Environment Conservation Journal 26 (3): 1116-1126, 2025

Journal homepage:https://www.environcj.in/

Environment Conservation Journal

ISSN 0972-3099 (Print) 2278-5124 (Online)

Consequences of climate change on medicinal plants in the Western Himalayas with special reference to Johar valley, Uttarakhand: A systematic review

Shalini Rawat

Department of Environmental Science, Graphic Era (Deemed to be University), 566/6, Bell Road, Society Area, Clement Town, Dehradun, Bharu Wala Grant,(Uttarakhand), India

Pradeep Kumar Sharma ✉

Department of Environmental Science, Graphic Era (Deemed to be) University, 566/6, Bell Road, Society Area, Clement Town, Dehradun, Bharu Wala Grant,(Uttarakhand), India

Suman Naithani

Department of Environmental Science, Graphic Era (Deemed to be) University, 566/6, Bell Road, Society Area, Clement Town, Dehradun, Bharu Wala Grant,(Uttarakhand), India.

VP Uniyal

Department of Biotechnology, Graphic Era (Deemed to be) University, 566/6, Bell Road, Society Area, Clement Town, Dehradun, Bharu Wala Grant,(Uttarakhand), India.

ARTICLE INFO

Received : 31 January 2025
Revised : 25 June 2025
Accepted : 21 August 2025

Available online: 30 August 2025

Key Words:
Anthropogenic
Climate change
Ethno medicinal
Livelihood
Medicinal
Western Himalaya

ABSTRACT

The functioning of ecosystems, wellness for humans, and ecological diversity all have been severely endangered under the multifaceted worldwide catastrophe known as climate change. The consequences are particularly evident throughout regions like the westernmost Himalayas, specifically the Johar Valley in Uttarakhand, India, where medicinal plant species are particularly susceptible. Especially in remote areas that have restricted availability of conventional medical services, these plants serve as vital for primary healthcare and local economic development. However, the accessibility and efficiency of those species are currently being jeopardized by an amalgamation of climate-induced shifts in patterns of precipitation and temperature, as well as increasing human-induced factors such as degradation of habitat, excessive harvesting, and sociocultural disruptions. Insights from reviewed studies examining how climate change influences Western Himalayan ethno-medicinal vegetation, with a special focus on the Johar Valley, are systematically assembled in this review. The process of counting votes was implemented in a mixed semi-quantitative approach to determine discord, gaps in research, and points of consensus throughout research. However, the original research insights from the Johar Valley are also being incorporated in this review paper. Under heightened stresses from the environment, outcomes repeatedly demonstrate altered phytochemical patterns and decreasing biomass production among significant species. The plants' medicinal properties, as well as traditional wisdom structures and economics that depend upon them, are both at threat due to these shifts. A conspicuous shortcoming in climate-adaptive gauges that correspond to the biological products and social-cultural circumstances of the region in question persists, despite some constrained conservation endeavors. Integrative conservation models that integrate traditional ecological expertise (TEK) with climate-resilient approaches to management are of paramount importance, as this review illustrates clearly. Promoting climate-resilient expanding techniques, establishing frameworks for monitoring medicinal plants, and supporting community-based conservation are some of the policy concepts. An outline for future investigation and legislative action that would encourage the long-term utilization and safeguarding of medicinal plant diversity in the Western Himalayan ecosystem is presented by this study, which reveals important trends and challenges.

Introduction

Understanding the consequences of human endeavors on the overall supply of medicinal plants has frequently required investigations into vegetation and landscape changes (Nautiyal *et al*., 2005; Gunderson *et al*., 2002). The biological and ecological repercussions of regional changes in vegetation and forest patterns, which are triggered by human credibility with the natural environment, contribute to an improved understanding of the interactions between ecological and social structures. However,a few thorough investigations have been carried out in Nepal illustrating how the socioeconomic back-

Corresponding author E-mail: *pksharma@geu.ac.in*
Doi:https://doi.org/10.36953/ECJ.31513027

ground of the vicinity and shifts in forest ecosystems influence the harmonious functioning of human-plant relationships (Dhakal *et al*., 2012; Tsering *et al*., 2012; Deb *et al*., 2015). Rising relocation, influenced by the market plant gatherings, altered land use, slopes that are steep, "fragile ecological systems," and severe weather are all correlated with problematic effects in the Nepal Himalaya. By 2100, More probable to negatively impact biodiversity than climate change, the arrival of new species,and shifts in atmospheric carbon dioxide ratios are the human-induced impacts of shifting land use, especially with regard to traditional medicinal plants (Sala *et al*., 2000). According to Parviainen *et al*. (2008), plant use and propagation can be influenced by non climate-related variables including the terrain, vegetation diversity (Langhammer *et al*., 2024), classification (Kunwar *et al*., 2018), vegetation cover, and the utilization of land (Thuiller *et al*., 2004) or an intersection of all of these variables. Rodríguez *et al*. (2007).

The Johar Valley in Uttarakhand and the remainder of the Western Himalayas are experiencing enormous climate change, which has significant consequences for both the viability of indigenous species of medicinal plants and ecological stability. A persistent warming trend in the surrounding region has been demonstrated by recent data on the climate.Based on research, the average temperature has increased by 0.5°C to 1.5°C over the course of the past century, with the rise in temperatures having intensified since the 1980s (Dimri *et al*., 2021; IMD,2023). From 1980 to 2020, the Uttarakhand Himalaya's average temperature increased by approximately 0.03°C annually, with warming rates increasing at higher altitudes (Negi *et al*., 2020). Considering the trend toward greater intensity but uncommon rainfall events, patterns of precipitation have become more erratic. As stated by Singh *et al*. (2022), this issue includes an overall decrease in precipitation during the winter and an apparent spike in extreme weather events such as cloudbursts and flash floods. Although ecological systems and species in alpine valleys like Johar are extremely susceptible to even minimal changes in the climate, these changes are particularly important.

