odonate diversity of an organic terrace agroecosystem was compared to that of a forest ecosystem (Dewan et al., 2019). Rice terraces presented 20 species under three families, while forest ecosystem presented 18 species under 7 families. Beta diversity presented differences in incidence and abundance measures in both ecosystems. Many herpetofauna viz. *Ptyas korros*, *Herpetoreas platyceps*, *Xenochrophis piscator*, *Fejervarya* sp., *Polypedates* sp. live in the paddy fields. One of the most significant cash crops in North-East India is ginger, which is grown on rice terraces, SCs, buns, zabo, and plains. The local cultivars include Bola ada, Jatia ada, Moran ada, Naga Shing, Keki, Thingpuri, Tura, Shing Bhoi, Vaise etc. (Rahman et al., 2009). Some of the preferred fodder species in Sikkim Himalaya are *Artocarpus lakoocha*, *Ficus nemoralis*, *F. roxburghii*, *Saurauia fasciculata* etc. The agroforestry species along the terrace edges are *Schima wallichi*, *Engelhardtia spicata*, *Bridelia retusa*, *Bischofia javanica*, *Bombax ceiba*, *Rhus semialata*, *Castanopsis tribuloides*, *C. hystrix*, *C. indica*, *Ficus* sp., *Duabanga grandiflora* etc. (Sharma & Rai, 2012). The green manure crops like *Sesbania aculeata*, *Crotolaria juncea*, *Phaseolus aureus*, *Vigna sinensis*, *Cyamopsis tetragonoloba* provide N-added 84 kg/ha, 77.1 kg/ha, 38.6 kg/ha, 56.3 kg/ha, and 62.3 kg/ha respectively. Monpas in North-western Arunachal Pradesh grow major varieties of crops mainly *Zea mays*, *Eleusine coracana*, *Vigna cylindrica*, *Phaseolus vulgaris*, *Fagopyrum cymosum*, *F. esculentum* and *Glycine max*. The maize varieties include Bhamphinam, Phinam, Kashmiri Phinam and Nersaphinam (Saha & Bisht, 2007). The principal horticultural crops in Sikkim are large cardamom, turmeric, orange, apple, pear, flowers (gladiolus, orchids, lilies, carnation etc.) etc. Other plant species are cereals, pseudocereals and millets (*Amaranthus hypocondriacus*, *Fagopyrum esculentum* etc.), vegetables and tubers (*Momordica charantia*, *Dioscorea alata*, *D. japonica*, *D. lepcharum* etc.), *Cucurbita maxima*, *C. moschata*, *C. pepo*, endemic plants (*Acer hookeri*, *A. oblongum*, *Albizia arunachalensis*, *Camellia siangensis*), threatened economic species (*Acer osmastonii*, *A. sikkimense* etc.) etc. (Singh & Varaprasad, 2009).

3.4 Productivity Constraints

In EHR, pH and OC are the two important soil quality indicators (Singh et al., 2014). The pH of terraces was little higher (4.6) than the lowland (4.3). It was the lowest when compared with natural forest/ SC (5.3), plantation land (4.9), grassland (5.1). Also, the organic carbon (10.7 g/kg) was the lowest in all other land uses (12.1–28.7 g/kg). In this region, rampant deforestation has caused heavy soil degradation and erosion impacting agricultural production (Mishra et al., 2020). Apart from deforestation caused by SCs/commercial reasons, soil erosion is also caused by canal irrigation with unprotected cover system in the slopes and unterraced farming. Comparatively, rice productivity was more in settled terrace agriculture, however crop productivity was more in SCs. Comparatively, crop production in EHR is lower than Western Himalayas. Despite the fact that government-funded terraces have been built, farmers abandon them quickly due to a lack of capital, a high labour cost, changes in the social structure, and low yield (Mishra et al., 2020). Management of terraces with enhanced productivity requires integrated water/soil management practices. Terraces with wider width require management to be stable during rainfall. The constraints of terrace cultivation lie in socio-economical (labour shortage, maintenance cost, small/ dispersed land, less service/market/resource access and use efficiency, technical/ modern inputs/less tools/machinery uses), and environmental (heavy rainfall/surface run-off/soil erosion, climate change, water scarcity) challenges (Lama & Bordoloi, 2020; Mishra et al., 2020). Conversion of forest into settled agriculture-like terraces significantly reduced the nutrients like Mn (30.5 mg/kg), Cu (1.74 mg/kg), and Zn (2.13 mg/kg) up to 17.8, 0.81 and 1.42 mg/kg respectively (Choudhury et al., 2021). The soil micronutrients (54–64%) are maintained by clay, acidity and organic carbon content of the soil. Hence, micronutrients availability in the hilly agroecosystem soils is greatly dependent upon altitude-specific land use management. However, there is still a lack of knowledge regarding the complex interactions between soil acidity, soil properties, and changes in land use and cover (LULC) along altitudinal gradients on the availability of micronutrients in the EHR.

4 Socio-economic Perspective of Hill Agroecosystem

Climate change greatly impacts the agriculture and socioeconomic structure of EHR. More than 60% of the people are engaged in agriculture. Changes in monsoon patterns has caused to affect agriculture, thereby livelihood security (Maity et al., 2016). Climate change greatly impacts seed setting and quality parameters affecting the production of seeds. It requires adaptation to the changing climate by society, people participation supported by institutions with knowledge updates, water resource impacts, sediment load, and seasonal variability (Pramanik & Bhaduri, 2016). Apart from the anomalous rainfall during monsoon, post-monsoon water scarcity, reduced JH cycle, subsistence agriculture, lack of technology awareness, underdeveloped credit/market facilities etc. have affected the livelihood of the EHR people. Therefore, it requires a holistic approach toward production augmentation, productivity, sustainable generation of income and employment. The farmer's households in on-farm conservation present economic and sociocultural benefits of risk/uncertainty management, reduce labour bottleneck, provide nutritional requirements and forge social ties. "Grains for forest management program" would be valuable for livelihood security, and ecosystem resilience offering critical ecosystem services (Nath et al., 2022). Additional income may be generated by biomass carbon sequestration in restored SCs. The additional income is a benefit to the people of North-East India. In order to increase household food security, staple food self-sufficiency must be improved. However, it is limited by the poor development of rural/domestic/ infrastructure/socio-economic development, price volatility, food markets etc. (Behera et al., 2016). There exists a sociocultural attachment with shifting cultivation. Sustainable SC would be achieved by integrating with modern technologies. Various religious rites and festivals are attached to SC e.g., Kemovo (Earth Priest), Zhevo, Tsakro (the first sower), and Lidepfu (the first reaper) etc. in Nagaland. In SC, most of the operations are community-based working towards their needs rather than their capability (NAAS, 2016). Interestingly, SC was negatively (significant) related to family size, involved numbers of family members, land size, crop-selection, sowing methods, harvest timings (socio-economic/agroeconomical). Upper-stream forest loss and degradation impact the socio-economic structure, and downstream life forms (Panda et al., 2017). The climatic setback is considered to be due to the burning of bushes in SC. However, SC is linked with the cultural, ecological and socio-economic condition of the indigenous people (Deka & Sarmah, 2010). SC cannot be eradicated because it is a crucial component of cultural identity and a way of life connected to socioeconomic lives (Akoijam & Mahongnao, 2018). A sustainable and lucrative method would be useful in socio-economic upliftment of the indigenous people. In plantation sites, the indigenous people grow different socioeconomically valuable plant species viz. *Livistona jenkinsiana*, cardamom, tea, rubber tree, kiwi, plum, orange etc. (tribal agriculture, current science). In SCs, proper scientific management is necessary along with the preservation of the environment, crops, and production system sustainability for economic security and an abundance of high-quality food. (Wangpan & Tangjang, 2012). It has been observed that settled terraces are less remunerative than SCs. Diversification of economic activity is required for the hill region's development (Ninan, 1992). In the West Garo Hills, North-East India, the household dietary diversity score (HDDS), which measures a household's capacity to access food over a 24-h period, was calculated (Pandey et al., 2022). SCs presented significant dietary diversity to a maximum number of households (77.3%). However, food consumption had been changed due to increased attention to monoculture in SCs. New food consumption has caused vulnerable to the vagaries of the market impacting livelihood security. A different SC policy would be an alternative to monoculture. SC is permitted in the buffer zone with a strict 10-year rotation while the forest and valley areas are protected (Raman, 2001). Soli quality index (SQI) would be an important parameter for sustainability, crop productivity and livelihood security (Temjen et al., 2022). Although, several government policies have been deployed to reduce SC, scientists are recognizing the importance of the traditional SCs for livelihood/food security (Mukul & Herbohn, 2016). A total of 70–80% of JH has been replaced by agroforestry. It was useful in uplifting the social, environmental and economic status of the farmers of Arunachal Pradesh (Bani et al., 2022). SC is sustainable if the longer cycle is practiced (10–15 years). However, the population explosion has reduced it to 2–3 years (Longkumer et al., 2019). The practise of SC is carried out by indigenous people in accordance with their attachment as per the natural environment, social bonding (community/traditions attachment in the area), and economic bonding (livelihood/location attachment) (Pandey et al., 2022). Livelihood improvements in N. E. India have been achieved by fish-rice-vegetable-fruit farming in Dhalai (Tripura); integrated farming in SC at Saiha, Mizoram; SC farmers improvement by fish-cum-livestock-integrated farming, in Daporijo, Arunachal Pradesh etc. (Lama et al., 2017). In order to produce food sustainably and ensure food security, it is necessary to maintain biodiversity, which SCs do by preserving a wide variety of crops (Pandey et al., 2022). In East Sikkim (Rani Khola watershed), the socio-economic challenges were shortage of labour, the higher maintenance cost of the terraces, small land holdings, dispersed distribution of lands and ban on chemical fertilisers, poor accesses to services, markets and limited resources (Mishra et al., 2020). Respondents from EHR villages have expressed that present cultivation system was less productive with low yield and had a high cost of living. People looked for ways to increase their income, as well as opportunities with the Public Distribution System (PDS) and cheaper food options (Mukerjee et al., 2018). Limited arable land, low productivity, non-agricultural income sources, dependency on public distribution have substantially increased in the state of Arunachal Pradesh (Lobsang, 2022). The socioeconomic characteristics include household size, education level, working/nonworking members, and land size (Lama & Bordoloi, 2020). Permanent forest (timber, fire wood, cane, bamboo, palm leaves etc.), Jhum (Brinjal, chilli, ginger, paddy, millet etc.), orchard (orange, lemon, pineapple etc.) are the important source of livelihood for Galo tribe (Bora et al., 2013). The increased species diversity/richness in successive SC fallows may provide biodiversity enriched services uplifting forest-based economies (Gogoi et al., 2020). Imperfect tourism management, limited farmer strategies, and lagging land values are chaotic states of the farmers (Deng et al., 2023).

5 Conservation Policies of Hill Agroecosystems

The minimum support price, compensation, and crop insurance policies in agriculture need to be revised to benefit farmers (Maity et al., 2016; Mukherjee & Maity, 2015). The public and private extension systems are required to be converged for the awareness of the farmers. It is essential to strengthening the existing cultivation system (agro-based/site specific)/policy/act rather than imposing modern interventions (Kumar et al., 2016a, 2016b). Degradation levels can be reduced, and sustainable production of food, fuel, and timber can be continued through a complete forest policy (Kumar & Meena, 2016). Sustainable forest management is a part, and the unit of a policy framework is the landscape. The value of social benefits and conservation of biodiversity is not realized in the state policies converting SCs into settled terraces (Pandey et al., 2022). Afforestation programs plant trees with commercial/fuel importance, which deprive the farmers of food security. The existing divergence between SC lands and policymakers requires reappraisal and close attention. Biodiversity (plant/animal) in SCs must be assessed for appropriate policy development for biodiversity conservation and effective forest management. Different watershed development projects have been developed in SC areas with grants (100%) to the state plan (Satapathy & Sarma, 2003). However, these programs are yet to meet the socio-economic expectations of the people. The design of such programs should be related to the climate, physiography, traditional occupation, land use, etc. Irrigation could be assured by bench terraces, which would attract the farmers for settled agriculture. The jhummias in Tripura were resettled under the Government funded integrated schemes of horticulture, agriculture, pisciculture, animal husbandry, etc. in compact blocks. However, the discontinuation of the schemes led Jhummias to revert back to the SCs. Cultivation of glutinous JH-rice is required for performing traditional rituals by the communities, while HYVs are not suited. Additionally, there are discrepancies between empirical results and official government reports on SCs as a significant concern for deforestation, as was seen in the West Garo Hills (Shaw et al., 2022). Government policies must be based on accurate data; otherwise, they would be entirely based on misconceptions about monoculture and other land-use practices. Policymakers and mapping organizations should understand that changing the land also changes society. Setting up of protected areas under Wildlife Protection Act (1972) and government subsidies for staple foods were found to be a driving forces for reducing SCs. More than 400 people in Asia, mostly indigenous people rely on tropical forests and practice SCs. Any policy impacts the livelihood of a greater population. The policies can be learned and exchanged at regional and global levels to make changes to improve the SCs (Kerkhoff & Sharma, 2006). Recognizing the benefits of shifting cultivation, the strengthening of SCs rather than replacement is recommended. The benefits of conservation under shifting cultivation are more than the other mode of cultivation with secured land tenure and households. In SCs, fallow forests are considered as forestry phase. Indigenous knowledge, customs, and other practices promote biodiversity conservation. Governments have implemented sedentary farming and plantations but these are not much useful in uplands. The local customary institutions would be embedded within the state, formalized, capacitated, and strengthened. National-level policy support should exist. The Shillong Declaration (2004) has emphasized that the policies at local, regional, and national levels should be reappraised. The management approaches should be decentralized, participatory, interdisciplinary, adaptive, ecoregional, and based on a multi-stakeholder approach. Forested fallows should also be considered agricultural land, and are beneficial for government and cultivators (Kerkhoff & Sharma, 2006). Policy formulation should consider that SCs cause less loss to biodiversity. Settled agriculture causes permanent destruction to a large area. Controlled burning in agriculture and silviculture practices, farmers' innovation for SCs, organic farming, etc. should be emphasized. Carbon finance has been proposed by policymakers, where incentives to the communities of forest frontiers would transition away from SCs to less carbon emission (Ziegler et al., 2012). However, meta-analysis over 250 studies reveals uncertainties over such transitions. Policies should address non-forestry issues, which include landlessness outside of forests and less development in agricultural sectors, as this is the main cause of deforestation (Myers, 1992). Mission Organic Value Chain Development for North Eastern Region (MOVCDNER) promotes concentrated, specific and certified clusters of organic production linking growers and consumers supporting seeds, inputs, certification, creation of collection facilities, processing, aggregation, marketing, etc. (Department of Agriculture, 2023). The agroeconomic research centre (AER), Jorhat, Assam deals with the agroeconomic issues of N. E. India. National Mission on Edible Oils-Oil Palm (NMEO-OP), National Bamboo Mission (NBM), Establishment of Agri-Clinics and Agri- Business Centres (AC & ABC), Extension Education Institute (EEI), Mass Media Scheme in NE Region etc. are some of the supports in N.E. India. Regional networking, specially designed gene sanctuaries, genetic reserves/garden, identification, and recording niche prevalent crops/cropping system are among the policy recommendations (NAAS, 2001). The government started the "Pakke Tiger Reserve-2047 Declaration on Climate Change Resilient and Responsive Arunachal Pradesh" to safeguard the environment and combat climate change, including effective irrigation techniques.

6 Sustainable Hill Agriculture in Relation to SDGs

The most important link between people and the environment is agriculture (FAO, 2018). It helps to achieve a number of sustainable development goals (SDGs). The rural landscape can be revitalized by sustainable food and agriculture. Based on experience, data, technical know-how, and collective FAO knowledge, the action accelerates the transition to sustainable agriculture in order to meet the vision of the 2030 Agenda by integrating food, agriculture, livelihood, and management. The approach for a sustainable food and agricultural system is based on five key principles: productivity/employment/value addition; protection/improvement of natural resources; improvement of livelihoods with support for economic growth; improvement of people/community/ecosystem resilience; and adaptation to new challenges in governance. Action 1 which corresponds to access to productive resources/finance/services directly contributes to SDG 1, 2, 5, 7, 8, 9, 14, and 15. Action 2 is connecting smallholders and the market contributing to the SDGs 1, 2, 5, 8, 9, 11, 12, 14, and 15. Encouragement of production and income diversification contributes to SDG 1, 2, 8, 11, and 14. Action 4 is the producers' knowledge building and capacity development for SDG 1, 2, 4, 5, 8, 9, 13, and 15. Action 5 is the soil health enhancement and land restoration contributing to 1, 2, 11, 12, and 15. Water protection and scarcity management is Action 6 (SDG 1, 2, 6, 7, 8, 9, 11, 12, 14 and 15). Biodiversity conservation and ecosystem functioning is Action 7 (SDG 1, 2, 6, 11, 12, 14 and 15). SDGs 2, 7, and 12 are related to food loss reduction, encouraging reuse/recycling, and sustainable consumption (Action 8). Action 9 is empowering people while fighting inequalities contributing to SDGs 1, 2, 5, 8, 10, 13, 14 and 16. Action 10 is the promotion of secured tenure right related to SDGs 1, 2, 5, 8, 9, 13, and 14. Action 15 deals with the challenges of climate change (SDG 1, 2, 11, 13, and 14). The 2020 Agenda requires policy dialogue with coordination (Action 17) related to SDGs 1, 2, 5–7, 11- 17. In North-East India, the village council successfully manages most land resources including others at the community level. It enables sustainable, equitable livelihood/food security for the communities (Shaw et al., 2022). SC cultivators grow diverse food crops with in situ conservation, which contributes to the conservation of varieties of edible foods. National Bureau of Plant Genetic Research (NBPGR) has recorded diverse varieties of maize (674), upland rice (298), grain legumes (200), eggplant (37), ginger (60), taro (250), yam (242), etc. in SCs from N. E. India (Pradheep et al., 2011; Shaw et al., 2022). JH fallows also present non-timber forest produce essential for rural livelihoods (Shaw et al., 2022). In SCs, the dibbling method used for seeding is useful in preventing soil erosion, compared to conventional agriculture on slopes (20°). In SCs, resource management is accomplished by using zero tillage, mulching, graded weeding, sequential cropping and harvesting, adjusting crop timing, retaining tree stumps, laying logs across slopes to reduce erosion, mixing crops, and integrating farming with livestock, among other techniques (Shaw et al., 2022). SDG India index was calculated by the methods (Sustainable Development Solutions Network—SDSN) based on identification, normalization, weightage, individual goal score, and composite score. The latest report incorporated 16 goals with qualitative analysis of Goal 17; 70 targets; 115 indicators (76 completely aligned, 31 refined). Remarkably, Sikkim with a score of 71 is among the top 5 states in SDG performance. However, the bottom 5 states with low scores are Nagaland (61), Arunachal Pradesh (60), Meghalaya (60), and Assam (57). In the analysis of Goal-wise top states, Meghalaya, Tripura, and Arunachal Pradesh achieved Goal 10 (reduce inequality), Goal 12 (Responsible consumption and production), and Goal 15 (life on land) respectively. Indigenous knowledge together with sustainable development is closely related, necessitating documentation (Negi et al., 2023). To meet zero hunger and other SDGs, the required ten interlinked/interdependent elements (FAO regional Seminar) are Diversity; synergies; efficiency; resilience; recycling; co-creation, and sharing of knowledge (describing common characteristics of agroecological systems, foundational practices, and innovation); human together with social values; culture with food traditions (context features). It assists in achieving the "10 Elements" as a planning, management, and evaluation tool for agroecological transitions for practitioners, stakeholders, and policymakers.

Traditional knowledge-based ecosystems have a variety of genetic resources for both plants and animals (Sects. 2.1, 3.2 and 3.3). These productive agroecosystems are exclusive to the hilly region. Although productivity still needs to be increased, it is currently the only means of ensuring food security. For food security, indigenous communities have created various sustainable agricultural management techniques. In the hilly agroecosystems, crop diversification is common. Crop diversification, irrigation systems, various stress-resistant varieties, and integrated farming systems (which foster ecosystem synergies) as mentioned in earlier sections significantly enhance the productivity and preservation of agroecosystems. Among the cutting-edge agroecological techniques used in the Eastern Himalayas that can be applied to other regions of the world with comparable agroclimatic conditions are Zabo, Alder-based SCs, bun method, and drip irrigation. The environmental and financial costs are reduced by Apatanis' recycling of organic waste into productive land. Different rituals are used to protect crops (at various stages of crop growth), and the use of pest/disease resistant varieties by various communities boosts the resilience of the population, the community, and the ecosystems. The traditional agricultural methods used in the EHR all contribute to the ten elemental components of agroecology that have been compiled by FAO experts. The FAO's shared vision of sustainable social, economic, and environmental dimensions along the agricultural landscape is also met by this.

The "system of rice intensification" raises yield while steadily lowering water use. According to the primary data gathered from 200 small households (100 SRI and 100 non-SRI), Tripura's rice production benefited economically from the method (Singh & Feroze, 2019). The method benefitted food, health, nutrition and habitat with 76% more economy. Indigenous knowledge imparts its importance in strengthening the management of a sustainable ecosystem, addressing poverty, sustainable harvest, and utilization of natural resources. The sustainability as per the farming systems in eight cases in the far EHR showed that strengthening farming systems is possible if there is a comprehensive strategy that takes into account stakeholders' development and economic aspirations, ecological foundations, integrated processes and practises, resources, knowledge, and value systems, as well as the well-being of farming communities together with government support (Shakya et al., 2019). Sustainability science would bridge in between knowledge together with action through trans-disciplinary and transformative approaches (Tambe et al., 2020). Traditional agriculture must be improved and degraded lands are required to be rehabilitated to address people's requirements. Land rehabilitation extends benefits like carbon sequestration, soil conservation, biodiversity conservation and hydrological balance (Saxena et al., 2005). North Eastern Region (NER) SDG Index was evaluated for N. E. states, and the rank of the districts was evaluated on the basis of 15 SDG Goals (except Goal 14/17). Among 103 districts, 64 districts were under the front-runner category (all districts of Sikkim/Tripura), and 39 districts were the performer category. East Sikkim (75.78), Gomati, North Tripura (75.73), West Tripura (75.67), Serchhip-Mizoram (74.87), South Sikkim (74.80), Unakoti-Tripura (73.47) were among the top districts.

7 Conclusions

The EHR region has diverse geographic and climatic characteristics favorable for agriculture. In the North-East, agriculture plays a crucial role in soil and forest conservation, which supports many SDGs. This is due to the traditional ecological knowledge and customs of various communities. Even though SC intensification threatens the climate, the forest, and the endemic species that live there, it also supports livelihoods and protects biodiversity (crops, other plants, and animals). Crop failure is less likely in agroecosystems where there is mixed cropping. Terrace farming is productive, and conserves soil, water, and nutrients. Climate-smart agriculture would greatly benefit from integrated water/soil management practices in terms of socioeconomic gain. Indigenous agriculture with market potential includes Zabo, Paddy-Cum-Fish Culture, and drip irrigation. Implementing policies based on empirical findings requires strengthening the current traditional cultivation system while using a transdisciplinary approach.

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The *Pnar* Traditional Knowledge on Processing and Utilization of *Sama Bangbluh* Derived from the Fruits of *Rhus Chinensis* Mill.

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Abstract The *Pnar* in Jaintia Hills, are one of the three indigenous people inhabiting the state of Meghalaya, India. The *Pnar* also referred to as the '*Jaintia*', are known to have profound knowledge and know-how on traditional methods and best practices of uses of plants for generations. In this paper, the local knowledge of the artisanal and traditional methods of processing the fruits of *Rhus chinensis* Mill. and its utilization was documented for the first time in literature. The *Pnar* has been harnessing the fruits of these plants from time immemorial, locally known as *Sama Sapbluh,* which means a fruit covered with salts; and processed it traditionally to produce the fruit-derived product locally known as *Sama Bangbluh*, meaning a fruit with a salty taste. The fruits collected from the wild underwent a long and successive traditional and artisanal method of processing which includes collection, threshing, sun drying, and grinding followed by sieving and winnowing using hand-carved traditional tools and technique, storage, and finally are sold in the market as *Sama Bangbluh*. The *Pnar* people use it mostly as a flavoring or appetizing ingredient, because of its salty and sour flavor balance piquant taste. It is also used simply as a decoction for drinking by mixing it with water. Furthermore, it is believed to have enormous therapeutic properties particularly used as an effective detox in conjunction with dry fish and mushroom poisoning; and also in the treatment of liver diseases, kidney-related problems, diarrhea, stomach bloating, and diabetes. However, over the years, despite its important application as food (appetizer) and medicinal values in the *Pnar* tradition, the study found that there is a significant or drastic decline in the collection and processing of the plant parts; including the availability of the *Sama Bangbluh* in the market. The study also highlighted the current direct and indirect factors attributed to the decline in the continuation of this age-old traditional knowledge and practices.

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1 Introduction

The *Pnar* from Jaintia Hills, hence also known as the 'Jaintia', are one of three major tribes inhabiting the state of Meghalaya, India. The indigenous people belonging to the Jaintia tribe are blessed with profound traditional knowledge and practices about plant resources and their uses. However, with the changing lifestyles and the integration of modern knowledge systems; there has been a substantial decline in the flow of the valuable traditional knowledge and information from our ancestors, who are the great knowledge holders, to the next generations. Therefore, it is of great importance to document and preserve indigenous knowledge and best practices so that they can be conserved and protected for future generations.

The literature review revealed that the *Pnar* community has a rich diversity of traditional knowledge and best practices. Some of the well-known ones include ethnomedicinal uses of plants and their therapeutic practices (Myrchiang et al., 2018; Langshiang et al., 2020; Bamon & Lalnundanga, 2022); bamboo drip irrigation system (Ryngnga, 2018; Singh and Gupta, 2002); black clay pottery (MBMA, 2023) and use of rice-based food (Umdor et al., 2016) to name a few. The review of related literature also revealed that the *Pnar* tribal community has used different parts of the *Rhus chinensis* Mill. plants for the treatment of various ailments (Rymbai et al., 2016; Langshiang et al., 2020). However, no documentation has been done on the *Pnar* traditional method of processing and utilization of the *Rhus Chinensis* Mill. fruit derive product locally known as *Sama Bangbluh.* Therefore, this paper aims to document this artisanal and traditional knowledge and best practices which are on the verge of disappearance, and also to highlight the current challenges that strongly influence its degradation and waning.

Rhus chinensis Mill. is a shrub and it belongs to the Anacardiaceae Family. This plant species is mainly found in the temperate and subtropical regions of Asia (Zhang et al., 2022). In North-East India, the plant species is found to disperse in small groups in the open forest of the Khasi Hills and the Jaintia Hills (Rymbai et al., 2016) and also in Manipur (Heirangkhongjam and Ngaseppam, 2019). The *Pnar* in Jaintia Hills call the plant *Dieng Sama* (*Sama* Tree) and the fruits of the plant are called *Sama Sapbluh* which means a fruit covered with salts; whereas the processed fruits derived product is called *Sama Bangbluh* meaning a fruit with a salty taste.

2 Material and Methods

To acquire information related to the *Pnar* artisanal and traditional method of processing the drupe fruits of *Rhus chinensis* Mill. and its utilization pattern, the study was carried out in the West Jaintia Hills district of Meghalaya. The selected area of sampling includes the *Iawmusiańg* and the *Iaw-Thymme*; and the *Iawpynsień* (*Iaw* meaning Market) which are located in Jowai and Wahiajer, respectively. The information collected were acquired through field survey and by directly interviewing the sampling units which included the '*Kong'* vendors (In *Pnar* means the Ladies) who sells the fruit-derived product; the households where processing of *Sama Bangbluh* is still practiced; and the traditional medicinal practitioners locally known as '*Nong-ea- Dawai Kynbat' or 'Kobiraij'*.

3 Traditional Method of Processing of the Fruits of Rhus Chinensis Mill.:

3.1 Plant Part Used

The fruit is the only part of the plant the *Pnar* uses for the production of the fruit-derived products locally known as *Sama Bangbluh.* The aggregated fruits of the plant grow as clusters from the panicle, and each fruit-bearing seed is somewhat round or elliptical. The unique feature of the mature fruits of this plant is the enveloping of the waxy white coating layer of salts-like around it. Hence, it is locally called *Sama Sapbluh* which means a fruit covered with salts. This distinct feature produces a unique kind of salty and sour piquant taste after processing the fruit. Hence, the main and only reason the *Pnar* have been harnessing it for ages.

3.2 Traditional Method of Processing

As per the information assimilated from the local vendors and the households who deal with the collection of the fruits of *Rhus chinensis* Mill. from the forest; process it traditionally in their respective homes; and sell it in the market as fruit-derived products. The step-by-step traditional method of processing the drupe fruits is described as given in the following stages:

3.2.1 Collection

It is done simply by breaking or cutting the panicle of the shrubs bearing the fruits with hands or a knife when necessary (Fig. 1). The fruit clusters collected are then stored

Fig. 1 *Rhus chinensis* Mill. and its fruits. *Source* Lamare and Passah

inside a carry bag. The process of collection is normally repeated for a couple of days, till an adequate amount of the fruits are obtained. However, this significantly depends on the abundance or availability of the fruits in the wild. The method of collection is simple but time and energy-intensive. It is simple and easy because the height of the fruits can be reached with ease and the plants do not grow inside the thick forest. However, it is time and energy taking because they grow only in small patches/areas in the open forest, and are also confined in the slopes of the hills. Collection of the fruits from the wild generally takes place during the month of September–November. It is also believed that the best time for the collection of the fruits is when the green leaves of the plants turn brown, traditionally, it indicates the ripening season of the fruits. The *Pnar* also believe that morning time is the best time for the collection of the fruits because it is believed to contain a maximum concentration of waxy salty coating around its small fruits. However, as per the information from the locals, currently, the availability and abundance of the plants in the wild are declining with each passing season and year.

3.2.2 Threshing

Shortly after the collection period is over, the accumulated fruits that are intact to the panicle or branches undergo manual threshing either by gently striking or beating the panicle against the hard surface or simply by hand rubbing actions. The separated individual small-sized fruits are accumulated and kept in a '*Chang'* (Bamboo basket). This stage of processing is slow and time-consuming. However, it also depends on the

Fig. 2 *Chang*, the traditional basket made of bamboo. *Source* Lamare and Passah

quantity of fruit accumulated from the forest. Figure 2 shows the handmade bamboo basket locally known as '*Chang'* use for keeping the accumulated thresh fruits of *Rhus chinensis* Mill. and other food grains.

3.2.3 Sun Drying

Once the stage of threshing is completed, the drupe fruits undergo a long period of the natural process of sun drying. This stage continues for at least 3–4 months or throughout the winter season, till the drupe fruits dehydrate and are completely dried.

This process is done by manually spreading the thresh fruits in the open sun, using a traditional handmade '*Chyl-ni*' (Woven bamboo basket tray) if the quantity is not a lot and '*Chyl-liah*' (Woven bamboo mat) if quantity collected and need to sun dry is a lot. The locally made woven bamboo basket tray used for keeping the fruits for sun drying is displayed in Fig. 3.

3.2.4 Grinding

In this stage, the traditional tools used are called '*Thlong*' and '*Synrai*', which are large size wooden pestles and mortar that are hand carved out from the stem of a log and branch of a tree, respectively (Fig. 4). The traditional technique involved in this stage of processing is simply keeping the drupe sun-dried fruits into the empty '*Thlong*' and through continually pounding with the help of the '*Synrai*', the fruits are manually grinded till all the natural compositions in its seeds, fruits and

Fig. 3 Traditional bamboo tray '*Chyl-ni*' used for keeping the fruits for sun drying. *Source* Lamare and Passah

waxy salty coating commingled and are properly and thoroughly mixed. The end product of the grinding processes is the coarse to fine particle size brown texture fruit-derived products. It is from this stage onwards the fruit-derived products of *Rhus chinensis* Mill. is locally called as *Sama Bangbluh.* Traditionally, it is believed that the grinding processes induce the release of a distinct flavor and piquant taste in it and; if are not smashed or crushed immediately, the distinct taste of the fruits will be reduced and eventually disappear. Therefore, preferably it is considered best to grind it immediately after it reaches the saturated stage of sun drying. The picture showing a preview of the process of grinding the fruits using a handmade traditional wooden pestle and mortar is displayed in Fig. 5.

3.2.5 Sieving and Winnowing

The main objective of this stage of processing is to segregate the seed from the coarse to fine grain texture commingled fruit-derived product, *Sama Bangbluh.* The process is simple and it is done manually with the help of '*Chyl-ni',* where the composite commingled end product is separated through sieving and continuously tossing in the air till the seeds are separated from the mixtures. In addition, the purpose of this is basically because there is a price difference between the mixed and the sieved *Sama Bangbluh* in the market including people's preferences. However, it is edible in both form.

Fig. 4 Traditional tools called '*Thlong*' and '*Synrai*' use for grinding. *Source* Lamare and Passah

Fig. 5 Grinded and pounded sun-dried fruits of *Rhus chinensis* Mill. *Source* Lamare and Passah

3.2.6 Storage and Sale in the Market

The sieved and winnowed *Sama Bangbluh* are then accumulated in a '*Chang*' and then finally stored inside clean and dry rice bags. The final naturally fruit-derived products are transported into the market. It is sold either by measuring with a cup or

Fig. 6 Selling of the '*Sama Bangbluh'* in the market. *Source* Lamare and Passah

by weight, depending upon the requirement of the buyers. If stored properly, fruits-derived products can be stored for a long period and do not get spoiled. Figure 6 displays the '*Kong*' vendor selling *Sama Bangbluh* in the *Iaw-Thymme* market in Jowai, West Jaintia Hills District of Meghalaya.

3.3 Utilisation Pattern of the Sama Bangbluh by the Pnar

The *Pnar* community of Jaintia Hills is consuming or using the natural fruit-derived products of *Sama Bangbluh* directly or indirectly in one or both of the following ways:

3.3.1 Food (Appetiser) Values

The *Pnar* have been using *Sama Bangbluh* for ages because of its salty and piquant unique taste. It is mostly used as a flavoring or appetizing ingredient, replacing salts, while eating fruits or mixed fruits because it gives a gradient level of taste to the fruits. It is also used simply as a decoction for drinking by mixing it with water. Figure 7 shows the *Sama Bangbluh* stored in the bottle for ready use at home.

Fig. 7 Stored *Sama Bangbluh* for use at home. *Source* Lamare and Passah

3.3.2 Medicinal Values

Based on the information collected from the traditional medicinal practitioners, the *Pnar* has used and believes that *Sama Bangbluh* has diverse therapeutic properties and it is used as an effective natural detox in conjunction with dry fish and mushroom poisoning, treatment of liver-related diseases, kidney associated problem, stomach related problems like diarrhea, bloating; and also in treatment of diabetes. Furthermore, according to traditional healers, the salts that are present in the fruit are the most valuable ingredient that assist in the treatment of the mentioned ailments. Furthermore, *Sama Bangbluh* has also been used by the locals for the treatment of sick and weak poultry animals like pigs and chickens by adding it to their food. It is said to boost the capability of the animals to recuperate immediately. However, throughout the study period, the traditional medicinal practitioners were adamant about providing detailed information about the procedures and processes of traditional medicine preparation methods and additional ingredients needed to add with *Sama Bangbluh* for the treatment of the mentioned ailments.

4 Factors that Contribute to the Degradation of the Traditional Practices

Despite the important application and uses of the *Sama Bangbluh* in the *Pnar* tradition, the study found that there is a decline in the collection, processing of the plant parts; and availability of the *Sama Bangbluh* in the market. The study summarised the direct and indirect factors that contribute to the decline in the continuation of this age-old tradition and practices as given below:

4.1 Low Revenue in Return

The primary and direct factor that contributes to the decline in these traditional practices is the economic return is minimal and significantly low. Market survey revealed that normally, the price of *Sama Bangbluh* in the entire study area ranges from ₹20 to ₹30 per cup; and ₹350 to ₹600/kg. In addition, the efforts put into it are also time-consuming. The minimum amount of profit earned after processing and selling the *Sama Bangbluh* significantly discourages the locals to continue undertaking the traditional method of processing practices. Nowadays, its availability in the market has also reduced tremendously. This factor cumulatively has a great impact on the continuation and protection of this particular *Pnar*-aged old traditional practices.

4.2 Information Gap

The indirect contributing factor that led to the decline of these traditional practices is the lack of hierarchical passing of traditional knowledge and practices from our ancestors, who are great knowledge holders, to the next generation. This can be attributed to the integration of modern medicinal systems into our daily lifestyle; push factors for moving youth out of the villages/town and loss of interest in the youth.

4.3 Decline Availability in the Wild

The study also found that villagers are now reluctant to go to the forest and search for this particular forest product, due the reason that the availability of the plants in the forest is said to become limited to small plots; and to avail adequate amount the villagers need to cover large area, which is time and energy intensive.

4.4 Deforestation

Another indirect factor could be the intentional or unintentional forest fire that burns the forest during the dry season. The consequences of this lead to the loss of growing seedlings coupled with the clearing down of forest for other purposes has ultimately culminated in a long-term forest cover loss.

5 Conclusion

To circumvent the degradation and diminishing of the indigenous knowledge particularly with the processing and utilization of the fruit-derived product locally known as *Sama Bangbluh,* first of all, it is imperative to document in the written text the age-old traditional knowledge and best practices practiced by the *Pnar*, before it disappear from the tribal tradition and the world. It is also imperative to create awareness in the *Pnar* community about this vaguely noticed and underutilized plant and its potential and provision for food and medicinal biodiversity values. Most importantly, to revive or strengthen the practices and save this particular *Pnar* traditional knowledge and practices, the need of the hour is to encourage the promotion and enhance prioritization for conservation through the involvement of the government, institutions dealing with bioresources, and the local communities.

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Traditional Practices of Agroforestry Systems in the Cold Desert Area of Himachal Himalayas

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Abstract The present chapter gives an overview of indigenous knowledge of traditional agroforestry systems practiced by tribal communities such as *Gari, Todpa, Swangla, Tinnanba, Pitishag*, and *Bhot* in the Lahual and Spiti district. The identified agroforestry systems of the region are Agri-horticulture, Agri-silviculture, Agri-silvopastoral, Silvi-pastoral, and Horti-pastoral. Traditional agricultural practices are still used by the tribal communities of the district which involve cultivating traditional agricultural crops, use of traditional fertilizer such as night soil compost, using traditional cultural practices such as crop rotation, intercropping and mixed cropping for crop insurance, and considering the plantation of seabuckthorn, which provides medicinal, economic and ecological benefits to the local peoples living in cold desert area. These systems demonstrate the resilience of local communities in utilizing their deep knowledge of the environment to create integrated farming practices that enhance livelihoods, conserve resources, and promote ecological stability. However, as modernization advances, preserving and promoting these traditional practices remains essential for the overall well-being of both the ecosystem and the communities dependent on it. Therefore, the study indicates that the traditional agroforestry system plays a crucial role in the current situation of urbanization and climate variability of cold desert areas.

Keywords Traditional practices · Agroforestry · Cold desert · Lahaul and Spiti · Resilience · Urbanization · Himachal Himalayas

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1 Introduction

Lahaul & Spiti and Kinnaur district of Himachal Pradesh, Ladakh and Kargil district of Jammu and Kashmir represent diverse biogeographic of cold arid ecosystems in Indian Trans Himalayan regions (Chandra et al., 2019). In India, around 74,809 km^2 of area comes under cold deserts, of which about 35% is in Himachal Pradesh with 25% in Lahaul and Spiti district (Rawat et al., 2023). Lahaul & Spiti district is an integral part of the Indian cold desert region of the North-Western Himalayas located in the alpine arid zone of Himachal Pradesh. It is well known for its geographical ruggedness and harsh climatic conditions with dry summers and long freezing winters with high fluctuations of temperature, very scanty rainfall, and high snowfall (Aswal & Mehrotra, 1994; Singh et al., 1987).

Agriculture serves as a primary source of livelihood for the local residents in this region. Small and marginal farms predominate due to the limited availability of arable land. Given its location in a rain shadow area, the primary source of irrigation is glacial water. However, the region faces challenges stemming from insufficient snowfall during the winter season and the dwindling glaciers caused by climate change. This situation poses a significant threat to farmers who rely entirely on these snow reservoirs for irrigation. Consequently, the risk of crop failures is on the rise, endangering the livelihoods of the farming community. Also, there has been a shift in the cultivation of traditional crops and the use of traditional farming practices to high high-yielding variety of cash crops such as peas and cauliflower as well as vegetables and fruits to get larger monetary benefits (Oinam et al., 2005).

Extreme weather conditions in Lahaul and Spiti i.e. scanted rainfall, massive snowfall, wind, extreme temperature fluctuation, high radiation of UV rays, intense solar radiation, and extreme climatic conditions determine and regulate the life process and distribution of the vegetation (Rawat et al., 2010). Vegetation is very sparsely distributed in three systems (i.e., agroforestry, forestry, and forest) in the region. In general, the habitat is tree or a very few arboreous taxa like *Betula utilis, Hippophae rhamnoides, Juniperous marcopoda, Rhododendron companulatum, Pinus wallichiana, Cratagus songarica,* and small trees/shrubs of *Salix* spp. are found sparsely in small patches. At present, nearly 7.9% area of the district Lahaul & Spiti is under scant forest cover and the vegetation is under tremendous pressure due to increasing anthropogenic and biotic pressure (Aswal & Mehrotra, 1994). But around settlements willow-based and poplar-based agroforestry plantation systems are found (Rawat et al., 2006). Since during winter months, fuelwood is required to keep the houses warm there is limited fodder for the livestock as well as basic needs of food and timber have equal importance (Subba et al., 1995; Shashni & Sharma, 2022). To fulfill these needs of the tribal people of cold desert regions agroforestry can play a significant role in managing these challenges. Agroforestry systems include community forestry and trees on farms with a variety of local forest management and ethno-forestry practices (Basu, 2014). This practice of agroforestry will cover the naked, rugged, treeless uncultivable land with greenery, fuelwood, and fodder. Moreover, this approach will make the tribal communities of Lahaul and Spiti financially independent by providing numerous livelihood options, crop security, agriculture development, and environmental conservation (Oberoi et al., 1992).

Agroforestry is considered to be a multipurpose branch as it offers numerous opportunities to farmers to improve farm production, source earnings, and provide productive as well as protective ecosystem services (Sharma & Sharma, 2019). Agroforestry is extensively promoted as a practice that enhances sustainability by combining the strengths of both forestry and agriculture. This approach not only ensures food security but also contributes to poverty reduction and bolsters the resilience of ecosystems, particularly at the level of numerous smallholder farmers. Consequently, establishing stronger connections between different knowledge systems, with an emphasis on "Community" participatory management approaches, is now recognized as crucial for the sustainable management of forestry and agroforestry systems (Adhikari et al., 2007; Dhakal et al., 2007).