Native medicinal plant species' phenomenology dispersion and the phytochemical properties certainly indicate the outcomes of those modifications. In multiple high-altitude medicinal plants, for instance, early flowering indicates decreasing accumulation of biomass, and diminishing secondary substance compositions have been associated with fluctuations in the moisture and temperature regimes (Kala,2017; Bhat *et al*., 2022). In order to better understand ecological susceptibility and lead conservation strategies specifically to a certain geographical area,it is necessary to take into account localized data on climate.

The inhabitants of the Johar Valleys of the Higher Himalaya in Uttarakhand Himalaya (India) (Fig. 1) did their best to maintain their elevated standards of lifestyle despite challenges resulting from physiographic and environmental conditions and access to resources factors. Human interference has accelerated the persistent and untamed events of climate change. The general population appears to be starting to experience the implications of climate change, which frequently manifest themselves as adjustments to phenology, hydrology, agricultural output, and faunal and botanical populations. Due to anticipated negative consequences on their standard of existence and economic strategy, the people have recently been compelled to reconsider numerous of their common life-sustaining activities.

Whenever foreign plants collected in readily accessible woodland zones and artificial habitats acquired recognition, existing research was examined in view of the trend that hastened up the advancement of harvesting traditional medicinal plants. These patterns have been correlated with shifting economic status transitions, altering land usage, and diminishing old growth primary forests. Following these alterations, we could argue that vital landmarks and organisms are getting more deeply embedded in community traditions, thereby rendering traditional systems adaptive, numerous, and responsive (Kunwar *et al*.,2018). It has been confirmed that altered patterns of rainfall correlate with elevated temperatures and expanding proof of environmental degradation. The rainfall is one climatic variable that requires to be investigated in terms of magnitude for the purpose of gathering information on changes in the climate. This knowledge will subsequently assist us in comprehending more fully whether rural livelihoods and decreasing levels of susceptibility are associated.

The research results definitely show that the patterns of precipitation in the localities in the Kumaun region and the Pithoragarh district of Uttarakhand have undergone changes. Shrestha (2012) reported that multiple amenities would be disrupted by the shift, as would the people of the countryside who resided in the vulnerable highlands. Kunwar et al. (2006, 2009; Rokaya *et al.*, 2010) stated that residents of KSL and the Johar Valley frequently utilized commodities as remedies made from herbs. In Nepal's remote regions, the conventional utilization of plants for medicinal purposes is the most prevalent resource use (Manandhar, 2002; Shrestha *et al*.,2004).

A substantial number of the population who gather and utilize these herbs for healing diseases and ailments are traditional medical practitioners. Numerous diseases and disorders, including stomach problems, cuts, burns, coughs, colds, and asthma, can be recovered from utilizing remedies made from plants. The primary vegetation species used as medications in this region encompass *Aconites, Dactylorhiza hatagirea*, *Neopicrorhiza scrophulariiflora, Paris poly-*

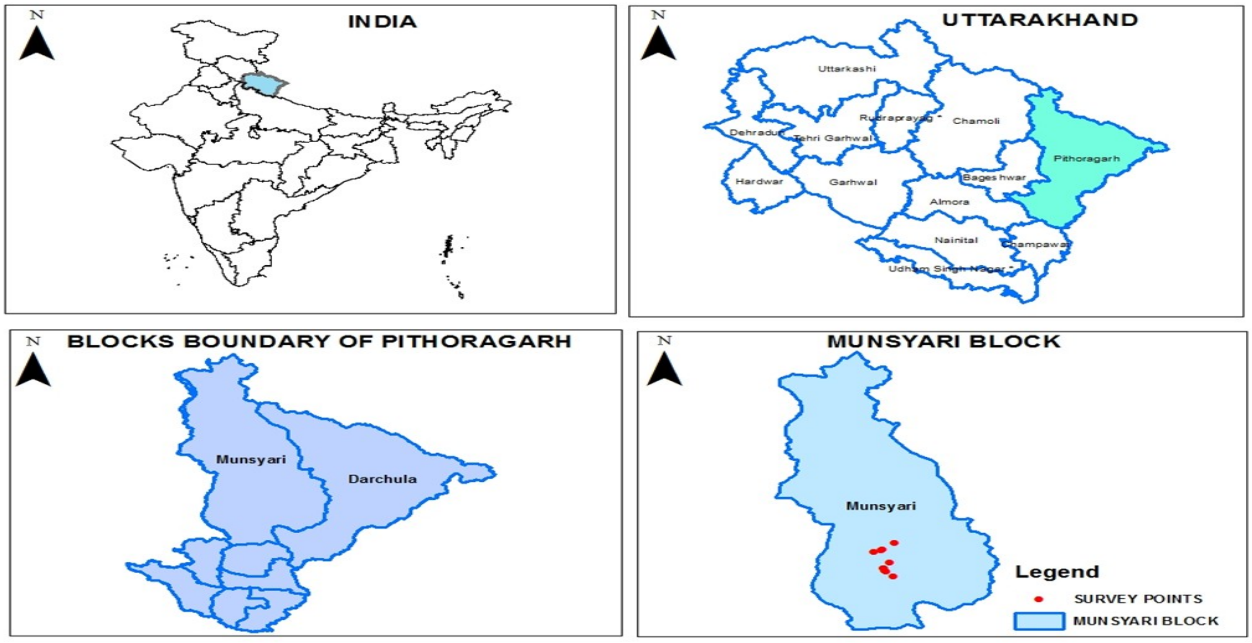

Figure 1: Map showing study area of Johar Valley

phylla, Diplazium stoliczkae, Lomatogonium carinthiacum (Tikta), *Aconitum heterophyllum* (Atish), *Aconitum spicatum* (Bish), *Ophiocordyceps sinensis* (Yarsagumbu), and *Dactylorhiza hatagirea* (Hattajadi). Fortunately, multiple widely recognized medicinal species, such as *Lomatogonium carinthiacum* and *Ophiocordyceps sinensis*, make use of the entire plant.

Based on the part being utilized and the specific kind of disease being medicated for, the dosage process will differ. Table 1 Shows the list of medicinal plants found in ohar valeey along with their benefits. A consistency of paste or powder derived from an identifiable matter (*Phyllanthus emblica, Paris polyphylla, Dactylorhiza hatagirea, Ophiocordyceps sinensis*, etc.) usually represents a commodity that the healer prescribes. Still, several portions of plants (including variables such as the rhizomes of *aconites, Bergenia ciliata, Paris polyphylla,* etc.) or their unprocessed counterparts (like *Dactylorhiza hatagirea, Neopicrorhiza scrophulariiflora, Lomatogonium carinthiacum*, etc.) may be beneficial (Chaudhary *et al*., 2017).

Climate change and its impact on medicinal plants in context to Western Himalayas and Kailash sacred landscape (KSL)

In accordance with Elliott *et al.* (2012), the investigation region's statistics were obtained from previous research and encompassed an assortment of forest types having an elevation difference of 257 to 7132, from highland *Betula-Rhododendron* ecosystems to tropical Sal (*Shorea robusta*) forests. This can be contrary to the alpine Darchula district of KSL, wherein trees comprise only 34 percent of the terrain. Dadeldhura and Baitadi are two highland districts at a moderate elevation that have 79% and 50% forest cover, respectively (Uddin *et al*., 2015). Johar Valley contains more than half of the alpine vegetation.

The average annual temperature in this research area remained 18.15°C, with 2326 millimeters of precipitation.The mean amount of rainfall has not varied substantially in the preceding 35 years, but the average temperature has (R^2 = 0.63). The key objective of the study on medicinal plants in the Indian Himalayan region has been to gather evidence of the availability, the nation, responsibility, and consumer demand for Himalayan plants for medicinal purposes (Kala, 2000; Garbyal *et al*., 2005; Bopana *et al*., 2007). In another study, Gras *et al*. (2017) reported that herbs that have been used traditionally in medicine have also been a focus of numerous research. Very rarely, nevertheless, has the severity of damage to these frequently utilized medicinal herbs been recognized.

Further, Samant *et al.* (1998) reported that the Himalayas are regarded to be one of the most important sources of therapeutically valued and aromatic vegetation. One of the world's biggest ecologically varied regions, the Indian Himalayan Region (IHR), is inhabited by about 1748 plant species, as reported by Samant *et al.* (1998). In another investigation, Samant *et al*. (1998) and Kala, (2005) stated that the plants with medicinal properties are prevalent in Sikkim, Uttarakhand in the Western Himalayas, and the IHR region in North Bengal. The studies conducted by Tewari *et al.*(2013) stated that there are actually around 337 plant species that have significant medicinal benefits in the cold desert region of the Indian Himalaya, specifically the KSL, which

Table 1: Medicinal plants and herbs of Johar Valley

Plant Name	Family	Local Name	Benefits of Medicinal Plant
Aconitum heterophyllum	*Ranunculaceae*	Atish	To treat diabetes, piles, fever, malarial fever, hysteria, and stomach ache.
Aconitum spicatum	*Ranunculaceae*	Bish	Use in the treatment of rheumatism, pain, and postpartum lethargy
Angelica archangelica	*Apiaceae*	Gananu	Cure disorders of the nerve system and brain
Ophiocordyceps sinensis	*Ophiocordycipitaceae*	Yarsagunbu	Improves energy and stamina
Dactylorhiza hatagirea	*Orchidaceae*	Hattajadi	Treat intestinal and kidney diseases and enhance the digestive system.
Saussurea obvallata.	*Asteraceae*	Kaunl Kaffu	cure for cold-related illnesses, wounds, and bruises.
Bergenia ciliata	***Saxifragaceae***.	Ghyu Patti/ Pattharchatta	utilize to treat kidney and bladder problems and dissolve and remove stones from the kidneys.
Neopicrorhiza scrophulariiflora	*Scrophulariaceae*	Kutki	Treat conditions include lung illness, fever, gastritis, and excessive blood pressure.
Zanthoxylum armatum	*Rutaceae*	Timoor	Colds, coughs, and asthma are treated with toothache and digestive aid.
Taxus baccata	***Taxaceae***	Thuner	use to treat colds, coughs, and asthma, lower inflammation and joint discomfort, and administer chemotherapy for cancer.

encompasses an area that measures approximately 74,809 square kilometers. Tewari *et al.* (2013) also stated that the Himalayan Mountain Range and its subsidiary ranges' rain shadowing phenomenon is substantially accountable for them in their final days stretching from the Indus Rift in the direction of the northwest to the Brahmaputra Rift in the northeast.

Solely certain areas in Sikkim, Pooh, Lahaul and Spiti, the Ladakh region of Jammu & Kashmir, and the Jadh Ganga to Malari possess freezing deserts. The indigenous groups who inhabit the faraway regions of IHR retain the capability to manage an extensive variety of diseases utilizing conventional remedies as well as expertise found in cold desert settings. Uniyal *et al.* (2006) investigated that more than fifty percent (50%) of the more than 1600 species of plants for medicinal purposes that have been used traditionally in India are believed to have originated in the Himalayan territory. However, the long-term viability of these essential resources and therapeutic plants is under threat by habitat destruction and continual commercialized extraction of these plants from wilderness, as is prevalent in different parts of the world (CBD, 2008). Bhattarai *et al.* (2010) found that many medicinal plants are also removed for financial gain in cold desert regions, such as the trans-Himalayan dry zone. But when wild plants are removed in large quantities, high-value medicinal plants (HMPs) are overused, which lowers their population. Therefore, a thorough investigation of population structure and regeneration rates is necessary to develop conservation strategies for the rich plant species of the IHR in light of their potential for medicinal use (Bhat *et al*.,2013).