India has a rich historical tradition of practicing traditional agroforestry, with practices adapted to suit the agro-climatic conditions and local needs. It can be considered the birthplace of agroforestry, featuring a wide array of agroforestry systems, as noted by Kumar et al., (2012). These systems encompass the tropical, subtropical, and temperate regions. While significant scientific attention has been directed towards tropical and subtropical agroforestry systems in the past (Singh, 1987), temperate agroforestry finds its primary application in the Indian Himalayan Region (IHR). In this region, various forms of hill agriculture coexist with a diverse range of tree species, covering approximately 13.6% of the IHR's total geographical area. This unique blend of agriculture and forestry practices reflects the adaptability and sustainability of agroforestry in diverse landscapes (Kumar et al., 2018). There have been different studies on agroforestry systems, which has shown how this system is beneficial to human as well as nature. For instance, Kala (2010) observed that local communities have developed woody perennial-based systems to fulfill their livelihood needs, particularly during challenging periods of scarcity. These systems, based on woody perennials, offer a means for farmers to address the escalating prices of fodder and fuelwood. These price hikes have resulted from heightened demand and reduced supply of fuelwood due to ongoing forest degradation (Bowonder et al., 1988). In addition to catering to household requirements for fuel, timber, fruits, and a variety of non-timber forest products (NTFPs), agroforestry practices play a pivotal role in ensuring livelihood security. They also offer crucial environmental services, including watershed protection, hydrological benefits, carbon sequestration, and contributions to both adaptation to and mitigation of climate change (Sharma et al., 2007). Moreover, Singh and Dagar (1990) have identified agri-silviculture systems, agri-horticultural systems, agri-horti-silviculture systems, silvi-pastoral systems, and homesteads in Mussorie hills in the Western Himalayas. In light of these findings, efforts have been undertaken to identify the existing tree-based models and their applications in the district, characterized by cold desert environments, within Himachal Pradesh. Similarly, Kumari et al. (2008) in Lahaul & Spiti found that five agroforestry systems are practices by the farmers, which included agri-horticultural, agri-silvicultural, agri-silvi-pastoral, pastoral-silvicultural, and pastoral-horticultural. Nayak et al. (2011) contributed valuable insights into the utilization of agroforestry practices in the district. Their findings underscored agroforestry as a traditional land-use adaptation strategy with the potential to enhance livelihoods. This is achieved through the simultaneous production of essential resources such as food, fodder, and firewood. Additionally, agroforestry was recognized as a means to mitigate the impact of climate change, further highlighting its multifaceted benefits for the local communities and the environment.

The Lahaul and Spiti district, according to the Census of India in 2011, is home to a population of 31,564 with a relatively low population density of 2 inhabitants per square kilometer. The district exhibits a sex ratio of 916 females for every 1000 males, and it boasts a literacy rate of 77.24%. In addition to its demographic characteristics, the district is renowned for its diverse attractions. These include awe-inspiring snow-covered mountain peaks, challenging rugged terrains, perennial rivers, picturesque lakes, and magnificent glaciers. The district is abundantly rich in its culture and traditions such as traditional dresses, functions, indigenous food, local languages, cultural values, songs, proverbs, customs, healing arts, and traditional agricultural practices, etc. (Kumar & Manohar, 2015). *Swanglas, Thakurs, Kanets,* and *Bhots* along with several scheduled caste communities of *Chahans, Dombas, Hessis, Lohars*, etc. are the inhabitants of the district (Chand et al., 2019; Negi, 1976). The main occupation of the locals is farming and livestock rearing in which agriculture contributes a major share in their household economy (Bajpai, 1987). Also, the district is a storehouse of numerous ecological services on which the locals are dependent among which soil has an important significance i.e. supporting service (Sharma & Sharma, 2019). The soil may be called the alpine sward type as the upper stratum of the earth and vegetable mould is filled with completely decomposed roots of grasses and supports a wide variety of herbaceous plants (Samant et al., 2007). Also, the soils of the district are alkaline in nature and consist of high organic matter, available nutrients, and support vast microflora which signifies that the region has a wide variety of biodiversity (Sharma & Singh, 2017; Kumar et al., 2018). An agricultural system is an agro-ecosystem, a complex assembly of interconnected components that has its overall purpose of production of crops and raising livestock to generate food, fibre, and energy using natural resources. All these components are intricately linked to one another (Jones et al., 2016).

This chapter mainly focuses on the status of different agroforestry systems of the region while identifying the traditional knowledge system which has future prospects. In recent years traditional crops like potato, barley, and black pea have been increasingly replaced by green pea, one of the conventional crops cultivated in the Lahaul and Spiti district, which is a new reliable source of good economic returns and other vegetables (Sharma & Chauhan, 2013; Shashni & Sharma, 2022). Also, the apple is a new choice as a major cash crop, which is gaining popularity due to climate variability in the region and has brought suitable chilling conditions to the apple crop (Rana et al., 2008). The main factor that has led to this transformation in the region is a decline in the demand for traditional crops, climatic suitability for new crops as well as technological interventions in terms of workload (Rana et al., 2011). This paper documents the status of traditional knowledge of the tribal communities on an agricultural system of the Lahaul and Spiti district and its changing pattern with climatic variability. This chapter encompasses information on agroforestry systems and their implementation in a region. It underscores their potential to address the growing demands for food, fuel, fodder, and timber within the community, while also highlighting their capacity to provide valuable ecosystem services. Furthermore, the chapter offers a summary and analysis of the evolving trends in agroforestry research within the cold desert, with the aim of introducing fresh perspectives and pathways to enhance agroforestry and similar systems. The agroforestry practices in this region, which have evolved over centuries, have not remained static and have adapted to changing circumstances and pressures. Therefore, the central focus here is on how agroforestry can be sustained and promoted as an improved land-use strategy, especially in the face of competing interests and external pressures.

2 Material and Methods

The research was conducted in the Lahaul and Spiti district of Himachal Pradesh from June 2016 to June 2019. This district is located within the geographic coordinates of 31°44′57″ to 32°59′57″ N latitudes and 76°46′29″ to 78°41′34″ E longitudes, encompassing a total area of 13,835 square kilometres. The district is divided into two subdivisions, with Lahaul having its headquarters in Keylong, and Spiti having its subdivision centre in Kaza (Kumar et al., 2018). Due to rough terrains, harsh climatic conditions, and snow-covered mountains, the region gets isolated from the outside world for approximately six months each year (Bajpai, 1987). The climate of the district varies considerably and the season cycle resembles the temperate and alpine zones. The district is enclosed between high mountains, which form a barrier against monsoon rains. The post-monsoon is very cold and starts from the month of October and continues till mid-March. January and February are the coldest months when the mercury dips to − 30 °C or below. This is followed by a short spell of spring (Mid-April to mid-May) and a bigger summer from June to September. During this time, monthly maximum temperatures range from 8.5 to 27.8 °C, while minimum temperatures vary between 14.3 and 0.9 °C. Rainfall in the area is scanty, which fluctuates from 3.0 to 164.0 mm depending on place to place. For documentation of traditional agricultural practices, a reconnaissance was done in different villages of the district, and information was gathered related to the hill agriculture system. Field visits, personal interviews and interactions with locals were scheduled for the data collection (Fig. 1).

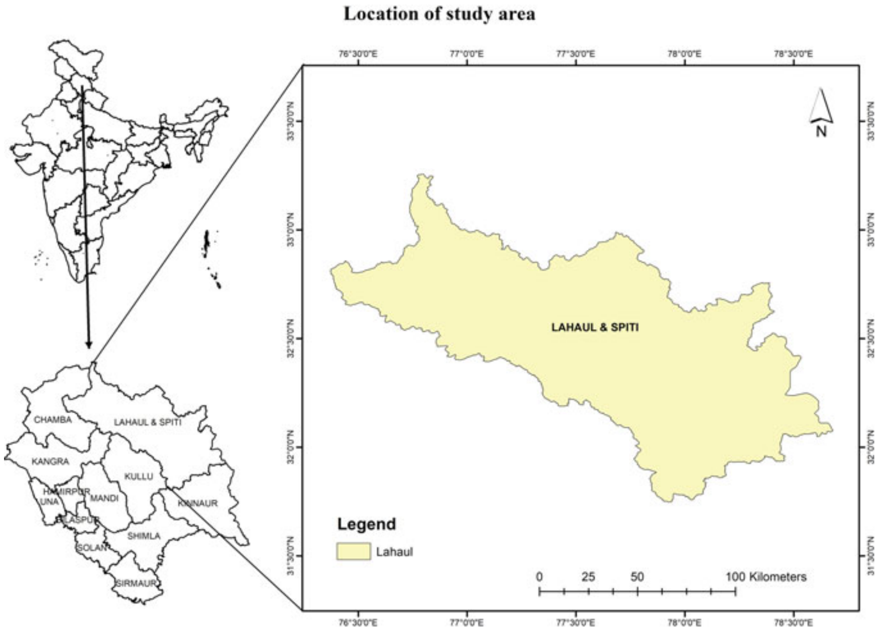

Fig. 1 Geographic location of study region

3 Results and Discussion

Agroforestry systems encompass both ecological and economic interactions among diverse components, incorporating the cultivation of trees in farming contexts, community forestry initiatives, and a range of local forest management and ethno-forestry practices. The tradition of cultivating scattered trees on agricultural land has a long history, with these trees serving various purposes, including providing shade, fodder, fuelwood, sustenance, and medicinal resources. Traditional agro-forestry systems involve this practice, where trees are intentionally grown on farm-lands for purposes such as fodder, fuelwood, and vegetable production. The primary objectives of the present study were threefold: first, to investigate the potential of agroforestry in sequestering carbon across different regions of India; second, to illustrate how agroforestry contributes to the welfare of communities and enhances their resilience in the face of climate change impacts; and finally, to evaluate government programs, including those related to afforestation, reforestation, community forestry, social forestry, and farm forestry, introduced by the Government of India.

3.1 Agroforestry Systems

During the survey and interaction with the tribal communities of the study region, it was found that tribal people practice six traditional agroforestry systems, which include Agri-Horticulture (AH), Agri-Silviculture (AS), Silvi-Pastoral (SP), Agri-Horti-Silviculture (AHS), Pastoral-Horticulture (PH), and Agri-Silvi-Pastoral (ASP) systems (Table 1). Also, they find these systems to be very useful as they benefit from food, fuelwood, fodder, timber, and other necessities. Moreover, these agroforestry systems make them financially secure by providing multiple livelihood options and environmental protection. Similar results have been authenticated by Kumari et al. (2008) and Yadav et al. who found that traditional agroforestry systems prevalent in the Lahaul area are agri-horticultural, agri-silvicultural, agrisilvi-pastoral, pastoral-silviculture and pastoral-horticultural.

The traditional agroforestry systems of Lahaul & Spiti district involve growing traditional agricultural crops such as crops *Eleusine coracana* Gaertn (Kodra), *Fagopyrum esculentum* Moench (Buckwheat), *Hordeum vulgare* L. (Barley/Jau), *Lathyrus* spp. (Kala Matar), *Phaseolus* spp. (Kidney Beans/Rajmash), *Triticum*

Table 1 Different agroforestry systems practices in Lahaul & Spiti

Agroforestry systems	Agriculture crops	Forest trees	Fruit trees	Others
Agri-Horticulture (AH)	Kala Matar/Pea/Potato/Barley/Rajmash	–	Apple/Almond/Apricot/Cherry	–
Agri-Silviculture (AS)	Wheat/Maize/Barley/Buckwheat/Finger millet/Kidney Bean/Rajmash/Bathua/Potato	Poplar/Willow/Juniper	–	–
Silvi-Pastoral (SP)	–	Poplar/Willow/Robinia/Akhrot	–	Grasses
Agri-Horti-Silviculture (AHS)	Kala Matar/Pea/Kidney Bean/Bandhgobi/cabbage/Phoolgobi/cauliflower/French Beans	Poplar/Willow/Juniper	Apple/Almond/Apricot/Cherry	
Pastoral-Horticulture (PH)	–	–	Apple/Almond/Apricot/Cherry	Grasses
Agri-Silvi-Pastoral (ASP)	Kala Matar/Pea/Kidney Bean/Bandhgobi/cabbage/Phoolgobi/cauliflower	Poplar/Willow/Juniper	–	Grasses

Source Sharma, A., Shashni, S. and Rathore, S.

aestivum L., (Wheat/Gehu) and *Zea mays* L. (Maize/Makka) in agri-horticulture, agri-silviculture, agri-silvi-pastoral systems (Table 1). Whereas, horticulture crops are giving good economic returns in cold desert regions in the study region, which include apple, apricot, almond, cherry, and walnut as well as grapes in some regions in association with cereal crops, vegetable crops such as *Brassica oleracea botrytis* L. (Cauliflower/PhoolGobhi) and *Brassica oleracea var. capitata* L. (Cabbage/Band Gobhi) and cash crops such as *Pisum sativum* L. (Pea/Matar) and *Solanum tuberosum* L. (Potato/Aalo).

Although farmers have recently started cultivating medicinal plants like *Inula racemosa* Hook. f. (Manu) and *Saussurea costus* (Falc.) Lipsch. (Kuth) in association with native tree species such as *Cedrus deodara* (Devdaar), *Juniperus* spp. (Juniper), *Populus* spp. (Poplar/Safeda), *Robinia* spp. (Kikar) and *Salix* spp. (Willow). Also, pasture-based agroforestry systems such as Silvi-pastoral, pastoral-horticulture, and Agri-Silvi-pastoral in the study region used by the local people provide them with both fuelwood and fodder resources throughout the year but most importantly during winters, when there is a scarcity of vegetation resources (Table 2).

3.2 Fruit-Based Agroforestry System

Fruit-based systems include three agroforestry systems such as agri-horticulture system, agri-horti-silviculture, and pastoral-horti-silviculture, which consists of growing agricultural crops, vegetable crops, fruit trees, forest trees, and grasses in the same land at the same time. The fruit-based agroforestry system consists of a mix of annual and perennial plant species on the same plot of land that is arranged in a geometry that allows for maximum use of space, which in turn leads to the maximum economic production of the system. Over the last decade, the Lahaul & Spiti district has experienced climate variability i.e. decline in snowfall and an increase in average temperature resulting in a change in the vegetation pattern especially making apple cultivation possible in the region. Apple-based agroforestry system is one most chosen practices utilized by the local farmers, which includes agri-horticulture system, agri-horti-silviculture, and pastoral-horti-silviculture (Fig. 2).

- **Agri-horticulture**: Kala Matar/Pea/Potato/Rajmash/Barley + Apple/Almond/Apricot/Cherry.
- **Agri-horti-silviculture**: Kala Matar/Pea/Kidney Bean/Bandhgobi/cabbage
- /Phoolgobi/cauliflower/French Beans + Poplar/Juniper + Apple/Almond/Apricot/Cherry
- **Pastoral-horti-silviculture**: Poplar/Willow/Juniper + Apple/Almond/Apricot/Cherry + Grasses.

Table 2 Plant species used under agroforestry systems in Lahaul & Spiti district

Botanical Name	Vernacular name	Family
(i) Traditional crops		
Amranthus paniculatus L.	Seul, Chaulai, Amaranth	Amaranthaceae
Brassica nigra Koch	Mustard/Sarson	Cruciferae
Chenopodium album L.	Bathua, Bathu, Chenopod	Chenopodiaceae
Eleusine coracana Gaertn.	Koda, Kodra, Ragi, Finger millet	Poaceae
Fagopyrum esculentum Moench	Buckwheat	Polygonaceae
Hordeum vulgare L.	Barley/Jau	Gramineae
Lathyrus spp.	Kala Matar	Leguminoceae
Phaseolus spp.	Kidney bean/Rajmash	Leguminoceae
Triticum aestivum L.	Wheat/Gehu	Gramineae
Zea mays L.	Maize/Makka/Makki	Gramineae
(ii) Vegetables		
Beta vulgaris L.	Chukandar	Chinopodiaceae
Brassica oleracea	Broccoli	Brassicaceae
Brassica oleracea botrytis L.	Cauliflower	Cruciferae
Brassica oleracea var. capitata L.	Cabbage	Cruciferae
Brassica rapa L.	China sarson	Cruciferae
Brassica tournefortii Gouan	Turnip	Cruciferae
Capsicum annuum L.	Chilly	Solanaceae
Daucus carota L.	Carrot	Umbelliferae
Lactuca sativa	Lettuce	Asteraceae
Lycopersiconly copersicum L.	Tomato	Solanaceae
Raphanus sativus L.	Radish	Cruciferae
Spinacia oleracea	Spinach	Amaranthaceae
(iii) Medicinal crops		
Inula recemosa Hook.f.	Manu	Asteraceae
Saussurea costus (Falc.) Lipsch.	Kuth	Compositae
(iv) Cash crops		
Pisum sativum L.	Pea	Leguminoseae
Solanum tuberosum L.	Potato	Solanaceae
(v) Trees (Fodder/Fuel)		
Cedrus deodara	Devdaar	Pinaceae
Juniperus spp.	Juniper	Cupressaceae
Populus spp.	Poplar/Safeda	Salicaceae
Robinia spp.	Kikar	Fabaceae
Salix spp.	Willow	Salicaceae

(continued)

Table 2 (continued)

Botanical Name	Vernacular name	Family
(vi) Fruit trees		
Prunu savium	Cherry	Rosaceae
Hippophae rhamnoides	Charmma	Elaeagnaceae
Humulus lupulus	Hops	Cannabaceae
Juglan sregia	Walnut/Akhrot	Juglandaceae
Malus pumila	Apple/Seb	Rosaceae
Prunus amygadalus	Almond/Badam	Rosaceae
Prunus armeniaca	Chuli/apricot	Rosaceae
Vitis vinifera	Grapes	Vitaceae
(vii) Shrubs (fodder/fuel)		
Astragalus strobiliferus	Kichoo	Fabaceae
Cotoneaster spp.	–	Rosaceae
Hippophae rhamnoides	Chharma	Elaeagnaceae
Juniperus communis	Bethar	Cupressaceae
Krascheninnikovia ceratoides	Sheeng	Chenopdiaceae
Loniceraob ovata	–	Caprifoliaceae
Rosa webbiana	Shyabala	Rosaceae
Salix spp.	Beli	Salicaceae
(viii) Herbs (fodder/fuel)		
Brachypodium pinnatum	–	Poaceae
Chaerophyllum spp.	Shakkara	Apiaceae
Cousinia thomsonii	Tulse	Asteraceae
Epilobium spp.	Jachipa	Onagraceae
Erigeron spp.	–	Asteraceae
Heteropappus spp.	–	Asteraceae
Persicaria nepalensis	–	Polgonaceae
Taraxacum leucanthum	–	Asteraceae

Source Sharma, A., Shashni, S. and Rathore, S.

3.3 Salix and Poplar-Based Agroforestry System

In this cold desert, the agroforestry systems cantered around willow and poplar trees (*Populus* spp.) play a pivotal role in fostering a thriving green canopy. Over the years, deliberate cultivation of poplar and willow trees in cold desert regions has become a notable endeavour. Today, local communities have cultivated a wealth of silvicultural expertise and sustainable practices to ensure the enduring vitality of these agroforestry systems. The abundance of indigenous terminology and an extensive array of tools are used in every aspect of management, from pinpointing optimal planting sites and tending to plantations, to selecting specific agroforestry models,

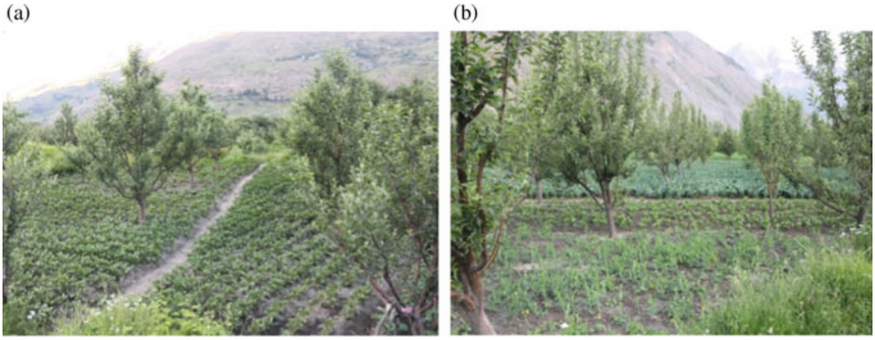

Fig. 2 Agri-horticulture based system, **a** Apple + Potato; **b** Apple + Pea. *Source* Sharma, A., Shashni, S. and Rathore, S.

executing harvests, and exploiting various applications. This serves as distinctive evidence of the enduring reservoir of traditional wisdom within this community (Fig. 3).

At present, the fortified agroforestry systems not only fulfil subsistence needs through the provision of ecosystem goods but also provide essential support for a variety of ecosystem services.

These forestry initiatives are playing a pivotal role in bolstering traditional dairy production within the region. Local communities have a rich heritage of crafting a diverse array of dairy products, deeply intertwined with their cultural identity. The economic dynamics of this model fluctuate based on several factors, including the choice of tree species, the spacing between individual plants, and the geographical location. These elements have a direct or indirect influence on aspects such as plant growth rates, rotation periods, and overall utilization of resources.

- **Agri-Silviculture**: Wheat/Maize/Barley/Buckwheat/Finger millet/Kidney Bean/Rajmash/Bathua/Potato + Poplar/Willow/Juniper
- **Silvi-Pastoral**: Poplar/Willow + Grasses

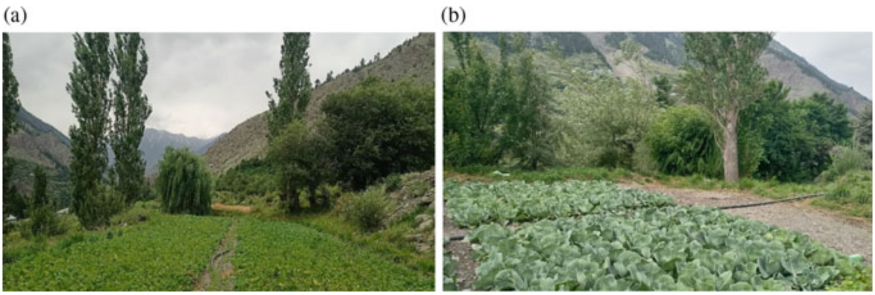

Fig. 3 Silvi-horticulture based system. **a** Poplar + Rajmash; **b** Willow + Cabbage. *Source* Sharma, A., Shashni, S. and Rathore, S.

- **Agri-Horti-Silviculture**: Kala Matar/Pea/Kidney Bean/Bandhgobi/cabbage/Phoolgobi/cauliflower/French Beans + Poplar/Juniper + Apple/Almond/Apricot/Cherry
- **Pastoral-Horti-Silviculture**: Poplar/Willow/Juniper + Apple/Almond/Apricot/Cherry + Grasses
- **Pastoral-Agri-Silviculture**: Kala Matar/Pea/Kidney Bean/Bandhgobi/cabbage/Phoolgobi/cauliflower + Poplar/Willow/Juniper + Grasses

3.4 Seabuckthorn-Based Agroforestry System

Seabuckthorn (*Hippophae rhamnoides*), a member of the Elaeagnaceae family, is a versatile plant species with a wide range of applications. It is particularly valuable for addressing various environmental challenges in the district. This thorny shrub is utilized for soil erosion control, wildlife habitat protection, land reclamation efforts, soil enhancement, and ecological restoration initiatives in this unique and fragile ecosystem as shown in Fig. 4. Seabuckthorn plantations are an ideal choice for soil and water conservation as well as reforestation efforts in fragile mountainous regions. Their remarkable attributes, including broad adaptability, rapid growth, robust coppicing, and suckering tendencies, combined with efficient nitrogen fixation capabilities, make them exceptionally well-suited. Soil serves as a dynamic habitat for a wide array of life forms, offering both mechanical support to plants and essential nutrients for their growth and development. The success of these activities relies on maintaining the health and fertility of the soil, which is crucial for sustaining ecosystems in such delicate environments.

It has proven to be a valuable resource in the cold deserts of the Himalayas, offering a diverse range of products and benefits. It serves as a source of health foods, cosmetics, and medicinal products. Additionally, it is widely used as fodder

Fig. 4 Seabuckthorn-based agroforestry system: Seabuckthorn + Apple. *Source* Sharma, A., Shashni, S. and Rathore, S.

for livestock, a source of fuelwood, and a natural soil binder in these regions. Of particular note is seabuckthorn's role in enhancing soil quality. Seabuckthorn plantations play a clear and vital role in increasing soil organic carbon levels and making nitrogen more readily available. These two factors, elevated soil organic carbon and improved nitrogen availability, are pivotal in enhancing soil fertility, a critical component in sustaining agricultural and ecological systems in these challenging environments. This shrub stands out as a distinctive and multifaceted solution for addressing the numerous challenges inherent in the fragility, marginality, inaccessibility, and diversity of mountainous regions. This versatility and potential for positive impact make seabuckthorn a valuable asset for sustainable development and environmental protection in mountainous areas.

3.5 Traditional Farming Systems Used in Cold Desert Region

Traditional agricultural practices in the Lahaul & Spiti district are characterized by their primitive and time-tested methods. These methods rely heavily on the extensive application of indigenous knowledge, traditional tools, natural resources, and organic fertilizers. Moreover, these practices are deeply rooted in the cultural beliefs of the local tribal communities. This holistic approach to farming underscores the significance of preserving and respecting the wisdom and heritage of these indigenous agricultural traditions.

i. **Terrace farming**: One of the traditional farming systems practiced in the district is terrace farming which is followed by terrace steps commonly used to farm on hilly or mountainous terrain. Terrace fields help in the decrease of both erosion and surface runoff and may be used to support growing crops that require irrigation. The purposive benefit of this system is that local people believe in the region is that soil nutrients are not lost due to runoff but pushed from one step to another, which keeps the soil full of nutrients and productive.
ii. **Vegetative barriers**: One of the very old traditional practices utilized in the study region is vegetative barriers. These are closely spaced plantations, usually a few rows of grasses or shrubs grown on contours of the farming system which not only controls erosion but also adds organic matter to soil on decomposition, which regulates water content in the soil and enhances its moisture and porosity.
iii. **Traditional fertilizers**: The use of traditional fertilizers is one of the old practices that have been followed by the local inhabitants of the region. It is a very essential requirement for enhancing agriculture yield by using traditional fertilizers which are available in the proximity of the areas where local people live such as Cow/Yak dung as manure, ash of burnt woods, and night soil compost.
iv. **Manual ploughing and harrowing**: One of the traditional techniques used by local farmers in the Lahaul and Spiti district is ploughing and harrowing agriculture fields. In this method, local people of the study site use a pair of

Yaks and a wooden plough to cut or loosen the soil and help in the removal of weeds.

v. **Crop Rotation, intercropping systems, and fallowing**: Crop rotation is the practice of growing a series of different types of crops in the same area in sequenced seasons. Intercropping includes growing of two or more crops together on the same land. This helps in the reduction of soil erosion, binds soil nutrients, increases soil fertility, and enhances crop yield. In fallowing, fields are left fallow for a certain period to allow the soil to recover its nutrients.

vi. **Traditional crops**: The local people of the district cultivate many crops related to the respective season fulfill their food demands and sell extra produce, which helps them to stay economically fit. From historical times it has been noticed that mainly three crops viz., wheat, barley, and buckwheat are cultivated in LahaulValley, whereas in Spiti wheat, pea, mustard, and two varieties of barley are grown which are similarly suggested by Devi (2018) in her study. Earlier there was no cultivation of vegetables done in the district. But at present local people of the region have started cultivating buckwheat, barley, wheat, and cash crops like cauliflower, cabbages, peas, potatoes, legumes, kuth, and hops which has been authenticated by a research study by Kuniyal et al. (2005). Lahaul & Spiti engages in the cultivation of a diverse range of crops like Mustard, radish, turnip, carrot, French beans, beetroot, tomatoes, soybeans, and other crops that are part of the agricultural repertoire. However, potatoes and peas stand out as the primary cash crops in the region.

vii. **Potatoes farming**: Local communities have been cultivating high-quality potatoes for a long time and are used as seeds in about every part of the country. It is an important crop that is grown in the relatively warmer months. They provide a valuable source of carbohydrates and can be stored for consumption during the harsh winters. Lahaul-Spiti's achievement of the highest per-hectare production of potatoes is a noteworthy accomplishment. This distinction reflects the region's successful agricultural practices and expertise in potato cultivation (Baumann & Singh, 2000). Growing potatoes during the off-season in the district not only showcases the region's unique agricultural capabilities but also allows farmers to command premium prices in the market. Moreover, producing potatoes in the hills extends the availability of fresh potatoes to consumers during the summer, rainy, and early autumn seasons, contributing to food security and meeting market demands. It has been noticed that due to the increase in the cultivation of other cash crops, there is a decreasing trend in yield as well as the area under cultivation of potatoes in the last few years.

viii. **Peas farming**: The district has gained popularity in the cultivation of another cash crop i.e. green pea which is now one of the main cash crops, leading to enhanced economic growth of the region. Similar results have been supported by Kumar and Negi (2015) who found that the hill regions of Lahaul and Spiti district support the practice of intercropping pea with French beans and local mustard (sarso), which has increased yield as well as good net return. Also, according to Sharma and Chauhan (2013) cultivation of green pea has not only promoted the economic viability of the region but at the same time is sustaining the hill agriculture ecologically.

ix. **Seed saving**: Given the isolation of the region and the specific crop varieties that have adapted to the local conditions, farmers often save seeds from their own harvests for the next planting season, maintaining a cycle of adapted crops.

x. **Traditional storage structures**: Since the region experiences harsh winters with heavy snowfall, traditional storage structures like underground pits or rooms are used to store harvested crops. This helps in preserving the crops for consumption throughout the year.

xi. **Other exotic vegetables**: In earlier times local farmers of the hill region of the Lahaul and Spiti district were engaged only in potato and peas cultivation as a main cash crop. However due to climate variability, there has been a shift from traditional crops towards off-season vegetables e.g. radish, tomato, carrot, lettuce, and red cabbage in the region (Rana et al., 2010–2013). These vegetables are in great demand not only in the local region but also outside the district with high prices.

xii. **Animal husbandry**: During the survey, it was recorded by the local people how animal husbandry has changed their standard of living. Local people have started businesses of dairy and believe that keeping livestock at home brings good luck. Local inhabitants of the region have smartly kept livestock on the first floor of their homes which provides two benefits, the first one is dairy products such as milk, ghee, cheese, etc. and the second one makes the home warm during the winter season. Similar results have been authenticated by Anupam (2016) who found that livestock holds a significant role as a crucial source of animal protein for farm households. This protein is obtained through the consumption of milk, dairy products, eggs, and meat. Farmers residing in the higher hills maintain a variety of animals, including sheep, goats, cows, mules, donkeys, and hybrid breeds of cattle and yaks. These animals serve multiple purposes, providing manure, meat, and milk to meet the needs of the local communities. Also, it has been indicated by the rural people that animal dung can be used in different ways such as dung cakes used for heating purposes by burning them and a source of indigenous fertilizers which are eco-friendly in nature as such enhance soil fertility. These results have been corroborated by many researchers such as (Raj et al., 2014; Singh et al., 2015) who indicated that animal husbandry is an integral part of a farming system that includes age-old livestock mixed farming practices, particularly in hilly areas and plays an important role in the security of human nutrition and health services.

In support, according to Kumar et al., (2015a, 2015b), the livestock sector plays a multipurpose role in the development of the socio-economic status of the local household. It acts as a storehouse of funds and also provides insurance when there is a loss in crop loss. It is true that livestock is mostly reared by poorer sections of society which overall supports their livelihood and the entire draught energy requirement for ploughing farms is also met by the livestock (Pratap, 2011; Singh et al., 2017) (Fig. 5).

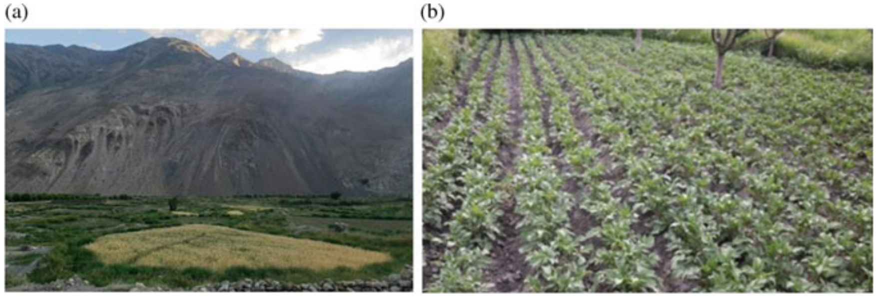

Fig. 5 **a** Barley cropping pattern of Spiti Valley; **b** Potato cropping pattern of Spiti Valley. *Source* Sharma, A., Shashni, S. and Rathore, S.

xiii. **Night Soil Composting**: For centuries, night soil or human waste has been a significant agricultural resource in hilly regions as shown in Fig. 6. These areas face challenges like low soil fertility, landslides, erosion, and nutrient leaching, making sustainable agriculture a struggle. Additionally, the cold climate and snowfall limit the production of sufficient farmyard manure. In response to these conditions, local communities have relied on night soil composting techniques. However, over the past two decades, the practice has declined due to several factors. These include the unhygienic conditions associated with traditional toilets, a shortage of labour, improved education and status leading to a shift away from traditional methods, and the ready availability of subsidized chemical fertilizers in modern times. Despite the effect of modernization, this traditional technique persists for several reasons. It remains a valuable agricultural resource, and modern toilets are often ineffective during harsh winter months. The use of night soil as compost and fertilizer not only helps maintain soil health but also enhances crop yields is also documented by Oinam et al. (2008). A similar study on night soil compost in Tanzania is also documented by Mwalukisa (2008).

xiv. **Water management and irrigation**: From the people's perception it has been found that the region in winter has extremely harsh conditions such as limited rainfall and heavy snowfall which is the source of drinking as well as irrigation purposes. Since historical times local people have been using various traditional methods to store snow melt water in artificial structures such as ponds and earthen tanks. This supports their daily household activities and irrigates the farms with the help of traditional means of channels called *kuhls*. Also, it was recorded that due to climate variation in the region, there is less rainfall as well as snowfall, which almost fulfills the daily requirement but for irrigation purposes, local people have started using the sprinkle method of irrigation. These results have been authenticated by Vishvakarma et al. (2005) who found that Lahaul and Spiti district has extreme climatic conditions such as scanty and rare downfall in terms of rain, which adds to the problems of water conservation. But there is high snowfall in the region which fulfils the

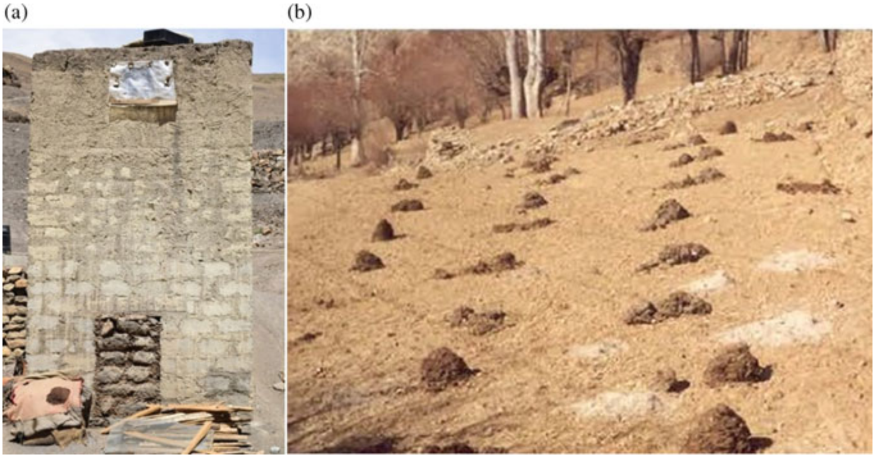

Fig. 6 **a** Outside view of the traditional toilet at Lahaul Valley; **b** Night soil heaps in agricultural fields. *Source* Sharma, A., Shashni, S. and Rathore, S.

needs of drinking, irrigation, and other domestic uses. Also, there are numerous traditional structures to harvest snow melt water such as *bawdi*, *chhrudu*, *kuhls*, earthen tanks, small ponds, springs, religious groves, etc. These structures help to fulfill the daily life requirements of the local people and also support the irrigation practices of the region for high growth in agriculture. In addition, these practices preserve soil moisture and recharge the groundwater table as suggested by Lal and Verma (2008) (Fig. 7).

The development of watersheds is a traditional technique aimed at conserving, regenerating, and wisely using natural resources. It seeks to establish an optimal equilibrium between resource demand and utilization. Also under watershed management, water harvesting structures, silt retention structures, concrete, masonry and check dams provide protection to irrigation practices (Sharma & Kanwar, 2013). Almost all cultivated lands are irrigated through this system now. Similar results

Fig. 7 Tradition water sources used for drinking and irrigation in Lahaul & Spiti district. *Source* Sharma, A., Shashni, S. and Rathore, S.

have been authenticated by Padigala (2013) who in his study recognized that the local people of the district are very dependent on the natural service of snowmelt water and the traditional practice of channels to fulfill the demand for fresh water for drinking and agriculture. Today, nearly all far-flung cultivated lands rely on this irrigation system. This observation aligns with the findings of Padigala (2013), who also recognized in their study that the local inhabitants of the district heavily depend on the natural supply of snowmelt water and the traditional use of channels to meet their needs for both drinking water and agricultural purposes.

4 Conclusion

The study inferred that agroforestry systems indeed play a crucial role in ensuring food security and providing job opportunities to the local people of the region. The continued use of traditional farming practices by the local communities in the study region serves as a symbol of conservation. Keeping in view the unique agro-ecological and socio-economic setting of the hilly region, local people are more focused on the utilization of new technology, traditional food crops, adoption of new horticultural crops, strengthening the animal husbandry, forestry practices, etc. which are providing them with high profits in terms of money and fame as well welfare of local communities of Lahaul and Spiti district. Furthermore, the adoption of agroforestry-based systems has garnered attention due to the rapid degradation of the ecology in hilly regions, global warming, the loss of biological diversity, disruptions in climatic patterns, unsustainable agricultural production, and the imprudent exploitation of natural resources in mountainous areas. So the only way to solve these problems is the preservation of hill agriculture practices by more and more use of traditional hill agriculture practice. Further, documentation by researchers is also recommended for the overall conservation of the hill agro-ecosystem.

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Traditional Agroforestry Practices in the Indian Eastern Himalayas: Case Studies and Lessons

Bandana Kurmi, Panna Chandra Nath, and Arun Jyoti Nath

Abstract This chapter examines the functioning of the various agroforestry systems, including silvopasture, agrisilviculture and agrisilviculture. Traditional agroforestry systems are considered as the classic example of sustainability due to their important role in conserving biodiversity, advancing food security and maintaining environmental health. In this chapter, these systems have been studied for their ability to sequester carbon and their contribution to food production and security. With Alder-based agroforestry in Nagaland, *Alnus* cardamom agroforestry in Sikkim, *Piper*-based agroforestry in Southern Assam, the Indian Eastern Himalayas is a region to diverse agroforestry paradigm. Globally, more than 1.2 billion people practice agroforestry on approximately 1 billion hectares of land, while in India, agroforestry is practiced on about 25.32 million hectares. Agroforestry systems offer significant environmental advantages and ecosystem functions above and beyond the farm level. These systems increase soil biodiversity and fertility, conserve water, and minimize pollution. In addition to these, the main regulatory role of agroforestry systems is to help slow down global warming. With immense potential, traditional systems can help achieve many of the sustainable development goals (SDG: 1, 2, 3, 12, 13, 15) and also help in the restoration of degraded lands.

Keywords Traditional agroforestry · Indian eastern Himalayas · Sustainable development goals

1 Introduction

Agroforestry is a technique of sustainable land management that combines the raising of livestock and/or agricultural commodities with the growth of trees and shrubs (Nair, 2005). It involves intentionally integrating woody perennial plants, such as fruit trees, timber trees, or nitrogen-fixing trees, into agricultural or pastoral systems. Agroforestry practices are designed to optimize the ecological, economic,

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and social benefits of the combined plantations (Castle et al., 2022). Traditional agroforestry systems are categorised as a group of indigenous agroforestry practises that have been used around the world with a variety of structural, functional, socioeconomic, and ecological implications (Viswanath et al., 2018). They do not involve the intensive production of agricultural or fodder crops. This system of farming is sustainable and has been passed down through generations with the knowledge and skill of agroforestry. These conventional agroforestry systems have emerged as of greater significance throughout the current the UN's decade-long ecological restoration programme,, which can significantly aid in addressing the decline in biodiversity caused by imminent climate change (Critchley et al., 2021).

The primary goal of agroforestry is to create a productive and resilient agricultural system that enhances biodiversity, improves soil fertility, conserves water, mitigates climate change, and provides a range of products and services (Tomar et al., 2021a, 2021b). By incorporating trees into agricultural landscapes, agroforestry systems can enhance ecosystem functions and provide multiple sources of income for farmers (Castle et al., 2022). Agroforestry practices based on the particular objectives and regional circumstances. According to the global definition given by Nair (1985) and Nath et al. (2021a), agroforestry systems are divided into agrisilviculture, agrisilvopastoral and silvopastoral. Agrisilviculture systems includes crops and trees including shrubs. Agrisilvipastoral systems includes crops and trees along with animals/ pasture. Silvipastoral systems include pasture/animals and trees. These systems can be adapted to different agro-ecological zones and cultural contexts, offering flexible and site-specific solutions to agricultural challenges.

In India, out of the total forest area (21.71% of the total geographical area), it has been estimated that the area under agroforestry accounts for 2.91% of the total geographical area (Panwar et al., 2022). The Indian Himalayan region is known for its diverse agro climatic conditions with ecological and environmental importance (Kumar et al., 2021). This region has the capability of reversing the regional climate change effects occurring throughout the globe. Although wide range of benefits exist, this region is facing severe impacts from climate variations, isappearance of biological diversity, developmental activities and threat to the livelihoods of the population (Kanwal et al., 2017). Additionally, shifting cultivation has accelerated soil erosion, necessitating urgent conservation of this area (Nath et al., 2021b). According to estimates, 60% of this region's land need erosion management, and 30% of it suffers severe soil erosion (Nath et al., 2021b).

Agroforestry systems are extremely important for the restoration and rehabilitation of deteriorated areas (Jinger et al., 2023). This strategy improves alleviating poverty, nutritional stability, and climate change resilience. It provides with multiple benefits including soil fertility improvement, reduction in erosion, conservation of fresh water, maintenance of shade for crops and livestock, and generating income through various timbers and non-timber forest products (NTFPs). Agroforestry systems have been represented to boost agricultural productivity while reducing carbon footprint, in line with the UN Sustainable Development Goals (SDGs) and the UN Decade of Ecological Restoration (2021–2030). Agroforestry practises can also aid in the achievement of other international goals, such as Land Degradation Neutrality (LDN), which aims to conserve sustainable management and rehabilitation of degraded land through local and national targets (Jinger et al., 2023). It is important that policies and programs are put in place to support and promote these practices to ensure their long term sustainability and effectiveness. We try to analyse the function of agrisilviculture, agrisilvopastoral, and silvipastoral systems in the Indian Eastern Himalayan region in this chapter.