Documenting HMPs (Himalayan Medicinal Plants) and their traditional use has also become a significant issue due to the market demand for herbal medicines growing quickly and concerns around access, benefit -sharing, and biopiracy. With the objective to arrive at a new extensive worldview of survival and sustainable utilization that is more politically reasonable, financially feasible, and less deleterious to the environment. According to Shinwari and Gilani (2003), this scenario provides a probability to integrate traditional understanding with contemporary ideas from science.

While there has been an increasing variety of academic work examining the variety of medicinal plant species in the Indian Himalayan Region (IHR), not much has been discovered concerning how variation in the climate specifically affects these species' distribution of wealth, prosperity, and phytochemical performance, especially among ecologically sensitive regions like the Johar Valley and the broader Kailash Sacred Landscape (KSL). Fewer investigations have carefully examined how stresses brought through environmental change translate straight away toward ecological and socioeconomic vulnerabilities for communities that are dependent on these natural resources, given that previous research has concentrated on documenting medicinal plants (Kala, 2000; Samant *et al.*, 1998; Tewari *et al.*, 2013).

The present investigation is organized by the investigations that follow with the intent to offer an individualized and comprehensive approach:

1. What changes in the climate have been noticed in the Johar Valley and nearby regions such as the Western Himalayas and KSL during the past few decades, such as temperature increases and variations in precipitation?

2. What consequences are these climate changes exerting on significant species of medicinal plants, especially with regard to their phenology, distribution of wealth, and the production of bioactive elements?
3. What are the main causes other than humans (such as exploitation and altering agricultural practices) that make high-value medicinal plants (HMPs) in this geographical region highly vulnerable?
4. Which empirical or indigenous methods for conservation are being used or offered as options to support the environmentally sound handling of Himalayan medicinal plants in an environment of climate change?

These inquiries make it conceivable to recognize significant gaps in understanding for the next empirical research and additionally the current body of knowledge. Significantly, these findings are in accordance with the growing urgency for a compromise between the contemporary science of conservation and traditional ecological understanding.

Perceptions of climate change and environmental shifts in Johar valley: Implications for agriculture and medicinal plant pependency

The Johar Valley in Uttarakhand offers valuable small-scale indications of the way climate change is influencing localized systems of agriculture, hydrodynamics, and dependency on medicinal plant resources, whereas this overview emphasizes the wider Western Himalayas. Tables 2 and 3 demonstrate an empirical knowledge of such modifications determined by community opinions using a poll of 150 respondents.

Trends of rainfall and snowfall are particularly impacted by climate change. A tremendous 96% of the respondents polled observed less snowfall, while 56% saw shifts in the snowfall's seasonal time frame. Patterns of rain were also characterized as being exceptionally unpredictable: 45% of the people surveyed highlighted erratic precipitation timing, while 50% of participants noted escalating rainfall, which contributed to crop calendar and accessibility to water instability. Additionally, 82% of the poll participants saw an apparent spike in catastrophes caused by nature, such as landslides and flash floods, which pose a direct threat to infrastructure and agricultural land, and 59% indicated a boost in cloudburst-like activity.Regional examinations also showed a strong influence of hydrological factors. A full 95% of respondents said that the availability of water had decreased, and 82% said that the overall quality of the water that was available was unchanged from earlier times.This two fold story stable quality but decreased quantity indicates the requirement for further indepth hydro-climatic studies in alpine watersheds.

These environmental shifts provoked varied socioeconomic behaviors. Due to diminished agricultural output (12%), frequent land loss from calamities (32%), and generalized livelihood insecurity, 85% of the people surveyed said they had departed their homeland. Others reported using additional forms of income 46% of the time when asked, with 22% stating a rise in the collection of high-value medicinal herbs, such as the highly valued ethnomedicinal fungus Keedajadi (Yarsa Gumbo). A redirection of local economies towards biodiversity assets that are both highly profitable and climate resistant has been suggested by this change.

The survey additionally emphasized this transition's sociocultural and multigenerational aspects. The younger generation's lack of involvement with traditional farming, along with the allure of alternate, frequently extractive, monetary options, isevident in the fact that just 16% of respondents reported enthusiasm for traditional farming. When utilized together, such localized findings provide significant evidence that the Johar Valley's climate change is changing not just the physical environment but also the way individuals connect with the region's land, agricultural resources, and medicinal plants. The significance for integrated environmental adaptation assessments that take into account both ecosystem and sociocultural resilience has been demonstrated by these alterations.

Preliminary research carried out on medicinal plants in context to cultural services in Johar Valley

The Ecosystem Assessment's findings indicate that cultural services are intangible advantages that people obtain from ecosystems (Heinrich, 2021). Gomez *et al.* (2010) reported in their study that the cultural services offered by ecosystems, however, have not received much attention in the discussion of ecosystem services, despite the fact that multifunctional landscapes include them. Benefits provided by cultural ecosystems that symbolize "cultural heritage" are the focus of KSLCDI, especially those with a spiritual or religious importance. Deacon (2003) found that the material artifacts, intangible qualities, and physiological traits that have been passed down from one generation to the next and preserved for the benefit of future generations are frequently referred to as a group's or civilization's cultural heritage.

The phrase "cultural heritage" in the context of Kailash Sacred Landscape ecosystems specifically refers to sacred natural regions, including the pilgrimage routes that traverse the region and the intangible traditional knowledge related to these sites, species, medicinal plants, and pathways. Arnold and Pérez (2001), Olsen (2005), and Maroyi (2013) reported that with reference to ecology, society, economy, and culture, the medicinal plants of the Himalayas are considered to be extremely valuable.However, overdrafting (Kala, 2006), vegetation, social changes Pirker *et al.* (2012) and land use changes (Maitima *et al.,* 2009; Paudyal *et al*., 2017) pose serious problems for many medicinal plant species. Many plant species' distribution and use are

Table 2 : Distribution of Respondent according to their knowledge about decline in agriculture practices in Johar Valley (n=150)

Statements	Number of Participants	Percentage of Participants
Inadequate agricultural yields	18	12%
A surplus of precipitation	39	26%
Shifting in snowfall Pattern	84	56%
Reduced amount of snowfall	144	96%
Frequent Natural Disasters Impacting Agricultural Land	48	32%
Out Migration of community	127	85%
Alternative Source of Income	69	46%
Younger generation shows less enthusiasm	24	16%
turned toward keedajadi (Yarsa Gumbo), or therapeutic herbs	33	22%

Table 3. Distribution of respondents according to their knowledge about the climate change and changes in environment in Johar Valley (n=150)

Observed Changes by Respondents	Statements	Respondent Percentage	No. of respondents
Rainfall	Unsettled rainfall timing	45%	67
	Escalating Rainfall	50%	75
	In Contrast to the season	3%	5
	A situation similar to flooding	2%	3
	No changes	0%	0
Snowfall Rate	Increasing	0%	0
	Decreasing	100%	150
Water Resources	Increasing	3%	5
	Decreasing	95%	142
	Stayed the same	2%	3
Water Condition	In good condition as previously	82%	123
	When it rains, insects are present.	14%	21
	The Worst State	4%	6
Cloud Burst Like Activities	Increasing	59%	88
	Stayed the same	21%	31
	Decreasing	2%	3
	never heard of this term before	5%	8
	We have heard this term lately, and it is occurring.	8%	12
	Exclusively occurs in Talla Johar	1%	2
	Nothing ever occurs in Malla Johar	4%	6
Natural Disasters	Increasing	82%	123
	Decreasing	2%	3
	Stayed the same	16%	24

poorly understood; Ghimire (2008) found that, making it difficult to forecast how their populations, particularly those of indigenous medicinal herbs, will react to the changes. Specifically, invasive species threaten indigenous medicinal plants (Anyinam, 1995; Alves and Rosa, 2007) and cause native herbs to be displaced (Petruzzella *et al.*, 2020).

The vegetation along the elevation gradient in Uttarakhand's arid, frigid Johar Valley, West Himalaya,is the main subject of this study. Because of their historic applications, trade demand, secondary databases, and the perception of rarity in society, it identifies plants that are very valuable and endangered. Additionally, it employs conventional techniques to evaluate the ecological and threat status of the plants, taking into account the high use value and conservation importance of HMPs. Research on medicinal plants in the Himalayan area of India is ongoing. Furthermore, Shrestha *et al.* (1999) and wester *et al*. (2019) stated that it appears that the Himalayas are especially vulnerable to climate change and have demonstrated that changes in land use and land cover have decreased.

However, investigations by Kunwar et al. (2009), Rokaya *et al.* (2010) and Mahara *et al.* (2024) showed that their influence on the availability and potential uses of local and indigenous medicinal plants in far western Nepal is still completely unresolved. According to traditional healers, remote regions of the Nepal Himalaya offer high-quality interventions (Adnan and Holscher, 2011). Chaudhary *et al.* (2009) investigated that there is disagreement on their effectiveness in halting global warming. Since land-use change, forest cover, and vegetation have an impact on local livelihoods, the Kailash Sacred Landscape (KSL) in far-western Nepal will be used as a model region. In order to understand how the shifting forest and flora impact the livelihoods of the local population, as well as the ways and locations of the usage of medicinal herbs in Nepal's Kailash Sacred Landscape, research was conducted by Kunwar *et al*. (2016).

Vulnerable and high value medicinal plants (HMPs) of Johar valley

Kunwar *et al.* (2019) reported that the Kailash Sacred Landscape includes the Johar Valley, which has historically been ruled by an indigenous civilization. A variety of forest types and beneficial plant species are among its many examples of its high biodiversity. This region's woods and other vegetation are impacted by the interplay of human (disturbance), climatic (temperature), and natural (elevation) factors. However, the ever-changing climate, land use, cultural practices, and human migration patterns have put the woods in jeopardy. The continued existence of relationships between people and the environment and sustainable handling of the forest and wildlife in the Johar Valley of the Kailash Sacred Landscape are dependent upon indigenous forestry initiatives that include protection and social norms.

In all, 219 species (208 angiosperms and 11 gymnosperms) and 132 genera were found in the study region. 22 of the 91 species that were reported to have known medicinal qualities were classified as THMPs due to their distinctiveness, economic value, and local customs. Since Milam (3430 m asl) had the highest concentration of THMPs (8 species;24%) and 7 species (21%), the route from Martoli to Nanda Devi base (4009 m asl) was selected. Plots at mid-altitude had the highest concentration of THMPs (40%) compared to those at higher and lower elevations (31.4% and 28.6%, respectively). Moreover, it was shown that more species were used medicinally at higher elevations than at lower ones (Malik *et al.,* 2015). The Kedarnath Wildlife Sanctuary in the West Himalaya (Kunwar and Bussmann, 2008) and the Nepal Himalaya also noted a similar tendency. The Milam bugyal community, which is pastureland/grassland, and Milam village, a recently defunct village in the Johar valley, are incorporated in the study's moderate height range. In order to ascertain the unconventional applications of medicinal herbs, a comparable earlier study was also carried out at several sites throughout the Dharchula area of the Pithoragarh district of Uttarakhand at various seasons. With 68 million inhabitants, India is home to 227 ethnic groupings and 573 tribal communities. The Kumaun region of the state is home to four of these tribes: the Tharus, Buxas, Rajis, and Bhotias. Located in a remote place encircled by thick forest in the Dharchula region, the Bhotiya tribe relies solely on nature to meet their daily needs. The state is inhabited by eight major Bhotia groups of people: the Marccha, Tolcha, Chudans, Byansi, Juthora, Darmi, Jad, and Johari. The Bhotia community not only constitutes 8.13% of the indigenous population but also comprises a staggering 18.70% of the nation. The primary objective of this study was to preserve significant indigenous traditional knowledge regarding the traits and applications of plants that the IUCN has classified as red data for ethnomedicine. It was provided by the community members, who used 17 plant species from 15 families as traditional remedies for various ailments. It was also attempted to write a description of the economic characteristics, customs, and environment of the Bhotia tribes.