1.1 Multistrata Agroforestry Systems

Mutlistrata agroforestry systems incorporate multiple layers emulate the composition of natural forests, resulting in abundant carbon sequestration and productive yields of both food and vegetation (Nair, 2017). These systems feature the combination of one or more layers of crops beneath taller trees, resulting in significant carbon sequestration alongside food production (Luedeling et al., 2016). Furthermore, they offer valuable ecosystem services such as habitat provision, erosion control, and maintenance of water quality. This multistrata systems are ecologically and economically significant. Agroforestry systems, which are considered as traditional resource management adaptations, have the potential to improve livelihoods by producing food, fodder, and firewood simultaneously in addition to mitigating the impacts of climate change (Pandey, 2007). Incorporating trees with agricultural practices, along with other vegetation management techniques in cultural landscapes such as farms, watersheds, and regional landscapes, can be integrated to utilize the benefits offered by adjacent natural, semi-natural, or restored ecosystems (Wilson & Lovell, 2016). Agroforestry is having a significant impact on maintenance of the resource base and enhancing overall productivity in rainfed regions to arid regions (Dhyani, 2018). There is abundant evidence to demonstrate that agroforestry systems generally exhibit higher overall (biomass) productivity, enhanced soil fertility, improved soil conservation, increased nutrient cycling, better micro-climate conditions, and greater potential for carbon sequestration compared to annual systems (Mathukia et al., 2016). Thus, agroforestry will play a crucial role in meeting the increasing demand for food, fruits, fuel wood, timber, fodder, biofuel, and bio-energy by the growing population, as well as in providing the perceived ecological benefits.

2 Traditional Agroforestry Systems of the Indian Eastern Himalayan Region

2.1 Agrisilviculture

In this approach, trees and crops are grown together on the same plot of ground. Along with trees, crops like cereals, legumes, vegetables, and aromatic plants are grown. 8.68 million hectares of India's total land area are thought to be now used for agrisilvicultural systems (Nath et al., 2021a). In the North Eastern Himalayan (NEH) region, agroforestry has a long history of integrating trees with the crop and livestock production systems in accordance with agroclimatic and other local requirements (Bhatt, 2001). In various agroclimatic zones, a wide range of grain crops, rhizomatous crops, pineapple, coffee, tea, and vegetables are grown alongside a wide range of fruits and other trees, including *Alnus nepalensis, Schima wallichii, Erythrina spp., Ficus spp., Bauhinia spp., and Terminalia spp* (Bhatt, 2001). In the Barak valley of North East India (NEI) agrisilviculture systems like *Piper* based agroforestry, pineapple agroforestry, tea agroforestry and bamboo based agroforestry systems are dominant (Brahma et al., 2018; Reang et al., 2021). The most common agroforestry systems in the Brahmaputra valley of Assam, however, include multipurpose trees on croplands, tea agroforestry, Morus and castor-based systems, and *Machillus*-based systems (Ulman et al., 2022). Successful and long-lasting agroforestry systems are based on Alder (*Alnus nepalensis*) in Nagaland and include high-value arable crops like cardamom (*Elettaria cardamomum*), large cardamom (*Amomum subulatum*), pineapple (*Ananas sativum*), many fruit trees, and tuber crops like turmeric, ginger, colocacia, and taros (Kehie et al., 2017). In farm-based agroforestry, farmers maintain multipurpose tree species for feed, fuel, and lumber, as well as other direct and indirect uses inside and around the nearby open cultivable area. Traditional farming practises in Mizoram continue to be based mostly on shifting (Jhum) cropping (Singh, 2019).

2.2 Agrisilvipastoral Systems

These systems can be identified by the integration of forestry, livestock, and agricultural activities in the same region over time and place (Nair, 1993). According to Dhyani et al. (2013) and the Forest Survey of India (2013), agrosilvopastoral systems in India covers 5.58 million ha. Home gardens are a great example in the North Eastern regions of India, specifically in Tripura and Assam (Das & Das, 2005). Examples of agrisilvipasture include beekeeping, aquaculture, and backyard gardens with animals.

Livestock and beekeeping along with the production of cardamom and other crops (like rice, maize, wheat, millet and pulses), cash crops (orange, ginger etc.) was reported by Sharma et al. (2016), from Sikkim. Assam has agroforestry systems based on the bushes Morus and Castor. Trees like *Morus alba* and Castor sp. Are grown in home gardens in the accessible areas to feed the silkworm species *Bombyx textor* and *Samia ynthia*, respectively (Ulman et al., 2022). In shady environments, silkworms are cultivated. Similar to this, certain Assam districts maintain agroforestry systems based on machilus. The *Machilus bombycina*, *Litsea polyantha*, and *Litsea salicifolia* leaves are consumed by the silkworm, *Antheraea assamensis*. To grow silkworms, most of these trees are planted in square patterns (Ulmana et al., 2022). *Schumannianthus dichtomus* also known as 'patidoi' or 'Murta' is found to be grown in Assam (Bhattacharjee & Seal, 2017). It is observed these are planted along with boundaries of fisheries and also planted in large scale. Similar to this, Assam hill regions have reported coconut and betel nut tree development along pond edges (Ulmana et al., 2022). Bun system (rice + fish along with crops) of the Jaintia hills of Meghalaya, Apatani method (paddy with fish culture) of Arunachal Pradesh and Zabo system (combination of forest, agriculture livestock and fisheries) of Nagaland (Selvan & Kumar, 2017) are examples of agrisilvipastoral systems.

2.3 Silvopastoral Systems

According to Shin et al. (2020), silvopastoral systems are those that integrate trees and cattle on grazing/range grounds. According to Nair et al. (2021), silvopastoral systems use a variety of techniques, such as planting trees on pastures or rangeland, creating protein banks, and growing plantation crops alongside grasslands and livestock. Due to their numerous conceivable component and arrangement combinations, these systems are remarkably adaptable to their environment and their user needs. In India, the total area currently covered by silvopastoral systems is projected to be 2.42 million ha (Nath et al., 2021a).

3 Case Studies from Indian Eastern Himalayan Region

3.1 Agrisilviculture and Livestock Management for Food Production in NEI

With the growing population, food security is in risk. Agroforestry systems can provide a range of food products including nuts, fruits, and vegetables. Additionally, the diversity of crops in agroforestry systems can provide more varied nutritious diet for local communities. Agrisilviculture systems like cardamom agroforestry system in Sikkim, NEI, is grown along with a number of trees which provide food (Avasthe et al., 2011). The Alder based agroforestry in Nagaland, is also an example which provides with numerous food crops such as rice, tuberous root (tapioca, potato, colocasia), large cardamom, and rhizomes (turmeric, etc.) (Kehie et al., 2017). In the west Garo hills of Meghalaya, intensified jhum cultivation has been the habitat for various food crops since decades. A total of 35 food crops are being grown and in addition four species of livestock being reared (Pandey et al., 2022). These 39 species being the structure of five food crop groups, and each group has each group has at least two predominant crop or animal species, demonstrating how traditional farming has a built-in diversity. This system hence signified as a buffer for the risks against local and national food security thereby ensuring around the year supply of food.

While mimicking the conventional agroforestry systems of NEI, in an experimental agroforestry setup at Meghalaya (Dhyani & Tripathi, 1999) represented the yield of Soybean, Linseed, Ground nut and Mustard grown with trees like *Alder, Albizia*, Cherry and Mandarin. Yield was not observed to have significant variation when intercropped with different tree species except Cherry. Soybean, Linseed, Groundnut and Mustard yield ranged between 6.4–6.8, 2.2–3.0, 4.2–5.2 and 1.6–2.3 Mg ha^{-1}. In Arunachal Pradesh, the Apatani system is eco-friendly and compared to the state average of less than 2.0 t ha^{-1}, the Apatani system in produces rice at a very high rate (4–4.5 t ha^{-1}). (Selvan & Kumar, 2017). In the Himalayan region of NEI, where erosion is a major land degradative process and the climate is humid subtropical, integrating trees with crops can aid in ecorestoration and the preservation of soil resources (Dhyani & Tripathi, 1999).

3.2 Agroforestry for Fodder Production in Sikkim

Agroforestry systems can provide feed for livestock through the use of forage leaves and shrubs. The use of fodder trees and shrubs can improve the productivity by providing a more balanced diet. Bhatt et al. (2001) showed 15 plants and their potentials to be incorporated in the agroforestry systems as fodder yielding species. Among them *Grewia oppositifolia* and *Ficus hispida* are dominant fibre yielding species having the green fodder potentials of 95.5 and 92.5 kg $tree^{-1}$ respectively. According to reports, agroforestry-grown trees meet 9–11% of the need for green fodder (CAFRI, 2015; Sharma et al., 2017; Singh & Pandey, 2011). Singh and Teron (2019) reported *Colocasia esculenta* and *Zea mays* as a fodder for pigs from an oak based agroforestry system in Sikkim.

3.3 Traditional Homegardens as Source for Fuel

Agroforestry systems can provide a sustainable source of fuel wood for cooking and heating. Transforming agricultural leftovers into biofuel addresses both the challenges of waste disposal and energy generation simultaneously (Ambaye et al., 2021). When compared to alternative renewable energy sources like solar and wind, biomass stands out as an affordable, energy-efficient and easily storable option. NEI is no different for the options of energy fulfilment from the rest of the country, where the local population heavily relies on plant resources to fulfil their energy requirements along with other diverse needs. The extensive use of fuel wood as the main energy source for household purposes in NEI has contributed significantly to deforestation. As a result, it has become imperative to establish energy plantations in fallow lands and wastelands of the region to address this issue (Kakati & Konwer, 2001). Diverse homegardens of Barak Valley, NEI represented fuel wood being one of the dominant use class for meeting the energy demands (Das & Das, 2005; Nath et al., 2020). Among them 61% of the managed trees are the most commonly used fuel wood species. *Albizzia lebbek*, *Alnus nepalensis*, *Melia azedarach*, *Phyllanthus emblica*, *Quercus serrate*, *Schima wallichii* reported from an oak based agroforestry system in Sikkim by Singh and Teron (2019) meet the requirements of fuel wood. Therefore, agroforestry plays a vital role in alleviating pressure on forests by cultivating trees on farms. These farm-grown trees serve as a source of fuel wood, effectively meeting local energy requirements and reducing reliance on forest resources.

3.4 Biodiversity Conservation Through Cardamom Agroforestry

A crucial part of sustaining human life and the health of our planet is biological diversity, often known as biodiversity (Jose, 2012). In the present time, the transformation to agriculture systems always takes place with the expense of the natural environment. The extent to which a system is affected differs vividly between regions and in progression the area becomes barren and degraded depending on the human pressure, population density, land use change etc. Agroforestry systems have the ability to help reverse the circumstances and restore these fragmented and barren areas (Scrotch et al., 2000; Tomar et al., 2021a, 2021b). The Indian Himalayas are home to a rich biodiversity, including a variety of flora and fauna that are endemic to the region. Agroforestry systems can significantly contribute to biodiversity preservation in this region by providing habitat for wildlife and promoting ecosystem services (Udawatta et al., 2019).

Sikkim's extensive cardamom agroforestry practise promotes the region's efforts to preserve its tree biodiversity (Sharma et al., 2007). Another study (Vineeta et al., 2022) from the Darjeeling Himalayas in a Cardamom based agroforestry reported the existence of certain IUCN red listed species indicating the conservation of supported by these systems. For instance the species (*Brugmansia suaveolens*) which is reported to be extinct from Brazil are reported from the Darjeeling Himalayas and adjoining foothills of West Bengal (Vineeta et al., 2022). Comparing this to other agroforestry techniques used in the area, it encourages the existence of extremely diversified tree species and tree diversity index. The birds and other creatures that the trees support have an impact on the agroforestry system's ecological makeup and ability to function. Additionally, agroforestry systems with multiple tree species and crops can support a greater diversity of wildlife and plant species than monoculture systems (Udawatta et al., 2019). However, the success of agroforestry systems in promoting biodiversity conservation in the Indian Himalayas is governed by factors such as local environment, design and management of the system, and involvement of local communities in the process. Hence, it is vital to tailor agroforestry practices to the specific needs and conditions of the region in order to achieve effective and sustainable biodiversity conservation.

3.5 Hedgerows and Alder for Maintenance of Soil Health

In general, agroforestry systems are believed to sustainably improve soil qualities (Dollinger & Jose, 2018). Agroforestry systems can have positive impacts on soil health by improving field capacity (FC), organic matter (OM), available potassium, available phosphorus, soil carbon stocks, and lower bulk density (BD); which retain water by increasing the water holding capacity (WHC) and release the water to plants gradually, like a sponge. The supply of OM is crucial for soil aggregation and for lowering the soil BD. This decreased soil BD helps with air circulation, circulation of water in the rhizosphere, soil nutrient quality, and groundwater recharge in arid and semi-arid conditions. Soil organic carbon has a direct and indirect impact on how well nutrients are used in agriculture. The greater availability and absorption of nitrogen from soil with rich organic matter and a healthy deep root system will increase the effectiveness of nitrogen use. Additionally, mycorrhizae are probably provided by the increased microbial diversity brought on by the addition of OM, which releases P and makes it available to crops. In agroforestry systems, the buildup of litter from the loss of leaves and twigs serves as the main source of nutrients and organic carbon. Additionally, the deep root systems of trees and shrubs in agroforestry systems can help to strengthen soil structure and reduce erosion by binding soil particles together. In their study of a maize-chili intercropping system with leucaena (*Leucaena leucocephala*) trees hedgerows, Hussain et al. (2021) found that soil loss is greatly reduced while the productive capacity of the land increases, all with a minimal usage of tillage and fertilisers. In the abandoned Jhum land in India's north-eastern area, Bambusa nutans has been discovered to be effective at binding soil nutrients. (Arunachalam & Arunachalam, 2002). Furthermore, agroforestry systems with leguminous trees and shrubs can fix atmospheric nitrogen, which can increase soil fertility and reduce the need for synthetic fertilizers. In the Khonoma village of Nagaland, NEI the Alder based system is an example of agroforestry system which has the capability of fixing nitrogen. The alder root nodule fertilises the soil, and the spreading nature of the roots helps to reduce soil washing on slopes (Das et al., 2012; Rathore et al., 2010). It has been reported that *Alnus* can fix up to 29–117 kg ha^{-1} of nitrogen.

3.6 Carbon Sequestration Through Agroforestry Transition

Agroforestry is crucial for sustaining soil organic carbon, which lowers greenhouse gas (GHG) emissions. Agroforestry systems store carbon in the woody biomass reducing the GHGs and this vary with respect to different tree species and different land management practices. The greatest potential for atmospheric CO2 absorption comes from converting underutilised agriculture and grasslands into agroforestry (IPCC 2000). In NEI, Brahma et al. (2018) assessed the ecosystem carbon sequestration capacity for the main land uses transitioned from the natural forest. According to their study, the management of degraded forests using *Piper betle* slash and mulch agroforestry and *Hevea brasiliensis* plantations resulted in carbon sequestration rates of 5 and 4 Mg ha^{-1} $year^{-1}$, respectively. The carbon sequestration reported was 0.5 and 4 Mg ha^{-1} $year^{-1}$ when *Imperata* grassland was turned into Areca catechu and *Hevea brasiliensis* plantations, respectively. Similarly, Reang et al. (2021), reported that pineapple agroforestry systems of > 15 years age has a carbon storage capacity of 175.65 Mg ha^{-1} while the ecosystem carbon storage was 247.46 Mg ha^{-1}. According to Manjaiah et al. (2017), the NEH area of India's agroforestry systems have a SOC stock that ranges from 85.3 to 121.9 Mg ha^{-1}. Agroforestry systems have the ability to store up to 0.29 to 15.2 Mg C ha^{-1} above ground and 30 to 300 Mg C ha^{-1} at a maximum soil depth of 1 m. (Nair et al., 2010).

The intensive management practices by the farm managers of agarwood (*Aquilaria malaccensis*) in the Barak Valley, NEI had induced the average soil organic carbon stock, and ranged between 11.9–28.9 g kg^{-1} at under different cultivation management systems. The economic management of different agarwood stands increased the incorporation of trees for various household needs. In addition Water Guard, Pumpkin, *Betel* leaf, Yardlong Beans, Flat Beans, Cucumber, Sponge Gourd, Spine Gourd, etc. are the crop varieties being cultivated. This inter-spatial crop-tree arrangement of agarwood agroforestry is subsequently leading to high production and accumulation of litter thereby releasing more organic materials into the system (Nath et al., 2020, 2022a, 2022b). In the same system, the suggested increase in the recalcitrant carbon pool with age indicates a higher carbon sink potential in the monoculture stands.

3.7 Alder Based Agroforestry for Microclimate Regulation

The contribution of trees and woody plant in the agroforestry system plays an important role in the microclimate regulation by providing shelterbelts. This also provides shade which are beneficial for air and water quality. Agroforestry offers a multitude of benefits, including the creation of a favourable site-specific climate, decline in erosion, enhancement of biodiversity, improved water quality, increased water infiltration resulting in effective groundwater recharge, enhanced and extended dry flow, habitat improvement, and enhancement of soil fertility (Tomar et al., 2021a, 2021b). In agroforestry systems, the performance of the crop component is typically improved when it has a greater preference for shade, especially during the initial stages of agroforestry establishment. This is because competition for light is a crucial factor that limits yields in such systems. Therefore, the presence of a tree canopy in agroforestry systems can create an optimized microclimate, benefiting the surrounding environment and crops (Burgess et al., 2022). Sharma et al. (2007), reported that, the presence of shade trees in the *Alnus*-cardamom based agroforestry system regulates the microclimate. Furthermore, it is crucial to emphasize the inclusion of local species in agroforestry systems. These species not only contribute to enhancing biodiversity but also possess adaptations to local microclimate conditions. They may have developed resilience to climate change and extreme weather events, making them valuable components of sustainable agroforestry practices (Burgess et al., 2022).

3.8 Indigenous Cultivation and Shade Management for Pest and Disease Control

The traditional farming system in the NEI stands out as intricate and distinct due to its dominance of slash and burn agriculture. In this region, the management of crops and pests is intricately linked with the integration of indigenous knowledge and traditional ecological practices passed down through generations. The land use system revolves around slash and burn agriculture, where the clearing of land and cultivation techniques are guided by the expertise and wisdom of the local communities (Chhetry & Belbahri, 2009). Agroforestry helps to create a more complex and diverse agro ecosystem, which is less vulnerable to pest and disease outbreaks. In agroforestry systems, trees can provide a natural habitat for predators, parasites, and beneficial insects that aid in the management of pest populations. By increasing the genetic diversity of the species and integrating it with other host species, it is possible to reduce the risks of pest and disease infestation by diversifying the tree component of agroforestry systems (Schrotch et al., 2000). Additionally, the presence of trees in agroforestry systems can alter the microclimate, which makes the environment less hospitable for some diseases and pests. Additionally, the presence of trees in agroforestry systems can change the microclimate, making the environment less suitable for some pests and illnesses. Shade trees frequently provide a habitat for beneficial organisms that feed on pests and pathogens, improving the level of pest and disease control (Ayalew et al., 2022). In addition, the inclusion of leguminous trees in agroforestry systems can improve the fertility and health of the soil, which will help to lower the prevalence of diseases that are transmitted through the soil. Studies have demonstrated that agroforestry practises can greatly reduce the usage of synthetic pesticides and herbicides, which are detrimental to both human health and the environment (Udawatta et al., 2019; Ollinaho & Kroger, 2021). Inbuilt approaches used in the agroforestry systems of NEI were reported by Chhetry and Belbahri (2009). The cultural customs of multiple or mixed cropping, zero tillage, clean cultivation, slash-and-burn methods, green manuring, successive cropping and harvesting, fallowing, flooding, and more. These customs, which have a strong cultural foundation, are an efficient technique of controlling diseases and pests. A sustainable and environmentally friendly method of farming is agroforestry. As a result, agroforestry is an environmentally responsible and sustainable method of controlling pests and diseases that can help farmers maintain their financial stability and ensure the long-term viability of agricultural systems.

3.9 Water Logged Agroforestry of Tripura

Reduced nutrient and sediment runoff from agricultural lands is the basis for the regulation of water quality through the use of agroforestry. By reducing the effects of leaching from rainfall-induced runoff, they may also be able to enhance groundwater quality (Anderson et al., 2009). The uptake of nutrients from the soil and water by trees in agroforestry systems can help to limit nutrient runoff. Additionally, trees' root systems can prevent soil erosion. Trees can also help to slow down water movement, allowing for infiltration into the soil and reducing surface runoff. Jinger et al. (2022) reported reduction in the total soil loss and runoff by 37.7% and 19.1%, respectively under agroforestry (sapota + cowpea + casto), compared to the sole crop (cowpea + casto) cultivation. Further, agroforestry systems can enhance soil health, which improves the water absorption capacity of soils, reducing the incidence of flood and drought.

The unique water logged agroforestry system of Tripura can be identified from dominance of woody perennial crops such as areca nut, mango, coconut, and locally adapted varieties of Colocasia. These crops are typically found in swampy areas. Additionally, the system includes certain fish species like *Anabas testudineus*, *Clarias batrachus*, *Puntius chola* etc. Other water-loving plant species such as *Enhydra fluctuans*, *Ipomoea quatic*, and *Achyranthes philoxeroides* are also commonly observed growing within these agroforestry systems. The overall benefit: cost ratio in the traditional waterlogged agroforestry systems of Tripura was 6.35 signifying livelihood potential of the system. This underscores the importance of scientific communities extending this approach to other regions of the country that share alike land-use characteristics. Such expansion can bring about positive economic outcomes and improve the overall sustainability of agricultural practices in those areas (Sarkar et al., 2019).

3.10 Alder, *Sericulture and Fruit Tree Based Agroforestry for Economy*

In the eastern Himalaya, traditional agroforestry techniques centred on cardamom are used to cultivate perennial cash crops on marginal soils and slopes beneath the existing forest canopy.. In the majority of cardamom plantations, *Alnus nepalensis* is commonly used as shade trees. The mixture of *Alnus nepalensis* and cardamom has been found to be ecologically and economically sustainable. Cardamom cultivation is primarily carried out in altitudes ranging from 600 to 2000 m, which includes subtropical to cool temperate zones. The total output from the agroforestry was reported at US$ 1619 with a output: input ratio of 13:2. This indicates that cultivating cardamom within an agroforestry system offers substantial economic advantages and serves as a viable and lucrative alternative for farmers in the region (Sharma et al., 2007). The cardamom agroforestry system is economically viable and particularly beneficial for marginal households that heavily rely on subsistence farming practices. By engaging in cardamom cultivation within the agroforestry system, these households can improve their income and livelihoods. The system provides them with a sustainable and profitable agricultural option, enabling them to enhance their economic well-being and reduce dependence on subsistence farming alone.

Agroforestry systems has the potential to contribute significantly to the country's economy especially in the developing countries. Agroforestry systems can provide multiple products and services, including timber, fuel wood, fruits, nuts, medicinal plants and animal fodder. This diversity of products can create more sustainable and resilient livelihoods for farmers, reducing their dependence on a single crop or source of income. In a sericulture based agroforestry system of NEI, intercropping was done with spacing ranged from (90 × 60) cm to (210 × 120) cm. The net cash return from the agroforestry systems was ranged between INR 9670.00–51,300.00 in low spacing categories with the highest cocoon and fuel wood yield. This was 1.5–5.6 folds more than the net income obtained from Mulberry and groundnut monocultures respectively. Due to the low temperature and deciduous nature of mulberry, rearing activities are not feasible during winter. However, intercropping between mulberry rows can still be practiced with relative ease (Dhyani et al., 1996). The fruit tree based agroforestry system of NEI represented the highest net income generated when groundnut, soybean, turmeric and ginger were intercropped with Khasi Mandarin (Bora et al., 2019). This is attributed to the compatibility and synchronized growth between the two crops, resulting in mutually beneficial outcomes.

4 Future Opportunities of Agroforestry Management

Agroforestry has the potential role to play a in the future by improving the agricultural community's economic status, efficient resource utilisation within the farm, and environmental resistance to climate change (Raj, 2020; Raj et al., 2020). According to a World Bank (2004) estimate, there are around 1200 million rural people who currently practise agroforestry on their farms. Tree cover reaches over 10% of a billion hectares of agricultural lands, and an estimated 1.6 billion hectares of land globally are anticipated to be transformed under agroforestry management in the foreseeable future (Nair & Garrity, 2012). According to CAFRI (2015), by 2050 the need for fodder will be 1.5, 2.0 and 3.0 times that of food grain, fuel wood and timber respectively. Agroforestry has the ability to supply the demand for food, fodder, firewood, and timber. As part of the United Nations Framework Convention on Climate Change (UNFCCC), the Intergovernmental Panel on Climate Change (IPCC), Nationally Determined Contributions (NDC), and National Adaption Plans (NAP) have recognised agroforestry systems in the achievement of climate change adaptation. Furthermore, according to the IPCC's land use cover, land use change and forestry report, 2000, agroforestry systems have been identified as having the largest potential for carbon sequestration by 2040 among all other land uses. Agroforestry compensets one-third (33%) of overall GHG productions from the agriculture sector and 6% of total GHG emissions at the national level (Ajit et al., 2016). Based on this efficiency, the agroforestry systems has the potential of creating carbon trading and carbon credits opportunities. Further selling of this carbon credits can generate income while contributing to climate change mitigation.

Introducing incentive mechanisms for the agroforestry managers of NEI can be helpful to establish link between end users of the ecosystem services managed by indigenous folks at the upstream of ecosystem service loop. Studies has provided insightful information on progressive impact of payment for ecosystems services. Such a mechanism had potentially responsible for biodiversity conservation, reduction in soil erosion and sedimentation of river, increase in biomass carbon sequestration opportunities and restoration of degraded lands through different government and functional non-governmental agencies (Nath et al., 2023).

5 Conclusion and Recommendations

Agroforestry has the potential to support food production and enhance the overall efficiency and stability of agricultural systems in the NEI region. By combining tree crops with food crops, agroforestry systems can provide multiple benefits such as improved soil fertility, enhanced water retention, reduced erosion, diversified income sources, and increased resilience to climate variability. This integrated approach can contribute to sustainable food production and promote long-term agricultural sustainability in the region. It holds great promise in meeting various human needs, including food, fuel, fodder, timber, and more. Additionally, it serves as an insurance against soil erosion, floods, and other natural calamities that are commonly experienced in the NEI region. Restoration of degraded landscapes and biodiversity can be achieved through agroforestry. The agroforestry systems of the Indian Himalayan region holds profound significance of storing a significant amount of carbon. Global issues of climate change and food insecurity can be addressed with the help of agroforestry further contributing in the reduction of carbon footprint. Generation of carbon credits through agroforestry can serve as a catalyst for a positive change. Moreover, the sale of carbon credits on global markets can open up an additional source of income, assisting in the eradication of poverty and the creation of stable means of subsistence. Collaborative approach of involving scientific community, well-structured policy frameworks and community participation can also help achieve the international targets of carbon neutrality.

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Ethonobotanical Documentation of Medicinal Plant Genetic Resources of West Garo Hills, Meghalaya

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Abstract Medicinal plants have attracted the attention of scientists both in India and abroad from chemical, pharmacological and clinical points of view. The state of Meghalaya, inhabited by the Garos tribe, has a long tradition of practicing indigenous medicine. The traditional use of medicinal plants for the cure and prevention of diseases, including the promotion of physical and mental well-being of the people, especially the members of the Garo tribes, has a high priority in almost every household. The traditional use of medicinal plants to treat certain health problems has been passed down from generation to generation in every community of Meghalaya. Objectives of the study was to obtain information, documentation and inventory of important medicinal plants. The required primary data were collected in the study areas through field surveys. With the help of selected informants, first-hand surveys of medicinal plants were conducted in their natural habitats during the four seasons of the year. Three blocks around Nokrek Biosphere Reserve dominated by Garo tribe, whose fast disappearing ethnobotanical knowledge of medicinal plants needs urgent documentation, were selected for the study: Rongram, Gambegre and Dalu. In each block, villages were surveyed about the different types of medicinal plants and their uses. All respondents were between 30 and 65 years of age. Data were collected through direct questioning and discussion in the local Garo language. During the interviews, information about ethnomedicinal plants, their local names, and the plant parts used in each disease were recorded. The investigation of this study revealed that the knowledge of medicinal plant treatment needs to be modernised in every aspect to complement and enhance the traditional health care system. It was found that the knowledge of treatment using medicinal plants still exists among the rural

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population and those who are not so educated. Special attention needs to be paid to this traditional healing system, as many rural people are still very dependent on this traditional health system.

Keywords Medicinal plants · Biosphere reserve · Ethonomedicinal plants

1 Introduction

Medicinal plants can be defined as plants that are commonly used to treat and prevent certain ailments and diseases and are generally considered harmful to humans when taken in large quantities (Anselem, 2004). Medicinal and aromatic plants possess aromatic compounds, mainly oils that are volatile at room temperature, and the specific properties they exhibit act as remedies for various diseases. These plants are traditionally used as raw materials for the extraction of essential oils, as well as a source of spices and other natural products such as traditional herbal medicines, pharmaceuticals, cosmetics, herbal pesticides, insecticides, other herbal products, and so on. The use of ethnobotanical information has contributed to health care worldwide (Fabricant & Farnsworth, 2001). Ethnic peoples around the world have their own well-developed practices, which include medicinal practices. Most traditional therapy involves the use of of plant extracts or their principles (Anon, 1993). According to the World Health Organisation (WHO), up to 80% of the world's population today relies on traditional medicine for their primary health care (Farnsworth et al., 1995). All modern medicines are derived directly or indirectly from medicinal plants, primarily through the application of modern technology to traditional knowledge. Both in India and abroad, scientists have paid attention to medicinal plants from chemical, pharmacological and clinical aspects (Hyniewta and Kumar, 2008). However, these three important integral elements for obtaining actual chemical substances from such plants have been investigated by only a few plants in comparison to the number of such potential plants for their active ingredients. At the same time, clinical investigations take a long time and are very expensive to analyse a large number of plants. Therefore, traditional knowledge is the best source of information for initial screening in such cases (Neogi et al., 1989).

The state of Meghalaya, inhabited by three ethnic tribes, namely Khasis, Jaintias and Garos, like all other tribal states, has a tradition of practicing indigenous medicine. The traditional use of medicinal plants to cure and prevent diseases, including the promotion of physical and mental well-being of the people, especially the people of Meghalaya, has a high priority in almost every household. The traditional use of medicinal plants to treat certain health problems in every community of Meghalaya has been passed down from generation to generation. Of the total 3331 plant species found in the state (Khan et al., 1997), an estimated 834 plants, or 31.3%, are used in health care (Lakadong & Barik, 2006).

Meghalaya has two national parks with globally endangered plant species, and it is one of the wettest places on earth. Rare species include the insectivorous pitcher plant

(*Nephenthes khasiana*), the wild citrus (*Citrus indica*), and the dwarf lily (*Nymphaea tetragona*). The Garo Hills, one of the districts in the state of Meghalaya, are richly blessed with many medicinal plant species. The Garos by nature have deep-rooted socio-religious beliefs and the age-old traditional practice of Jhumming. They practice "Samachik", a system of herbal medicine to treat their diseases. The tribesmen living in the Garo hills have developed their own method of treating and diagnosing diseases through trial and error. Because of their long experience, the use of indigenous plants as medicines has proven successful, and they have a vast knowledge of medicinal plants. People living in remote areas are highly dependent on medicinal plants for their primary treatment, and for this reason the use of medicinal plants in such communities is far more extensive than among urban populations.

The needs of the majority of people in developing countries for medicinal plants have been met by indiscriminate harvesting of spontaneous flora, including forests. Over exploitation of these wild sources has resulted in many species becoming extinct, threatened or endangered (Omobuwajo et al., 2008). Indiscriminate exploitation has been a trend in developing countries for decades, and therefore leads to problems in the conservation of these important plants. Also, the population explosion in developing countries has put undue pressure on commonly used medicinal plants and natural resources in general. As markets for medicinal plant products grow, wild populations are being decimated.

The sustainable practice of traditional medicine and the provision of plant material for drug development depend heavily on concerted efforts to conserve these indigenous plants. Many medicines have already been derived from the knowledge of people in tropical forests, and more will be in the future. There are still too few systematic studies and documentation on endangered medicinal plants of the Garo Hills s available. The status of most of the medicinal plants of the area is unknown in terms of their geographic distribution, so it is anticipated that this chapter will add to the existing knowledge of the area. Much of the knowledge about the use of medicinal plants is still in the hands of traditional societies, and little of this information has been systematically recorded. This chapter is an attempt to systematically document the knowledge acquired by ethnic peoples about important medicinal plants in the region. The biodiversity of medicinal plants and access to traditional herbal medicine have been little studied in the Garo Mountains and especially among the Garo population. Therefore, the biodiversity of medicinal plants and access to traditional herbal medicine among the Garo people need serious study.

1.1 Sampling

The West Garo Hills, one of the districts in the state of Meghalaya, are also richly blessed with a variety of medicinal plant species. The Garos of the Bodo family of Tibeto-Burman descent live in the West Garo Hills. Nokrek Peak (1412 m) is the highest mountain in the Garo Hills. Its forested slopes are home to numerous species of flora. The study is confined to the West Garo Hills district of Meghalaya.

The district has the largest geographical area (3715 km^2), the highest population (642,923), the highest population density (173/km^2), the lowest literacy rate (68.38%) and is the most influential district compared to the other districts of Garo Hills. The district also has the highest number of traditional healers. West Garo Hills, the largest district of Garo Hills region in Meghalaya state with a total area of 2778 square kilometres and most of the hilly area and part of the plains with 1102 villages (2011 census), was selected as the study area. The population of West Garo Hills district is 496933 people according to 2011 census, of which 421,855 live in rural areas and 75,078 in urban areas. West Garo Hills district has been divided into six C& RD blocks namely Rongram, Dalu, Gambegre, Selsela, Tikrikilla and Dadenggre (2011 census).

The sample size was drawn from such stratified subpopulations to ensure unbiased and equal representation.

Sample of fifteen percent (15%) villages from each three Community and Rural Development Blocks of West Garo Hills viz; Rongram, Gambegre and Dalu were selected as a manageable sample size. The selection of villages were done randomly basing on the size of the population and the vegetation coverage (Table 1).

The respondents were stratified from among 30 to 40 years of age (younger generation), 41 to 50 years of age (middle aged generation) and 51 to 65 years of age group (older generation). The ratio of male and female was considered as 2:3 in all.

Fifteen percent (15%) villages are selected from each C & RD Block and twenty percent (20%) households are selected from each selected villages for the purpose of the sampling. The villages taken for sampling are base on the number of the households. Villages were divided into three strata:

(a) Villages with above 300 households
(b) Villages with 101–300 households and
(c) Villages with 10–100 households

Base on these criteria they were than randomly selected for sampling (Lyngdoh, 2012). Villages with less than ten household were not included. The number of respondents taken was 20% each from the total household of each selected villages of three household strata shown above.

2 Documentation of Ethno-Medicinal Information in Three Blocks

The ethnobotanical informations about the plants and its various uses in treatment of ailmenst collected through interviews and discussions with elderly people having knowledge of plants, local healers/Ojhas etc. from three blocks has been collected, compiled and an elaborate account of the same is presented below:

Table 1 Household of selected villages and respondents in Rongram C & RD Block

Sl. No.	Name of villages—Rongram (15%)	No. of household	No. of respondents (20%)
1	Rongdenggre	82	16
2	Chinapgre	38	8
3	Renchapara	53	11
4	Bawegre	47	9
5	Baljek Agal	59	12
6	Kemragre	52	10
7	Dollong Manda	51	10
8	Asanang	129	26
9	Nengkalgre	64	13
10	Botregre	66	13
11	Rongdikgre	50	10
12	Dopananggre	47	9
13	Chiokgre	71	14
14	Wadagre	75	11
15	Kalchengre	50	10
16	Marakapara	70	14
17	Selbalgre	124	25
18	Dipogre	43	9
19	Tebronggre	150	30
20	Chibra Agal	422	84
21	Chibokgre	44	9
22	Selbalgre	124	25
23	Balupara	66	13
24	Sropgre	44	9
25	Mongalgre	41	8
26	Chibragre	112	22
	Total	2174	430

2.1 Dalu Block

A total of 80 plant species belonging to 69 families have been recorded from the Dalu block which is being used in the treatment of 71 diseases by the local people. These collected species have been listed with botanical names, local/common name (s), families, parts used, mode of preparation and formulation in Table 4. Amongst the 80 plant species recorded, the maximum number of genera belongs to the family of Zingiberaceae (12) which was followed by Rubiaceae (10), Fabaceae (10), Apocynaceae (9), Araceae (9), Euphorbiaceae (9), Asteraceae (8), Amaranthaceae (6), Cucurbitaceae (6), Poaceae(5), Solanaceae (5), Apiaceae (4), Arecaceae (4), Menispermaceae (4), Amaryllidaceae (3), Crassulaceae (3), Dilleniaceae (3), Lamiaceae (3), Malvaceae (3), Phyllanthaceae (3), Rosaceae (3), Verbenaceae (3), Acanthaceae (2), Araliaceae (2), Athyriaceae (2), Balsaminaceae (2), Basellaceae (2), Bignoniaceae (2), Brassicaceae (2), Convulvulaceae (2), Dioscoreaceae (2), Moringaceae (2), Musaceae (2), Oleaceae (2), Papilionaceae (2), Passifloraceaea (2), Plumbiginaceae (2), Polygonaceae (2) and Urticaeae (2). The least represented families having single genus and single species are Anacardiaceae, Asparagaceae, Asphodeloidceae, Bixaceae, Bombacaceae, Bromeliaceae, Caricaceae, Colchicacaea, Combretaceae, Costaceae, Gentianaceae, Gleicheniaceae, Hypoxidaceae, Iridaceae, Marantaceae, Melastomataceae, Ophioglossaceae, Orchidaceae, Oxalidaceae, Pedaliaceae, Pontederiaceae, Portulacaceae, Rhamnaceae, Sapindaceae, Saururaceae and Vitaceae. Proper selection of species, parts, as well as preparation and administration methods were given very important in traditional health care systems. Most of the preparations included only one plant species and in few cases mixture of different plant species was used. Mode of preparation included juice, paste, powder, infusion, and hewing raw plant parts. The administration of the therapy is raw, dried form in small pieces or powdered, solution or mixed with water/milk/honey and paste/lotion.

2.2 Gambegre Block

From the present study, it has been observed that in Gambegre development block, 154 plant species belonging to 70 families is being used in the treatment of 81 diseases by the local people. The details of the recorded species have been presented in Table 5. It is clear from Table 3 that the maximum number of genera belongs to the family of Asteraceae (8) and Fabaceae (8) which was followed by Solanaceae (7), Zingiberaceae (6), Rubiaceae (6), Araceae (6), Euphorbiaceae (5), Rutaceae (5), Apocynaceae (4), Malvaceae (4), Poaceae (4), Acanthaceae (3), Amaranthaceae (3), Araliaceae (3), Convulvulaceae (3), Cucurbitaceae (3), Lamiaceae (3), Menispermaceae (3), Phyllanthaceae (3), Amaryllidaceae (2), Anacardiaceae (2), Apiaceae (2), Arecaceae (2), Brassicaceae (2), Cyperaceae (2), Dilleniaceae (2), Dioscoreaceae (2), Gentianaceae (2), Moraceae (2), Orchidaceae (2), Papilionaceae (2), Polygonaceae (2), Verbenaceae (2). Families represented by Asclepiadaceae, Asparagaceae, Aspleniaceae, Athyriaceae, Balsaminaceae, Basellaceae, Begoniaceae, Bixaceae, Bombaceae, Bromeliaceae, Caesalpinaceae, Cannabinaceae, Caricaceae, Colchicaceae, Commelinaceae, Costaceae, Crassulaceae, Gleicheniaceae, Hypoxidaceae, Iridaceae, Lauraceae, Leguminaceae, Nephenthaceae, Oleaceae, Ophioglossaceae,Oxalidaceae, Passifloraceae, Pedaliaceae, Piperaceae, Plumbiginaceae, Pontederiaceae, Rhamnaceae, Rosaceae, Sapindaceae, Saururaceae, Urticaceae and Vitaceae were recorded to have a single genus and single species.

As presented in Table 3, it can also be noted that most of the plant species recorded is being used to cure more than one type of disease. Amongst the different plant species recorded, *Physallis minima* find its maximum use in curing 4 different types of disease viz. cough and cold, as an expectorant, as laxative and for strangury. *Amorphopalli bulbifera, Basella alba, Cajanus cajan, Calotropis gigantea and Rhyncostylis retusa* are being administered for three (3) different types of ailments. For curing two different diseases, plant species like *Aegle marmelos, Areca catechu, Boehmeria nivea, Careya arborea, Carica papaya, Cassia alata, Celosia argentea, Citrus medica, Clerodendrum viscosum, Cochorus olitorius, Curculigo capitata, Curcuma aromatic, Curcuma longa, Cuscutta reflexa, Euphorbia antiqourum, Gloriosa superba, Houttuniya cordata, Jasminum sambac, Jathropa gossypifolia, Lantana camara, Litsea monopetalla, Leucas aspera, Moringa oleifera, Panax pseudoginseng, Piper longum, Plumbago indica, Polygonum capitatum, Rauvolfia serpinta, Tinospora cordifolia, Xanthium strumarium* and *Zingiber officinale.*

2.3 Rongram Block

The data recorded for the medicinal plants used for treatment of various ailments in Rongram development block have been presented in Table 6. It is evident from the table that in Rongram block, 66 diseases were reported to be common and around 118 plant species belonging to 62 families are being used as a medicine by the local people. The family Asteraceae has the highest number of genera of eight (8) species which is followed by Fabaceae and Zingiberaceae of seven (7) each, Araceae (6), Euphorbiaceae (5), Rutaceae (4), Amaranthaceae (3), Apocynaceae (3), Arecaceae (3), Cucurbitaceae (3), Malvaceae (3), Menispermaceae (3), Phyllanthaceae (3), Poaceae (3), Solanaceae (3), Acanthaceae (2), Amaryllidaceae (2), Araliaceae (2), Dioscoreaceae (2), Gentianaceae (2), Papilionaceae (2), Polygonaceae (2) and Rubiaceae (2). While on the other hand, families belonging to Apiaceae, Asparagaceae, Aspleniaceae, Athyriaceae, Balsaminaceae, Basellaceae, Begoniaceae, Bixaceae, Bombaceae, Brassicaceae, Caesalpinaceae, Caricaceae, Colchicaceae, Combretaceae, Convolvulaceae, Crassulaceae, Cyperaceae, Dilleniaceae, Hypoxidaceae, Lamiaceae, Lauraceae, Leguminaceae, Maranthaceae, Melastomatceae, Moraceae, Moringaceae, Musaceae, Oleaceae, Ophioglossaceae, Orchidaceae, Passifloraceae, Piperaceae, Plumbiginaceae, Portulaceae, Rhamnaceae, Rosaceae, Sapindaceae, Saururaceae and Verbenaceae were recorded to have a single genus and single species.

From the present study, it is observed that the plants are being used for the treatment of more than one kind of ailment. *Moringa oleifera, Rauvolfia serpentina* and *Saccharum officinarum* are being used to treat three different kinds of disease. *Moringa oleifera* is being used against eye disease, as a tonic and for toothache, while *Rauvolfia serpentina* is used for curing gastric, chicken pox and as a sedative. *Saccharum officinarum* is being administered for eye related diseases and infection and jaundice. Species like*Acacia auriculiformis, Allium sativum, Alocasia macorrhiza, Alstonia scholaris, Bryophyllum pinnatum, Cajanus cajan, Carica papaya, Celosia argentea, Centella asiatica, Citrus lemon, Cucumis sativus, Diplazium esculentum, Euphorbia antiquorum, Gloriosa superba, Jathropa curcas, Lantana* *camara, Leucas aspera, Momordica foetida, Plumbago indica, Swertia chirayita* are being used for treating two kinds of diseases amongst the local people.