The Bhotia tribe is native to the Johar Valley, the Dharchula region, and Uttarakhand's Pithoragarh District. The examination delivers comprehensive information on their environment, customs, economic benefits, and traditional therapeutic applications of plants. Research in the selected locations can employ plant resources in a traditional way, as is commonly recognized after looking through the literature database. Many species are used by the indigenous people to treat a wide range of ailments. They utilize a variety of plant parts in different ways to

fulfill their daily needs. It is essential to identify, record, and disseminate all ethnobotanical and cultural knowledge across the diverse ethnic groups in order to keep traditional civilizations from completely disappearing.

The traditional knowledge base of our country is currently disintegrating at a faster rate, according to studies. Data on ethnomedicinal use must be documented in order to preserve knowledge. Bhatt *et al.* (2013) said that integrating this sort of data into additional IHR parts could enable subsequent generations to consult an extensive catalog of the plants employed for multiple purposes. Pandey *et al.* (2018) discussed in their study that the Johar Valley's population had dropped by 30% during the previous decade. The genus has applied to be classified as "Vulnerable" for regions by the IUCN, according to its analysis. 50% of the THMPs were found to be growing on slopes that were either gravel/soil or stony/rocky.

Steep slopes and a profusion of rocks are characteristics of the chilly desert area of all living things; only two species of western Himalayan trees have been discovered in the chilly desert of the Johar Valley. *Juniperus semiglobosa* was surpassed by *Betula utilis* in terms of density. The most prevalent of the five shrub species found was *Rhododendron anthopogon*. The remaining four were *Ephedra gerardiana,Juniperus indica, Juniperus communis*, and *Ephedra intermedia*. The research article identifies about 15 THMPs (herbaceous life forms), with *Thymus linearis* and *Polygonatum cirrhifolium* having the highest numbers. *Aconitum heterophyllum, Nardostachys jatamanasi*, and *Rheum moorcroftianum* had the lowest quantities during their study.

According to the study, species such as *J. semiglobosa, J. indica, E. intermedia,* and *E. gerardiana* have relatively low populations (density 100 ind ha^{-1}) in the valley, indicating that there is not enough supply for widespread exploitation. The lowest concentrations were detected in *Rheum moorcroftianum, Nardostachys jatamanasi,* and *Aconitum heterophyllum.* Since species like *J. semiglobosa, J. indica, E. intermedia,* and *E. gerardiana* have relatively low populations (density 100 ind ha^{-1}) in the valley, the study concludes that there is insufficient supply for widespread exploitation. A variety of THMP components are utilized in the manufacturing of pharmaceuticals, including the root, inflorescence, leaf, bark, stem, and seed. Roots and rhizomes are examples of the below-ground portion that is utilized most frequently (64%) and least frequently (9%). According to similar findings by Kuwar *et al.* (2013), West Nepalese plants' rhizomes and roots were the most commonly used plant parts. Moore (1994) reported that the significant relevance of the subsurface part was explained by the large concentration of bioactive chemicals found there.

Concerning linked effects of climate change in context to Medicinal plants in western Himalayas

In addition to inherent environmental fragility and significant reliance on resources from the environment, the Western Himalayas have become particularly susceptible to the significant breaches of natural balance and health care security brought about by climate change (Dimri *et al*., 2021; Singh *et al*., 2022). The availability and quality of medicinal plants are directly impacted by variations in temperature regimes, cyclical nature, and patterns of precipitation in the Johar Valley of Uttarakhand, which forms a part of the bigger Kailash Sacred Landscape (KSL).In parts of the Uttarakhand Himalayas, the average temperature every year increased by around 0.03°C annually between 1980 and 2020, based upon contemporary meteorological statistics; the rise in temperatures is evident at higher altitudes (Negi *et al*., 2020). Furthermore, the process of precipitation, while regularly influencing the snowfall and replenishment of groundwater, is becoming increasingly unpredictable, resulting in greater uncertainty in the monsoon commencement and intensity and reduced wintertime precipitation (IMD, 2023; Singh *et al*., 2022).Assessments of the inhabitants in the Johar Valley's field investigation identified unique ecological consequences associated with these climate shifts. Among those surveyed, 64.9% witnessed phenological alterations, which involve greater or pushed-back blooming and fruiting instances. Alpine medicinal plants like *Picrorhiza kurroa* (Kutki), *Nardostachys jatamansi* (Jatamansi), and *Aconitum heterophyllum* (Atis), all of which are generally used to treat fevers, neurological illnesses, and problems with the liver, have noticed changes in their developmental stages as an outcome of these shifts, and these have been associated with prolonged periods of drought and more substantial spring temperatures (Kala, 2005 and Bhatt, 2013).

Additionally, 49% of the people surveyed experienced an abrupt shift in the exact moment of the anthesis process and fruiting, as well as 48% indicating early blooming and 35.5% observing delayed occurrences. Rising spring temperatures and less moisture availability were primarily blamed for the difference. These factors can impact the generation of secondary metabolites and induce developmental stress in young plant tissues (Dalal *et al*., 2018). 58.5% of community members indicated saying that they had changed both harvesting and planting strategies to take into consideration climate-related uncertainty. It demonstrates an evolving local recognition of climate- plant dynamics in conjunction with behavioral adaptation.