3 Conclusion

From the above data on ethnomedicinal plants in three different blocks, it appears that the natives of the Gambegre development block use the most plant species (154) to cure 81 different types of diseases. This is followed by the Rongram block where 118 plant species are used as medicine for 66 types of diseases, while the Dalu block recorded the lowest number of species (80) used as medicine for 71 different types of diseases. Thus, the highest use of plant species to treat diseases in this block can be attributed to the population density and traditional knowledge of people about herbal remedies. Another observation that emerges from the enumeration is that among the different plant species recorded for folk medicinal use in this study, a large number of plant species are used for the treatment of more than two diseases (Tables 2, 3 and 4). Plant species such as Rauvolfia serpentine, Bryophyllum pinnatum, Cajanus cajan, Calotropis gigantean, Celosa argentea, Centella asiatica, Cucumis sativus, Murraya koenigii, Zingeber officinale, Physallis minima, Amorphophallus bulbifer, Basella alba, Rhyncostylis retusa, Moringa oleifera, and Saccharum officinale are used to treat more than three diseases. The use of more than one plant species to produce a remedy for a disease can be attributed to the additive or synergistic effects of one or the other plant species. Similar results were also reported by Singh et al., (2014) using indigenous people of the Garo Hills in the Nokrek Biosphere Reserve, where they reported that prescriptions with single plants or plant parts were used more frequently, although polytherapeutic prescriptions were also used for a range of ailments. They observed that extracts of boiled leaves of Ardisia paniculata and Smilax ovalifolia, Bridelia tomentosa were used to treat jaundice. A decoction of the rhizome of Pyrrosia adnascens and powdered seeds of Piper nigrum were used to relieve coughs, colds and flus. In contrast, the study conducted by Das et al. (2015) on the ethnic medicines of Garo tribe in Kamrup district, Assam, revealed that some diseases are cured by using a single plant. For example, Boerhavia diffusa is used for swollen feet during pregnancy. However, Zingiber officinale is also used to treat asthma.

This study of ethnobotanical case studies in this region yielded interesting insights into plant use and indicates a high degree of consensus within the Garo ethnic community. Some general ethnobotanical studies conducted so far in Meghalaya have focused on this ethnic group (Sawain et al., 2007; Jeeva, 2009; Kar et al, 2012; Singh et al., 2012; Buragohain et al, 2013; Seal et al, 2013; Seal & Chaudhuri, 2014). However, less attention seems to be paid to these people in terms of their medical ethnobotany. Therefore, the present study provides first-hand information on the folk medicinal uses of many plant species from the region. The traditional healers known as 'ojha's' are generally found in every village in the region. They usually collect plants from the surrounding plant communities, process the drug, and keep it in

Table 2 Household of selected villages and respondents in Gambegre C & RD Block

Sl. No.	Name of villages—Gambegre (15%)	No. of household	No. of respondents (20%)
1	Lower Sangsanggre	110	22
2	Lower Darengre	154	30
3	Somonpara	110	22
4	Sandagre	89	18
5	Dadelagre	71	14
6	Chenggapara	72	10
7	Rimrangpara	73	15
8	Rakwapara	77	15
9	Badupara	82	16
10	Hajongpara	78	16
11	Tochapara	87	17
12	Dorenggagre	75	15
13	Saka Boldamgre	91	18
14	Okkapara Songgitcham	76	15
15	Daronggre	75	15
16	Chengburigri	78	16
17	Dikimpara	60	12
18	Bolchugre	87	17
19	Upper Darengre	90	12
20	Jenggitchakgre	67	13
21	Matalagri	66	13
22	Daren Agal	75	15
23	Aminda Simsang	68	14
	Total	1911	370

their home gardens. Mandal (2013) also studied tangible Garo medicine, which is considered one of the "indigenous" knowledge systems in India. He concluded that the Garos have a body of medical knowledge that, upon closer examination, could prove useful to all of humanity.

Methods of preparation included juice, paste, decoction, powder, infusion, and chewing raw plant parts. More often, a medicine for a particular disease is a mixture of several local plants, and sometimes it also contains some minerals. The usual method of preparation is grinding, regardless of the number or type of ingredients. When a medicine is prescribed either for consumption or for application to the affected part(s) of the body, or both, it is recommended in most cases to mix it with a little water. There was no standardized dosage for the herbal remedies, and most were administered by approximation. Ignacimuthu et al. (2006) also reported that generally the fresh part of the plant was used to prepare the medicine. Most formulations were prepared as

Table 3 Household of selected villages and respondents in Dalu C & RD Block

Sl. No.	Name of villages—Dalu (15%)	No. of household	No. of respondents (20%)
1	Babelapara	97	19
2	Darong Adu	134	27
3	Sanjengpara	60	12
4	Rohonpara	63	13
5	Sandagre	77	15
6	Naronggre	42	8
7	Nektalgre	68	14
8	Posengagre	79	16
9	Akinpara	73	15
10	Gonchudaregre	61	12
11	Moropgre	42	8
12	Marapara	63	13
13	Kerapara Songma	77	15
14	Jarangkona	82	16
15	Purakasia	174	30
16	Rimrangpara A	93	19
17	Barengapara	158	32
18	Kujikura	124	25
19	Madragre	54	11
20	Naronggre	42	8
21	Ranggapara	52	10
22	Chasinpara	46	9
23	Ganipara	67	13
24	Murigre	51	10
25	Dimagre	47	9
26	Baruapara	45	9
27	Chongpot Dopogre	43	9
28	Chanapara	54	11
	Total	2068	408

juice, followed by paste and decoction. The underground parts were generally used in dried form as also reported earlier (Samant et al., 2007; Uprety et al., 2016; Rokaya et al., 2014).

Table 4 Medicinal plant used for treatment of ailments in Dalu development block

Name of diseases	Local name	Botanical name	Family name	Part used	Mode of preparation and formulation
Abdominal pain	Akon	*Calotropis gigantea*	Apocynaceae	Leaves, roots, bark and buds	Grind together and apply in the infected area
Abortion	Jakriting	*Gloriosa superb*	Colchicaceae	Tubers	Grinded to mixed with water and taken orally
	Chimandal gipok	*Jathropa curcas*	Euphorbiaceae	Leaves, Seeds	Grinded together to mixed with water and taken orally
Aczema	Dadimildang/ dadupatta	*Cassia alata*	Fabaceae	Leaves	Grinded to paste and apply it on the infected area
	Kampuneng	*Momordica charaetia*	Cucurbitaceae	Fruits and roots	Grinded to paste and apply it on the infected area
	Chimandal gitchak	*Jathropa gossypifolia*	Euphorbiaceae	Barks, leaves and seeds	Grinded together to paste and apply it on the infected area
Allergy	Me·puri	*Basella alba*	Basellaceae	Roots, leaves	Boil in the water and taken orally
Anaemia	Brokoli	*Brassica oleracea*	Brassicaceae	Flower	Grind to mix with water and taken orally
Antihelmintic	Gokarek	*Costus speciosus*	Costaceae	Rhizome	Grinded to paste and apply it on the infected area

(continued)

Table 4 (continued)

Name of diseases	Local name	Botanical name	Family name	Part used	Mode of preparation and formulation
	Songrura	*Amorphophallus bulbifer*	Araceae	Leaves and corms	Grinded to paste and apply it on the infected area
	Gue	*Areca catechu*	Arecaceae	Seeds	Grinded to paste and apply it on the infected area
Anti-inflamatory	Salpatreng bol	*Sida cordifolia*	Malbaceae	Roots and stem	Grind to paste and apply it on the infected area
	E·ching	*Zingiber officinale*	Zingiberaceae	Rhizome	Grind to paste and apply it on the infected area
Antioxidant	E·ching	*Zingiber officinale*	Zingiberceae	Rhizome	Grind to mixed with water and taken orally
Antiseptic	Ripuji budu	*Mikania micrantha*	Asteraceae	Leaves	Grind to paste and apply it on the infected area
	Nakap/genasi	*Dolicos lablab*	Fabaceae	Whole plant	Grinded to paste and apply it on the infected area
	Donggam	*Clerodendrum colebrookianum*	Verbenaceae	Leaves	Grinded to paste and apply it on the infected area

(continued)

Table 4 (continued)

Name of diseases	Local name	Botanical name	Family name	Part used	Mode of preparation and formulation
	Holdi	*Curcuma longa*	Zingiberaceae	Rhizome	Grinded together to paste and apply it on the infected area
Antidote for poisioning	Dikge meseng	*Curcuma slecies*	Zingiberaceae	Leaves	Grind to paste and apply on the infected area
Boil	Dikge simil	*Curcuma aromatic*	Zingiberaceae	Rhizome	Grinded to paste and apply it around the boil area
	Gajili/Garo bokchi	*Monochoria hastata*	Pontederiaceae	Leaves	Grinded to paste and apply it on the boil
	Wal·kam	*Bryophyllum pinnatum*	Crassulaceae	Leaves	Leave paste is applied around the boil
Bone fracture	Me·mang ta·matchi	*Asparagus racemosus*	Asparaceae	Roots	Grinded to mix with oil and cover by the bandage
	Gonda mande	*Panax pseudoginseng*	Araliaceae	Roots	Grinded to mix with oil and cover by the bandage
	Saff pul	*Carthamus tinctorius*	Asteraceae	Seeds	Grinded to mix with oil and cover by the bandage
	Gimbil	*Careya arbora*	Sapindaceae	Bark	Grinded to mix with oil and cover by the bandage

(continued)

Table 4 (continued)

Name of diseases	Local name	Botanical name	Family name	Part used	Mode of preparation and formulation
	Do·ja gipi/ do·champek	*Justica gendarusa*	Acanthaceae	Leaves	Grinded to mix with oil and cover by the bandage
Burn	Ta·a	*Colocasia esculenta*	Araceae	Corms	Grinded to paste and apply it on the burning area
	Stilchi	*Potulaca oleraceae*	Portulacaceae	Leaf and Stem	Grinded together to mixed with potato and apply it on the burning area
Cancer	Matchipu bol	*Croton tiglium*	Euphorbaceae	Bark and seeds	Grind together and taken orally
Carminative	Jasmine	*Jasminum sambac*	Oleaceae	Leaves, flowers and leaves	Grinded together to extract a juice and used as an eye drop
	Agun julai	*Plumbago indica*	Plumbaginaceae	Roots and leaves	Grinded together to paste and apply it
	Dike simil	*Curcuma aromatica*	Zingiberaceae	Rhizome	Grinded together to paste and apply it
Chicken fox	Do·grikme	*Rauvolfia serfentina*	Apocynaceae	Roots	Boil and juice is taken orally
Cholera	Manamuni	*Centella asiatica*	Apiaceae	Leaves	Grinded to mixed with water and taken orally

(continued)

Table 4 (continued)

Name of diseases	Local name	Botanical name	Family name	Part used	Mode of preparation and formulation
	Molmi	*Mucuna poggei*	Papilionaceae	Seeds	Grinded to mixed with water and taken orally
Cold and cough	Me·kri do·nok	*Polygonum capitatum*	Polygonaceae	Whole plant	Boil in the water and decoction is taken orally
	Tumkut	*Leucas aspera*	Lamiaceae	Whole plant	Boil in the water and decoction is taken orally
	Ja·lik meseki	*Capsicum frutescens*	Solanaceae	Fruits	Taken with salt and onion
Contraceptive	Ta·jong	*Alata deoscorean*	Dioscoreaceae	Yam	Grind to mixed with water and taken orally
	Ta·tilak	*Dioscorea bulbbifera*	Dioscoreaceae	Tuber	Grind to mixed with water and taken orally
Cut and Wounds	Chimandal	*Jathropa curcas*	Euphorbiaceae	Oil of seed	Grind to paste and apply
	Wal·kam	*Bryophyllum pinnaum*	Crassuilacaceae	Leaves	Grind to paste and apply it on the cut and wounds
	Kakku	*Malastoma malabathricum*	Melastomataceae	Leaves	Grind to paste and apply it on the cut and wounds
Dandruff	Do·dim	*Glysine max*	Fabaceae	Whole plant	Extract the juice to mixed with water and apply it as a shampoo on the hair

(continued)

Table 4 (continued)

Name of diseases	Local name	Botanical name	Family name	Part used	Mode of preparation and formulation
	Gila budu/sui	*Entada scandens*	Leguminaceae	Seeds	Extract the juice to mixed with water and apply it as a shampoo on the hair
	Spin	*Seasamum indicum*	Pedaliaceae	Leave and seeds	Extract the juice to mixed with water and apply it as a shampoo on the hair
Diabetes	Du·mandal	*Tinospora cordifolia*	Menispermaceae	Whole plant	Boil in the water and taken orally
	Do·dim	*Glysine max*	Fabaceae	Whole plant	Grinded to mixed with water and taken orally
	Agatchi	*Dillenia pentagyna*	Dillenniaceae	Flower and bark	Grinded together and taken orally
Diarrhoea	Me·gong pul (pink)	*Bauhinia purpurea*	Plantaginaceae	Root, bark, flower	Grind together to mixed with honey and taken orally
	Te·rik re·bok	*Musa balbisiana*	Musaceae	Fruit, seed	Ripen fruit is taken directly
Diphtheria	Me·rakku	*Zea mays*	Poaceae	Stigmas and styles	Grinded together to mixed with water and taken orally
	Du·rimit	*Cuscuta reflexa*	Convolvulaceae	Whole plant	Grinded together to paste and apply it

(continued)

Table 4 (continued)

Name of diseases	Local name	Botanical name	Family name	Part used	Mode of preparation and formulation
Dropsy	Denggasak Baringrong	*Amarauthus cruntus*	Amaranthaceae	Leave, steam	Grinded to mix with water and apply it on the body
	Kektas	*Euphorbia antiquorcum*	Euphorbiaceae	Bark, stem and latin	Grinded to mix with water and apply it on the body
Dysentery	Komchit	*Celosia argentia*	Amaranthaceae	Whole plant	Grinded to mixed with honey and taken orally
	Kilkra local	*Boehmeria macrophylla*	Urticaceae	Leaves	Grinded to mixed with honey and taken orally
	Chirore	*Terminalia chebula*	Combretaceae	Bark and leaves	Grinded together and taken orally
	Manamuni	*Centella asiatica*	Apiaceae	Roots and Leaves	Grinded together and taken orally
	Sokchon	*Alstonia scholaris*	Apocynaceae	Bark, latex and leaves	Grinded together and taken orally
Evil influence	Dike chisik	*Catharantus roseus*	Apocynaceae	Root, leaves	Grind together to paste on the forehead and message on the whole body
Expectorant	Gakpok	*Physallis minima*	Solanaceae	Whole plant	Grind to paste and apply on the infected area

(continued)

Table 4 (continued)

Name of diseases	Local name	Botanical name	Family name	Part used	Mode of preparation and formulation
Eye disease	Sojona	*Moringa olifera*	Moringaceae	Leaves, bark and roots	Grinded together to extract a juice and used as an eye drop
	Chenong	*Morinda angustipolia*	Rubiaceae	Root, barks and leaves	Grinded together to extract a juice and used as an eye drop
Fever	Nolsing/ Curry Leaf	*Murrya koenegii*	Rutaceae	Leaves with honey	Boil and mixed with water and taken orally
	Nolsing/ curry leaf	*Murrya koenegii*	Rutaceae	Leaves with honey	Grinded to mix with honey and taken orally
	Manamuni	*Centella assiatica*	Apiaceae	Leaves	Grinded to mixed with water and taken orally
Gastric	Do·grikme	*Rauvolfia serpentinea*	Apocynacae	Roots	Grinded to mixed with water and taken orally
	Panet	*Ocimum basilicum*	Lamiaceae	Roots and juice	Grinded together and taken orally
	Rani rikgitok balgito	*Rhynchostylis retusa*	Orchidaceae	Leaves and roots	Grinded to mixed with water and taken orally
Gonorrhea	Rikoksi	*Curculigo capitulata*	Hypoxidaceae	Rhizome	Grind to mixed with water and taken orally

(continued)

Table 4 (continued)

Name of diseases	Local name	Botanical name	Family name	Part used	Mode of preparation and formulation
Gout	Du·giteng	*Tinospora crispa*	Menispermaceae	Leaves	Grinded to paste and apply it on the infected area
	Kektas	*Euphorbia antiquorcum*	Euphorbiaceae	Bark, stem and latex	Grinded together to paste and apply it on the infected area
Head ache	Golap	*Rosa sp.*	Rosaceae	Roots	Grinded to mixed with ginger and apply it on the forehead
	Golap	*Rosa species*	Rosaceae	Roots	Grind to paste and apply it on the forehead
	Me·katchi	*Corcorus capsularis*	Malbaceae	Leaves	Grind to paste and apply it on the forehead
	Bolchu	*Bombax malabaricum*	Bombacaceae	Bark and flowers	Grind together to paste and apply it on the forehead
Heart diseases	Te·mit	*Cucumis sativa*	Cucurbitaceae	Fruits	Fruits are taken directly
	Dorai	*Abelmoscus esculentas*	Malbaceae	Fruits and seeds	Grind together to mixed with honey and taken orally
Hiccup	Balsam	*Impatiens balsamina*	Balsaminaceae	Flower and leaves	Grind together and taken orally

(continued)

Table 4 (continued)

Name of diseases	Local name	Botanical name	Family name	Part used	Mode of preparation and formulation
High blood pressure	Squash	*Sechium edule*	Cucurbitaceae	Fruits	Grinded to mixed with lemon juice and taken orally
	Do·grikme	*Rauvolfia serpentina*	Apocynaceae	Roots	Grinded to mixed with water and taken orally
	Ambari segun	*Emblica officinalis*	Phyllanthaceae	Bark, fruits, leaves	Grinded together and taken orally
High cholesterol	Narikel	*Cocos nusifera*	Arecaceae	Fruit water	Extract from fruit water and taken orally
Indigestion	Stroberi	*Fragaria vesca*	Rosaceae	Fruits	Extract a juice and taken orally
	Me·mang kakji	*Citrus medica*	Rutaceae	Fruits	Extract a juice and taken orally
	Memang atchili	*Achyranthes aspera*	Amaranthaceae	Leaves, seeds and roots	Grind together to mixed with water and taken orally
	E·ching	*Zingiber officinale*	Zingiberaceae	Rhizome	Grinded to extrac a juice and taken orally
	Rasin gipok	*Allium sativum*	Amaryllidaceae	Bulb	Grinded to extract juice and taken orally
	Pesin prut	*Passiflora edullis*	Passifloraceae	Leaves and fruits	Grinded to mixed with water and black salt is taken orally

(continued)

Table 4 (continued)

Name of diseases	Local name	Botanical name	Family name	Part used	Mode of preparation and formulation
	Ree	*Calamus erectus*	Arecaceae	Stem and seeds	Grinded to mixed with water and taken orally
	Te·rik re·bok	*Musa balbisiana*	Musaceae	Fruits	Grinded to mixed with water and taken orally
	Ambari raja	*Phyllantus acidus*	Euphobiaceae	Fruits, leaves	Grinded to mixed with water and taken orally
	Chupal dikge	*Kaempferia parviflora*	Zingiberaceae	Rhizome	Grinded to mixed with water and taken orally
	Mongma ja·pa	*Amorphophallus companulatus*	Araceae	Corms	Grinded to mixed with water and taken orally
	Elatchi	*Elettaria cardamomum*	Zingiberaceae	Seeds	Grinded to mixed with water and taken orally
	Gongginjak	*Diplazium esculentum*	Athyriaceae	Leaves	Grinded to mixed with water and taken orally
Insect bite	Gambilori	*Momordica foetida*	Cucurbitaceae	Roots	Grind to paste and apply it around the insect bite
	Duhindol	*Alocasia macrorrhiza*	Araceae	Stem	Grind to paste and apply it on the infected area

(continued)

Table 4 (continued)

Name of diseases	Local name	Botanical name	Family name	Part used	Mode of preparation and formulation
	Kektas bijak dalgipa	*Maehlenbeckia platryclados*	Polygonaceae	Leaves and stem	Grind together to paste and apply it on the infected area
Jaundice	Grit	*Saccharum officinarum*	Poaceae	Culms	Extract a juice and taken orally
	Buga salgro	*Stephania hemandifolia*	Menispermaceae	Younger Leaves	Grinded to mixed with water and taken orally
	Kesunat	*Anacardium occidentale*	Anacardiaceae	Bark	Grinded to mixed with water and taken orally
	Kiring	*Oroxylun indicum*	Bignoniaceae	Roots, barks, seeds and leaves	Grind together and taken orally
	Chenong	*Morinda angustipolia*	Rubiaceae	Roots, barks and Leaves	Grind together and taken orally
Kidney stone	Mandarin Komila	*Citrus reticulatea*	Rutaceae	Leaves and fruits	Extract a juice and taken orally
	Matchu wagam samsi	*Eleusine indica*	Poaceae	Whole plant	Grinded to mixed with water and taken orally
	Te·mit	*Cucumis sativa*	Cucurbitaceae	Fruits	Extract a juice and taken orally
	Mendu	*Cajanus cajan*	Fabaceae	Leaves, seeds	Grinded to mixed with water and taken orally
	Wal·kam	*Bryophylum pinnatum*	Crassulaceae	Leaves	Grinded to mixed with water and taken orally

(continued)

Table 4 (continued)

Name of diseases	Local name	Botanical name	Family name	Part used	Mode of preparation and formulation
Laxative	Ta·marang	*Spomoea batata*	Convolvulaceae	Leaves	Grind to mixed with water and taken orally
	Te·gitu/tibe	*Dellenia indica*	Delliniaceae	Fruits	Grind to mixed with water and taken orally
	So·re/ me'konchek budu	*Dicranopteris lineris*	Gleicheniaceae	Leaves and roots	Grind to mixed with water and taken orally
Leprosy	Agunjolai	*Plumbago indica*	Plumbaginaceae	Roots and leaves	Grinded together to paste and apply it on the infected area
Lumbago	Mikkol baring	*Solanum xanthocarpum*	Solanaceae	Roots	Grind to paste and apply on the infected area
Malaria	Ka·gija kimka	*Solanum torvum*	Solanaceae	Fruits, leaves, roots	Grinded to mixed with water and taken orally
	Sambesual dal·gipa	*Artimisia indica*	Asteraceae	Whole plant	Grinded to mixed with water and taken orally
Measles	Raja ambare	*Phyllanthus acidus*	Phyllanthaceae	Roots, leaves and fruits	Grind together and taken orally, with apply it on the infected area
Menstrual disorder	Begonia	*Rex begonia*	Begoniaceae	Leaves and stem	Grind together to mixed with water and taken orally

(continued)

Table 4 (continued)

Name of diseases	Local name	Botanical name	Family name	Part used	Mode of preparation and formulation
	Makkalibak	*Mucuna pruriens*	Papilionaceae	Roots and pods	Grind together to mixed with water and taken orally
	Modipul	*Carica papaya*	Caricaceae	Root, leaves, flower and fruits	Grind together to mixed with water and taken orally
Migraine	Kopi	*Coffee arabica*	Rubiaceae	Ripen fruits	Grind to mixed with water and taken orallyor Ripen fruit is taken directly
Mumps	Lantana	*Lantana camara*	Verbenaceae	Leaves and roots	Grinded to paste and apply it on the infected area
	Ta·gong pul	*Caladium bicolour*	Araceae	Roots and tubers	Grinded to paste and apply it on the infected area
Nose bleeding	Ruat tip	*Helminthostashys zeylanica*	Ophioglossaceae	Leaves	Grinded to paste and apply into the nose
Piles	Soroli	*Carum caral*	Apiaceae	The seeds	Grinded to mixed with water and taken orally
	Chandili burung (bu·su)	*Amaranthus spinosus*	Amaranthaceae	Whole plant	Grinded to mixed with water and taken orally
	Mongma ja·pa	*Amorphophallius sp.*	Araceae	Underground corus	Grinded to mixed with water and taken orally

(continued)

Table 4 (continued)

Name of diseases	Local name	Botanical name	Family name	Part used	Mode of preparation and formulation
Pneumonia	Jengjil	*Schefflera venulosa*	Araliaceae	Bark, leaves	Boil and juice is taken orally
Rheumatism	Dikge beholi	*Curcuma caesia*	Zingiberaceae	Rhizome	Grinding and paste on the infected area
Scurvy	Me·mang kakji	*Citrus medica*	Rutaceae	Roots and juice	Extract to mix with water and taken orally
	Jakritchu	*Cissus quadranggularis*	Vvitaceae	Root and juice	Grinded to mix with honey and taken orally
Sedative	Samte dal·gipa	*Xanthium strumarium*	Asteraceae	Whole plant buds	Grinded to mixed with water and message on the body
	Pesinprut	*Passiflora edulis*	Passifloraceae	Leaves and fruits	Grinded to mixed with water and taken orally
	Do·grikme	*Rauvolfia serpentina*	Apocynaceae	Roots	Grinded to mixed with water and taken orally
Skin diseases	Mandal bol	*Erythrina stricta*	Fabaceae	Flower, bark	Grinded together to paste and apply it on the infected area
	Ambari segun	*Phyllantus officinalis*	Phyllanthaceae	Bark, fruit, leaves	Grinded together to paste and apply it on the infected area

(continued)

Table 4 (continued)

Name of diseases	Local name	Botanical name	Family name	Part used	Mode of preparation and formulation
	Akon	*Calotropis gigantea*	Apocynaceae	Leave, root, bark	Grinded together to paste and apply it on the infected area
Small fox	Du·mandal	*Tinospora cordifolia*	Menispermaceae	Whole plant	Boil and juice is taken orally
Snake bite	Duhindol	*Alocasia macrorrhiza*	Araceae	Stem	Grinded to paste and apply it on the infected area
	Nakap/genasi	*Dolichos lablab*	Fabaceae	Whole plant	Grinded to mixed with oil and apply it on the infected area
	Zebra samchipu	*Sensevieria trifasciata*	Dracaenaceae	Leaves	Grinded to mixed with oil and apply it on the infected area
Sprain	Wire samsi	*Eleusin indica*	Poaceae	Whole plant	Grind to paste and apply it on the infected area
	Lantana	*Lantana camara*	Verbenaceae	Leaves and roots	Grind together to paste and apply it on the infected area
Stomachache	Nepali pang	*Artemesia nilagirica*	Asteraceae	Leaves	Grind to extract a juice and taken orally

(continued)

Table 4 (continued)

Name of diseases	Local name	Botanical name	Family name	Part used	Mode of preparation and formulation
	Rangre	*Vitex quinata*	Lamiaceae	Bark	Grind to mix with water and taken orally
	Sambang guri	*Eupatorium odoratum*	Asteraceae	Leaves	Ground to extract juice and taken orally
Tonic	Do·dike/ Ledis slipper rokomsa	*Kaempferia laotica*	Zingiberaceae	Rhizome	Grind to mixed with water and taken orally
	Te·gutu/te·be	*Delllenia indica*	Dellinaceae	Fruits	Grind to mixed with water and taken orally
	Kadam bol	*Anthocephalus sp.*	Bixaceae	Leaves, roots, seeds	Grinded together to mixed with water and taken orally
	Gongki	*Etlingera linguiformis*	Zingiberaceae	Roots	Grinded together to mixed with water and taken orally
	Balsam	*Impatiens balsamina*	Balsaminaceae	Flower, leaves	Grinded together to mixed with water and taken orally
	Che·eng pul	*Biophytum sensitivum*	Oxalidaceae	Leaves, roots	Grinded together to mixed with water and taken orally
Tooth ache	Sam rimit/ wagam sam	*Spilanthes acmella*	Asteraceae	Flower	Grind to paste and apply it
	Sojona	*Moringa oliefera*	Moringaceae	Leaves, barks and roots	Grind to paste and apply it

(continued)

Table 4 (continued)

Name of diseases	Local name	Botanical name	Family name	Part used	Mode of preparation and formulation
Tuberculosis	Diki re·koksi	*Eleutherine palmifolia*	Iridaceae	Bulb	Grind to mixed with water and taken orally
	Chi·rota	*Swertia chirayita*	Gentianaceae	Whole plant	Grinded to mixed with water and taken orally
	Jingjot/ matgonggong	*Typhonium trilobatum*	Araceae	Leaves, root, tuber	Grinded to mixed with water and taken orally
	Wool bibal samsi	*Celosia argensia*	Amaranthaceae	Whole plant	Grinded to mixed with water and taken orally
Tumor	Rasin gipok	*Allium sativum*	Amaryllidaceae	Bulbs	Grind to paste and apply it on the infected area
	Landu	*Cajanus cajan*	Fabaceae	Leaves and seeds	Grind together to paste and apply it on the infected area
	Kangkil	*Ziziphus jujuba*	Rhamnaceae	Roots, leaves, bark and seeds	Grind together to paste and apply it on the infected area
Typhoid	Anaros	*Ananas comosus*	Bromeliaceae	Fruits	Grinded to mixed with water and taken orally
	Kalmek	*Andrographis paniculata*	Acanthaceae	Leaves and stem	Grinded to mixed with water and taken orally

(continued)

Table 4 (continued)

Name of diseases	Local name	Botanical name	Family name	Part used	Mode of preparation and formulation
Ulcers	Mendu	*Cajanus cajan millsp*	Fabaceae	Leaves and seeds	Grind together to mixed with honey and taken orally
	Sunflower	*Helianthus annus*	Asteraceae	Leaves, flower and seeds	Grind together to mixed with honey and taken orally
	Komchit	*Celosia argentia*	Amaranthaceae	Whole plant	Grinded to mixed with water and taken orally
	Matcha duri/ jamaldo	*Houttuynia cordata*	Saururaceae	Leaves	Grinded to mixed with water and taken orally
	Akon	*Calotropis gigantea*	Apocynaceae	Leaves, roots, bark and buds	Grinded to mixed with water and taken orally
	Jasmine	*Jasminum sambac*	Oleaceae	Leaves, flowers and fruits	Grinded to mixed with water and taken orally
	Kilkra	*Boehemeria nivea*	Urticaceae	Leaves	Grinded to mixed with water and taken orally
	Ta·bolchu	*Manihot esculenta*	Euphorbiaceae	Tuber poultise	Grinded to mixed with water and taken orally
	Mesguri (noni)	*Morinda citrifolia*	Rubiaceae	Leaves, roots and fruits	Grinded to mixed with water and taken orally
	Rasin biret	*Allium chinence*	Amaryllidaceae	Whole plant	Grinded to mixed with water and taken orally

(continued)

Table 4 (continued)

Name of diseases	Local name	Botanical name	Family name	Part used	Mode of preparation and formulation
	Me·rimil gitchak	*Basella alba*	Basellaceae	Roots and leaves	Grinded to mixed with water and taken orally
Urinal infection	Datura	*Datura innoxia*	Solanaceae	Leaves	Grinded to mixed with water and taken orally
	Alovera	*Aloe vera*	Asphodeloidceae	Whole plant	Extract to juice and taken orally
	Ararut	*Maranta arudenceae*	Marantaceae	Root	Grinded to mixed with water and taken orally
	Tusidmu	*Mimosa pudica*	Fabaceae	Whole plant	Grinded to mixed with water and taken orally
	Samsi bipek bonga	*Cynodon dactylon*	Poaceae	Whole plant	Grinded to mixed with water and taken orally
Vermicide	Dadimildang	*Cassia alata*	Fabaceae	Leaves	Grinded to paste and apply it on the infected area
	Mula	*Raphanus sativas*	Brassicaceae	Root, seeds and leaves	Grinded to paste and apply it on the infected area
	Gue	*Areca catechu*	Araceae	Seeds	Grinded to paste and apply it on the infected area
Vomiting	Chimandal Gitchak	*Jatropa gossypifolia*	Euphorbiaceae	Bark, leave, seed	Grinded to extract the juice and taken orally

(continued)

Table 4 (continued)

Name of diseases	Local name	Botanical name	Family name	Part used	Mode of preparation and formulation
	Nolsing	*Murraya Koenegii*	Rutaceae	Leaves	Grinded to mixed with water and taken orally
Weakness during conceivation	Sarat	*Diplazium esculentum*	Athyriaceae	Leaves	Boil in the water and taken orally

The Garo community has empirical knowledge about the use of medicinal plants, their ailments and diseases. This confirms the general understanding that traditional forms of health care still govern the lives of people around the world, especially in developing countries. However, the medicinal flora of the West Garo Hills is sparsely documented. There is an urgent need to document these plants and indigenous knowledge for future reference. Scientific validation of plant species could aid in the discovery of new medicines to combat emerging and resistant pathogens. Not all plants were included in the present study; more comprehensive documentation should be done to include them. It is also advisable to intensify environmental education on sustainable harvesting and good harvesting techniques so that such plants harvested for drug production are not eradicated but also propagate in designated areas.

Table 5 Medicinal plants used for treatment of ailments in Gambegre Development Block

Name of diseases	Local name of M.P	Botanical name of M.P	Family name of M.P	Part used	Mode of preparation and application
Abdominal pain	Akon	*Calotropis gigantea*	Apocynaceae	Leaves, roots, bark and buds	Grind together to mix with oil and message on the infected area
Abortion	Jakriting	*Gloriosa superba*	Colchicaceae	Tubers	Grind it and taken orally
	Chimandal gipok	*Jathropa curcas*	Euphorbiaceae	Seeds	Grind it and taken orally
Abscises	Che·eng pul	*Biophytum sensitivum*	Oxalidaceae	Leaves and roots	Boil in water and is taken orally
Aczema	Prap	*Ficus bengalensis*	Moraceae	Leaves	Grind it to paste and apply it on the infected area
	Dadimildang/dadupatta	*Cassia alata*	Fabaceae	Leaves	Grind it to paste and apply it on the infected area
	Chimandal gitchak	*Jathropa gossypifolia*	Euphorbiaceae	Barks, leaves and seeds	Grind it to paste and apply it on the infected area
Allergies	Me·puri	*Basella alba*	Basellaceae	Roots, leaves	Grind together,mix with lime and apply it
Amenorrhea	Kesunat	*Anacardium occidentale*	Annacardiaceae	Bark	Boil in water and taken orally
Anaemia	Rangre	*Vitex quinata*	Lamiaceae	Bark	Boil in water and is taken orally
Anthelmintic	Brokoli	*Brassica oleracea*	Brassicaceae	Flower	Boil in water and is taken orally
	Songrura	*Amorphophallus bulbifera*	Araceae	Leaves and corms	Boil in water and mix with lime water and taken orally
	Gue	*Areca catechu*	Arecaceae	Seeds	Grind it and taken orally

(continued)

Table 5 (continued)

Name of diseases	Local name of M.P	Botanical name of M.P	Family name of M.P	Part used	Mode of preparation and application
	Sa·ra samsi	*Cyperus rotundus*	Cyperaceae	Whole plant	Grind it and taken orally
	Gokarek	*Costus speciosus*	Costaceae	Rhizome	Grind it and taken orally
Antidote for poisoning	Dikge meseng	*Curcuma sp.*	Zingiberaceae	Leaves	Grind it and and taken orally with water
Anti-hepatitis B	Ramie	*Boehemeria nivea*	Urticaceae	Leaves	Grind it and mix with water and taken orally
Anti-inflammatory	Salpatreng bol	*Sida cordifolia*	Malbaceae	Roots and stem	Grind it together and apply it on the infected area
	E·ching	*Zingiber officinale*	Zingiberaceae	Rhizome	Grind together and apply it on the infected area
Antioxidant	E·ching	*Zingiber officinale*	Zingiberceae	Rhizome	Grind it and apply it on the infected area
Antiseptic	Sambesual dal·gipa	*Artimisia Indica*	Asteraceae	Whole plant	Grind it to paste and apply it on the infected area
	Nakap/genasi	*Dolicos lablab*	Fabaceae	Whole plant	Grind it to paste and apply it on the infected area
	Donggam	*Clerodendrum colebrookianum*	Verbenaceae	Leaves	Grind it to paste and apply it on the infected area
	Ripuji budu	*Mikania micrantha*	Asteraceae	Leaves	Grind it to paste and apply it on the infected area
	Holdi	*Curcuma longa*	Zingiberaceae	Rhizome	Grind it to paste and apply it on the infected area
Appetizer	Gal·da mesta	*Hibiscus cannbinus*	Asterceae	Leaves, flower and seeds	Boil in water and taken orally

(continued)

Table 5 (continued)

Name of diseases	Local name of M.P	Botanical name of M.P	Family name of M.P	Part used	Mode of preparation and application
Astringent	Sata samsi	*Cyperus involucratus*	Cyperaceae	Whole plant	Grind it and taken orally
Astringent	Laham bol	*Litsea monopetala*	Lauraceae	Bark and seeds	Grind to mix with cinnamon and taken orally
Beriberi	Baring	*Solanum melongena*	Solanacea	Seeds and leaves	Grind together and message it on the body
Boils	Me·rimil	*Basella alba*	Basellaceae	Roots and leaves	Grind together and apply it on the infected area
	Akon	*Calotropis gigantea*	Asclepiadaceae	Latex	Grind together and apply it on the infected area
	Dikge simil	*Curcuma aromatiac*	Zingiberaceae	Rhizome	Grind it and apply it on the infected area
	Gajili/Garo bokchi	*Monochoria hastata*	Pontederiaceae	Leaves	Grind it and apply it on the infected area
	Bang	*Cannabis sativa*	Cannabaceae	Leaves and flowers	Grind it and apply it on the infected area
	Wal·kam	*Bryophyllum pinnatum*	Crassulaceae	Leaves	Grind it and applied it around the boil area
Bone Fracture	Gimbil	*Careya arbora*	Sapindaceae	Bark	Grind to paste and bandage
	Do·ja gipi/do·champek	*Justica gendarusa*	Acanthaceae	Leaves	Grind to paste and bandage
	Me·mang ta·matchi	*Asparagus racemosus*	Asparaceae	Roots	Grind it to paste and bandage
	Gonda mande	*Panax pseudoginseng*	Araliaceae	Roots	Grind it to paste and bandage

(continued)

Table 5 (continued)

Name of diseases	Local name of M.P	Botanical name of M.P	Family name of M.P	Part used	Mode of preparation and application
Cancer	Matchipu bol	*Croton tiglium*	Euphorbaceae	Bark and seeds	Boil in water and taken orally
Carminative	Matcha pan/asira	*Piper longum*	Piperaceae	Leaves and roots	Grind it together and taken orally
	Agun julai	*Plumbago indica*	Plumbaginaceae	Roots and leaves	Grind it together and taken orally
	Dike simil	*Curcuma aromatica*	Zingiberaceae	Rhizome	Grind it together and taken orally
Chicken pox	Do·grikme	*Rauvolfia serfentina*	Apocynaceae	Roots	Boil in water and taken orally
Cholera	Chi·rota	*Swertia chirata*	Gentianaceae	Whole plant	Boil it and taken orally with water
	Manamuni	*Centilla asiatica*	Apiaceae	Leaves	Grind it and taken with water
	Molmi	*Mucuna poggei*	Papilionaceae	Seeds	Grind it and taken with water
Cold and cough	Ja·lik meseki	*Capsicum frutescens*	Solanaceae	Fruits	Fruits are eaten with salt and onion
	Tumkut	*Leucas aspera*	Lamiaceae	Whole plant	Grind it and taken with water
	Me·kri do·nok	*Polygonum capitatum*	Polygonaceae	Whole plant	Grind it and taken with water
Contraceptive	Ta·jong	*Alata deoscorean*	Dioscoreaceae	Yam	Grind it together and taken orally

(continued)

Table 5 (continued)

Name of diseases	Local name of M.P	Botanical name of M.P	Family name of M.P	Part used	Mode of preparation and application
	Ta·tilak	*Dioscorea bulbbifera*	Dioscoreaceae	Tuber	Grind it together and taken orally
Cough and cold	Gakpok	*Physallis minima*	Solanaceae	Whole plant	Boil in water and taken orally
Dandruff	Do·dim	*Glysine max*	Fabaceae	Whole plant	Grind it together and apply it on the hair
	Gila budu/ sui	*Entada scandens*	Leguminaceae	Seeds	Grind it and apply it on the hair
	Spin	*Seasamum indicum*	Pedaliaceae	Leave and seeds	Grind it together and apply it on the hair
Debility	Kejur bol	*Phoenix dactylifera*	Arecaceae	Fruits and seeds	Grind it and apply it on the body
Diphtheria	Me·rakku	*Zea mays*	Poaceae	Stigmas and styles	Grind it and taken orally
	Du·rimit	*Cuscuta reflexa*	Convolvulaceae	Whole plant	Grind it and apply it on the body
	Denggasak Baringrong	*Amarauthus cruntus*	Amaranthaceae	Leave and stem	Grind it to paste and apply it on the body
Dropsy	Kektas	*Euphorbia antiquorcum*	Euphorbiaceae	Bark, stem and latex	Grind it to paste and apply it on the body
Dysentery	Jamaldo	*Houttuynia cordata*	Saururaceae	Leaves	Grind it and mix with water and taken orally
	Sokchon	*Alstonia scholaris*	Apocynaceae	Bark, latex and leaves	Boil it and taken orally with water

(continued)

Table 5 (continued)

Name of diseases	Local name of M.P	Botanical name of M.P	Family name of M.P	Part used	Mode of preparation and application
	Passim	*Paederia foetitum*	Rubiaceae	Whole plant	Boil it and taken orally with water
	Matcha pan/Asira	*Piper longum*	Piperaceae	Leaves and roots	Grind it together and taken orally
Epilepsy	Gol·matra	*Hollarrena antidysentrica*	Apocynaceae	Bark, seeds and leaves	Grind it and mix with water and taken orally
Evil influence	Dike chisik	*Catharantus roseus*	Apocynaceae	Root, leaves	Grind it and mix with water and apply on the whole body
Expectorant	Gakpok	*Physallis minima*	Solanaceae	Whole plant	Grind it and apply it on the infected area
Eye disease	Sojona	*Moringa olifera*	Moringaceae	Leaves,bark and roots	Grind it together to extract a juice and use as an eyes drop
	Chenong	*Morinda angustipolia*	Rubiaceae	Root, barks and leaves	Grind it together to extract a juice and use as an eyes drop
	Jasmine	*Jasminum sambac*	Oleaceae	Leaves, flowers and leaves	Grind it together to extract a juice and use as an eyes drop
	Datura	*Datura innoxia*	Solanaceae	Leaves	Grind it to extract the juice and use as an eyes drop
	Grit	*Saccharum officinarum*	Poaceae	Culms	Grind it to extract the juice and used as an eyes drop

(continued)

Table 5 (continued)