Traditionally primary healthcare depends upon medicinal flora, which contributes to the consequences of climate-induced phenological alterations. A combination of extended periods of drought and reduced rainfall, which subsequently hinder vegetative regen-

eration, means springs that originate outdoors, like Naula-Dhara, which is a crucial water source, are disappearing in outlying KSL territories (Uddin *et al.*, 2015). Weather constraints and excessive harvesting have rendered species like *Rheum emodi* (used for gastrointestinal disorders), *Bergenia ciliata* (used for kidney stones), and *V aleriana jatamansi* (which is employed as a relaxant) harder to find in natural environments. Traditional methods are required to be blended with a comprehensive understanding of the environment. Rich systems of knowledge concerning cyclical harvesting, ethical collecting, and multifunctional utilization of plants persist to be maintained by indigenous elders and healers (Vaids). *Angelica glauca*, for instance, is frequently employed for diagnosing bronchial and digestive disorders, and *Saussurea costus*, which is currently critically endangered, has been for decades an important trading commodity and medicinal plant. When developing culturally compatible conservation tactics, it is vital to document certain ancestral customs and independently examine climatic and biological modifications.

Conclusion and recommendations

Biological diversity, the biomass, and vegetative cover have all been significantly affected by climate change, specifically in the Highlands. Plants with medicinal properties are now harder to come by owing to shifts in vegetation and woodland covering triggered by changing values for conservation and alterations in culture. Communities that depend upon these forests for grazing, spiritual practices, and medicinal foragers, the pilgrims, and collectors face challenges as environmental degradation ravages forests and native species in preference towards nonnative ones. Alpine populations have become especially susceptible owing to their rural setting, lack of assets, and dependence on rainfall-based agriculture, especially in rural areas like the Johar Valley. The research study underscores that the primary root cause of migration and vulnerability is the absence of capacity to adapt through the use of in-depth interviews and a comprehensive vulnerability assessment. Rising numbers of youth migrants typically confront structural shortcomings, which escalate the hazards. It is crucial to support sustainable harvesting approaches, cultivate medicinal plants on a local level, safeguard traditional knowledge, and develop mechanisms for quality assurance in order to improve resilience and sustainability. To assess how climate change affects plant quality, certification processes for wild-collected commodities and the tracking of indicators for medicinal plants are vital.

In order to save species, aided migration and ex situ seed banking might also be necessary. In order to guarantee vulnerable populations' continuous access to high-quality traditional medicines, these steps must be combined with other initiatives. To protect livelihoods and health, these measures should be given top priority by governments, nongovernmental organizations, and the public health sector.

Acknowledgement

Authors are incredibly thankful to the local Johari people for providing tremendous field support and basic understanding about the significance of medicinal plants. We are thankful to Graphic Era (Deemed to be) University, Dehradun, Uttarakhand (India) for providing infrastructural support in preparing this review.

Conflict of interest

The authors declare that they have no conflicts of interest.

References

Adnan, M., & Hölscher, D. (2011). Medicinal plants in old-growth, degraded and re-growth forests of NW Pakistan. *Forest Ecology and Management*, 261(11), 2105-2114.https://doi.org/10.1016/j.foreco.2011.03.004.

Anyinam, C. (1995). Ecology and ethnomedicine: exploring links between current environmental crisis and indigenous medical practices. *Social science & medicine*, 40(3), 321-329. https://doi.org/10.1016/0277-9536(94)E0098-D

Arnold, J. M., & Pérez, M. R. (2001). Can non-timber forest products match tropical forest conservation and development objectives?. *Ecological economics*, 39(3), 437-447.

Alves, R. R., & Rosa, I. M. (2007). Biodiversity, traditional medicine and public health: where do they meet?. *Journal of ethnobiology and ethnomedicine*, 3(1), 14.

Bhat, B. A., Negi, G. C. S., & Bhatt, A. (2013). Impact of climate change on medicinal plants in the Indian Himalayas. *Journal of Mountain Science,* 10(3), 300–311. https://doi.org/10.1007/s11629-012-2432-2.

Bopana, N., & Saxena, S. (2007). Asparagus racemosus—Ethnopharmacological evaluation and conservation needs. *Journal of ethnopharmacology*, 110(1), 1-15.

Bhat, B. A., Negi, G. C. S., & Bhatt, A. (2022). Influence of climate change on alpine vegetation in the Indian Himalayas: A review. *Environmental Monitoring and Assessment*, 194(1), 1-20. https://doi.org/10.1007/s10661-021-09619-3.

Bhattarai, K. R., Ghimire, S. K., & Aumeeruddy-Thomas, Y. (2010). Impact of harvesting on some important medicinal plants in the Himalaya. *Ethnobotany Research and Applications*, 8, 251–264.

Chaudhary, O. P., & Chand, R. (2017). Economic benefits of animal pollination to Indian agriculture. *Indian Journal of Agricultural Sciences*, 87(9), 1117-1138.

Chaudhary, P., & Aryal, K. P. (2009). Global warming in Nepal: challenges and policy imperatives. *Journal of Forest and livelihood*, 8(1), 5-14.

Dalal, P., Kumar, M., Tiwari, R. K., & Negi, G. C. S. (2018). Climate change and its impact on traditional agriculture: Evidence from Indian Central Himalayas. *Current Science*, 115(7), 1297–1303.

Deacon, H. (2003). *Convention for the safeguarding of the intangible cultural heritage. Unesco.*

Deb-Rinker, P., León, J. A., Gilbert, N. L., Rouleau, J., Andersen, A. M. N., Bjarnadóttir, R. I., ... & Canadian Perinatal Surveillance System (Public Health Agency of Canada). (2015). Differences in perinatal and infant mortality in high-income countries: artifacts of birth registration or evidence of true differences?. *BMC pediatrics*, 15(1), 112.