Name of diseases	Local name of M.P	Botanical name of M.P	Family name of M.P	Part used	Mode of preparation and application
	Akasia	*Acacia auriculiformis*	Fabaceae	Roots and bark	Grind it to extract the juice and used as an eyes drop
Fever	Me·katchi	*Corchorus olitorious*	Malbaceae	Leaves	Grind and made it into paste and apply on the forehead
	Agatchi	*Dillenia pentagyna*	Dilleniaceae	Flower and bark	Grind it and and taken orally with water
	Mekatchi	*Corcorus olitorious*	Malbaceae	Leaves	Boil it and taken orally with water
	Sal·a	*Thysanolaena maxima*	Poaceae	Roots	Boil it and taken orally with water
	Samskal	*Eryngium foetidium*	Apiaceae	Leaves	Boil it and taken orally with water
Gastric	Rani rikgitok balgito	*Rhynchostylis retusa*	Orchidaceae	Leaves and roots	Grinded to mixed with water and taken orally
Gonorrhea	Rikoksi	*Curculigo capitulata*	Hypoxidaceae	Rhizome	Grind it and and taken orally with water
Gout	Du·giteng	*Tinospora crispa*	Menispermaceae	Leaves	Grind it to paste and apply it on the infected area
	Kektas	*Euphorbia antiquorum*	Euphorbiaceae	Bark, stem and latex	Grind it to paste and apply it on the infected area
Headache	Bolme·cheng	*Rhus acuminate*	Anacarbiaceae	Leaves	Grind it to paste and apply it on the forehead

(continued)

Table 5 (continued)

Name of diseases	Local name of M.P	Botanical name of M.P	Family name of M.P	Part used	Mode of preparation and application
	Bolchu	*Bombax malabaricum*	Bombacaceae	Bark and flowers	Grind it to paste and apply it on the forehead
	Golap	*Rosa sp.*	Rosaceae	Roots	Grind it to paste and apply it on the forehead
	Me·katchi	*Corhcorus capsularis*	Malbaceae	Leaves	Grind it to paste and apply it on the forehead
Heart diseases	Dorai	*Abelmoscus esculentas*	Malbaceae	Fruits and seeds	Grind it together and taken orally with water
	Te·mit	*Cucumis sativa*	Cucurbitaceae	Fruits	Fruit are eaten directly
Hemorrhoids/ piles	Jakriting	*Gloriosa superba*	Colchicaceae	Tuber	Grind it and apply it on the infected area
Hiccup	Balsam	*Impatiens balsamina*	Balsaminaceae	Flower and leaves	Grind it and mix with water and taken orally
High cholesterol	Narikel	*Cocos nusifera*	Arecaceae	Fruit water	Extract a fruit juice and taken orally
Indigestion	Me·mang kakji	*Citrus medica*	Rutaceae	Fruits	Extract to juice and taken orally as much as possible
	Modupol	*Carica papaya*	Caricaceae	Fruits	Grind it and taken orally
	Selpri	*Aegele marmelos*	Rutaceae	Roots, leaves and fruits	Grind it and taken orally
Insect bite	Kektas bijak dalgap	*Maehlenbeckia platryclados*	Polygonaceae	Leaves and stem	Grind together and apply it on the infected area
	Duhindol	*Alocasia macrorrhiza*	Araceae	Stem	Grind together and apply it on the infected area

(continued)

Table 5 (continued)

Name of diseases	Local name of M.P	Botanical name of M.P	Family name of M.P	Part used	Mode of preparation and application
Insomnia (children)	Do·reng ja·si	*Schefflera arbonicola*	Araliaceae	Bark and leaves	Grind together and apply it on the body
Jaundice	Mendu	*Cajanus cajan*	Fabaceae	Leaves, seeds	Grind it together and taken orally
	Masanta	*Massaenda globrata*	Rubiaceae	Roots and leaves	Grind it together and taken orally
	Buga salgro	*Stephania hemandifolia*	Menispermaceae	Leaves	Grind it and taken orally
	Podina	*Mentha spicata*	Lamiaceae	Leaves	Grind it and taken orally
	Tattoo bol	*Bixa orellana*	Bixaceae	Leaves, bark	Grind it and taken orally
	Rani rikitok balgito	*Rhynchostylis retusa*	Orchidaceae	Leaves, roots	Grind it and taken orally
	Holdi	*Curcuma longa*	Zingiberaceae	Rhizome	Grind it and taken with water
	Du·rimit/ nawang budu	*Cuscuta reflexa*	Convovulaceae	Whole plant	Grind it and apply it on the body
	Rikoksi	*Curculigo capitulata*	Hypoxidaceae	Rhizome	Grind it and taken with water
	Gimbil	*Careya arbora*	Sapindaceae	Bark	Boil it and taken orally with water
	Asoka	*Saraca indica*	Caesalpiniaceae	Bark	Boil it and taken orally with water
Laxative	Baring belati	*Lycopersicum esculentum*	Solanaceae	Fruits	Extract to juice and taken orally

(continued)

Table 5 (continued)

Name of diseases	Local name of M.P	Botanical name of M.P	Family name of M.P	Part used	Mode of preparation and application
	So·re/me·konchek budu	*Dicranopteris lineris*	Gleicheniaceae	Leaves and roots	Grind it together and taken orally
	Selpri	*Aegele marmelos*	Rutaceae	Roots, leaves and fruits	Grind it together and taken orally
	Dengasak gitchak	*Amaranthus gangeticus*	Amaranthaceae	Whole plant	Grind it together and taken orally
	Gakpok	*Physallis minima*	Solanaceae	Whole plant	Grind it together and taken orally
	Ta·marang	*Ipomoea batata*	Convolvulaceae	Young Leaves	Boil it and taken orally
	Te·gitu/tibe	*Dellenia indica*	Delliniaceae	Fruits	Grind it together and taken orally
Leprosy	Chamolja	*Aporusa dioca*	Phyllanthaceae	Bark	Grind it and apply it on the infected area
	Laham bol	*Letsia monopetala*	Lauraceae	Bark and seeds	Grind it together and apply it on the infected area
	Agunjolai	*Plumbago indica*	Plumbaginaceae	Roots and leaves	Grind it and apply it on the infected area
Low blood pressure	Du·mandal	*Tinospora cordifolia*	Menispermaceae	Whole plant	Boil in water and taken orally
Lumbago	Mikkol baring	*Solanum xanthocarpum*	Solanaceae	Roots	Grind it and apply it on the infected area
Masticator	Wakpatra	*Koemferia galanga*	Zingiberaceae	Leave and tuber	Grind it and mix with water and taken orally

(continued)

Table 5 (continued)

Name of diseases	Local name of M.P	Botanical name of M.P	Family name of M.P	Part used	Mode of preparation and application
Measles	Raja ambare	*Phyllanthus acidus*	Phyllanthaceae	Roots, leaves and fruits	Grind it together and taken orally with water
Menstrual disorder	Begonia	*Rex begonia*	Begoniaceae	Leaves and stem	Grind it together and taken orally
	Makkalibak	*Mucuna pruriens*	Papilionaceae	Roots and pods	Grind it together and taken orally
	Modipul	*Carica papaya*	Caricaceae	Root, leaves, flower and fruits	Grind it together and taken orally
Migraine	Kopi	*Coffee arabica*	Rubiaceae	Ripe fruits	Boil in water and taken orally
Mumps	Lantana	*Lantana camara*	Verbenaceae	Leaves and roots	Grind it to paste and apply it on the infected area
	Ta·gong pul	*Caladium bicolour*	Araceae	Roots and tubers	Grind it to paste and apply it on the infected area
Night blindness	Me·mang koksi	*Nepenthes khasiana*	Nepenthaceae	Juice	Extract a juice and used as an eyes drop
Nose bleeding	Ruat tip	*Helminthostashys zeylanica*	Ophioglossaceae	Leaves	Grind it to paste and apply it on the nose
	Gitchak tangsek anaros pul	*Tradescantia spathaceae*	Commelinaceae	Leaves and flowers	Grind it to paste and apply it on the nose
	Samsko gitchak	*Clerodendrum viscosum*	Verbinaceae	Leaves and roots	Grind it to paste and apply it on the nose
Oedema	Gradek	*Massaenda frondosa*	Rubiaceae	Leaves	Grind it together and taken orally

(continued)

Table 5 (continued)

Name of diseases	Local name of M.P	Botanical name of M.P	Family name of M.P	Part used	Mode of preparation and application
	Kampuneng	*Momordica charaetia*	Cucurbitaceae	Fruits and roots	Grind it together and taken orally
	Bolka·sin	*Pongamia pinnata*	Fabaceae	Roots leaves, flowers and seeds	Grind it together and taken orally
	Do·reng ki·me	*Aerides multiflorum*	Orchidaceae	Leaves	Grind it together and taken orally
	Sinaru	*Cassia fistula*	Fabaceae	Leaves	Grind it together and taken orally
Paralysis	Datura	*Datura stramonium*	Solanaceae	Whole plant	Grind together, mix with oil and message on the body
Piles	Mongma ja·pa	*Amorphophallus sp.*	Araceae	Underground corus	Grind it together and taken orally
Pneumonia	Jengjil	*Schefflera venulosa*	Araliaceae	Bark, leaves	Boil in water and taken orally
Psoriasis	Tungkut	*Leucas aspera*	Lamiaceae	Whole plant	Grind it and and taken orally with water
Rheumatism	Te·brong	*Artocarpus heterophyllus*	Moraceae	Fruits, leaves and latex	Grind it together and taken orally
	Rani rikgitok balgito	*Rhynchostylis retusa*	Orchidaceae	Leaves and roots	Grind it together and taken orally
Scurvy	Jakritchu	*Cissus quadranggularis*	Vvitaceae	Root and juice	Grind it and taken orally
	Me·mang kakji	*Citrus medica*	Rutaceae	Roots and juice	Grind it and taken orally

(continued)

Table 5 (continued)

Name of diseases	Local name of M.P	Botanical name of M.P	Family name of M.P	Part used	Mode of preparation and application
	Kakji	*Citrus lemon*	Rutaceae	Fruits	Grind it and taken orally
Sedative	Pesinprut	*Passiflora edullis*	Passifloraceae	Leaves and fruits	Grind it to paste and apply it on the infected area
	Do·grikme	*Rauvolfia serpentina*	Apocynaceae	Roots	Grind it to paste and apply it on the infected area
	Samte dal·gipa	*Xanthium strumarium*	Asteraceae	Whole plant buds	Grind it to paste and apply it on the infected area
Small fox	Du·mandal	*Tinospora cordifolia*	Menispermaceae	Whole plant	Boil in water and bath
Snake bite	Me·kri do·nok	*Polygonum capitatum*	Polygonaceae	Whole plant	Grind it and bandaged on the infected area
	Gambilori	*Momordica foetida*	Cucurbitaceae	Roots	Grind it and taken orally
	Samsko gitchak	*Clerodendrum viscosum*	Verbinaceae	Leaves and roots	Grind it to paste and bandage
Sprain and fracture	Lantana	*Lantana camara*	Verbenaceae	Leaves and roots	Grinded to paste and bandaged
	Wire samsi	*Eleusin indica*	Poaceae	Whole plant	Grind to paste and bandage
Stimulant	Gongmintri	*Homalomena aromatica*	Araceae	Rhizome	Grind it and apply it on the infected area
Stomachache	Sambang guri	*Eupatorium odoratum*	Asteraceae	Leaves	Grind it and taken orally
	Nepali pang	*Artemesia nilagirica*	Asteraceae	Leaves	Grind it and taken orally
	Alot rimit	*Phlogacanthus thyrsiformis*	Acanthaceae	Leaves	Grind it and taken orally

(continued)

Table 5 (continued)

Name of diseases	Local name of M.P	Botanical name of M.P	Family name of M.P	Part used	Mode of preparation and application
Strangury	Gakpok	*Physallis minima*	Solanaceae	Whole plant	Grind together and apply it on the infected area
Thyroid gland	Samte dal·gipa	*Xanthium strumarium*	Asteraceae	Whole plant	Grind together and mix with black salt and taken orally
Tonic	Gonda mande	*Panax pseudoginseng*	Araliaceae	Roots	Grind it and taken orally with water
	Susanat/sarat	*Asplenium esculentum*	Aspleniaceae	Leaves	Grind it and taken orally with water
	Gasampe/do·ju	*Baccaurea ramiflora*	Phyllanthaceae	Fruit	Fruits are eaten directly
	Agol	*Aquilqria agallocha*	Malvaceae		Grind it together and taken orally
	Neergundu	*Vitex negundo*	Fabaceae	Roots, bark, leaves, fruits	Grind it together and taken orally
Tooth ache	Sam rimit/ wagam sam	*Spilanthes acmella*	Asteraceae	Flower	Grind it to paste and apply it on the tooth or decay
	Sojona	*Moringa oliefera*	Moringaceae	Leaves, barks and roots	Grind it to paste and apply it on the tooth or decay
	Eching burung	*Zingiber zerumbet*	Zingiberaceae	Rhizome	Grind it to paste and apply it on the tooth or decay
Tuberculosis	Jingjot/ matgonggong	*Typhonium trilobatum*	Araceae	Leaves, root, tuber	Grind it and taken orally
	Diki re·koksi	*Eleutherine palmifolia*	Iridaceae	Bulb	Grind it and taken orally

(continued)

Table 5 (continued)

Name of diseases	Local name of M.P	Botanical name of M.P	Family name of M.P	Part used	Mode of preparation and application
	Chi·rota	*Swertia chirayita*	Gentianaceae	Whole plant	Grind it and taken with water
	Wool bibal samsi	*Celosia argensia*	Amaranthaceae	Whole plant	Grind it and taken with water
Tumor	Landu	*Cajanus cajan*	Fabaceae	Leaves and seeds	Grind together and apply it on the infected area
	Rasin gipok	*Allium sativum*	Amaryllidaceae	Bulbs	Grind it and apply it on the infected area
	Kangkil	*Ziziphus jujuba*	Rhamnaceae	Roots, leaves, bark and seeds	Grind together and apply it on the infected area
Typhoid	Anaros	*Ananas comosus*	Bromeliaceae	Fruits	Extract juice and taken orally
	Kalmek	*Andrographis paniculata*	Acanthaceae	Leaves and stem	Grind it together and taken orally
Ulcer	Rasin biret	*Allium chinence*	Amaryllidaceae	Whole plant	Grind it and taken orally
	Me·rimil gitchak	*Basella alba*	Basellaceae	Roots and leaves	Grind it and taken orally
	Mendu	*Cajanus cajan*	Fabaceae	Leaves and seeds	Grind it and taken orally
	Komchit	*Celosia argentia*	Amaranthaceae	Whole plant	Grind it together and taken orally
	Sunflower	*Helianthus annus*	Asteraceae	Leaves, flower and seeds	Grind it together and taken orally
	Matcha duri/jamaldo	*Houttuynia cordata*	Saururaceae	Leaves	Grind it together and taken orally

(continued)

Table 5 (continued)

Name of diseases	Local name of M.P	Botanical name of M.P	Family name of M.P	Part used	Mode of preparation and application
	Kilkra	*Boehemeria nivea*	Urticaceae	Leaves	Grind it and taken orally
	Ta·bolchu	*Manihot esculenta*	Euphorbiaceae	Tuber poultise	Grind it and taken orally
	Mesguri (noni)	*Morinda citrifolia*	Rubiaceae	Leaves, roots and fruits	Grind it together and taken orally
	Akon	*Calotropis gigantea*	Apocynaceae	Leaves, roots, bark and buds	Grind it together and taken orally
	Jasmine	*Jasminum sambac*	Oleaceae	Leaves, flowers and fruits	Grind it together and taken orally
Vermicide	Dadimildang	*Cassia alata*	Fabaceae	Leaves	Grind it together and taken orally
	Gue	*Areca catechu*	Araceae	Seeds	Grind it together and taken orally
	Mula	*Raphanus sativas*	Brassicaceae	Root, seeds and leaves	Grind it together and taken orally
	Jambura	*Citrus maxima*	Rutaceae	Fruits and juice	Extract juice and taken orally
Vomiting	Chimandal Gitchak	*Jatropa gossypifolia*	Euphorbiaceae	Bark, leave, seed	Grind it and taken orally
	Nolsing/Curry leaf	*Murraya koenegii*	Rutaceae	Leaves	Grind it and taken orally
Weakness during conceivation	Sarat	*Diplazium esculentum*	Athyriaceae	Leaves	Grind it and and taken orally with water

Table 6 Medicinal plants used for treatment of ailment in Rongram Development Block

Name of diseases	Local name of m.p	Botanical name of m.p	Family name of m.p	Part used	Mode of preparation and application
Abortion	Chimandal gipok	*Jathropa curcas*	Euphorbiaceae	Stem	Grind and juice is taken orally
	Jakriting	*Gloriosa superba*	Colchicaceae	Leaves and stem	Grind together and juice is taken orally
Aczema	Prap	*Ficus bengalensis*	Moraceae	Leaves	Grind it and apply it
	Dadimildang/ dadupatta	*Cassia alata*	Fabaceae	Leaves	Grind it and apply it
	Chimandal gitchak	*Jathropa gossypifolia*	Euphorbiaceae	Barks, leaves and seeds	Grind it and taken orally
Allergy	Me·puri	*Basella alba*	Basellaceae	Roots, leaves	Grind to paste and apply it
Anaemia	Brokoli	*Brassica oleracea*	Brassicaceae	Flower	Grind and juice is taken orally
Antidote for poisoning	Dikge meseng	*Curcuma slecies*	Zingiberaceae	Leaves	Grind and paste on the infected area
Antihelmintic	Sa·ra samsi	*Cyperus rotundus*	Cyperaceae	Whole plant	Grind it and apply it
	Gue	*Areca catechu*	Arecaceae	Seeds	Grind it and taken orally
Antiseptic	Ripuji budu	*Mikania micrantha*	Asteraceae	Leaves	Grind and paste on the cut and wounds
	Nakap/genasi	*Dolicos lablab*	Fabaceae	Leaves and roots	Grind it and apply it
Astringent	Laham bol	*Letsia monopetala*	Lauraceae	Bark seeds	Grind and paste it
Boils	Wal·kam	*Bryophyllum pinnatum*	Crassulaceae	Leaves	Grind to paste and apply around the infected area

(continued)

Table 6 (continued)

Name of diseases	Local name of m.p	Botanical name of m.p	Family name of m.p	Part used	Mode of preparation and application
Bone fracture	Me·mang ta·matchi	*Asparagus racemosus*	Asparaceae	Roots	Grind and paste properly on the fracture area
	Asoka	*Saraca indica*	Caesalpiniaceae	Bark	Grind to paste and apply it
	Gimbil	*Careya arborea*	Sapindaceae	Bark	Grind to paste and apply it
	Do·ja gipi/ do·champek	*Justica gendarusa*	Acanthaceae	Leaves	Grinded to mix with oil and cover by the bandage
Burn	Ta·a	*Colocasia esculenta*	Araceae	Corms	Grind and paste on the infected area
	Stilchi	*Portulaca oleraceae*	Portulacaceae	Leaf and stem	Grind and paste on the infected area
Cancer	Matchipu bol	*Croton tiglium*	Euphorbaceae	Bark seeds	Boil and juice is taken orally
Carminative	Matcha pan/ asira	*Piper longum*	Piperaceae	Leaves	Grind to paste and apply it
	Dike simil	*Curcuma aromatica*	Zingiberaceae	Rhizome	Grind to paste and apply it
	Agun julai	*Plumbago indica*	Plumbaginaceae	Roots and leaves	Grind together paste and apply it
Chicken pox	Do·grikme	*Rauvolfia serpentina*	Apocynaceae	Roots	Boil and juice is taken orally
Cholera	Chi·rota	*Swertia chirayita*	Gentianaceae	Whole plant	Grind and taken orally
	Manimuni	*Centella asiatica*	Apiaceae	Leaves	Grind and taken orally

(continued)

Table 6 (continued)

Name of diseases	Local name of m.p	Botanical name of m.p	Family name of m.p	Part used	Mode of preparation and application
	Molmi	*Mucuna poggei*	Papilionaceae	Seeds	Grind and taken orally
Cold and cough	Me·kri do·nok	*Polygonum capitatum*	Polygonaceae	Whole plant	Boil with water and taken orally
	Ja·lik meseki	*Capsicum frutescens*	Solanaceae	Fruits	Grind it and taken orally
	Tumkut	*Leucas aspera*	Lamiaceae	Whole plant	Grind it and taken orally
Contraceptive	Ta·jong	*Alata deoscorean*	Dioscoreaceae	Yam	Grind and taken orally
	Ta·tilak	*Dioscorea bulbbifera*	Dioscoreaceae	Tuber	Grind and taken orally
Cut and wounds	Chimandal	*Jathropa curcas*	Euphorbiaceae	Oil of seed	Grind to paste and apply it on the cut and wounds
	Kakku	*Malastoma malabathricum*	Melastomataceae	Leaves	Grind to paste and apply it on the cut and wounds
Dandruff	Do·dim	*Glysine max*	Fabaceae	Barks, leaves and seeds fruits	Grind it and apply it
	Gila budu/ sui	*Entada scandens*	Leguminaceae	Seeds	Grind to paste and apply it
Diabetes	Agatchi	*Dillenia pentagyna*	Dillenniaceae	Bark, fruit, leaves	Boil together and taken orally
Diphthera	Du·rimit	*Cuscuta reflexa*	Convolvulaceae	Leaves	Grind it and apply it
	Me·rakku	*Zea mays*	Poaceae	Leaves	Grind it and taken orally
Dropsy	Denggasak baringrong	*Amarauthus cruntus*	Amaranthaceae	Leave, steam	Grind it and apply it
	Kektas	*Euphorbia antiquorcum*	Euphorbiaceae	Bark, stem and latin	Grind it and apply it

(continued)

Table 6 (continued)

Name of diseases	Local name of m.p	Botanical name of m.p	Family name of m.p	Part used	Mode of preparation and application
Dysentery	Chirore	*Terminalia chebula*	Combretaceae	Bark and leaves	Boil together and taken orally
	Sokchon	*Alstonia scholaris*	Apocynaceae	Whole plant	Grind and boil in water. Taken orally for 1 or 2 cup
Evil influence	Dike chisik	*Catharantus roseus*	Apocynaceae	Root and leaves	Grind together and paste on the forehead
Eye disease	Jasmine	*Jasminum sambac*	Oleaceae	Leaves, flowers andleaves	Grind it and apply it
	Datura	*Datura innoxia*	Solanaceae	Leaves	Grind it and apply it
	Grit	*Saccharum officinarum*	Poaceae	Culms	Grind it and apply it
	Akasia	*Acacia auriculiformis*	Fabaceae	Roots and bark	Grind it and apply it
	Sojona	*Moringa oleifera*	Moringaceae	Leaves, bark and roots	Grinded together to extract a juice and used as an eye drop
	Chenong	*Morinda angustipolia*	Rubiaceae	Root, barks and leaves	Grinded together to extract a juice and used as an eye drop
Eye infection	Akasia	*Acacia auriculiformis*	Fabaceae	Roots and bark	Extract a juice from root and bark is used as an eye drop
	Grit	*Saccharum officinarum*	Poaceae	Culms	Extract juice and used as an eye drop
Fever	Manimuni	*Centella asiatica*	Apiaceae	Leaves	Boil and taken orally

(continued)

Table 6 (continued)

Name of diseases	Local name of m.p	Botanical name of m.p	Family name of m.p	Part used	Mode of preparation and application
	Nolsing/curry pata	*Murrya koenegii*	Rutaceae	Leaves with honey	Grind it and mix with honey
	Kakji	*Citrus lemon*	Rutaceae	Fruits	Grind to extract a juice and is taken orally
Gastric	Do·grikme	*Rauvolfia serpentina*	Apocynaceae	Whole plant	Grind together and taken orally
	Rani rikgitok balgito	*Rhynchostylis retusa*	Orchidaceae	Leaves, flower and seeds	Grinded to mixed with water and taken orally
Gonorrhea	Rikoksi	*Curculigo capitulata*	Hypoxidaceae	Rhizome	Grind to extract a juice and is taken orally
Gout	Du·giteng	*Tinospora crispa*	Menispermaceae	Leaves	Grind it and apply it
	Kektas	*Euphorbia antiquorum*	Euphorbiaceae	Bark, stem and latex	Grind it and apply it
Head ache	Me'katchi	*Corhcorus capsularis*	Malbaceae	Leaves	Grind to paste and apply it
	Golap	*Rosa sp.*	Rosaceae	Roots	Grind to paste and apply on the forhead
	Bolchu	*Bombax malabaricum*	Bombacaceae	Bark	Grind to paste and apply on the forehead
Heart diseases	Te·mit	*Cucumis sativa*	Cucurbitaceae	Fruits	To make a seven pieces and to soak for 1 h, then water is taken orally

(continued)

Table 6 (continued)

Name of diseases	Local name of m.p	Botanical name of m.p	Family name of m.p	Part used	Mode of preparation and application
	Dorai	*Abelmoscus esculentas*	Malbaceae	Fruits and seeds	To make a seven pieces and to soak for 1 h, then water is taken orally
Hemorrhoids	Jakriting	*Gloriosa superba*	Colchicaceae	Tuber	Grind and juice is taken orally
Hiccup	Balsam	*Impatiens balsamina*	Balsaminaceae	Flower and leaves	Grind together and juice is taken
High cholesterol	Narikel	*Cocos nusifera*	Arecaceae	Fruit water	Fruits water is taken orally
Indigestion	Gongginjak	*Diplazium esculentum*	Athyriaceae	Leaves	Boil and juice is taken orally
	Te·rik re·bok	*Musa balbisiana*	Musaceae	Fruits	Boil and taken orally
	Ree	*Calamus erectus*	Arecaceae	Stem and seeds	Boil together and taken orally
	Me·mang kakji	*Citrus medica*	Rutaceae	Fruits	Extract a juice and mix with honey
	Elatchi	*Elettaria cardamomum*	Zingiberaceae	Seeds	Grind it and taken orally
	Modipol	*Carica papaya*	Caricaceae	Fruits	Grind it and taken orally
	Selpri	*Aegele marmelos*	Rutaceae	Roots, leaves and fruits	Grind it and taken orally
	E·ching	*Zingiber officinale*	Zingiberaceae	Rhizome	Grind it and taken orally
	Rasin gipok	*Allium sativum*	Amaryllidaceae	Bulb	Grind it and taken orally
	Mongma ja·pa	*Amorphophallus companulatus*	Araceae	Corms	Grind it and taken orally
Insect bite	Duhindol	*Alocasia macrorrhiza*	Araceae	Stem	Grind to paste and apply it

(continued)

Table 6 (continued)

Name of diseases	Local name of m.p	Botanical name of m.p	Family name of m.p	Part used	Mode of preparation and application
	Gambilori	*Momordica foetida*	Cucurbitaceae	Roots	Grind to paste and apply it
	Kektas bijak dalgipa	*Maehlenbeckia platryclados*	Polygonaceae	Leaves and stem	Grind to paste and apply on the infected area
Jaundice	Grit	*Saccharum officinarum*	Poaceae		Extract a juice and taken orally
	Mendu	*Cajanus cajan*	Fabaceae	Leaves, seeds	Grind together and taken orally
	Ambari raja	*Phylanthus acidus*	Euphobiaceae	Fruits, leaves	Grind together and taken orally
	Buga salgro	*Stephania hemandifolia*	Menispermaceae	Younger leaves	Grinded to mixed with water and taken orally
Kidney stone	Te·mit	*Cucumis sativa*	Cucurbitaceae	Fruits	Grind it and taken orally
	Wal·kam	*Bryophylum pinnatum*	Crassulaceae	Leaves	Grind it and taken orally
Leprosy	Agunjolai	*Plumbago indica*	Plumbaginaceae	Roots and leaves	Grind it and apply it
Malaria	Gominda	*Cucurvita maxima*	Cucurbitaceae	Fruits, seeds	Boil and taken orally
	Sambesual dal·gipa	*Artimisia indica*	Asteraceae	Whole plant	Grind together and juice is taken orally
Masticatory	Wakpatra	*Kaemferia galanga*	Zingiberaceae	Leave and tuber	Grind to extract a juice and is taken orally
Measles	Raja ambare	*Phyllanthus acidus*	Phyllanthaceae	Flower and leaves	Fruit is eaten directly
Menstrual disorder	Makkalibak	*Mucuna pruriens*	Papilionaceae	Roots and pods	Boil and juice is taken orally

(continued)

Table 6 (continued)

Name of diseases	Local name of m.p	Botanical name of m.p	Family name of m.p	Part used	Mode of preparation and application
	Modipul	*Carica papaya*	Caricaceae	Root, leaves, flower and fruits	Boil and juice is taken orally
	Begonia	*Rex begonia*	Begoniaceae	Leaves and stem	Grind together and juice is taken
Migraine	Kopi	*Coffee arabica*	Rubiaceae	Ripen fruits	Grind it and taken orally
Mumps	Lantana	*Lantana camara*	Verbenaceae	Leaves and roots	Grind it and apply it
	Ta·gong pul	*Caladium bicolour*	Araceae	Roots and tubers	Grind it and apply it
Nose bleeding	Ruat tip	*Helminthostashys zeylanica*	Ophioglossaceae	Leaves	Grind properly and block in to the nose
Piles	Chandili burung (bu·su gnanggipa)	*Amaranthus spinosus*	Amaranthaceae	Whole plant	Grinded to mixed with water and taken orally
	Mongma ja·pa	*Amorphophallius sp.*	Araceae	Underground corus	Grinded to mixed with water and taken orally
Pneumonia	Jengjil	*Schefflera venulosa*	Araliaceae	Bark, leaves	Boil and juice is taken orally
Psoriasis	Tungkut	*Leucas aspera*	Lamiaceae	Whole plant	Grind together and apply in the infected area
Sedative	Samte dal·gipa	*Xanthium strumarium*	Asteraceae	Whole plant	Grind it and apply it
	Pesinprut	*Passiflora edullis*	Passifloraceae	Root, leaves	Grind it and taken orally
	Do·grikme	*Rauvolfia serpentina*	Apocynaceae	Seeds, roots	Grind it and taken orally
Skin diseases	Ambari segun	*Phyllanthus officinalis*	Phyllanthaceae	Bark, fruit,	Grind together and apply on the infected area

(continued)

Table 6 (continued)

Name of diseases	Local name of m.p	Botanical name of m.p	Family name of m.p	Part used	Mode of preparation and application
Small pox	Du·mandal	*Tinospora cordifolia*	Menispermaceae	Whole plant	Boil and juice is taken orally
Snake bite	Gambilori	*Momordica foetida*	Cucurbitaceae	Roots	Grind to paste and apply it
	Duhindol	*Alocasia macrorrhiza*	Araceae	Stem	Grind to paste and apply it
Sprain	Lantana	*Lantana camara*	Verbenaceae	Leaves andstem	Grind to paste and apply on the infected area
	Wire samsi	*Eleusin indica*	Poaceae	Roots and pods	Grind to paste and apply on the infected area
Stomachache	Nepali pang	*Artemesia nilagirica*	Asteraceae	Leaves	Grind to mix with water and taken orally
	Sambang guri	*Eupatorium odoratum*	Asteraceae	Root, leaves, flower and fruits	Grind together and juice is taken orally
Strangury	Gakpok	*Physallis minima*	Solanaceae	Whole plant	Grind together and apply in the infected area
Tonic	Kadam bol	*Anthocephalus cadamba*	Bixaceae	Roots	Boil and juice is taken orally
	Sam besual chongipa	*Artimisia annua*	Asteraceae	Whole plant	Grind it and taken orally
	Gasampe/ do·ju	*Baccaurea ramiflora*	Phyllanthaceae	Fruit	Grind it and taken orally
	Agol	*Aquilaria agallocha*	Malvaceae	Bark and wood	Grind it and taken orally
	Neergundu	*Vitex negundo*	Fabaceae	Roots, bark, leaves, fruits	Grind it and taken orally
	Do·ka rasin	*Crinum asiaticum*	Amaryllidaceae	Bulb	Grind it and taken orally

(continued)

Table 6 (continued)

Name of diseases	Local name of m.p	Botanical name of m.p	Family name of m.p	Part used	Mode of preparation and application
	Gonda mande	*Panax pseudoginseng*	Araliaceae	Roots	Grind it and taken orally
	Susanat/sarat	*Asplenium esculentum*	Aspleniaceae	Leaves	Grind it and taken orally
	Sokchon	*Alstonia scholaris*	Apocynaceae	Barks, latex and leaves	Grind it and taken orally
	Do·dike/ledis slipper rokomsa	*Kaempferia laotica*	Zingiberaceae	Rhizome	Grind it and taken orally
	Sojona	*Moringa oliefera*	Moringaceae	Leaves, barks and roots	Grind it and taken orally
Tooth ache	Sam rimit/ wagam sam	*Spilanthes acmella*	Asteraceae	Flower	Crushed inflorescence is put into aching tooth
	Sojona	*Moringa oliefera*	Moringaceae	Leaves, barks and roots	Crushed inflorescence is put into aching tooth
	Eching burung	*Zingiber zerumbet*	Zingiberaceae	Rhizome	Crushed inflorescence is put into aching tooth
	Kakji	*Citrus lemon*	Rutaceae	Fruits	Extract a juice and put into aching tooth with cotton
Tuberculosis	Wool bibal samsi	*Celosia argensia*	Amaranthaceae	Whole plant	Boil and juice is taken orally
	Chi·rota	*Swertia chirayita*	Gentianaceae	Whole plant	Grind and taken orally
	Jingjot/ matgonggong	*Typhonium trilobatum*	Araceae	Leaves, root, tuber	Grind it and taken orally
	Chi·rota	*Swertia chirayita*	Gentianaceae	Whole plant	Grind together and taken orally
Tumor	Kangkil	*Ziziphus jujuba*	Rhamnaceae	Fruits	Boil and juice is taken orally

(continued)

Table 6 (continued)

Name of diseases	Local name of m.p	Botanical name of m.p	Family name of m.p	Part used	Mode of preparation and application
	Landu	*Cajanus cajan*	Fabaceae	Roots	Grind together and juice is taken orally
	Rasin gipok	*Allium sativum*	Amaryllidaceae	Fruits and seeds	Grind together and juice is taken orally
Typhoid	Kalmek	*Andrographis paniculata*	Acanthaceae	Leaves and stem	Grind together and taken orally
Ulcer	Matcha duri/ jamaldo	*Houttuynia cordata*	Saururaceae	Leaves	Grind it and taken orally
	Komchit	*Celosia argentia*	Amaranthaceae	Whole plant	Grind together and taken orally
	Sunflower	*Helianthus annus*	Asteraceae	Leaves, flower and seeds	
Urinal infection	Ararut	*Maranta arudenceae*	Marantaceae	Whole plant	Grind together and taken orally
	Tusidmu	*Mimosa pudica*	Fabaceae	Leaves, flower and seeds	Grind together and taken orally
Weakness during conceivation	Sarat	*Diplazium esculentum*	Athyriaceae	Leaves	Grind to extract a juice and is taken orally

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The Role of Traditional Knowledge of Himalayan Nettle in Mitigating the Climate Crisis with Special Reference to Textile Production

Deepti Pargai

Abstract Climate crisis is one of the major problems of this era and Himalayan region is one of the most susceptible regions to it. It is the need of the hour to address this problem by looking into some traditional knowledge. The Himalayan nettle (*Girardinia diversifolia*) is a perennial plant found in the Himalayan region. The nettle plant has many environmental benefits, including its ability to grow in poor soil conditions, its low water requirement, and its ability to sequester carbon dioxide from the atmosphere. This plant does not require any pesticide and herbicide to flourish. Traditional use of Himalayan nettle in textiles has been around for centuries, with the nettle fiber being used to create durable and versatile clothing and household items. However, the use of nettle plant fibers in contemporary textile design has recently gained popularity due to its sustainable and eco-friendly qualities. Cotton fibers plays a major role in textile but its cultivation requires lots of pesticides, herbicides as well as water. If proper machinery will be used nettle plant fibre has potential to replace the cotton fiber. The utilisation of Himalayan nettle in textiles can mitigate environmental problems by reducing reliance on synthetic materials, sequestering carbon dioxide, and supporting local communities by providing economic opportunities in as sustainable way. Traditional knowledge can guide sustainable practices in fiber production, such as promoting organic cultivation methods, avoiding chemical inputs, and utilizing natural dyes. By adopting sustainable fiber production processes, the textile industry can reduce its environmental impact and contribute to climate change mitigation.

Keywords Himalayan Nettle · *Girardinia Diversifolia* · Sustainable development · Climate change · Textile

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1 Introduction

The Himalayan nettle (*Girardinia diversifolia*) is a plant species that is native to the Himalayan region. It is known for its versatile uses in different application particularly in the production of textile fibres (Sharan Shrestha et al., 2020). There are several nettle species in the *Urticaceae* that produces fiber, Himalayan nettle (*Girardinia Diversifolia)* is one of them. It is true that the Himalayan nettle plant possesses some traits that may enable it to endure climatic difficulties of the earth. But it is crucial to remember that no species of plant is immune to the consequences of the climate crisis. Rising temperatures, shifting precipitation patterns, and an increase in the frequency of extreme weather events are just a few of the problems that the climate crisis involves (United States Environmental Protection Agency (USEPA), 2022). Although climate crisis would have significant influence on Himalayan Nettle as on others plants. But the Himalayan nettle plant has several adaptations abilities that make it robust. These adaptation abilities include its capacity to flourish in a diverse environment and have capacity to endure temperature changes.

Along with changing temperatures, climate change also has an impact on elements like water availability, which are essential for plant species to develop and survive. Several plant species are susceptible to negative impacts from changes in precipitation patterns, including droughts or extreme rains (Anjum et al., 2021). It has been reported that nettle plant requires less water as compare to other commercial crop such as cotton. Nettle is a perennial crop. Fertiliser or pesticides are not required to cultivate nettle plant (Clothing from Himalayan Nettle Fibre, Fibres & Yarns, 2019). It may even be grown on polluted or otherwise inappropriate terrain. Because of this, it may be cultivated in places where other crops might not do well, making it a sustainable crop. Furthermore, the Himalayan nettle and its ecological function may be preserved through supporting biodiversity protection and sustainable agricultural methods. The chances of the survival of Himalayan nettle plant can be increased by preserving its natural environment, encouraging ethical harvesting, and aiding regional communities engaged in its production.

While the Himalayan nettle itself lacks the capacity to directly maintain the equilibrium between the environment and development. But the cultivation and use of nettle plant have some favourable effects on both. It is possible to contribute to the preservation of the Himalayan nettle's native environment by encouraging its sustainable cultivation and harvesting. It helps to keep biodiversity alive by protecting ecosystems. Himalayan nettle helps to slow down climate change by absorbing carbon dioxide while it grows as a plant.

Since the Himalayan nettle's deep roots anchor the soil and lessen the likelihood of landslides, its cultivation can aid in preventing soil erosion and degradation. Even textile product of nettle plant i.e. nettle fibers can be used as geotextile for protecting the landslide (Kumar & Das, 2018). Due of the strength of its fibres, which may be used to create fabrics, ropes, and handicrafts (Nettle Fabric Craft, 2018; Pargai & Gahlot, 2020a; Sett et al., 2014). Himalayan nettle has a marketable application.

Therefore, in addition to the benefits it has for the environment, encouraging its cultivation can open up chances for local people to generate cash, aiding in the socioeconomic growth of such areas. the growth of environmentally friendly enterprises in the Himalayan area. Himalayan nettle can promote environmentally beneficial practises such organic cultivation, ethical harvesting, and product enhancement. This might encourage ecologically friendly business practises and boost the local economy. This chapter provides an overview of nettles, with a focus on the Himalayan Nettle. This chapter analyses how traditional knowledge and recent research studies can be helpful to utilisation on this plant to mitigate the current climate crisis. The chapter not only gives a brief on benefits but also discuss the challenges with solution-oriented approach.

2 Overview of Nettle Plant

2.1 General Description and Its Varieties

Nettle plants are found in various regions around the world. These plants belong to genus *Urtica*. Nettle species can vary in appearance and habitat, but they generally share the characteristic of stinging hairs on their leaves and stems. Frank reported that there are approximately 500 members of the *Urticaceae* family distributed worldwide. Plants in this family belonging to the *Girardinia*, *Boehmeria*, *Laportea* and *Urtica* genera. These plants are are well known for their fiber yielding properties. In Europe, most familiar species is *Urtica*, particularly *Urtica dioica*, although in Russia and Siberia *Urtica cannabina* has long been used as a source of fiber which is sometimes referred to as Swedish Hemp (Franck, 2005a). Cook reported Nettles are plants of the family *Urticaceae* of the 30 odds species found in temperate climate. Among these, three plant species are commonly used as a source of fiber i.e. *Urtica dioica*, *Urtica urens* and *Urtica pilulifera. U. dioica* is a perennial while *Urtica Urens and Urtica Pilulifera* are annuals (Cook, 2005). Nettles may be found in many varieties across the world, including common nettles, dwarf nettles, roman nettles, Australian nettles, and Himalayan nettles etc. (Australian Nettle, 2020; Dwarf Nettle, 2023; Lodwick, 2014; Nettle & Divesifolia, 2023; Petruzello, 2023). The most common kind of nettle is the common nettle (*Urtica dioica*), which may be found in North America, Europe, Asia, and North Africa (Petruzello, 2023). It is frequently seen as a weed because of the stinging hairs on its leaves and stems. Additionally, it is being used in herbal treatments. Common nettle is also utilised in cooking. Dwarf nettle (*Urtica Urens*), is a species that is smaller than common nettle. It is known as dwarf nettle for its size It may be found throughout North America, Europe, and Asia. Like other nettles, it has stinging hairs. The species of Roman Nettle (*Urtica Pilulifera*) is indigenous to the Mediterranean and portions of Asia It is also known as Pill-bearing Nettle as it produces a small round structure that contain plant seeds. round structures it produces that contain the plant's seeds and with stinging hairs and serrated edges (Lodwick, 2014). Rainforests and wet sclerophyll forests are two examples of damp environments where Australian Nettle is generally found. It is also referred to as Himalayan nettle in certain literature because it grows in the Himalayan area at high altitudes. It is well renowned for its strong fibres, which are used to make textiles, and has broad, ovate leaves. Wood Nettle (*Laportea canadensis*) found in Canada region (Jakarta Post, 2020). *Urtica Parviflora* is a smooth leave nettle found in Himalayan regions of India (Flowers of India, 2023). *Girardinia diversifolia* also found in Himalaya region and has been used to extract textile fibres.

It is important to note that not all plants called "nettles" are part of the same taxonomical family. For example, hemp nettle, flame nettle (*Coleus*), hedge nettle (*Stachys*), dead nettle (*Lamfum*) have similar appearance to nettle but belongs to the mint family. Similarly, Ball nettle (*Solanum carolinense*) and Horse nettle (*Agastache urticifolia, Solanum carolinense, Solanum dimidiatum, Solanum elaeagnifolium, Solanum rostratum*) resembles like a nettle in appearance but part of the nightshade family. Spurge nettle (*Cnidoscolus stimulosus*) resembles a nettle in appearance but it is part of the spurge family. False nettle (Boehmeria) is a type of nettle that does not have stinging hairs (Canadian Encyclopaedia, 2023; NCSU Education, 2023; PSU Education, 2021).

Nettles have undoubtedly been used for fibre in Europe, although primarily for handicrafts and occasionally in conjunction with other. From the twelfth century to the seventeenth century, when silk took its place, nettle thread was utilised in Poland. Regrettably, the nettle fibre textile business was shut down due to technical and financial concerns (Bodros & Baley, 2008). Germans produced 85% of their clothing from nettle during World War II, including socks, undershirts, and tents (Krishnan & Karthick, 2012). The long tradition of removing fiber from this plant and using it for textiles has continued up to the present however fiber properties from different species can be varied. Each of these plants have its own distinctive geography and culture (Franck, 2005b).

*2.2 Himalayan Nettle (*Girardinia Diversifolia*)*

The Himalayan nettle (*Girardinia diversifolia*) is a perennial plant found in the Himalayan region. The Himalayan nettle is indeed a species of nettle that is found in the Himalayan region, particularly in Nepal and in the Himalayan parts of India such as Uttarakhand, Himachal Pradesh, and Jammu and Kashmir, and in vast parts of China. *Girardinia diversifolia* plant flourishes in the sub-tropical and temperate Himalayas from Kashmir to Sikkim up to 2100 m, in Assam, and in the Khasia hills; Burma, Java, and China; and from Marwar and central India to Travancore and Ceylon. In Nepal, it has been reported from district of Dolkha, Kalikot, Jumla, Mugu, Parbat, Sallyan, Surkkhet, Iiam, Rasuwa, Kathmandu etc. (Singh & Shrestha, 1988). The Himalayan Giant Nettle, *Girardinia diversifolia* which belongs to the family Urticaceae, is locally known as Allo in the eastern and central regions of Nepal, and Puwa in the western part of Nepal (Friis, 1981). There are several vernaculars to name it: *Bhangre Sisnu, Lekhko Sisnu*, *Thulo Sisnu, Potale, Nagai* etc. (Gurung, 1988). It grows naturally at elevations between 1200 to 3000 m (3900 to 9800 feet) (Sphere, 2020). *Girardinia diversifolia* grows abundantly without cultivation in the hilly and mountainous regions of Nepal. It is a shade-tolerant, tall, stout, and erect herb growing up to 3 m in height with a perennial rootstock. Botanical parameter of *Girardinia diversifolia is as follows:*

Kingdom: *Plantae,* ***Order:*** *Rosales,* ***Family****: Urticaceae,* ***Genus:*** *Girardinia* **Clade:** Tracheophytes, angiosperms, Eudicots ***Synonymous****: G. Heterrophylla, G. palmata and Urtica* heterophylla. **Common names:** Himalayan nettle, Nilghiri nettle, Rosids (PFAF, 2023; Textile Sphere., 2020).

It occurs abundantly in the forests of hills in moist and damp soil. It is used as leafy vegetables for preparing snacks. The plant has been evaluated for its potential pharmaceutical, cosmetic, and nutraceutical uses. The plant is employed in traditional medicine for the treatment of several diseases. Recently, *Girardinia diversifolia* has become an important livelihood option for people living in the Himalayan region as it is a fiber-yielding plant. It is also known for its strong fibres, which are used for making high-quality textiles. The plant has large, heart-shaped leaves and can grow to be several meters tall. It is a shade-tolerant, tall, stout, and erect herb growing up to 3-m height with perennial rootstock. The plant grows as a clump, and each clump has many stems. The stem contains bast fiber of unique quality which is strong, smooth, and light. It has cultural, economic, medicinal, and traditional values to many ethnic groups in Nepal.

2.3 Commercial Value of Himalayan Nettle

Himalayan Nettle (*Girardinia diversifolia)* is not just a plant. It has economic, medicinal, environmental as well as social benefits. This shows that it has potential to attain all dimension of sustainable development. It is a fiber yielding non-timber forest product that can be used to make a variety of products, such as textiles, paper, and handicrafts (Pandey et al., 2020; Shah et al., 2017). As a Medicinal benefits, *Girardinia diversifolia* has been found to have potential as a candidate ingredient for pharmaceutical and nutraceutical applications. Phytochemical analysis and in vitro bioassays have shown that it has antioxidant, anti-inflammatory, and antimicrobial properties (Gunardi et al., 2023). Its cultivation and use can also help to preserve the biodiversity of the region as a social benefit. The Himalayan nettle value chain has been identified as an innovative livelihood strategy that can transform the lives of women of Himalayan region. It provides them with an opportunity to earn a sustainable income and improve their social status.

Nettle fibers are biodegradable they require little energy to produce. They are extracted from a renewable source. Nettle fiber can be as fine as cotton and they are far finer than flax (Krishanan & Karthick, 2012). The plant-based fibers are cellulosic in nature. The fibers are classified into hard and soft fibers categories according to availability in a particular part and also based on stiffness associated with it in the raw state. Stem fibers such as jute, flax, hemp and nettle are called soft fibers which can be utilised for fabric purpose. The cellulose content of *Girardinia* fibers range from 88.9 to 89.6% and lignin content of *girardinia* fibers range from 9.52 to 9.82 (Madan, 2000). One of the remarkable characteristics of Himalayan nettle fibers is their strength. The fibers have a high tensile strength, which makes them ideal for making sturdy textiles. (Protim et al., 2021) The resulting nettle textiles have a unique appearance and texture. They have a slightly coarse feel and a natural beige or off-white color. Nettle fabrics are known for their breathability, moisture-wicking properties, and ability to keep the body cool in hot climates. These characteristics make nettle textiles well-suited for warm weather clothing (Samanta et al., 2021).

The popularity of Himalayan nettle textiles has spread beyond the local communities, attracting attention from designers and sustainable fashion enthusiasts worldwide. The eco-friendly and sustainable nature of nettle fiber production aligns with the growing demand for environmentally conscious textiles. There are several fashion brands that use nettle fibers in their products. Sorazora Fashion Brand offers a line of organic Himalayan nettle fabrics that can be used for fashion apparel (Fashion, 2023). Weaver Studios is a sustainable fashion brand that uses nettle fibres in their clothing and accessories (Vasudev, 2015). Gesine Jost, a German designer uses nettle fibres and fabrics to create her sustainable fashion apparel (Preuss, 2017). Similarly, Knokkon is a Finnish company that produces sustainable textiles made from nettle fibers (Knokkon, 2020).

2.4 Traditional Knowledge of Himalayan Nettle in Climate Change Crisis

The use of Himalayan nettle in textiles can be traced back centuries in the Himalayan communities. In addition to its functional properties, the use of Himalayan nettle in textiles also has cultural significance for the Himalayan communities. Traditional knowledge of Himalayan nettle can indeed be helpful in mitigating the climate crisis. Nettle fiber extraction and textile production are often traditional practices passed down through generations. They provide a source of income and livelihood for many rural communities, particularly women who are actively involved in the processing and weaving of nettle textiles. Extraction of nettle fibers involves a labour-intensive process. According to Krishnan and Karthick (2012), the overall processing steps of nettle fiber are started from harvesting of nettle stalks. Retting, Breaking and scutching, Hackling, Spinning, Weaving (Nettle fabric), Dyeing and Finishing (Krishanan & Karthick, 2012; Viotti et al., 2022). Nettle are harvested between September and December (Franck, 2005). Nettle is a natural bast fiber and according to Kadolph (2006), bast fibers come from the stem of the plant near the outer edge (Kadolph, 2006). Bast fiber lie in bundles in the stem of the plant just under the outer covering or bark, they are sealed together by a substances pectins, waxes and gums to loosen the fibers so that they can be removed from the stalk, the pectin must be decomposed by a bacterial rotting process called retting. Retting process soften the outer bark. The outer bark is then stripped away, revealing the inner fibers. These fibers are then separated, cleaned and spun into yarn using traditional methods such as hand spinning on a spindle or using a spinning wheel (Sett et al., 2016). These yarns are then used to make various textile products, including clothing, bags etc. by using weaving and knitting techniques (The Print, 2023).

Nettle plants have also been traditionally used for their dyeing properties. Nettle plant dye has a long history in traditional dyeing practices, particularly in regions where nettle plants are abundant. Many artisans and textile enthusiasts continue to explore the use of nettle plant dye for its unique properties and connection to cultural heritage. The leaves, stems, and roots of the nettle plant can yield various shades of yellow and green, depending on the part of the plant used and the dyeing process employed (Dragon, 2023; Katumba, 2009; Rebeccadesno, 2023). These plants contain natural pigments, such as chlorophyll and flavonoids, which can be extracted and used as natural dyes (Repajić et al., 2021). The leaves or stems of the nettle plant can be harvested, processed, and used to dye textiles. Depending on the mordants (substances used to fix the dye) and dyeing techniques employed, nettle dyes can produce a range of colors, including yellows, greens, and earthy tones. It's important to note that the exact dyeing process and resulting colors can vary depending on factors such as the specific nettle species, part of the plant used, dye extraction methods, mordants, and dyeing techniques employed. Experimentation and expertise in natural dyeing are often required to achieve desired results.

Traditional knowledge of Himalayan nettle can contribute to climate crisis mitigation via several ways. The cultivation of Himalayan nettle promotes carbon sequestration as the plants absorb carbon dioxide from the atmosphere (Sadik, 2019). Increased cultivation and utilization of Himalayan nettle plant can help in reducing greenhouse gas emissions and combating climate change. Traditional communities in the Himalayan region have been using Himalayan nettle for centuries for making textiles and handicrafts (Down to Earth, 2023; Gurung et al., 2012). By supporting the preservation and revitalization of this traditional knowledge, sustainable livelihood opportunities can be created for local communities. This helps in reducing poverty and dependence on activities that contribute to environmental degradation. Himalayan nettle is an indigenous plant species that is well-adapted to the local environment. By promoting its cultivation and sustainable harvesting, traditional knowledge contributes to the preservation of biodiversity. This is crucial for maintaining healthy ecosystems and resilience in the face of climate change.

This will also reduce the dependence on synthetic materials. The use of Himalayan nettle fibers for textile production provides an eco-friendly alternative to synthetic materials. Synthetic textiles like polyester and nylon are derived from fossil fuels and have a significant carbon footprint. Cotton also a resource intensive by utilizing Himalayan nettle, traditional knowledge helps reduce reliance on these environmentally harmful materials. The cultivation of Himalayan nettle can contribute to soil conservation and restoration. The plant has a deep root system that helps prevent soil erosion, improves soil fertility, and enhances water retention. This is particularly important in mountainous regions where soil erosion is a significant challenge exacerbated by climate change. Indigenous communities in the Himalayan region have developed traditional land management practices that incorporate the cultivation of Himalayan nettle. These practices often involve agroforestry and sustainable farming techniques that promote biodiversity, soil health, and resilience to climate change. By recognizing and valuing traditional knowledge related to Himalayan nettle and integration of these practices into sustainable development strategies and climate change mitigation efforts. It is important to engage local communities, respect their rights and ensure equitable sharing of benefits to effectively harness the potential of traditional knowledge for addressing the climate crisis.

2.5 Research Studies on Himalayan Nettle Plant for Sustainable Textiles and Fashion

Nettle plant have always been a centre interest point of researches due to its unique and unexplored properties. Nettle fibres have been used as a sustainable alternative to conventional textiles. These fibres are known for their strength and durability. Various researches have been conducted on blending nettle fibres such as cotton, viscose wool or silk to enhance their properties (Lanzilao et al., 2016a; Samanta & et al., 2023; Samanta et al., 2021). Nettle fabrics have been used in clothing, accessories, and home textiles (Kartick et al., 2021; Nettle, 2023). Nettle fibre is a sustainable and eco-friendly alternative to synthetic fabrics. It is known for its excellent tensile properties due to the cellulose volume fraction, making it the most stable fibre in the natural fibres range. Nettle fibres are also porous, making them the most transparent of all other natural fibres, which allows for better breathability than flax or linen. Nettle is currently the subject of scientific interest and development in the European countries such as Austria, Germany, Finland and U.K. for producing natural fiber (Bisht et al., 2012). The nettle fibers become longer, finer, and stronger, and they are used to make handicraft products. Nettle blend creates a strong and durable fabric that is also breathable and hypoallergenic, making it an ideal choice for clothing and household items (Blog, 2019).

Nettle fiber has potential applications in textile production, including technical textiles. They have been used in the development of composites, reinforcing materials, and nonwoven fabrics. Nettle-based composites have been explored for their potential in automotive components, construction materials, and sporting goods as well as some acoustic applications (Abbès et al., 2022; Bogard et al., 2021; Mudoi et al., 2021; Periyasamy, 2023). Additionally, nettle fibres have been used as reinforcing materials for polymer composites due to their high cellulosic content, tenacity, and low density.

Nettle fabrics in pure or in blends exhibit good oil sorption properties (Thilagavathi & Praba Karan, 2019). Nonwoven fabric prepared with 100% nettle fibers exhibited good thermal conductivity (Koru et al., 2022). Fabric created with nettle fibers will keep warmth in well, but will also be breathable. A nettle fiber matrix, which is made up of hemicellulose, lignin, and pectin, becomes highly anisotropic.

While there is no direct mention of nettle fiber use in acoustic textiles, the properties of nettle fibre suggest that it could be a viable material for such applications. For example, the good oil sorption properties of nettle fabrics could translate to sound absorption properties Additionally, the thermal conductivity and anisotropic nature of nettle fibers could contribute to the acoustic properties of textiles made from this material (Agus Suryawan et al., 2020; Deepa et al., 2023; Raj et al., 2020). Further research is needed to determine the suitability of nettle fibre for acoustic textiles. It is reported by that weave variations can also enhance the UV protection property of the fabric but weave should be compact (Pargai & Gahlot, 2020b).

Studies have shown that nettle fabric dyed with natural dyes such as cutch and madder provide excellent UV protection properties (Pargai et al., 2015, 2016). This makes nettle fabric a promising material for UV protective textiles, which are in high demand due to the harmful effects of UV radiation on human health. Overall, the value addition of UV protection properties in nettle fiber is significant, as it makes nettle fabric a viable and sustainable alternative to synthetic fabrics for UV protective textiles (Pargai & Gahlot, 2020a).

Nettle fibers have been investigated for their potential in wound dressings and medical textiles. The antibacterial and anti-inflammatory properties of nettle have led to research into utilizing nettle fibers in healthcare settings and built-in fire-retardant properties (Ketema & Amare, 2020).

Nettle plant dye offers an eco-friendly alternative to synthetic dyes, as it is a renewable resource that can be grown and harvested sustainably. Using nettle plant dye helps reduce the environmental impact associated with synthetic dye production and disposal. Nettle plant dye can be combined with other natural dyes to create a broader spectrum of colors. For example, nettle can be blended with other plant-based dyes like indigo or madder to achieve a wider range of hues and shades.

2.6 Role of Himalayan Nettle in Achieving Sustainability in Himalayan Region with Special Reference to Textiles

As discussed earlier, Himalayan nettle holds significant potential in mitigating climate change problems, particularly in the context of textiles. Himalayan nettle plays a very important role in addressing climate change issues in the textile industry. It plays very diverse role such as carbon sequestration, reduced deforestation, biodiversity conservation, water conservation, soil improvement, promotes local flora and fauna, enhanced resilience, less resource-intensive thus lesser carbon footprint, organic production, Biodegradability, versatility, economic benefits, Local production, rural livelihoods and economic development, sustainable Fibre Production. Cultural values. Brief of each of these roles are being given below:

Himalayan nettle is a fast-growing plant that has a high carbon sequestration capacity. By planting and cultivating nettle crops, carbon dioxide (CO_2) from the atmosphere can be captured and stored in the plant biomass, thus reducing greenhouse gas emissions and mitigating climate change (Jeannin et al., 2020).

The textile industry is often associated with deforestation, as trees are cut down to produce fibers like cotton (Mongabay, 2022). By promoting the cultivation of Himalayan nettle, which is a sustainable alternative fiber source, the reliance on deforestation for textile production can be minimized. This helps in preserving forest ecosystems and their ability to absorb CO_2.

The cultivation of Himalayan nettle supports biodiversity conservation in the Himalayan region. By promoting the growth of this native plant species, it helps preserve the local ecosystem and protect endangered species that rely on it for habitat and food. Biodiversity conservation is crucial for maintaining ecological balance and resilience in the face of climate change (Cristina Colon UNICEF, 2020).

Compared to water-intensive crops like cotton, Himalayan nettle requires relatively less water for cultivation. By promoting nettle-based textiles, water resources can be conserved, reducing pressure on freshwater ecosystems. This is especially important in regions where water scarcity is a growing concern due to climate change (Virgilio et al., 2015).

Nettle is a nitrophilous herbaceous plant, which means it may improve soils overloaded with nitrates and phosphates. This can help to reduce the negative impact of agriculture on the environment (Britannica, 2023).

Nettle promotes local flora and fauna diversity. This is important because biodiversity loss is a major contributor to climate change (Kregiel et al., 1664).

Climate change poses various challenges to the textile industry, including disruptions in supply chains, changing weather patterns, and increased frequency of extreme events. By diversifying the fiber sources and incorporating Himalayan nettle into textile production, the industry can enhance its resilience by reducing dependence on climate-vulnerable crops and adapting to changing environmental conditions (Lampoon, 2022). Nettles require fewer resources to grow than other crops, such as cotton, and can even thrive in poor soil that's unsuitable for other crops. Nettle fibers can be produced organically, which reduces the use of synthetic fertilizers and pesticides and promotes biodiversity. Himalayan nettle fibers are long, strong, and durable, making them suitable for textile applications. These fibers can be used to produce a range of sustainable textiles, such as clothing, bags, and accessories. Compared to conventional textile fibers, Himalayan nettle fibers have a lower environmental footprint as they require fewer chemical inputs, water, and energy during processing (Viotti et al., 2022).

Nettles are biodegradable, making them a desirable alternative to plastic-based fibers such as nylon, acrylic, and polyester (Mudoi & Sinha, 2021).

Nettle fibers are strong, flexible, and versatile, making them suitable for a wide range of applications, including textiles, composites, and technical textiles (Gahlot et al., 2019; Lanzilao et al., 2016b; Nandi & Das, 2017)

The production of Himalayan nettle can provide economic benefits to local communities. This can help to reduce poverty and increase resilience to climate change. Nettles grow in cooler climates, making them a good candidate for local or regional production and processing. Himalayan nettle cultivation and the production of nettle-based textiles can provide sustainable livelihood opportunities for local communities, particularly in rural areas. This helps in reducing poverty, improving socio-economic conditions, and fostering resilience against climate change impacts (Pargai & Gahlot, 2020a). The cultural value of local communities is changing due to climate change, and Himalayan nettle is an important part of the cultural heritage of the region. By promoting the use of Himalayan nettle, we can help preserve the cultural heritage of the region.

Nettle fibers are a promising alternative for sustainable fashion due to their environmental benefits (Pargai et al., 2015; Study of stinging nettle (*Urtica dioica l.*), 2017; Sunil Kumar Sett, 2016; Clothing from Himalayan Nettle Fibre, 2023). Overall, the use of Himalayan nettle can provide a sustainable and culturally appropriate solution to some of the challenges posed by climate change in the Himalayan region. The production of fibers from the nettle plant can be helpful in achieving sustainable development goals in several ways.

3 Conclusion

Himalayan nettle has a potential to play a vital role in mitigating climate change problems in the textile industry. Its cultivation and utilization offer opportunities for carbon sequestration, reduced deforestation, sustainable fiber production, biodiversity conservation, rural livelihoods, water conservation, and enhanced resilience. By incorporating Himalayan nettle into textile practices. A step can be taken for a more sustainable and climate resilient future by revitalise the traditional knowledge of Himalayan nettle plant in context to textiles. This is the need of the hour to promote and preserve the traditional knowledge and practices related to Himalayan nettle textiles. Organizations and initiatives have emerged to support nettle fiber production, improve processing techniques, and create market opportunities for the products. These efforts aim to ensure the continued existence of this traditional craft and its contribution to the cultural heritage and economic development of the Himalayan region. While nettle fibers have many benefits for sustainable fashion, there are also some challenges in using them in clothing production such as excessive cost of extraction as extracting fibers from the nettle plant is a long and strenuous process that requires specialized equipment and expertise. This can make the production of nettle fibers more expensive than other fibers. Other key challenge is lower yield of fibres The yield of nettle fibers per hectare is lower than other crops such as cotton, which can make it less economically viable for large-scale production. Similarly, The quality of nettle fibers can vary depending on the growing conditions and processing methods used, which can make it difficult to ensure consistency in the final product. Limited availability which can make it difficult for designers and manufacturers to source them and lack of awareness which can make it challenging for sustainable fashion brands to market their products. Overall, while there are some challenges in using nettle fibres in clothing production, the benefits of these fibers for sustainable fashion make them a promising alternative to synthetic fibers and conventional cotton-growing. With further research and development, it is possible that these challenges can be overcome, making nettle fibers a more widely used material in the fashion industry. These problems can be solved by cultivation on large scale and using advanced specialized machinery for processing of nettle fibers as well as yarn.

While Himalayan nettle cultivation can have positive implications, it is crucial to ensure that it is done sustainably and in harmony with the local environment. This includes practices such as responsible harvesting, biodiversity conservation, and community involvement. Additionally, it is important to consider the broader context of development, including the need for comprehensive environmental policies, effective governance, and the integration of sustainable practices in other sectors. Ultimately, maintaining the balance between the environment and development requires a holistic approach, considering various factors, stakeholders, and long-term sustainability goals. The Himalayan nettle can be a part of this broader strategy with some above discussed solution.

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Situating Culture in Sustainable Development Discourse: Reflections in the Context of the Himalayas

Sachin Kumar and Amit Shoshta

Abstract "Culture" and "development" are two concepts in social and behavioural sciences that have always eluded exact and universally agreed definitions. At the same time, the interrelationships between these two constructions have gained significance in recent years, and discussions about culture *in*, *for,* and *as* development abound. This chapter is based on the basic idea that unless the paradigm behind an intervention is consistent with the history, values, and beliefs of a specific community, it will be ineffective. It eventually concludes that in the context of the Himalayas, the diversity of cultural expressions and assets must be documented, preserved, and promoted; a cultural perspective should inform all developmental aspects (livelihoods, industries, housing, social and environmental policies); and, in the long run, efforts must be made to engender broader transformations towards more holistically sustainable mountain societies through increased awareness and capacity. This chapter begins with a summary of the complicated implications of the terms "development" and "culture," presents and analysis of significant discourses around their relationships, and identifies essential imperatives for implementing a culture-resonant developmental paradigm. The next section presents the backdrop of the Himalayas and then briefly describes two illustrations of culture-resonant development initiatives in the Himalayan state of Himachal Pradesh, the first one is an example of a product-based initiative and the second one exemplifies a service-based enterprise. The final section lists key imperatives for putting Himalayas on a culturally-driven and culturally-concordant developmental trajectory.

Keywords Culture · Development · Himalayas · Mountain development · Sustainable development goals

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1 Introduction

Pleasant be thy hills, O earth,
They snow-clad mountains and thy woods
Earth — brown, black, ruddy and multi coloured
the firm earth protected by Indra,
on this earth i-I stand, unvanquished, unslain, unhurt
(Atharv Veda 12-1-11)

Our planet Earth is facing unprecedented crises at multiple levels. It appears that lord *Indra*, the mythical king of Gods, is not able to 'protect' it any longer and humanity no longer stands 'unvanquished, unslain, unhurt'. These crises have been attributed largely to a developmental discourse that privileges economy over ecology and equity. As a consequence, paradigms are getting transformed at several scales—global, national and local and the idea of sustainable development is being advocated for. This transformation assumes greater salience in the context of mountains. Mountains cover 24% of the land area, are home to 12% of the world and provide various provisioning, regulating, cultural and supporting services to entire planet (Grover, 2015). However, accelerated anthropogenic interventions guided by fallacious development paradigm coupled with global macro processes such as climate change and globalization have brought mountains under spotlight and mountain -specific development trajectories are being proposed. Mountains are specifically listed as one of the ecosystems to be preserved, restored, and utilised sustainably in accordance with international agreements in Target No. 1 of sustainable development goals (SDGs). On the other hand, while importance of culture for development of humanity is not new (Sabatini, 2019), the idea of sustainability in development typically encompasses three dimensions, namely, economic, environmental and social (e.g., Duran et al., 2015; Mensah, 2019) and inclusion of culture as the fourth dimension is relatively recent and still not prevalent in mainstream discourse despite incessant efforts being made by agencies like UNESCO. This chapter argues that while this inclusion is critical for global development, development interventions in mountain has to be culturally resonant, culturally concordant in order to remain sustainable. It begins with a summary of the complicated implications of the terms "development" and "culture," analyses significant discourses around their relationships, and identifies essential imperatives for implementing a culture-resonant developmental paradigm. The next section defines the backdrop of the Himalayas, which is known for its rich, lively, and diverse cultural assets. The final section briefly presents two cases of culture-resonant development initiatives in the Himalayan state of Himachal Pradesh, the first one is an example of a product-based initiative and the second one demonstrates a service-based enterprise. These cases have been written on the basis of content analysis of organisational reports and interviews conducted with officials of concerned organisations. The final section lists out key imperatives for putting Himalayas on a culturally-driven and culturally-concordant developmental trajectory.

2 Development and Culture: The Interface

Perhaps because they are polysemic and have multiple disciplinary perspectives, the terms "development" and "culture" remain impossible to define. Let us examine the word "development" first. Since the term "development" "takes on particular meanings in the context of specific intellectual, institutional, and political moments" (Lawson, 2007, p. 5) and each connotation "embodies competing political aims and social values and contrasting theories of social change" (Thomas, 2000, p. 23), it is impossible to come up with a definition of development that is universally accepted. However, it is important to remember that development has been described as a vision of a desirable world, a historical process of social changes brought about by inevitable processes over a long period of time, and as an action, a set of deliberate efforts aimed at bringing about positive change (Thomas, 2000). Although the desire to improve human situations has always existed throughout all societies, it was not until the late 1940s that this desire began to articulate itself and find a public voice (Morris, 1998). The term "development" was defined throughout the post-war decades (1940s–1950s) in terms of economic growth, which is defined as a rise in a country's production or consumption. This idea was disproved by the 1960s, when socioeconomic development began to take precedence over traditional measures like per capita GNP and other social indicators like health, education, housing, and nutrition began to be factored into the development index (e.g., Morris, 1998; Potter et al., 2012). The third stage of development thought, which emerged in the 1980s, includes environmental considerations including pollution-free living. At that time, the concept of quality of life encompassed both social and economic factors, such as income levels and access to healthcare and education. Following the historic release of the Brundtland Committee report (WCED, 1987), the concept of sustainability—the pursuit of policies that maintain resource levels for the future—came about in the same decade. Indicators of development were expanded to include indicators of environmental quality, political and human rights, and gender equality throughout the same decade (Potter et al., 2012). Sen (1999) later defined development as freedom, stating that it is the process of "removing various types of unfreedoms that leave people with little opportunity to exercise their reasoned agency" (Sen, 1999: xii). Goulet recognized the multidimensionality of the concept of development as early as 1971. This concept encompassed three aspects: life sustenance (providing for basic requirements), self-esteem (feelings of self-respect and independence), and freedom (people's capacity to control their own destiny). These three elements roughly equated to personal, economic, and social liberty. It is therefore obvious that the many advancements in human society that growth is supposed to bring about defy exact prediction (Chant & McIlwaine, 2009).

The term "culture" also remains a difficult term to define. For example, as early as in 1952, Kroeber and Kluckhohan listed nearly 160 proposed definitions classified under 6 categorical labels, summing up a range of meanings including, among other things, activities and behaviours of the people; heritage and tradition; rules and norms; elements of social organizational elements. As Williams (2015) points out in his exposition of the etymological and semantic evolution of the term "culture", all its early uses meant a process of tending of something, basically crops or animals, as in agriculture, horticulture. Then from meaning tending to natural growth, it got extended to a process of human development as in cultivation of mind which remained the dominant meaning for a long time. Culture as an independent noun, an abstract process or the product of such a process, is not important before the middle of the nineteenth century. Currently, it is being largely used to communicate three connotations: the independent and abstract noun which describes a general process of intellectual, spiritual and aesthetic development; the independent noun, whether used generally or specifically, which indicates a particular way of life, whether of a people, a period, a group, or humanity in general; the abstract noun which describes the works and practices of intellectual and especially artistic activity-music, literature, painting, sculpture, theatre and film at times even philosophy, scholarship and history (Williams, 2015). Disciplinarily speaking, it has been noted that culture is: primarily material production in archaeology and cultural anthropology; symbolic systems in history and cultural studies (Williams, 2015). In sociology, culture has been seen as a macro-concept and in psychology it has been viewed as an individual construct (Matsumoto, 1996) focusing not that much on objective culture manifested in human-made parts of environment (Herskovits, 1955) but on subjective culture such as values, beliefs, attitudes (Triandis, 1972). Psychologically speaking, "culture" has been defined as "the set of attitudes, values, beliefs, and behaviours shared by a group of people, but different for each individual, communicated from one generation to the next" (Matsumoto & Juang, 2013, p 27). In line with its varied conceptualisations, integrating viewpoints from various disciplines Ferraro (1990) defines "culture" as "everything that people have, think and do as members of their society", consisting of "1) material Objects; 2) ideas, values, and attitudes; and 3) normative or expected patterns of behavior, which is shared by at least two or more people" (p. 18). Culture has been differentiated from both universal human nature and unique individual personality. In his three levels of uniqueness in human mental programming, Hofstede (1994) points out that human nature is inherited and universal while culture is learned and is specific to a social group. On the other hand, personality is unique to an individual which is an assemblage of partly inherited and partly learned behaviours. However, the boundaries are blurred because culture possesses both emic (distinctive) and etic (universal) attributes (Spencer-Oatey, 2012).

Despite their varied connotations, both the terms "development" and "culture" have become ubiquitous in their usages in recent times assuming particular meanings in the specific intellectual, institutional and political contexts. It would now be useful and interesting to explore interrelationships between these two terms which are getting articulated differently owing to competing political aims and social values and contrasting theories of change and transformation.

As Isar (2016) notes, culture was deemed as an obstacle to development in the 1950s and non-Western nations were expected to do away with their 'retrogressive' cultural beliefs and practices in order to modernise themselves and catch up with development of the West. Then after the decolonisation process in Africa in 1960s, culture had been viewed as a national resource and with such vehemence that development was seen as a threat to cultural survival. Since the late 1960s, UNESCO has been expounding on the notion of 'cultural development' and defined it as 'a process of development or progress in the cultural life of a community, aimed at the attainment of cultural values and related to the general conditions of economic and social development'(UNESCO, 1981). The idea of cultural development was succeeded by the 'cultural dimension of development'. A number of intergovernmental conferences helped shift the emphasis from progress in the cultural life of the community to integration of culture in the process of national development since culture was visualised as the whole complex of spiritual, material, intellectual and emotional features that characterize a society or social group…' (UNESCO, 1982). So 'protecting and promoting cultural expressions' is advocated, not primarily for the sake of those cultural expressions themselves, but because they embody the symbols of 'ways of life' that are seen to be threatened by development in a globalised and globalising world.

Through UNESCO's efforts, a number of resolutions have been passed by UN Assembly that acknowledge role of culture as a driver and enabler of sustainable development (UNESCO, 2019; Wiktor-Mach, 2020). Culture is explicitly mentioned in Target 4 under SDG 11and it has been mentioned both as a sector of and contributor across other sectors. UNESCO has also developed Framework for Cultural Statistics (FCS) of UIS, the Culture for Development Indicators Suite (CDIS), Culture 2030 indicators over recent years to facilitate effective implementation, monitoring and reporting of culture's contributions to development.

Amidst various articulations, the one proposed by Dessein et al. (2015) and Soini and Dessein (2016) deserves special mention. It observes that in the sustainable development discourse, culture has been represented in three ways: culture *in*, *for* and *as* development. The most prevalent representation, particularly from policy and practice point of view, has been the first one, i.e., *culture in development* which adds a fourth pillar to the three existing pillars of sustainable development, namely economic, ecological and social considerations. Here, culture assumes a supportive and self-promoting role and it is articulated that cultural resources or cultural and creative industries provide content for economic growth through production and consumption of cultural goods and services. Here the importance of conservation, maintenance and preservation of cultural capital in different forms as arts, heritage, knowledge, and cultural diversity for the next generations takes primacy. The second representation, *culture for development* refers to culture having a mediating and contextualising role to achieve overall development. In this formulation culture aims at influencing and shaping the aims of other public policies, like livelihood, industries, social and environmental well-being. In the third representation, *culture as development*, which is a relatively recent conceptualisation, culture is given a more fundamental role and is seen as the essential foundation integrating and guiding all aspects of sustainable action. In this formulation, policy will promote broader transformations towards more holistically sustainable societies, for example through increased awareness and behaviour changes that can provide catalysts and enablers for grassroots collective actions, and through the development of the capacity and capability of individuals and communities to adapt and carry on more sustainable ways of life. As such, culture becomes an overarching dimension of sustainability.

To sum up, the paradigm of *culture in development* contributes to the achievement of establishing and recognizing culture and cultural diversity implying conservation, maintenance, and preservation of tangible and intangible culture and the diversity of cultural expressions. *Culture for development* helps frame development in the cultural context resulting in locally relevant outcomes shunning from adoption of generic top-down paradigm driven macroeconomic theory. In *culture as development*, development itself is deemed as a cultural process and a culturally-embedded development paradigm is shared among development practitioners –policy-makers, bureaucrats, citizens, public and private institutions.

In recent past, a number of dimensions of culture-sustainable development have been explored from several perspectives. Few examples are: legal perspective (Du Plessis & Rautenbach, 2010), cultural content digitisation (Fanca-Ivanovici, 2018), tourism context (Lajçi et al., 2021; Mutana & Mukwada, 2018; Nofiyanti et al., 2021); urban development (Kagan et al., 2018); forest related culture (Ngo et al., 2021), development of fishermen settlement (Sharvina et al., 2018); green building (Wu et al., 2016). Most of these studies appear to have adopted *culture for or in development* perspectives and *culture-as-development* perspective stands missing. At the same time, most of the works come from Europe (e.g., Streimikiene et al., 2019; Verina et al., 2021).) and South-East Asia (e.g., Pham, 2020), Studies on culture and sustainable development from other geographies remain few and far between.

3 Rationale for a Culture-Resonant Development Paradigm

A summary of discourses around the relationships between culture and development, both prevalent and proposed, presented in the previous section itself points out to the rationale behind adoption of a culture-resonant development paradigm. However, this section attempts to list a few imperatives that constitute the justification of bringing culture at the core of any policy and/or programme of advancement specifically in the mountainous region.

Post-globalisation process of market driven development has been associated with the gradual obliteration of cultural diversity (e.g., Tomlinson, 1999); erosion of indigenous and traditional knowledge (e.g., Smith & Ward, 2000) moving towards a homogenized, westernized, consumer culture (e.g., Kraidy, 2005); and growing marginalisation of self-sufficient societies creating deprivation of masses. It is important that the tide of unwanted transformation is turned back by leveraging traditional knowledge, finding and harnessing cultural practices and artefacts for a pro-people and pro-planet development.

At the same time, the discourse on *culture in development* necessitates a focus on finding, acknowledging, preserving, maintaining and monetising cultural expressions in order to leverage cultural economy which has been defined as comprising of "all those sectors in modern capitalism that cater to consumer demands for amusement, ornamentation, self-affirmation, social display and so on…… outputs have high symbolic value relative to utilitarian purpose" (Scott, 1999, p. 807). These industries produce cultural goods and services that involve creativity, embody intellectual property and convey symbolic meaning (Throsby, 2001).

Further, a number of international declarations, conventions and rights regimes make it obligatory for nations to ensure that culture cannot be overlooked. For example, the United Nations Declaration on the Right to Development (UN, 1986) states that the right to development is an inalienable human right by virtue of which every human person and all peoples are entitled to participate in, contribute to, and enjoy economic, social, cultural and political development, in which all human rights and fundamental freedoms are fully realized. The UNESCO Convention on the Protection and Promotion of the Diversity of Cultural Expressions (UNESCO, 2005) envisages informing and shaping national policies and programmes for protecting and promoting production and distribution of diverse cultural goods and services. United Nations Declaration on the Rights of Indigenous Peoples (UN, 2008) affirms the individual and collective rights of indigenous peoples in critical spheres of their lives such as culture, identity, language, employment, health, education. Article 23 gives them 'the right to determine and develop priorities and strategies for exercising their right to development," while Article 31 states that 'they have the right to maintain, control, protect and develop their cultural heritage, traditional knowledge and traditional cultural expressions…".

In the context of a mountain system, a culture –resonant development approach assumes more salience (Messerli & Bernbaum, 2004) because of the specificities that it entails. The idea of mountain specificities propounded by Jodha (1992, 2000) provides a useful framework to understand constraints and possibilities of developing mountain-based communities and economies. These specificities include: inaccessibility, fragility, marginality, heterogeneity/diversity, niche or comparative advantage, human–environment adaptation. Cultural specificities accrued due to these characteristics necessarily provide niche advantages for development unavailable to other ecological contexts. Perhaps that is why the Ministry of Culture has a special scheme of giving financial assistance for preservation and development of cultural heritage of Himalayas (www.indianculture.nic.in).

The key theoretical rationale for culturally mediated approach may be deduced from the Cultural Preparation Process Model (Arulmani, 2011, 2014; Arulmani et al., 2021). This model primarily attempts to understand how culture mediates the process by which individuals and communities engage with their careers and livelihood. The model posits that macro global trends form a backdrop against which livelihood development occurs. The socializing forces of enculturation engender a cultural preparation status equilibrium in relation to work orientations. This equilibrium is getting disturbed by a number of acculturative forces that require the individuals and/or the groups to change and align themselves to a new way of engaging with work necessitating efforts towards achieving a new equilibrium. It can be safely surmised that a culture-resonant approach to development would bring the equilibrium back.

At the same time, in many cases existing developmental activities violate human as well as cultural rights of the community (Isar, 2016). There is also a strong imperative for ensuring cultural justice for communities which has been conceptualised as the principle of accommodating the culturally-specific values and practices within the overall developmental regime (Meyjes, 1999). These imperatives also necessitate adoption of culture- sensitive and culture-informed approach to development.

The final rationale emanates from the evidence showing that certain types of cultural projects are likely to engender better social cohesion. In a review Sacco (2011) found that such projects have outcomes such as juvenile crime prevention, pro-social vocational orientation, or conflict resolution.

4 The Context of the Himalayas

The Himalayas, literally meaning the *abode of snow*, in an Asian mountain system that spreads over five countries, major part lying in India. The Indian Himalayan Region (IHR), situated in the north of the great Indian plains, occupies an area of 533,000 km^2. across 13 states/union-territories (NITI Aayog, 2018). Spread over nearly 2500 kms in length and 200–250 km in width, with a mean elevation of central axial range of about 6000, Himalayas form the largest feature on the Asian landscape (Molnar & Tapponnier, 1975), and influences the climate of much of Asia (Pant, 2003). About 10–20% of the area is covered by glaciers, while 30–40% remains under seasonal snow cover (Singh, 2006). Being termed as the 'water tower of Asia', Himalayan glaciers feed the major drainage systems of south and central Asia and the combined basin of these systems supports some 600 million people out of which 53 million people live in the Himalayas (Dimri et al., 2019). These mountains, with its extensive green cover, serves as a carbon dioxide sink, and contains half of the flowering plants in India with 30% of the flora being endemic (Singh, 2006).

Himalayas have been providing a number of ecosystem services since millennia (Dasgupta & Shakya, 2023; Singh, 2007; Xu et al, 2019). However, the Anthropocene epoch, especially the last century has witnessed critical transformations in the region in several domains and at several scales. A comprehensive assessment of this region which was contributed by more than 300 leading experts authoritatively brings together evidence of major changes that have occurred during the recent past (Wester et al., 2019). Several environmental, economic and sociocultural drivers have been identified (Wang et al., 2019). These include: demographic changes, land use and land cover change, over-exploitation of natural resources, rapid urbanisation, loss of traditional culture, and climate change, reckless infrastructural development to environmental degradation and weak governance. These intrinsically linked and continuously interacting change agents are increasingly influenced by regional and global changes affecting the effectiveness of eco-system services as well as livelihood opportunities of the mountain communities. To illustrate, in the context of Himalayas, poverty incidence is one-third compared to one-fourth for the national average (Gioli et al., 2019).

At the same time, concerns have been raised about deteriorating environmental assets, outmigration, and the rapidly disappearing cultural fabric and social value of collectivism specific to the Himalayas (NITI Aayog, 2018). It has been argued that development in the Himalayas must be fully integrated with the environmental and socio-cultural traditions that have characterized Himalayas since time immemorial. This assertion assumes greater salience because mountains worldwide, including Himalayas, are home to a rich cultural diversity (e.g., Bannerji & Fareedi, 2009; Mehta, 1995). The great variation in topographical features and their relative remoteness and seclusion of Himalayas led to immense diversity in climatic conditions, ecosystems, vegetation, terrain as well as in habitat conditions engendering development of various micro-cultures characterized by diversity of ethnic identities, social structures and customs, culinary styles, religions, languages, art forms, craft traditions and ways of life (Banerji & Fareedi, nd). The Himalayas have both vertical and lateral cultural diversity. While vertical variation is mostly influenced by environmental variables, lateral variance in cultures is influenced by ethnicity and migration. One of the biggest resources waiting to be leveraged in this region is its distinctive cultural heritage developed over centuries.

5 Culture-Resonant Developmental Initiatives in Himalayas

5.1 Case of **Dona- Pattal** *(Leaf Bowl and Plate) Making Project: An Initiative of ERA*

ERA is a non-governmental organization based in the *Changar* region of *Khundian* tehsil in Kangra district of Himachal Pradesh. Situated in the rain shadow area of inner Shiwalik ranges, *Changar* region is a resource-deficit area characterized by high temperature range, uneven precipitation, severe soil erosion, and hence infertile soil with poor agriculture yield, excessive weed growth and pest infestation, and rugged-degraded terrain. This region has a considerable population from marginalized communities. ERA aims at promoting sustainable mountain development ensuring empowerment of communities with a special focus on women and disadvantaged.

Dona-Pattal is the local nomenclature for bowls and plates made of leaves of certain plants/creepers. In the *Changar* region, leaves of *Taur* (Bauhinia vahlii), a wild climbing shrub, are used for making *Dona-Pattal* (Figs.1 and 2). They are used to serve food especially during community feasts/marriages/*langars*. *Dona-Pattal* making, a small income generating activity, has been pursued at household level by landless rural poor, marginal or small farmers generally belonging to marginalized social groups as a livelihood option or to supplement farm income.

Earlier there used to be an elaborate cultural tapestry woven around the activity of making *Dona-Pattal* which was made by a particular community. Once a social event such as marriage used to be fixed these communities used to get orders for supplying the requisite number of *Dona-Pattals* with advance amounts. On the day of the event, other than the price of the *Dona-Pattal* they used to receive grains, pulses, spices, jaggery and other household necessities along with money and clothes as well. This symbiotic relationship between buyers and sellers continued for generations under *Jijmani* system. Over the years, customer preferences changed. They started to go for cheaper, better looking, sturdier but harmful and environmentally undesirable substitutes such as bowls and plates made of thermocol/chemical coated papers. Bowls and plates made of leaves could not compete with these substitutes. As a consequence, despite growing demands for serving dishes from local communities and nearby temples, demand for dishes made of leaves started to dwindle and many families stopped following their traditional occupation of *Dona-pattal* making.

ERA decided to make this occupation viable again by enhancing the quality, durability, standardization and finishing of handmade *Dona-Pattals*. It identified and organized *Dona-Pattal* making families/communities; provided technical inputs for long term leaf preservation and eco-friendly production technologies; conducted several training programmes pertaining to transportation of hand stitched *Dona-Pattals*, sustainable plucking practices, marketing methods, entrepreneurship development. ERA also explored technology improvisation through research institutions and introduced a small scale, decentralized, labour-intensive, energy-efficient, environmentally sound, and locally autonomous technological solution. It envisaged using a pressing machine to improve quality, durability and aesthetics of handmade leaf-plates, considering that the pressed plates would fetch a better price (Figs. 3 and 4). It also used cultural leaders such as local purohits who used to fix *muhurat* (auspicious time) for social functions, for marketing of *dona-pattals*.

This project was successful in enhancing economic viability and profitability of a traditionally practiced occupation, empowering disadvantaged community specially

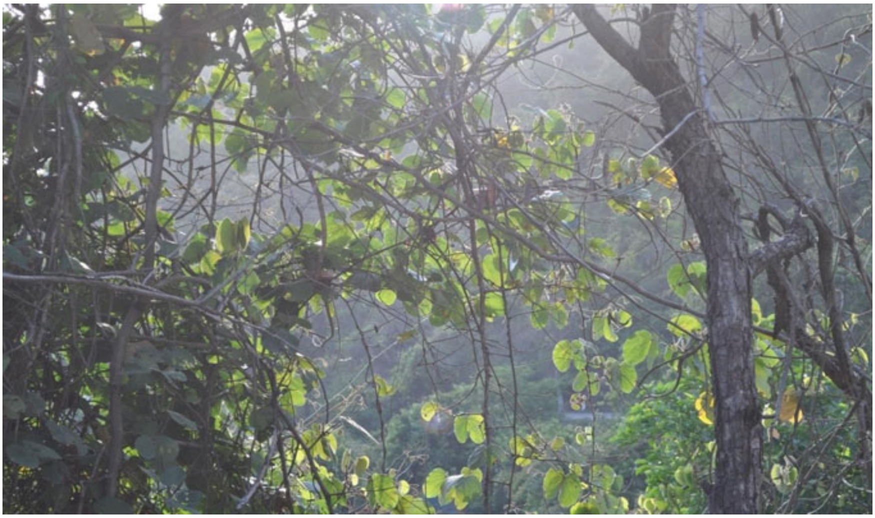

Fig. 1 Taur climbers in the forest

Fig. 2 Sorting of leaves

women, conserving environment and promoting sustainable consumption amongst consumers. This project promoted use of hand-made, eco-friendly, healthy and biodegradable *dona-pattal* and discouraging carcinogenic, non-biodegradable and polluting thermocol. It contributed in reducing emission of greenhouse gases, saved energy needed to produce and transport other alternatives, minimized use of water needed to produce paper/thermocol products or needed for washing steel or other metal plates. ERA's initiative also aided in reducing the drudgery and increasing the income of participating households by 25–40%. Compared to employment generated through MGNREGA, an employment guarantee scheme of the government, *dona-pattal* making proved to be an option which was more profitable, flexible in terms of time, more comfortable to perform, lesser labour intensive, available yearlong.

Further, capacity building programmes enhanced their awareness of rights, skills, health and educational issues, and also bolstered their sense of self-esteem and self-determination. This project has created a multiplier effect as well. Officials of Forest Department visited the area, interacted with the community and learnt about the project and later the Department procured and distributed similar machines to other forest dependent communities in other parts of the state. ERA was perhaps the first NGO in the state which advocated for banning thermocol due to its harmful effect on human health and environment, and deliberated with various temple committees to use eco-friendly plates while organizing community feasts.

Fig. 3 Hand stitched plates

This project had immense possibilities for scaling up because firstly, there is abundant availability of the Taur climbers in the region; secondly, the *dona-pattal* plate manufacturing is a traditional livelihood activity, and community is culturally prepared for production and consumption of such *Dona-Pattals*; and thirdly, there is unlimited market due to its proximity to famous temples and other religious/cultural places. This is a good example of how cultural enterprises can be created leveraging cultural tools.

5.2 *Case of H_2O House, a Homestay: A Not On Map Initiative*

NotOnMap, with the tagline *Live Like a Local*, is a community-based responsible tourism enterprise aimed at producing alternative livelihoods and reducing unskilled migration from villages. It began with the intention of bridging the gap between travellers seeking real cultural adventure and locals who can provide the same but

Fig. 4 Machine pressing

lack the necessary expertise and exposure. NotOnMap identifies new places, protects cultural and natural assets, and encourages travel to these locations to ensure that inhabitants from marginalized groups earn a living and feel empowered, while tourists have a once-in-a-lifetime experience. So far it has restored more than 200 traditional houses across nearly 15 Indian states creating approximately 1000 jobs across remote areas. Its efforts have been recognised by a number of national and international awards (https://notonmap.com/awards) and its model has been shared at multiple platforms and replicated at many places.

H_2O House was the first homestay identified, nurtured and promoted by NotOnMap. H_2O House is a 150+ years old ancestral homestay, built on land transferred to the owners in the thirteenth century as evidenced by a copper plate. It is located at the confluence of rivulets *Saal* and *Hul* amidst the *Pir Panjal* ranges in the idyllic village of *Chaminoo*, 12 kms away from the historic *Chamba* town in Himachal Pradesh. The region is home to the ethnic communities of the *Gujjar* and *Gaddi* tribes. It is perhaps the only homestay in the world that sits atop a *Gharaat*, a traditional grinding mill flour mill run by the naturally flowing water stream. *Gharaat* is a indigenous technology that converts the kinetic energy of flowing water into mechanical energy and is used to grind grain, maize, and spices. Ages ago, this place used to be the prime rendezvous for villagers, who used to come here to get their wheat and maize converted into flour. The vision behind renovation of this property was to make it again a hub of community activities and development.

Living its tagline, ‘*where nature meets culture*’, H_2O House aims to preserve the environment as well as culture. The place has been rebuilt, renovated and furnished by local artisans, primarily using locally available materials such as mud, stone and driftwood (Fig. 5). The objective was to reduce carbon footprints and preserve traditional architecture. The kitchen is being run by a women self-help group where local and traditional dishes are prepared using ingredients sourced locally or from nearby villages. The earnings go directly to the villagers. It also promotes cultural experiences for travellers in the form of village walks, meals with locals (Fig. 6), celebration of local fairs and festivals, craft sessions (Fig. 7), story-telling sessions. H2O House has also been documenting traditional cuisine and indigenous games (Fig. 8), and conducting workshops to promote them. It gives a platform to the community members for selling farm produce as well as craft articles. Performances by folk artists are also organized for guests. It also houses: *Kala kendra* (art centre) for artists and artisans for nurturing local talent; Baal Gyan Kendra (knowledge centre for kids) for local children who were taught occasionally by the visiting guests; a community library which got started using books donated by travellers. Over the years, the place has become a hub of cultural and developmental activities.

H_2O House has also taken a number of steps for environmental conservation. For travellers, it has adopted the policy of ‘Take Your Trash Back Home.’ It attempts to produce minimum waste (e.g., use of spring water instead of bottled water) and manages waste well through proper segregation and disposal. All biodegradable

Fig. 5 Room constructed with locally available materials

Fig. 6 Meal with locals: Sharing food, sharing culture

Fig. 7 Workshop on Chamba embroidery: Preserving and promoting craft

waste, especially any plastics, is collected and sold to the municipality as per the government scheme of recycling plastics. All edible biodegradable waste is fed to the cattle, while all non-edible biodegradable waste is used as compost for crops and plants. H_2O House also aims to conserve energy as much as possible. Electrical appliances such as coolers, air-conditioners, room heaters, television, immersion

Fig. 8 Preserving local cuisine

rods are not used. Cottages have been designed in such a way that electric lighting is not needed during the day time. Natural, organic cleansers are used in order to ensure that when water is discharged, the underground water table or the river do not get polluted. Natural farming is being done on the land within the premises which has inspired other farmers and is also being used as a demonstration unit by the government department of agriculture for training purposes.

For the local community, a number of capacity building programmes are organized on a regular basis on issues such as waste management, clean village campaign, zero budget natural farming, menstrual hygiene sessions. H_2O house has inspired, nurtured and promoted five homestays in the vicinity involving community. A number of agencies, both governmental and non-governmental, regularly visit this place for learning about culture resonant sustainable practices for replication. It also works with community-based organizations, other homestays, hotels, tour operators, and with local governments for adopting principles of sustainable and responsible tourism. Few travellers have also taken the responsibility of bearing educational expenses of few children of the community. Due to its efforts the village has been recognised as the model eco-tourism village by the government. It has also received several prestigious awards such as South Asia's Travel and Tourism Exchange (SATTE) award, and Indian Responsible Tourism Award (IRTA).

6 Culture-Resonant Development of Himalayas: Key Imperatives

The previous section showcases that it is possible to adopt a culture-resonant developmental pathway. Both the cases exemplify building an economic enterprise around a cultural product which is environmentally sustainable and socially equitable. It should also be noted that number of such instances are limited and concerted and comprehensive measures need to be taken. This section sums up key imperatives in the context of Himalayas.

6.1 Imperatives from Culture- in-Development *Perspective*

Culture in development discourse necessitates development of an economy around cultural goods and services. Himalayas present a panoply of cultural heritage in terms of arts, crafts, dance forms, music, rituals, fairs, festivals and oral traditions. There has been a tradition of economic exploitation of and social support for these cultural products and practices but it has been inadequate, unsustainable and sometimes even antithetical to the tenets of inclusive development. Following needs to be done:

- In order to preserve and promote cultural products, practices, expressions and traditions we should know what are to be preserved and promoted. As a first step, it is important to create a comprehensive database of various components of cultural heritage. The simple template developed by UNESCO (2009) to collect cultural statistics can be modified for this endeavour. Additionally, over the years, students, scholars, travellers, researchers have studied different aspects of Himalayan culture. It is critical to create a repository of knowledge on a single platform for researchers, citizens and practitioners.
- There have been frequent mentions of prevalence of a number of art forms, crafts, festivals, dances, rituals, jewellery, costumes, musical genres in various reports, books, research publications, dissertations and guidebooks on various Himalayan destinations. However, in the national and provincial surveys just few of them are mentioned and as a consequence policies, provisions and interventions also revolve around just a chosen few at the expense of a number of other equally vital forms. Let us look at an example of the Chamba district of Himachal Pradesh. *Dorukha kadhai* (double stitched embroidery form) of Chamba, Chamba *chappal* (footwear), miniature painting and metal craft are the most celebrated and most studied aspects of Chamba culture but a look at Appendix A of this chapter, which presents an illustrative list of existing cultural traditions of Chamba, gives a glimpse of diversity that needs to be studied, publicized, preserved, monetized and promoted across Himalayas.
- One of the key limitations of efforts made hitherto to promote cultural economy is the fact that most of these efforts address one aspect of the value chain. Let us take an example of promotion of craft. Promotional efforts should have focussed

on strengthening the value chain but they centered on just one or two aspects. In a typical case, the agencies that provide credit would not worry about ensuring marketing linkages and vice versa. Similarly, the agency giving design support would not be even aware of the fact that there is no facility available to transport the goods to the market. As a consequence of the neglect of the value chain, even sincere efforts are not getting converted into tangible impacts.

- Besides adopting a value chain approach, it is equally important to develop an enabling ecosystem by activating all the stakeholders in order to nurture the cultural sector. As Tyagi (2019) enumerates in the context of promotion of craft, these stakeholders include government agencies, local populace, voluntary organisations with a mandate to promote cultural goods and services, industry and artisans or practitioners themselves. The government needs to see conservation and promotion of cultural goods and services not just from an ethical imperative, as a "social" activity but should consider this sector as a profit-generating economic activity. It should provide direct support to practitioners rather than reaching them through subsidiary support agencies. The Department of Language, Art and Culture should redefine its mandate and move from tokenism to "real" actions that are transformative in nature. Local people need to be sensitised about the importance of these traditions, feel proud about its heritage and must appreciate promotion of this sector for ensuring a sustainable future. Voluntary organisations with a mandate to promote culture need to: help develop both consumer and market; link with government and CSR support services. Industry needs to: engage with this sector in product making, manufacturing, brand building/co-branding, and give credit to makers who contributed to new ideas of products and processes. Professional institutions need to provide design support and marketing support, value chain research, propose possible business models and organisational structure (cooperative or producer company). The practitioners need to: preserve and upgrade skills and knowledge; learn packaging, marketing, standardisation; network with agencies; contemporise their craft by innovating without losing authenticity; train and inspire the next generation- not just their family members and clan members but through any youngster who cares to learn. Bringing craftsperson, brands, retailers, industry and consumers together is a difficult but doable endeavour.
- A number of efforts have been made to develop the economy around cultural products in the Himalayas both by government and non-government agencies. An impact evaluation of these initiatives would be helpful. For example, the government has accorded a GI tag to the number of products. We do not know whether this tag has helped artisans or not and what could be possible ways to ensure that objectives of such efforts are achieved.
- In the entire process of promotion of cultural economy, convergence is going to be the key. Convergence at four levels is warranted: an inter-departmental convergence of policies and programmes; convergence of researchers so that their work gives a complete picture; convergence between researchers and practitioners; and finally, a convergence among research, policy and practice.

6.2 Imperatives from **Culture-for-Development** *Perspective*

As explained earlier, in the representation *culture for development,* culture takes a mediating and contextualising role to achieve overall development by shaping other public policies. Let us look at illustrations from four sectors crucial in the context of the Himalayas: health, agriculture, forestry and tourism.

- Before introduction to the modern health system, communities used to take care of their own health and the health of their animals with the help of traditional medical practitioners who used their indigenous knowledge of medicinal plants to treat people. It is important to rejuvenate the traditional health care system, the *lok-ayurveda* through proper support and promotion. Intention here is not to undermine the existing health care centres established by the Ministry of Health and Ayurveda and promote quackery in the name of treatment. It is evident that the existing system is not sufficiently equipped to universalise health care, to reach each and every individual residing in distant corners of the district. At the same time, health care requirements vary from community to community while the current system assumes a similar disease profile everywhere. To illustrate, medicines being supplied in primary health centres (PHCs) by the department are similar and do not take into account local disease profile. This policy is based on a ridiculously erroneous assumption that medical needs are common! In fact, all types of health care systems have a role to play. Revival of the traditional system would not just preserve indigenous knowledge, it will help provide timely care to communities in culturally-concordant ways.
- Another key sector which needs a cultural revival is agriculture. Prevalent wisdom advocates for putting more and more arable land under cash crop and examples of experiments in other districts are cited in favour of this suggestion (e.g., apple in Kullu). However, a number of similar experiments have failed (e.g., ginger production in Kullu; floriculture in Chamba). While crop diversification is crucial, mindless introduction is neither economically feasible, nor environmentally sustainable and nor culturally compatible. Public distribution system has done wonders in feeding poor people but it has put undue emphasis on wheat and rice. As a consequence, other traditionally produced cereals and grains got neglected and people stopped their cultivation. Traditional crops are known to have: better edaphic and climatic adaptability, population-specific nutrition value; and a rich culinary heritage. Some crops, especially millets have potential to fight climate changes by reducing consumption of irrigation water and ensuring food security (Davis et al., 2018). Many traditional crops grown in the Himalayas have potential to be positioned as super food or health foods in order to capitalise on the growing consumer awareness and market for such products. Studies need to be conducted about the status, potential and economics of these crops.
- A commercial/exploitative approach towards forests continued from the British period, has led to gradual dwindling of these precious resources over the years across Himalayas. A number of environmentally insensitive and anti-people campaigns have been introduced in the Himalayas in the name of "improvement

forestry" and "clean floor forestry" (Kumar, 2022). As a consequence, ecologically disastrous species such as pine and eucalyptus were planted and bushes, grasses and short statured vegetation were destroyed systematically affecting biodiversity and livelihood of forest dependent communities. Focus on commercial species had a telling effect on the lives of animal grazers and those who were dependent on forests for fodder, fuel and other NTFPs. Over the years, due to degradation of natural habitat, human-wildlife conflict increased and monkeys and wild boar started raiding crops destroying livelihoods of largely agrarian communities. On the other hand, communities have always taken care of their forests and they know which species need to be planted at what time. It is important to leverage cultural knowledge about useful species and community led forest management practices. Only those species should be planted that can become a recurring source of sustenance and cash income without any need to cut them. Forest should be developed as a productive garden to be managed by communities or/and a sacred space then only it can be saved. People are likely to plant and preserve those trees that are economically and culturally relevant to them.

- Currently mass tourism is being followed in Himalayas wherein travelers are largely being offered places of scenic beauty, salubrious weather and religious locations. However, a cursory glance at Appendix A is sufficient to convince anyone about the formidable array of cultural expressions that can be offered to tourists. Even if a self-motivated tourist goes to a place of historical- architectural significance, there is no one to demystify these structures to them, guiding and interpretation services are almost absent. At the same time, if the tourist is sensitive to cultural and artistic significance, they feel utterly dismayed to see that in the name of restoration and renovation, marble tiles have been put everywhere. This process, which we call "marblisation" of temples, has robbed off their original look and authentic grace. At the same time, traditional mass tourism has been found to be environmentally untenable. The new generation of discerning travelers do not want to do conventional tourism and they are more interested in ecotourism. In conventional mass tourism, focus is on pleasure, on what the tourist is seeking but ecotourism focuses on what the traveller does. It also focuses on the impact of this travel on both the environment and the host community. Initiatives like that of H_2O House are few and far between. Other forms of tourism can also be promoted here such as: culinary tourism, art tourism, dance tourism, festival tourism, *jaatar* (community pilgrimage treks) tourism. Religious tourism too needs a better promotional strategy. Not just temples of the region, the churches, mazars and gompas also need promotion.

6.3 Imperatives of Culture-as-Development *Perspective*

As mentioned earlier, in the third representation—*culture as development,* culture takes on a transformative role in pursuit of achieving sustainability. Here, development itself is seen as a cultural process. Culture is no longer a structural component or a crosscutting perspective but a necessary agency. This new paradigm necessitates innovative policies and practices. It is perhaps the most ambitious formulation in order to develop an eco-cultural society. In the case of the Himalayas, cultural literacy of all the actors is necessary since a culturally-embedded development paradigm has to be shared among all at all the levels. A shared view has to be developed among policy-makers, bureaucrats, citizens, public and private institutions, educational and professional institutions and civil society organisations, academia and industries. It can only be achieved through increased awareness, capacity building and behaviour changes enabling collective actions at grassroots. As of now, both government and citizens are far away from making culture as development yet this is the ultimate target we should aim at. Here, it is worthwhile to invest resources in preparing students in schools and colleges for actualising the dream may be in distant future because they are going to be: consumers and producers of cultural products and services; policy makers and administrators; legislators and citizens; researchers and teachers; local grassroots level actors as well as global movers and shakers. Investing in the cultural literacy of this most important constituency is going to pay rich dividends for making *culture -as- developmen*t paradigm a reality.

7 Concluding Thoughts

The Himalayas have been in the cultural memory of the Indian sub-continent since millennia. Krishna said in the ancient text *Shrimadbhagvatgeeta,* “amongst immovable things I am the Himalayas” (10/25). However, due to forces unleashed during the Anthropocene, Himalayas are no longer ‘immovable’. These mountains and the communities inhabiting these mountains are facing unprecedented challenges of alarming magnitude in various domains. Since culture is known to have a positive impact on sustainability and well-being across countries (Bacchini & Valentino, 2020), it is critical to adopt policies, devise strategies and initiate programmes that put Himalayas on a culture-sensitive and culture-informed developmental trajectory. Thankfully, there is a gradual awakening both within the governmental as well as in non-government sector that cultural traditions and practices need to be preserved and promoted by making them economically viable because they are likely to help achieve sustainable development goals as they involve marginalised communities using green practices. However, efforts made in this direction remain piecemeal, uncoordinated and fragmented, and in many instances, even antithetical to the basic premises of development. The two cases described in this chapter are examples of islands of appropriate developmental models exemplifying potential and possibilities of such initiatives. Such cases need to be documented, replicated and brought to scale so that dividends may reach to the communities, culture gets preserved, promoted and leveraged for equitable development and the mountain ecosystem gets healed as well. At the same time, in the context of Himalayas. the diversity of cultural expressions and assets need to be documented, preserved and promoted; a cultural perspective should inform all developmental aspect (e.g., livelihoods, industries, housing, social and environmental policies); and in the long run, we must aim to engender broader transformations towards more holistically sustainable societies through increased awareness and capacity building of citizens especially youth. It must be borne in mind that a culture-resonant approach is a necessary but not sufficient condition for development. Besides having a robust, integrative cultural policy we need to create cultural literacy as well as cultural infrastructure. Most importantly, development practitioners should not forget what an ex-President of Mali, Alpha Oumar Konaré, pointed out: 'the negation of the cultural specificities of any people is tantamount to the negation of its dignity' (quoted in WCCD, 1996).

Appendix

Cultural expressions and assets of chamba in Himalayas: an illustrative list[a]

Domain	Examples
Visual arts and crafts	Pahari Painting, Chamba Rumaal (Dorukha kadhai), Bangdwari chitran, lost-wax metal casting, wood craft, stone craft, horse hair jewellery, silver and gold jewellery, handloom work (shawl/pattu), knitting craft (pullan), leather craft (chappal), carpet weaving, pine needle craft, bamboo craft, pottery
Performances and celebrations[b]	**Folk dances**: Dandaras, Gaddi or Bharmouri Nati, Nat, Nachan, Ghurei/ Ghurehi.Chhinjhoti, Shain, Sal-kukdi Nach, Dhamal,Til-Chauli, Mixed Ghurei, Mask dances, Dance of Gujjars, Dance of Gurkhas, Dance of Parachinari, **Folk music traditions**: Musadha, Sukrat, Dholru, Basoa, Basant bahar, Kunjdi malhar **Folk theatre/folk ballads**: Harnatar, Ainchli, Jhanki, Suang, Bhagat **Fairs/Festivals**: Minjar, Bhojri, Suhi mata jaatar, Chaundi jaatar, choohe-billi kij jatar, Chameshni ki jaatat, Khundi maral jatar, Manimahesh jatar, Rath-rathini jaatar, Panj bhikhami ekadash, Chambyali lohri, Phool Jatra, Sainj, Iwaan, Unoni, Daikhan, Miglyath, Sarjaat, Jukaroo, Sheel, Pareed, Punahi, Lishoo, Uttain, Baar
	Temples[c]: In Bharmour (Ganesh, Lakhna Devi, Narsing, Manimahesh), Chamba (Brajeshwari, Bansigoplal, Champavati, Luxminarayan, Hari Ray, Sita Ram, Rock sculptures of Ram, Sita Hanuman;) and at Chhtarari (Shakti devi) **Churches**: In Dalhousie (St.Patrick's, St Andrew's, St. John's, St Francis) and in Chamba (Church of Scotland) **Dargah**: At Rajpura, Manjeer, Thalli, Shamdhar **Gurudwaras**: In Chamba **Gompa**: Bhanodi **Palaces**: Akhand Chandi, Rang Mahal, Jandrighat **Fortresses**: Taragarh, Ganeshgarh, Lodhargarh **Museum**: Bhuri Singh Museum
Books and press	Manuscripts, Inscriptions, Publications on Chamba by: visitors, local residents in different souvenirs, researchers, scholars, travellers

(continued)

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Domain	Examples
Audiovisual media	Photographs and video and audio clips
Sports and recreation	Traditional sports and games such as Chaupad, Khinno,Brag gitti, Walnut games, Bajik etc.; Boating and water sports in Taleru, Adventure sports in Bharmour
Intangible heritage	Folk songs (e.g., Ritu Geet, Sanskar Geet), folk tales, folklores, culinary art, idioms and sayings, knowledge of medicinal plants
Natural heritage	5 Wild life sanctuaries, nearly 30 trekking routes, Mini Swiss Khajjiar, Sach and Basodan pass

[a]Format adapted from UNESCO (2009)
[b]Out of 40 monuments of national importance in the state of Himachal Pradesh, 12 are in Chamba which are being listed here. There are a number of other temples and shrines available in different parts of the district
[c]Religious-cultural events in Chamba almost invariably involve music, dance and song. Hence some cultural forms may be classified under more than one category

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Folklore, Traditional Beliefs, Taboo and Practices on Climate and Weather Forecasting by the Meitei Community of Manipur, North East India

Huidrom Birkumar Singh

Abstract Manipur state, which falls within the "Indo-Burma" centre of biodiversity "hotspot" of global significance and a part of the tertiary ranges of the Eastern Himalayas is the abode of more than 30 ethnic people and is closely associated with nature in their day-to-day life. They hugely rely upon their needs for food, shelter and healthcare from the surrounding forest and its resources and have rich knowledge of plant utilization and conservation. They are worshipers of nature, forest and sylvan deity. The people have a rich traditional knowledge system of prediction and forecast of weather and climate. By observing certain characteristics of plants and animals people predict the rainfall, lightning, wind or storm pattern. Many plants and animals are climate and weather-sensitive and indicative. Some of the plants that are used as indicators of weather and climate are Indian hemp (*Hibiscus cannabinus*), century plant (*Agave americana*), mango (*Mangifera indica*), Indian staghorn fern (*Platycerium wallichii*), Rumpf's fig tree (*Ficus rumphii*), tree bean (*Parkia roxburghii*), Mosquito fern (*Azolla pinnata*), dwarf rotala (*Rotala rotundifolia*), etc. whereas some of the animals are jungle crow (*Corvus macrorhynchus*), spotted dove (*Spilopelia chinensis*), black-kite (*Milvus migrans*), carpenter ants (*Camponotus* spp.), ngasang (*Esomus danrica*), climbing perch (*Anabas testudineus*), spotted snakehead (*Channa punctata*), cattle (*Bos taurus*), greater coucal (*Centropus sinensis*) and Indian spotted dove (*Spilopelia chinensis*), etc. Sudden characteristic and intense noise of animals and birds are signs of possible earthquakes. The paper describes the traditional knowledge system and practice of the Meitei community of Manipur that are associated with plants and animals in predicting weather and climate.

Keywords Folklore · Traditional beliefs · Climate and weather forecasting · Meitei community · Manipur · Northeast India

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1 Introduction

The ancient relationship between the people and their traditional knowledge of such bioresources around them is indicative of the fact that bio-folklore is strongly prevalent in the communities (Singh et al., 2022). For centuries indigenous communities have witnessed local changes in climate conditions in their surroundings. They have a rich experience with their ecosystem's natural rhythms and processes (Vogt et al., 2002). Indigenous peoples of Manipur state in the far northeastern parts of India, which falls within the Indo-Burma biodiversity hotspot region are closely associated in various ways with their surrounding landscapes and resources, mainly plants and animals, for their day-to-day requirements (Singh, 2011). The people of the state are nature worshipers like trees, animals, rivers, lakes and mountains. The majority of the state's population are rural villagers who still follow their traditional beliefs, including botanical folklore, and still adhere to the traditional ways of conserving biodiversity that were passed down from their ancestors (Singh & Singh, 1996). Conservation of biodiversity in the form of sacred grooves is a very common practice amongst ethnic communities. As the sacred forests are comparatively least exploited, a good number of big-sized primitive and economically, religiously associated plants are still preserved and protected. Big-sized trees and old plants are taken as having supernatural power and are worshipped. In the traditional system of the Meitei community, collection of plant parts for use in healing is strictly done by aged people that too after a formal invitation by offering Areca nut (*Areca catechu* L., locally called Kwa) and betel leaf (*Piper betle* L., locally called Kwa-mana) on a piece of banana leaf. One such example is the collection of wood-bark of *Terminalia arjuna* Roxb. (locally called Mayokpha) and *Terminalia tomentosa* (Roxb.) Weight & Arn. (locally called as Mayokpha-Arjun) which are used for the treatment of heart diseases. Breaking and falling of living branches of trees especially, *Ficus* species are a sign of bad omen for those people inhabiting around it, especially in the direction where the branch has fallen. There are numerous bio-folklores and practices in Manipur. The traditional boat-racing festival called Heigru-hidongba, romantic novel called Urirei-Madhabi, caste-based romantic novel Lamphel Nawa kombirei are all plant-based folklores and practices of Meitei community of Manipur (Singh et al., 2022).

The Earth is a changing, dynamic place and because it is our home, we should think about the various changes that occur. Daily and seasonal changes and long-term changes all have an impact on our lives (Mauseth, 2013). Several catastrophes, like extreme-events, loss of biodiversity and changing planetaory systems, are happening on our planet due to numerous factors. We are facing and experiencing such catastrophes which cause damage to properties and even loss of life. To safeguard their life people, create awareness and efforts to avoid or minimise the loss. Based on the long experience, people try to understand the impending catastrophes like rainfall, sunshine, and earthquakes by observing the characters and behaviours of some plants and animals. Necessary alerts and precautions may be taken if they feel some calamities may occur by observing the characteristics of the plants and animals.

Ethnic people believe that some plants and animals are more sensitive than human beings in numerous aspects like climate, calamities, etc.

The Manipur state falls between 23°27′ to 25°41′ N and 93°61′ to 94°48′ E, and stretches a geographical area of 22,327 sq. km. in the far north-eastern region of India. Around 33 communities and tribes or subtribes are inhabited in the state. Meitei, Naga and Kuki are the dominant communities. Manipuri is the state language and is spoken by most of the communities. The state is nature's paradise for its wild flora and fauna, harbouring over 3000 species of higher plants within an area of 22,327 sq. km hence being an important source for germplasm (BSI, 2000). The region is considered the centre of origin of angiosperms due to the maximum number of flowering plants (Takhtajan, 1969). The state is, therefore, a unique habitat region because of its features such as biological diversity, landscape of high mountains and low wetland habitats, and agro-climate (Singh, 2013). The indigenous peoples of Manipur state are closely associated in various ways with their surroundings landscapes and resources, mainly plants and animals, for their day-to-day requirements (Singh, 2011). Many bio-folklores are associated with their lives. The present communication is on bio-folklore, traditional beliefs, taboos and practices on climate and weather forecasting by the Meitei community of Manipur. As many of the traditional knowledges are eroding very fast, documentation of it is extremely important. Many of the information may be useful in understanding the climate and disasters, helping in reducing catastrophes.

2 Methodology

The data were collected by the author through interaction discussion and records with a large number of local resource persons, herbalists and knowledgeable persons locally called "Maiba" for males and "Maibi" for females since the last 28 years in Manipur mainly of the Meitei community through interactions and questionnaire of descriptive type. The purpose of collecting data was disclosed to the informants and resource persons and their informal consent for publication. The author recalls the stories and folklore narrated by his grandfather, (Late) H Ibomcha Singh and grandmother namely, (Late) H Ibemhal Devi who narrated numerous stories and folktales when the author was a school student (1980–1985). Many folktales related to plants and animals are already in the public domain in the form of story but documented in this communication.

Literature survey was also conducted and cited from numerous literature sources (Singh, 2011; Singh & Devi, 2014; Singh & Singh, 1996). This compilation is being made to give an outline idea of the age-old beliefs and practices of the ethnic people of Manipur, North East India, particularly of the Meitei or Meetei community on traditional bio-folklores, prediction of weather, rainfall, drought and lightening or other calamities based on the observation of characters of some plants and animals. The plant species are identified through the available literature source (BSI, 2000; Singh & Devi, 2014; Singh et al., 2003; Sinha, 1996). A few animal species are identified through some literature sources (Shamungou, 2000; Shamungou & Devi, 2017). Scientific identity of the three fish species reported in this communication was cross-checked with Dr L. Kosygen Singh, Scientist of the Zoological Survey of India, Kolkata through personal communication. Scientific names, family, common English name, vernacular names of the species enumerated are presented;

3 Enumerations

3.1 Plants

1. *Agave americana* L. (f. Agavaceae)

English name: Century or Agave plant or American aloe
Vernacular names: Kewa (Manipuri), Sisal (Hindi)
The flowering pattern of this plant is useful information to predict the intensity and direction of storms and winds for a particular year or season. The storm or winds are expected to blow from the opposite direction from where the greatest number of flowers are positioned on an inflorescence. If the plant bears more flowers is indicative of stronger storms and rainfall. The plant is fondly planted as a hedge or live-fencing plant around private lands to protect from livestock grazing animals. The leaf fibre (obtained after rotting of the soft tissue by dipping it under water for several days) of the plant is used as a traditional wiper for claning surfaces.

2. *Azolla pinnata* R.Br. (f. Azolaceae, Salviniaceae)

English name: Mosquito-fern or Water velvet (English)
Vernacular name: Kang-koop (Manipuri); Azolla (Hindi)
It is assumed that if the colour of this aquatic floating plant just before the rainy season is dark green, then the season is expected to have good rainfall while the colour is slightly reddish and dull, the season may receive lesser rainfall. It is assumed that the greenness of the plant is an indication of high moisture content in the air resulting to possible rainfall. This plant is a good feed for poultry, duckery and piggery. It is also used as a good bio-compost in traditional agricultural practices (Plate 1.a).

3. *Bambusa* spp. (f. Bambusaceae, Poaceae)

English name: Bamboo
Vernacular name: Waa or Khok-waa (Manipuri), Bans (Hindi)
Certain species of bamboo especially, the *Bambusa nana* is used in funeral in Manipuri tradition. The whole length of the bamboo, 4 in number with a top canopy is erected in a square shape and tied with a funeral flag so that the flag is burnt by the funeral fire. If bamboo is observed with the top crown canopy in a living bamboo colony, it is cut down immediately, otherwise, a person may soon die in the family. Bamboo is used from the birth of a child to the death of a person. Bamboo is used in house construction, making household items, ropes, fishing gears, and checking

soil erosion. The bamboo shoots both fresh and fermented play a vital role in the traditional cuisines in Manipur. Bamboo splits and small branches are still using as a substitute of toothbrush in romote localities.

4. *Ficus rumphii* Blume (f. Moraceae)

English name: Rumpf's fig tree
Vernacular name: Khongnang pambi (Manipuri); Paras papal (Hindi)
If the plant bears a huge canopy with dark green leaves, then the season will receive good rainfall while canopy is less, the season may receive less rainfall. The Rumpf's fig tree is regarded as a sacred tree and cutting down the tree and its branches is taboo, if done so the person may suffer. This plant is regarded as sacred and not planted in private lands with the belief that devils stay near the tree. It is generally planted in community or public lands and grounds, preferably along roadsides (Plate 1.b).

5. *Hibiscus cannabinus* L. (f. Malvaceae)

English name: Deccan hemp or Indian hemp
Vernacular name: Sougri (Manipuri); Pastan or Pitwa (Hindi)
The leaf of this plant is consumed as a seasonal vegetable (generally cooked with dried or roasted fish, potato slice with or without edible oil) by the native people and extensively cultivated and sold in local markets. The availability of rain in a particular season is determined by the flowering of this plant. If the plant starts bearing flowers and leaves become reddish, it is presumed that the rainy season of the year will end shortly (Plate 1.c).

6. *Mangifera indica* L. (f. Anacardiaceae)

English name: Mango
Vernacular names: Heinou (Manipuri), Aam (Hindi)
If the mango plants produce an extraordinarily large number of flowers or inflorescence, the current year may have stronger wind or storms and heavier rainfall. It is also assumed that if the colour of the mango leaves is dark green at the beginning of a season, there will be good rainfall for the year. Mangoes are extensively planted in home gardens, parks and in the campuses of schools, colleges and institutions (Plate 1.d).

7. *Parkia roxburghii* G.Don. (f. Mimosaceae)

Tree bean or Stinking bean (English)
Yongchak (Manipuri), Khorial (Hindi)
The pod of this medium-sized deciduous tree is a highly-priced vegetable for the native people and is regarded as a delicacy. The matured seeds and pods are used in preparation for a traditional dish called "Eronba" and are regarded as a delicacy The inflorescence is also consumed by locals as a traditional salad called "Shingju". It is in high demand in the markets and fetches a good price. The intensity of flowering of this plant is traditionally been believed to be weather-indicative. If the plant bears an exceptionally large number of inflorescences mostly in the lower branches, the

current year may have strong wind or storms and will have heavier rainfall (Plate 1.e).

8. *Platycerium wallichii* Hook. (f. Polypodiaceae)

English name: Staghorn fern or Indian staghorn or Elkhorn fern
Vernacular name: Saji-machi-changkhrang (Manipuri)
This is a rare epiphytic fern found in Moreh region of Manipur. If the colour of the vegetative fronts of this plant is dark green, it is presumed that there is a possibility of good rainfall in that particular year while the colour of the plant is dull in colour, then no rain is expected in the immediate future. The plant is highly-priced as a pot plant. The plant is a very rare epiphytic fern from Manipur (Moreh region) reported for the first time in India (Jain & Sastry, 1980).

9. *Rotala rotundifolia* Koehne (f. Lythraceae)

English name: Roundleaf toothcup or Dwarf rotala
Vernacular name: Loubuk-leiri (Manipuri)
This plant is generally grown in paddy fields and nearby streams and water bodies or swampy localities in valley areas and foothills of Manipur. If the plant is grown luxuriantly, is an indication of good rainfall in that particular year while the plant has stunted growth is an indication of possible drought. The luxuriant growth of this plant is also assumed as an indicator of good soil fertility. The plant has applications in the traditional healing system to stop bleedings as well as to treat calculi in which the soup obtained by boiling the plant in water is taken 2–3 glassws daily for a period of 30–45 days (Plate 1.f).

3.2 Animals

1. *Anabas testudineus* (Bloch, 1972) (f. Anabantidae)

English name: Climbing perch
Vernacular name: U-kabi (Manipuri)
If the Climbing perch fishes come heavily (moshing) at the periphery (bank) of the ponds or water bodies, it is assumed as a sign for immediate heavy showers to come. In a sudden and heavy rainfall, particularly in the first strong shower of a season, a large number of these fish is coming up to the lands (Plate 1.g).

2. *Anopheles* spp. (Meigen, 1818) (f. Culicidae)

English name: Mosquito or Marsh mosquito
Vernacular names: Kaang (Manipuri), Mashar (Hindi)
During a rainy season, if mosquitoes come out and fly exceptionally in large numbers by evening sunset time (mostly from 5.30 pm to 6.30 pm), it is expected that rain may come in that night.

3. *Bos taurus* (Linnaeus, 1758) (f. Bovidae)

English name: Cattle

Vernacular names: Shan (Manipuri), Gai (Hindi)

During a rainy season, the cattle graze freely in paddy fields or grazing grounds if they come back early to home, it is believed that there may be heavy rainfall and possible thunderstorms and lightning. It may be noted that cattle in India are sacred and generally worshipped by Hindus.

4. *Camponotus* spp. (Mayr, 1861) (f. Formicidae)

English name: Carpenter ants

Vernacular name: U-kakcheng (Manipuri); Badhee cheentee (Hindi)

If these ants make their nest high on trees, it is presumed that there may be heavy rainfall and possible flood while the nest is made in lower heights of the tree is a sign of lesser rainfall or possible drought of the season.

5. *Centropus sinensis* (Stephens, 1815) (f. Cuculidae)

English name: Greater coucal or Crow pheasant

Vernacular: Nong-goubi (Manipuri); Bhardwaj (Hindi)

It is traditionally believed that the Greater coucal has the capability to call rain as narrated in many folktales of Manipur, especially of the Meitei community. If the Greater coucal bird does a hissing threat call, rain may come soon. There is a folktale in Manipur that Indra (God of rivers or earth) invited the Greater coucal bird to participate when God and living creatures dug rivers on earth but the Greater coucal dot not participate; so, God was angry and banned the bird from using water from the rivers. As the bird is unable to drink water from rivers, they always call rainwater. Therefore, if the bird makes a hissing threat call, rain may follow.

6. *Channa punctata* (Bloch, 1793) (f. Channidae)

English: Spotted snakehead

Vernacular: Ngamu (Manipuri)

In the off or dry season, if the spotted snakehead fish is hiding penetrating deep inside mud is an indication that the particular year may receive rainfall late and may be drier. This fish is frequently used in religious offerings by releasing in water as a substitiute of bad omens of the family. This may be considered as one measure to conserve the fish in traditional practice (Plate 1.h).

7. *Coptotermes formosanus* (Shiraki, 1909) (f. Rhinotermitidae)

English: Formosan subterranean termite

Vernacular: Mukthrubi or Leishou (Manipur)

During a course of trending rainfall, if the winged termite comes out in masses and flies around, it is assumed as an indication that the rain may stop within a short while.

8. *Corvus macrorhynchus* (Wagler, 1827) (f. Corvidae)

English name: Jungle crow or Large-billed crow

Vernacular names: Kwak (Manipuri), Kawa (Hindi)

The nest of the Jungle crow is generally made on the branches of Rumpf's Ficus (*Ficus rumphii* Blume), locally called Khongnang pambi. If the nest is made on the top of the tree, it is assumed that there may be heavy rainfall and a high possibility of flood. If the nest is made in the lower branches of the tree, it is assumed that there may be strong wind and storms for the year. If the crow produces a caw sound repeatedly in the late morning (10 am to noon) is regarded as a sign of possible rainfall. Resting of the bird on the rooftop is regarded as a bad omen.

9. *Duttaphrynus melanostictus* (Schneider, 1799) (f. Bufonidae)

English name: Common toad or Asian common toad

Vernacular name: Hangoi-borabi or Hagoi-borobi (Manipuri); Mendak (Hindi)

During a rainy season, if a large number of common toads repeatedly croak together, it is assumed as a sign of rain within a short while. In a traditional belief and practice, if someone wants to stop rain for a particular time (for important events or festivals), the toad is kept in captivity with a bamboo basket till the function is over.

10. *Esomus danricus* (Hamilton, 1822) (f. Cyprinidae)

English: Indian flying barb

Vernacular name: Ngashang (Manipuri)

If this surface-feeding fish is extraordinarily fluttering on the surface of the water, it is expected that rain may come within a short while. If the fish is calm inside the water, there is no expectation of immediate rainfall. This fish is consumed by cooking or steamed and regarded as a delicacy.

11. *Milvus migrans* (Boddaert, 1783) (f. Accipitridae)

English name: Black kite

Vernacular name: Umaibi (Manipuri)

If the black kite birds are frequently flying high in the sky, it is assumed as an indication of a possible flood of the year whereas if the birds are flying low, it is a sign of wind or storm and less rainfall. Resting of this bird on the house is taken as a bad omen for the family. In that case, some religious ceremonies are performed to protect from the evils.

12. *Spilopelia chinensis* (Scopoli, 1786) (f. Columbidae)

English name: Spotted dove or Indian spotted dove

Vernacular name: Lam-khunu (Manipuri); Chotroka fakhta (Hindi)

If the spotted dove fully expands their wings while resting on the ground (locally term it as "Khunu masa fouba") in the rainy season is a sign of rain within a short while. The Meitei ethnic people believe that spotted doves are an incarnation of their forefathers and foodgrains and fruits are offered especially during the month of Manipuri traditional "Langban" calendar month (which generally falls in August) (Plate 1).

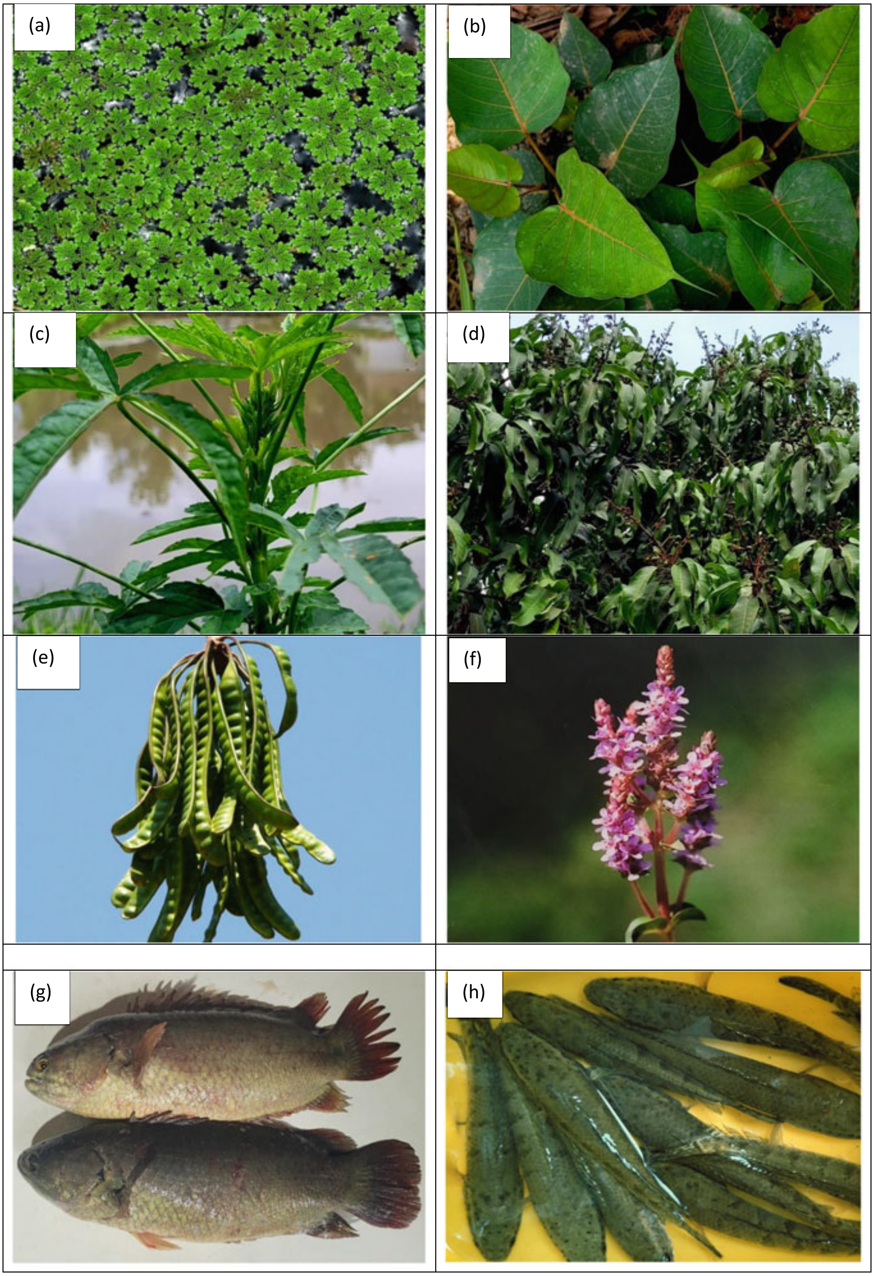

Plate 1 Some of the plants and animals that are assumed as bio-indicator by ethnic people of Manipur; (a) *Azolla pinnata*, (b) *Ficus rumphii*, (c) *Hibiscus cannabinus*, (d) *Mangifera indica*, (e) *Parkia roxburghii* (f) *Rotala rotundifolia*, (g) *Anabas testudineus*, (h) *Chana punctatus* (all the photos are taken by the author)

4 Discussion and Conclusion

In the present communication, a total of 9 plants and 12 animal species are recorded which are traditionally believed to be indicator of weather and natural calamities by the Meitei or Meetei community of Manipur. All these plants and animal species also have other economic uses. Honouring and practicing the traditional knowledge is one effective method of biodiversity conservation and living harmoniously with the nature. In the traditional belief, bearing of exceptionally large number of flowers or inflorescence in a plant is assumed to be an indicator of strong wind and high rainfall in a particular season. The flowering pattern and intensity of some plants are also assumed to indicate climate and natural calamities like rainfall, drought, storm, earthquake, etc. as elaborated in the enumeration section. Bamboos are an integral part of the lives of Manipuri people, as bamboo is needed from childbirth to death of a person (Singh et al., 2003). Traditional knowledge plays a vital role in modern research and development. Many of the findings are made based on traditional knowledge. It is agreed that the traditional knowledge system greatly helps in research (Singh, 2011). Citing a few examples; many of the folk medicines are proved logical e.g. the blood congulant activity of *Gynura cusimbua*, blood pressure control of *Allium hookeri*, cough suppression of *Phlogacanthus thyrsiformis*, etc. The information or knowledge acquired amongst the ethnic or native people has been transferred from one generation to another generation as filtered and acceptable information. Many of the traditional information and practices are proven correct by science. The significance of the knowledge-practice-belief complex of indigenous peoples relating to the conservation of biodiversity should be acknowledged entirely to enable sustainable management and development of our local environment (Singh et al., 2022).

As some disasters and other calamities are difficult to predict accurately by science, traditional knowledge may be used as a precautionary tool to take vigil and minimize damages from disasters (Singh, 2021). The ethnic people of Manipur have profound knowledge of forecasting weather climate and lightning by observing the characteristics and behaviour of some plants and animals for ages. In the present communication, 9 plants and 12 animal species which are regarded as weather, climate and calamities indicators are discussed and documented. These plant and animal species also have economic values other than those used as weather and calamity indicators. This information is necessary to document properly, finding possible scientific explanations and made available to the mass populace so that preparedness be made before any calamities. If the traditional knowledge has scientific explanation (and validated), such a traditional knowledge system may be included in the national database of climate change prediction and strategy of disaster management as it involves local communities that are the major causalities in calamities (Singh, 2011). The present communication is an attempt to document old-age believes and practices involving some plants and animals on climate and weather forecasting by Meitei community of Manipur, North East India to throw some light on thematic research but not trying to substitute the science. The scientific basis of the traditional information and practice be logistically explained and established and made a proper document.

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Traditional Ecological Knowledge Repository in the Indian Himalayas: An Overview

P. Sahana Florence and Achyutananda Mishra

Abstract "Traditional ecological knowledge" (TEK) refers to a body of information that is also referred to as "local knowledge," "traditional knowledge," "native knowledge," and "indigenous technological knowledge." A number of studies show the role of traditional ecological knowledge in decision-making in social-ecological systems that support sustainability and resilience. International agencies have also highlighted and emphasised the importance of TEK practises in the preservation of biological variation. For instance, the UN Convention on Biodiversity, Article 8 (j), makes it very plain that "respect, maintain, and promote innovation and practises of indigenous and aboriginal populations connected with sustainable use of biological diversity" are essential. The benefits of TEK for sustainable forest management were acknowledged in the 2005 Millennium Ecosystem Assessment Report by the World Bank. As environmentalists, anthropologists, and arborists share interests in TEK for academic, social, or economic reasons, this highlights the significance of TEK in difficulties relating to biodiversity protection. Numerous components of TEK are seen favourably by experts in fields of forestry, irrigation, architecture, ethnobiology, irrigation, agriculture, medicine, sun and water conservation, conventional weather prediction, adaptation to climate change, and disaster risk reduction. Indian Himalayan Region (IHR) is predominantly populated by indigenous peoples and local societies, which are quite diverse in terms of socio-culture and race. The region has nearly 40% of all of India's indigenous tribes. This area is also special for its traditional ecological knowledge. Many of the TEK-based practices have supported local communities in earning a livelihood. The indigenous people's expertise and experiences are said to play a crucial part in preventing climate change, and they may give important information on the implications of climate change. Hence, sustaining biodiversity in the IHR is also a means of defending indigenous peoples' rights. By making the TEK the focal point of governance systems at the IHR, the variety of options for sustainable growth and even the co-production of the body of knowledge would be expanded. Therefore, it seems sensible to get knowledge from the TEK before it is lost to the onslaught of modernity. However, there are numerous

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problems or issues with traditional ecological knowledge in India, including ignorance in considering conservation policies by the Indian government and the lack of effective documentation of this priceless knowledge. To develop sustainable and culturally suitable management techniques, it is currently a challenge to combine indigenous knowledge standards and management methods with Western science. Realising the above, this chapter attempts to comprehend the concept of TEK and its application throughout a variety of resource management contexts throughout a variety of resource management scenarios. Further, it will explore various issues and challenges and examine the regulations thereof. Lastly, this chapter concludes by highlighting the strategies and suggestions for an effective repository of traditional ecological knowledge in the Indian Himalayan Region.

Keywords Biodiversity · Traditional ecological knowledge · Repository · Indigenous peoples · IHR

1 Introduction

Traditional ecological knowledge (TEK), which implies local knowledge, traditional knowledge, native knowledge, indigenous technological knowledge, etc., is widely acknowledged as an intellectual endeavour and is described as such by a variety of environmental, cultural, and social factors (Tynsong et al., 2020). A TEK is a crucial component in terms of the social values used in developing countries to generate food, improve health, and mould local views and perspectives on the world and people (Finn et al., 2017). Traditional ecological knowledge was transmitted from one generation to the next, and over time, it was enhanced and honed into a corpus of profound local knowledge and customs (Nautiyal & Goswami, 2022). Furthermore, in addition to providing ecosystem benefits, TEK and management strategies may help us understand systems for adaptive and socio-ecological management (Pandey, 2002). TEK is a crucial resource for addressing issues with socio-cultural practises, food security, the environment, and biodiversity (Rai & Mishra, n.d.). Unfortunately, when looking at natural resources in underdeveloped countries, TEK and its merits are generally overlooked. Regulations in India, such as the Biological Diversity Act of 2002, the Forest Rights Act of 2006, and intellectual property rights, have been developed to own TEK and share benefits with the local population (Pandey, 2002). TEK has been preserved, promoted, and documented with a lot of effort on both the national and international levels. However, there hasn't been any influence at ground level (Harisha et al., 2023). Traditional ecological knowledge encompasses multiple facets of climate change adaptation, medicine, weather forecasting, irrigation, agriculture, ethnobiology, and disaster risk reduction. If TEK were placed at the centre of environmental governance, the variety of opportunities for ecological sustainability and the co-production of a body of knowledge would indeed be enlarged (Traditional Knowledge System in the Himalayan Region: Key to Sustainable Development – Kalinga Institute of Indo-Pacific Studies, 2023). Therefore, it makes sense to get knowledge from the TEK before it is lost to the forces of modernity (Rai and Mishra, n.d.). In light of the aforementioned, this chapter makes an effort to comprehend the idea of TEK and how it may be used in diverse resource management scenarios.

2 Traditional Ecological Knowledge: A Conceptual Framework

2.1 Concept and Meaning of TEK: Meaning and Significance

Traditional ecological knowledge (TEK) is a notion that has many other names, including local knowledge, traditional knowledge, native knowledge, indigenous technical knowledge, etc. (Rai and Mishra, n.d.). It refers to indigenous and other traditional understandings of regional resources. The term "traditional" is a bit abstract in this notion. For some groups of people, the term "traditional" denotes a continuing adherence to outdated practices or a belief system rooted in superstition (Tynsong et al., 2020). While for many others, TEK means possessing or understanding information in various ways, it is distinct from the actual dimension of knowledge because it is formed in a manner that preserves the communities' traditions. TEK is adapted to the indigenous ecosystem and developed from the experiences gathered over the ages (Rai and Mishra, n.d.). Generally speaking, it has to do with understanding the composition and operation of nearby natural ecosystems and how to utilise them sustainably for human benefit (Tynsong et al., 2020).

TEK can be defined as the assimilation of knowledge acquisition and dissemination more straightforwardly. Any community, society, or culture's traditional indigenous knowledge is a special form of local knowledge (Jenkins, 2022). TEK is focused on how living things—including humans—interact with their surroundings and with the social groups that make up their traditional communities. Indigenous knowledge (local knowledge), though not a term that all communities use, refers to a set of information, traditions, or practices that have a strong place component (Usher, 2000). When few environmental baselines have been scientifically recorded, such information is used for managing natural resources to either replace or augment Western scientific approaches to ecological management (Jenkins, 2022). TEK can also be thought of as a self-management system, a very important source of environmental expertise that helps indigenous or other remote native cultures protect and maintain their way of life (Nautiyal & Goswami, 2022). It serves as the foundation for local decisions about social, economic, and political organisation, resource management, education, health, hunting, and agriculture. It is widely acknowledged that there is a connection that cannot be broken between biological and cultural variation (Nautiyal & Goswami, 2022). The biotic and abiotic environments, which vary depending on the types of society and culture, have an impact on the ongoing process of modification that resource users use to create TEK rather than specialists

(Rao et al., 2003). In a nutshell, it is a comprehensive corpus of knowledge, belief, and practise, growing from the TEK worldwide among indigenous and local people, and verbally transmitted from one generation to the next cultural values, beliefs, proverbs, folklore, and traditions, as well as regional laws, dialects, and agricultural practices (Tynsong et al., 2020) such as breeding changes in plants and animals, which are considered the community's intellectual property and intangible heritage (Nautiyal & Goswami, 2022).

2.2 Development of TEK

Traditional ecological knowledge (TEK), sometimes known as "traditional knowledge," is the specialised knowledge that societies that have traditionally lived near natural environments have amassed about those ecosystems and environmental resources (Kala, 2011). TEK serves as an example of the knowledge accumulated over centuries through direct human interaction with the environment. Although TEK has been used since the dawn of hunter-gatherer societies, tribal elders first used the phrase in the 1980s with a conceptual model to advance a deep understanding and raise awareness of TEK's significance (Kala, 2011). It was at this time that TEK began to get international attention for its potential use in sustainable development and resource management strategies. The World Commission on Environment and Development (WCED), established in 1983, released a report titled "Our Common Future" in 1987. The report was given the name "Brundtland Report" in honour of Commission Chairwoman Gro Harlem Brundtland (Commission on Environment, n.d.). It created the fundamental ideas of sustainable development as we know them today. The document noted how current trends increased ecological degradation "amidst diminishing resources and an ever-cleaner world" were brought on by the twentieth century's accomplishments (Commission on Environment, n.d.). But there was still hope for conventional ways of living. The study's findings indicated that indigenous peoples and cultures have ways of life that may teach modern nations how to manage resources in intricate forest, mountain, and dryland environments (Finn et al., 2017).

Since its origin, TEK as a natural substitute for knowledge systems in the environmental and biological health sciences has drawn increased attention from a variety of municipalities, governmental agencies, and academics (Kodirekkala, 2017). Scholarly experts and government organisations are beginning to see the importance (Kodirekkala, 2017) that such regional historical information can have for preserving biological processes, conservation areas, biodiversity, as well as other elements on indigenous territory (Bureau of Indian Affairs (BIA), 2016). The organisations that deal with indigenous people throughout the globe used components of TEK to valorise a body of knowledge made up of rich, historical data accumulated by decades of observers whose lives and cultures relied on this knowledge and its application (Finn et al., 2017).

Several disciplines, such as agriculture, pharmacy, and ethnobotany, respect it since it currently indicates a seamless connection between ecosystems and people (Kala, 2011). Additionally, taking into account the current environmental problem, the destruction of organic habitats, and climatic alterations, TEK is regarded as a crucial instrument to mitigate the impact of shifting ecological and climatic conditions globally since it promotes the ideas of coexistence and sustainability (Kala, 2011). TEK assists in the creation of processes for local decision-making in several activities, including agriculture, pastoralism, food preparation, healthcare, and the management of natural resources (Lemi, 2019). It is a collection of particular local knowledge that has been refined over time. The concept of TEK was developed in an attempt to reassert the authority of regional groups whose voices and interests had been drowned out by the prevalent rhetoric of science-based modernization and development. Western scientists increasingly consider TEK in tribal research (Lemi, 2019). When Agenda 21 was established at the UN Conference on Environment and Development (UNCED), which was held in Rio de Janeiro in 1992, Traditional Ecological Knowledge Systems (TEKS) gained significance (Traditional Knowledge System in Himalayan Region: Key to Sustainable Development—Kalinga Institute of Indo-Pacific Studies, 2023). This was in response to new research and political acknowledgement of indigenous rights (Lemi, 2019). The Convention on Biological Diversity (CBD), which specifically addressed concerns regarding traditional knowledge, created international agreements that provide the sharing and protection of national biodiversity (Pandey, 2002). The UN Convention on Biological Diversity's Article 8(j) makes it very apparent that indigenous and aboriginal groups' innovations and practises related to the sustainable use of biological diversity must be respected, preserved, and supported. The Nagoya Protocols (2010) provide such a legal structure for effectively achieving the relevant CBD objectives (Traditional Knowledge System in Himalayan Region: Key to Sustainable Development—Kalinga Institute of Indo-Pacific Studies, 2023). The benefits of TEK for sustainable forest management were accepted by the World Bank and the Millennium Ecosystem Assessment Report, 2005 (Lemi, 2019). Support for indigenous wisdom, traditions, and customs is acknowledged in Article 31 of the United Nations Declaration on the Rights of Indigenous Peoples, 2007 (United Nations Declaration on the Rights of Indigenous Peoples United Nations, n.d.). As ecologists, anthropologists, as well as arborists (a tree surgeon) share a passion for TEK in academic, social, or commercial objectives, this highlights the significance of TEK in difficulties relating to biodiversity protection (Lemi, 2019).

2.3 Benefits of TEK

TEK has been used since the beginning of time. TEK contributes significantly to conservation efforts and, by saving time and money, helps pave the way for modern research and development (Benefits of TEK—Traditional Ecological Knowledge (U.S. National Park Service) 2023). A variety of TEK-related characteristics are widely acknowledged by scientists in the fields of ethnobiology, conservation of soil, forestry, medicine, agriculture, irrigation, architecture, catastrophe risk reduction, climate change adaptation, water conservation, and forecasting (Gómez-Baggethun et al., 2013b). Application of TEK fosters cooperation with Indigenous peoples on environmental issues of shared interest offers transversal information for action planning connected to climate change and improves decision-making concerning species and ecosystems. The range of alternatives for sustainable development and knowledge base co-production would be increased if TEK were to be the focal point of environmental governance (Benefits of TEK: Traditional Ecological Knowledge (U.S. National Park Service), 2023). It promotes the ideas of cohabitation and sustainability. In light of the current environmental situation, the destruction of climatic change, and natural ecosystems, TEK is viewed as a crucial instrument to lessen the effects of altering global climatic and biological circumstances. The design of methods for decision-making at the local level in a range of disciplines, including livestock husbandry, food preparation, medical care, and resource development, is aided by TEK (Kala, 2011), which is a collection of specific local knowledge that has been refined over time (Garkoti & Semwal, 2015).

2.4 Aspects of TEK

Many writers have made an effort to compare the indigenous tribes' environmental information and that of the colonisers to better understand the two knowledge systems (Houde, 2007). A group's traditional ecological knowledge is made up of a variety of knowledge elements that have been categorised by some individuals (Usher, 2000). This research aims to comprehend how traditional ecological knowledge (TEK) may enhance environmental management or advance scientific knowledge. Houde lists the following six features or elements of conventional ecological knowledge (Rai and Mishra, n.d.). The elements of conventional ecological knowledge can be used and understood in a variety of ways. When attempting to combine two different methods of knowing and thinking. These are instructional illustrations of how it is applied from different angles and how they intersect, emphasising it even more. To more precisely pinpoint areas of convergence and divergence, collaborative management is used (Houde, 2007) (Fig. 1).

I. **Factual Observation**

The list of precise observations which TEK bearers can produce is the first and most well-known component of TEK (Houde, 2007). Non-aboriginal researchers studied folk taxonomy, requiring TEK components to name, identify, and classify environmental components (Gagnon & Berteaux, 2009). It includes knowledge of facts about animals, information about the habitat and behaviour of animals, information about the anatomy of different species, and information that has been synthesised from various scientific discoveries. Monitoring ecosystem health indicators requires understanding species relationships, biophysical connections, spatial

Fig. 1 Aspects of traditional ecological knowledge. *Source* The Authors

distributions, and historical trends in population and spatial patterns (Houde, 2007). Understanding ecosystem dynamics is crucial for environmental science advancement, database addition, and detecting changes in ecosystems. The management of endangered species and environmental impact assessments are seen as the contexts in which this is most helpful. Detecting unintended development implications helps First Nations (indigenous peoples) engage in decision-making processes (Houde, 2007). Factual TEK can be misinterpreted if it doesn't serve state or private interests, as First Nations lack control and participation in resource management decisions. Many Aboriginals have expressed grave concern about this lack of responsibility for TEK and its application (Kala, 2011).

II. **Management System**

In terms of management systems, the sustainable and ethical use of resources is the second component of TEK (Houde, 2007). Therefore, the TEK study's main emphasis is on the management of resource methods and how they have been modified for regional settings. The second TEK component involves measuring resource status and strategies for sustainable use, including pest control, conservation, and cropping patterns (Herrmann & Torri, 2009). This face acknowledges that TEK, which adapts to change by developing effective technology, is a "complex web of behaviours" (Houde, 2007) connected to an understanding of animals and their interactions.

III. Current and Past Uses

The temporal dimension of TEK, which is the third component, is concerned with environmental uses that have been verbally transmitted in the past and present, such as land usage, habitation, harvest, and settlement rates (Gagnon & Berteaux, 2009). Particularly important issues include historical sites and medicinal plants. This TEK component includes life tales that are handed through stories that foster a sense of family and community, tales are passed down through generations (Houde, 2007). In the course of land claim talks, Canadian First Nations frequently disclose this aspect of TEK. The Supreme Court of Canada, in Delgamuukw v. British Columbia [(1997) 3 SCR 1010], ("Delgamuukw v. British Columbia, SCC Cases," 2023) observed that oral history now has more legitimacy. First Nations identify toponyms, historical locations, and occupancy patterns using charts to demonstrate their native connection and regain lost terrain. First Nations compromised on TEK to increase integrity in the context of Western science, waiting for authority's recognition of their knowledge systems (Herrmann & Torri, 2009).

IV. Ethics and Values

The fourth aspect discusses the relationship between belief systems and facts, focusing on environmental ethics and values concerning human relationships and species' habitats (Janaki et al., 2021). Resource management struggles to effectively transfer TEK cultural rights as policy documents may not fully accommodate land ethics. First Nations assert their principles through position papers with minimal consequences. Examples of state and indigenous ethics that conflict but are rarely properly addressed include trophy hunting and catch-and-release fishing (Houde, 2007).

V. Culture and Identity

This fifth facet emphasises the significance of language and historical imagery in preserving culture. The culture that defines Aboriginals (original inhabitants) depends on the relationship between them and their surroundings (Finn et al., 2017). The notion is that indigenous civilizations are centred on the land and that if the land disappears, those cultures would perish or undergo far too much alteration, and civilizations also individuals would follow, it is essential to preserve these locations if aboriginal culture is to endure over the long term (Gagnon and Berteaux, 2009). Local histories, cultural practises, and social structures are all taken into account in this TEK component as they relate to the persistence, of indigenous cultures' and identities' expansion and regeneration. It highlights how cultural landscapes have healing qualities and may serve as sites for spiritual rebirth (Houde, 2007).

VI. Cosmology

The final recognisable facet of TEK is a cosmology with cultural roots that serves as the foundation for and is inextricably linked to the earlier faces. Cosmology is an idea that many cultures have about how the world functions. The laws that govern how people and animals interact with one another and how humans fit into the greater scheme of things are laid forth in this worldview, which also outlines how everything is interrelated (Houde, 2007). Many anthropologists and cultural ecologists have studied this aspect of TEK to comprehend, for example, how "Cree" or "Inuit" peoples understand human-nonhuman animal relationships and how they affect managerial practices, social responsibility to others in the community, and social interactions. This dimension's resemblance to religion has been suggested. Others have refuted this assertion, claiming that TEK is more of a philosophy than an ideology and that the state's resource management was, in any case, founded on a particular philosophy that had a significant influence on the Christian worldview (Characteristics of the Six Faces of Traditional Ecological Knowledge (TEK) | Download Table, 2023).

3 Western Science and TEK: A Comparison

> Traditional Ecological Knowledge is complementary to Western science, not a replacement for it—David Suzuki

Many academics have recently been interested in the vast group of knowledge named "traditional knowledge" (TK), "indigenous knowledge" (IK), or "traditional ecological knowledge" (TEK), with other titles (Finn et al., 2017). These systems of multigenerational knowledge are founded on individual and group worldviews and experiences that have been approved by seniors. They also draw on oral traditions, various kinds of record-keeping, and directed and transmitted experiential learning. The TEK's more encompassing components include a wide and deeper knowledge of how people interact with various aspects of the physical, social, and spiritual environment, beyond conventional conceptions like actual assertion and co-management standards (Houde, 2007). On the other hand, when it is found that TEK conflicts with scientific results, its usefulness is called into doubt or it is written off as a myth. In popular culture, science is depicted as being impartial, quantitative, and the basis for advancement and assessment of "real" information, whereas TEK might be seen as hearsay, incorrect, or written unusually (Finn et al., 2017). Fulvio Mazzocchi of the Institute of Atmospheric Pollution of the Italian National Research Council contrasts TEK and Western scientific knowledge as follows: The interconnection of humans and nature has become a central theme in traditional ecological knowledge's development of an understanding of the environment. It provides a strategy for regional growth that takes account of ecosystem density and co-evolution with the surroundings (Mazzocchi, 2006). It may be useful for environmental evaluation, development planning, and natural resource management. It may also aid in conservation education (Arruda & Krutkowski, 2017). In addition to the usual advantages for individuals who rely on this information, it may provide mankind with a whole set of new ecological and biological insights. In comparison to Western science, which is scientific and materialistic, traditional knowledge is eternal and does not differentiate between the sacred and the secular. Traditional knowledge is mostly qualitative and intuitive, as opposed to Western science, which is scientific and quantifiable (Mazzocchi, 2006). The elders often verbally pass on traditional knowledge from one generation to the next. whereas Western science was founded on the exchange of intellectual and literary information (Finn et al., 2017). While Western science uses reductionist techniques and a linear cause-and-effect mechanism, TEK considers the issues affecting the overall biological community. The human brain is used in TEK to gather, filter, and evaluate observational data (Kodirekkala, 2017). In terms of its demands for consistency and proof, traditional ecological knowledge (TEK) differs from Western science. It is dispersed and produced differently from Western science and is frequently viewed as folklore. Modern tradition holds that Western science alone possesses the truth, frequently as a result of the tension between science and conventional wisdom. In other cases, Western scientific knowledge and TEK are not fundamentally different; both ultimately come from scientific findings regarding the surroundings and the methodical process of establishing order and stability out of a survival necessity (Arruda & Krutkowski, 2017). TEK's cultural and religious environmental ideas are essential to understanding and safeguarding the environment, even though some of them may be illogical in terms of modern science. As a result, it is hard to discern between scientific and conventional knowledge with precision based on method, epistemology, context, or content (Stephens, 2000). Consequently, to disprove the notion that such a Westernised knowledge structure is the sole workable solution to the global environmental crisis, globalisation should be utilised effectively to have or ingrain indigenous expertise into the globalised world (Gagnon & Berteaux, 2009). Although epistemology is the study of universal knowledge, different types of information might be acquired based on the sociocultural circumstances in which knowledge claims are established and made explicit. There is a need to close the epistemic gap that emerges from not understanding how local or indigenous knowledge is acquired when people with different worldviews work together on the same subject (Stephens, 2000).

3.1 Integration of TEK & Western Science

The ability of traditional ecological knowledge, which represents centuries of experience, to manage complex systems is widely accepted. A TEK approach for understanding the complex relationships between ecosystems, together with correctly collected longitudinal data and insightful information, can substantially help scientific research (Lemi, 2019). TEK may also be included in Western scientific studies as a component or as an additional tool for quantitative Western methodologies. Unlike scientific knowledge, which relies on separating traditional knowledge, which is founded on connection, knowing from the known (Lemi, 2019) Academic scholars have recently started to investigate, assess, and, in some instances, seek to integrate indigenous knowledge systems into modern scientific theories and institutional frameworks. These academics are conversant with the ideas and practices of TEK (Finn et al., 2017).

According to research conducted in the Arctic, there are five areas where TEK and Western science can integrate. The area of focus includes local scale expertise; sources of historical climate data; hypotheses and research questions; effects and community adaptation; and neighbourhood-based surveillance (Lemi, 2019).

TEK can be highly helpful in deciding on adaptation measures for climate change as well as in analysing its effects (Lemi, 2019). Traditional knowledge may support scientific knowledge by allowing people to gain practical experience navigating ecosystems and adjusting to change. For example, India's advancement in science has benefited from the ancient wisdom and knowledge that have been developed in several fields, including management of natural resources, mathematics, metallurgy, surgery, and medicine (Pandey, 2002). Traditional knowledge, local skills, and rural craftsmanship all have a wide range of applications in India. We must take into account both science and verified local knowledge in developing a strong sustainability science because "knowledge cannot be split." (Pandey, 2002). Local knowledge systems can assist with problems like forest management, sustainable water management, biodiversity preservation, and climate change mitigation because they are still commonly employed in India. We must make use of all available knowledge in order to create effective mitigation strategies for the ecological repercussions of climate change (Pandey, 2002). The potential advantages of TEK for resource management are growing in popularity. Governmental and non-governmental organisations are beginning to include TEK in planning, policies, teaching, and research pertaining to climate change throughout the world. The TEK project has been funded by the National Science Foundation so that it may be used in the study of climate change (Traditional Knowledge Holders Formalize a Network for Community to Community Exchange—Institute for the Advanced Study of Sustainability, n.d.). By establishing the Traditional Knowledge Initiative, the Convention on Biodiversity Conservation, the United Nations University (an academic division of the UN), and other affiliated organisations have also recognised the significance of TEK (Traditional Knowledge Holders Formalize a Network for Community to Community Exchange—Institute for the Advanced Study of Sustainability, n.d.). TEK is essential for understanding and promoting its ethical use in international initiatives (Lemi, 2019).

In this context, the merging of formal and traditional sciences is urgently needed. The following factors could be helpful in this respect (Pandey, 2002):

1. The development of numerous approaches allowing locals and formal scientists to study together.
2. In order to apply indigenous practices in forest development and management initiatives, institutional structure in the community and ethical forestry must receive full attention in forest development regulations and forest management procedures.
3. The application of traditional knowledge and practises might be advantageous for developing village micro plans for sustainable, cooperative forest protection, and rural development. Both governmental and conventional community borders should be considered in the planning.

4. Restoration of water management practice techniques which have long supported civilisation but are now in danger.
5. In order to implement adaptive techniques for natural resource management, it is obvious that traditional and formal sciences must be integrated.

TEK has become more widely used in conservation planning and resource evaluation because of its effectiveness, additionality, and community engagement. Information gathering with TEK might be more successful when there is a strong correlation between TEK and scientific data (Finn et al., 2017). Although such systems of knowledge take a long time to establish and require a significant investment from experts in social science, rigorous experimentation and observation approaches may frequently be able to obtain some of this knowledge more quickly and inexpensively than via conventional ecological study (Pandey, 2002).

4 TEK and Resource Management

In recent years, study into traditional ecological knowledge and wisdom has given birth to a new language and point of reference in the management of natural resources (Chettri & Sharma, 2022). The role that TEK plays in decision-making in social-ecological systems that support resilience and sustainability is being highlighted by an increasing number of studies. Academics are becoming increasingly interested in TEK, and development organisations concur that the concept and its use in managing natural resources are essential (Chettri & Sharma, 2022). Due to the widespread decrease in quality and ecological services that affect human well-being, more attention is being paid to indigenous communities' TEK rules and processes for ensuring sustainable natural resource management and use. In recent years, TEK has come to be recognised as an essential beginning point for the development of effective environmental management and preservation programmes (Rai and Mishra, n.d.). TEK was originally mocked as being unscientific, but today it is viewed as being more productive and environmentally responsible, and it is frequently necessary for the development of successful sustainable development initiatives (Rai and Mishra, n.d.). The practise of TEK predates the hunter-gatherer cultures themselves, even if the name didn't start to be used often until the 1980s. In various disciplines, including environmental sciences, studying traditional knowledge is crucial. In Our Common Future (Commission on Environment, n.d.), it is stated:

> The way of life of tribal and indigenous peoples can teach modern cultures a lot about how to manage resources in the complicated forest, mountain, and dry land ecosystems.

Indigenous and tribal populations will need particular consideration whenever the strains of economic growth disrupt their traditional ways of existence. These people have a lot to teach contemporary cultures about resource management in difficult forest, mountain, and dryland settings (Negi et al., 2018). Some people are practically in danger of extinction due to irresponsible development that they have no control over. They should have a major say in establishing how resource development in their areas will be controlled, and their customary rights should be upheld. These organisations act as repositories for a vast collection of conventional knowledge and wisdom that trace humanity back to its origins in prehistory. Their passing is a loss for contemporary society, which would greatly benefit from their traditional understanding of how to sustainably manage enormously complex natural systems (Negi et al., 2018). The IUCN Programme on Traditional Knowledge for Conservation claims that much of the traditional ecological knowledge is still relevant for managing natural resources today, particularly in places like wetlands. Traditional ecological knowledge (TEK), despite having helped to preserve nature and natural resources for millennia, is disappearing as a consequence of cultural homogeneity and globalization (Kala, 2011). Applying scientific research with local knowledge enhances environmental sustainability as well as equity, prosperity, stability, and the empowerment of locals. Local knowledge is helpful for the gathering of information, strategic planning, creation of flexible learning and acceptance procedures, scenario evaluation, and support mechanisms for implementing policies (Negi et al., 2018).

5 The Indian Himalayan Region's Traditional Ecological Knowledge for Climate Change Adaptation

5.1 Indian Himalayan Region

The Indian Himalayan (IHR) area is home to over 51 million people, many of whom practise hill farming in delicate and diverse settings, including species-dense forests (NMSHE: National Mission For Sustaining The Himalayan Ecosystem, 2023). Numerous perennial rivers in the region that rely on the survival of glaciers for water supply and power generation have tremendous hydropower potential in the region (Dimri et al., 2019). The IHR is home to about 40% of India's indigenous communities and tribes, giving the entire nation a notable socio-cultural and ethnic diversity (Government of India, 2013). The biodiversity of the Himalayas is primarily caused by several biophysical elements, notably IHR.

The extensive biodiversity in the area is a result of the people's conservation and management practices (Negi et al., 2018). Due to the IHR's great ecological and socio-cultural diversity, it has been named one of 34 "biological hotspots." (i.e., an area of the natural world with such biodiversity that is home to a significant number of endangered indigenous species) (Sharma et al., 2022) Traditional knowledge-based businesses have helped local communities in the area generate money (Dimri et al., 2019). Indigenous peoples of IHR are expected to play a significant role in the fight against climate change since they possess crucial knowledge about its consequences. In the IHR, indigenous traditional knowledge and resource-use techniques have been passed down through the years. Local communities preserve biodiversity by adoring nature and caring for sacred landscapes (Negi, 2021). Indigenous peoples of the IHR have an intimate grasp of and connection to their natural environments. Due to their culture's symbiotic interaction with the environment and their awareness of the clear connection between biodiversity and changing climatic circumstances, a wealth of traditional ecological knowledge has emerged (General/Latest News: Envis Centre, Ministry of Environment & Forest, Govt. of India, 2023).

Natural catastrophes, biodiversity loss, climate change, and food security issues threaten Indian Himalayan ecosystems (General/Latest News: Envis Centre, Ministry of Environment & Forest, Govt. of India, 2023). The Indian Himalaya area is divided into 12 states (IHR). According to a risk analysis conducted by the Department of Science and Technology (DST), Mizoram and Assam are the two states most sensitive to climate change's consequences. Of the eight missions, included in the National Action Plan on Climate Change, the Indian Government formed the NMSHE (National Mission on Sustaining Himalayan Ecosystem).after realising that IHR is an extremely susceptible and fragile ecosystem (General/Latest News: Envis Centre, Ministry of Environment & Forest, Govt. of India, 2023). To create adaptation plans and manage the area's ecosystems, it is crucial to understand how vulnerable the Himalayan region is to climate change, The Indian Institutes for Technology in Guwahati, Mandi, and Bengaluru conducted a collaborative study entitled "Climate Vulnerability Assessment for the Indian Himalayan Region Using a Common Framework". This study outlined the four primary factors that define vulnerability: the socio-economic, demographic, and health conditions of the populace; the susceptibility of agricultural output; living standards dependent on the forest; and data access and infrastructure services (Climate Vulnerability Assessment for the Indian Himalayan Region Using a Common Framework, n.d.). This project also offered a wonderful opportunity to collect and share locally relevant knowledge, for developing innovative responses to climate change's consequences on mountain communities, and for raising awareness of the issues worldwide (The Himalayas and Climate Change WCS-India, 2023).

5.2 The Impact of TEK in Adapting to Climate Change

Indigenous peoples are the first to detect environmental changes since they depend on natural resources and biodiversity. Indigenous peoples have been dealing with regional changes in the climate for millennia (Lemi, 2019). The implication is that conventional ecological knowledge may be used to build protracted datasets obtained via years of trial and error. Indigenous peoples are employing a range of strategies to cope with the loss of biodiversity and adapt to climate change, such as land reclamation, migration, irrigation, water-saving methods, and modifying plant cultivation's schedule, location, and altitude, to mention a few. Thus, using their customs and traditional ecological knowledge, indigenous people have created a variety of techniques to create societal structures that are tailored to deal with the damaging effects of natural disasters (Ingty & Bawa, n.d.). Indigenous peoples' views as well as experiences are essential for scientists to test hypotheses on preventing climate change and gearing up for it. Additionally, they are crucial for adaptation because they are the ones who experience most of climate change's consequences (Ingty, 2017).

The evident connections between indigenous knowledge as well as climate change adaptation need public attention (Gómez-Baggethun et al., 2013b). Indigenous societies could adapt or assist themselves, as seen in previous parts of this chapter for tribes that have recently adapted both to the effects of climate change and to a variety of pressures that have existed for generations (Gómez-Baggethun et al., 2013a). It has been demonstrated via research on indigenous people's perceptions of changing climatic conditions throughout the world that the primary sources of information for climate sciences are traditional knowledge, local observations, and personal experience (Gómez-Baggethun et al., 2013a). Indigenous people might be a significant asset because of their wealth of ecological knowledge in completing scientific investigations in a location like the IHR where there is a dearth of research on climate change's consequences (Gupta & Gupta, 2008). Women are heavily involved in IHR's management of interrelated subsystems, such as agriculture and management of natural forests, farming, and other aspects of the local subsistence sector (Traditional Knowledge System in Himalayan Region: Key to Sustainable Development—Kalinga Institute of Indo-Pacific Studies, 2023). Recent policy, institutional, and technological developments bring to light the IHR's biophysical and social weaknesses, including the fusion of the local subsistence economy, acculturation, dialect disappearance, lifestyle changes, and youth migration (Gupta & Gupta, 2008). Even though there are currently few studies on how indigenous people's TEK contributes to research on climate change, it is acknowledged for its applicability in environmental and social evaluations as well as its contributions to interpreting ecosystem processes. The TEK should therefore be studied before they are lost to the forces of modernity (Traditional Knowledge System in Himalayan Region: Key to Sustainable Development—Kalinga Institute of Indo-Pacific Studies, 2023).

6 Issues and Challenges of Change in Traditional Ecological Knowledge

In light of current world concerns, TEK has become a valuable tool. Particularly about biodiversity loss and accomplishing sustainable development goals (Traditional Ecological Knowledge, 2023). As part of their tens of thousands-year-old way of life, the people of the Indian Himalayan Region had long lived in peace with nature and created a variety of traditional systems. However, due to causes including the expanding human population, and the fragile alpine environment's low productivity, these old knowledge systems are presently vanishing more quickly due to the rising usage of contemporary and/or irresponsible practices (Traditional Ecological Knowledge, 2023).

The IHR is being developed in a way that will preserve ecosystems at the level of biodiversity, organisms, and genetic variation. The IHR is a rich reservoir of biodiversity and culture (NMSHE: National Mission For Sustaining The Himalayan Ecosystem, 2023). According to an analysis of TEK in India, it covers a variety of subjects, including sustainable forest management, preservation of biodiversity by use of precious groves, sacred settings, sacred plant species, agricultural, farm, and animal management, as well as the healing effects of Ayurveda (Traditional Knowledge, 2023). However, the growth of economic interests in forests and biodiversity resulted in a lack of respect for indigenous philosophy and practises, particularly the religious strategy employed by the local inhabitants to maintain biodiversity (Sharma et al., 2009). This caused several inconsistencies and issues with the management and conservation of natural resources (Traditional Ecological Knowledge, 2023). The practicality of TEK faces major challenges despite the promise of increased knowledge:

- When TEK and Western Science are compared, one of the main issues is that TEK loses its significance when applied in a Western scientific atmosphere and taken out of its original context.
- The TEK's close linkages to indigenous languages and culture present another challenge. Oral traditions provide a lot of knowledge that is pertinent to Western scientific investigation, but since it is not comprehended, this information is typically ignored or misunderstood.
- The question of whether or not indigenous peoples still own ownership rights on traditional knowledge systems and need to get authorization before using them is up for dispute. This scenario is particularly complicated by the fact that TEK is often transmitted verbally and could not have any objectively validated evidence.
- The TEK which was able to preserve long-term sustainability has been marginalised by the commodification of environmental assets. These organisations frequently play no active role in the current legal and legislative frameworks for TEK conservation.
- The importance of TEK in climate change adaptation is beyond dispute, although some locals and those outside the scientific community are still unaware of its importance.

In India, particularly in the IHR, no particular legislative framework recognises TEK's importance.

7 Conclusion/Strategies and Suggestions for an Effective Repository of TEK

Many indigenous peoples around the world view TEK as a positive and powerful component of their indigenous identity that is distinctive to their culture and location. For them, the application of TEK in environmental assessment as well as maintenance is a rejection of such a long tradition of undervaluing this kind of knowledge, experience, and talent as well as a validation of the accuracy and applicability of their own. To safeguard the Himalayan ecosystems and the well-being of humanity, these extensive TEK systems must be fully comprehended and adequately documented. For the Indian Himalayan region's sustainable development, formal decision-support systems can benefit from a platform for indigenous knowledge systems. It is important to recognise, accept, and mainstream some of these advantages of TEK practises to protect the sustainability of ecological services and biodiversity in the IHR's fragile mountains. Despite certain obvious limitations, TEK substantially aids in adapting to climate change. However, many people, including indigenous people and researchers, have expressed scepticism about the application of TEK in this circumstance. Major concerns have been made about the identification, preservation, and documenting of TEK in the literature and the now available data, and these worries are valid. Following are a few suggestions to strengthen the TEK**:**

- To integrate TEK systems and referencing technologies into the social settings of the nation, strategic knowledge systems should solicit input from a variety of stakeholders, including representatives of indigenous tribes.
- Respect for indigenous knowledge, voices, and experiences can be seen through digital storytelling. It can convey important messages and aid in the preservation of traditional languages.
- Understanding TEK could serve as a basis for effective co-management methods between Tribes and the government.
- It is essential to scale up TEK to manage resources and decrease climate change's impacts. Empowering neighbourhood groups to use TEK to prepare for climate change.
- To recognise the intellectual property of tribes, policy frameworks are necessary. The TEK and IK should be used to guide and illuminate strategic decisions to fight against natural disasters.
- Tribal-based programmes that are rooted in culture and geography must include TEK.

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