Dimri, A. P., Yasunari, T., Wiltshire, A., Kumar, A., Mathison, C., Ridley, J., & Jacob, D. (2021). Climate change over the Himalayas: An assessment of CMIP6 climate projections. *Climate Dynamics*, 56, 2313–2333. https://doi.org/10.1007/s00382-020-05518-z.

Dhakal, B., Bigsby, H., & Cullen, R. (2012). Socioeconomic impacts of public forest policies on heterogeneous agricultural households. *Environmental and Resource Economics*, 53(1), 73-95.

Elliott, M. A., & Ainsworth, K. (2012). Predicting university undergraduates' binge-drinking behavior: A comparative test of the one-and two-component theories of planned behavior. *Addictive behaviors*, 37(1), 92-101. https://doi.org/10.1016/j.addbeh.2011.09.014.

Garbyal, S. S., Aggarwal, K. K., & Babu, C. R. (2005). Traditionally used medicinal plants in Dharchula Himalayas of Pithoragarh district, Uttaranchal.

Gómez-Baggethun, E., De Groot, R., Lomas, P. L., & Montes, C. (2010). The history of ecosystem services in economic theory and practice: From early notions to markets and payment schemes. *Ecological economics*, 69(6), 1209-1218.

Gras, A., Garnatje, T., Ibanez, N., Lopez-Pujol, J., Nualart, N., & Valles, J. (2017). Medicinal plant uses and names from the herbarium of Francesc Bolòs (1773–1844). *Journal of Ethnopharmacology*, 204, 142-168.

Ghimire, S. K., Gimenez, O., Pradel, R., McKey, D., & Aumeeruddy-Thomas, Y. (2008). Demographic variation and population viability in a threatened Himalayan medicinal and aromatic herb Nardostachys grandiflora: matrix modelling of harvesting effects in two contrasting habitats. *Journal of Applied Ecology*, 45(1), 41-51.

Gunderson, L. H., & Holling, C. S. (2002). Panarchy: *Understanding transformations in human and natural systems* (pp. xxiv+-507).

Heinrich, M., Jiang, H., Scotti, F., Booker, A., Walt, H., Weckerle, C., & Maake, C. (2021). Medicinal plants from the Himalayan region for potential novel antimicrobial and anti-inflammatory skin treatments. *Journal of Pharmacy and Pharmacology*, 73(7), 956-967.

Indian Meteorological Department (IMD). (2023). *State-level climate change trends in India*: 1901–2020. Ministry of Earth Sciences, Government of India. Retrieved from https://mausam.imd.gov.in.

Kala, C. P. (2000). Status and conservation of rare and endangered medicinal plants in the Indian trans-Himalaya. *Biological Conservation*, 93(3), 371–379.

Kala, C. P. (2005). Indigenous uses, population density, and conservation of threatened medicinal plants in protected areas of the Indian Himalayas. *Conservation Biology*, 19(2), 368–378.

Kala, C. P., Dhyani, P. P., & Sajwan, B. S. (2006). Developing the medicinal plants sector in northern India: challenges and opportunities. *Journal of Ethnobiology and Ethnomedicine*, 2 (1), 32. https://doi.org/10.1186/1746-4269-2-32.

Kala, C. P. (2017). Climate change and indigenous medicinal plants in the Indian Himalayas. *Journal of Forest and Environmental Science*, 33(1), 1-9. https://doi.org/10.7747/JFES.2017.33.1.1

Kunwar, R. M., Mahat, L., Acharya, R. P., & Bussmann, R. W. (2013). Medicinal plants, traditional medicine, markets and management in far-west Nepal. Journal of ethnobiology and ethnomedicine, 9(1), 24. https://doi.org/10.1186/1746-4269-9-24.

Kunwar, R. M., Shrestha, K., Malla, S., Acharya, T., Sementelli, A. J., Kutal, D., & Bussmann, R. W. (2019). Relation of medicinal plants, their use patterns and availability in the lower Kailash Sacred Landscape, Nepal. *Ethnobotany Research and Applications*, 18, 1-14. https://doi.org/10.32859/era.18.7.1-14.

Kunwar, R. M., Fadiman, M., Cameron, M., Bussmann, R. W., Thapa-Magar, K. B., Rimal, B., & Sapkota, P. (2018). Cross-cultural comparison of plant use knowledge in Baitadi and Darchula districts, Nepal Himalaya. *Journal of Ethnobiology and Ethnomedicine*, 14(1), 40. https://doi.org/10.1186/s13002-018-0242-7.

Kunwar, R. M., Shrestha, K., Malla, S., Acharya, T., Sementelli, A. J., Kutal, D., & Bussmann, R. W. (2019). Relation of medicinal plants, their use patterns and availability in the lower Kailash Sacred Landscape, Nepal. *Ethnobotany Research and Applications*, 18, 1-14.

Kunwar, R. M., Nepal, B. K., Kshhetri, H. B., Rai, S. K., & Bussmann, R. W. (2006). Ethnomedicine in Himalaya: a case study from Dolpa, Humla, Jumla and Mustang districts of Nepal. *Journal of ethnobiology and ethnomedicine*, 2(1), 27. https://doi.org/10.1186/1746-4269-2-27.

Kunwar, R. M., Uprety, Y., Burlakoti, C., Chowdhary, C. L., & Bussmann, R. W. (2009). Indigenous use and ethnopharmacology of medicinal plants in Far-west Nepal.https://ethnobotanyjournal.org/index.php/era/article/view/223.

Langhammer, P. F., Bull, J. W., Bicknell, J. E., Oakley, J. L., Brown, M. H., Bruford, M. W., ... & Brooks, T. M. (2024). The positive impact of conservation action. *Science*, 384 (6694), 453-458.

Manandhar, N. P. (2002). *Plants and people of Nepal* (pp. 599-pp).Timber Press. ISBN 978-0-88192-527-2.

Maitima, J. M., Mugatha, S. M., Reid, R. S., Gachimbi, L. N., Majule, A., Lyaruu, H., ... & Mugisha, S. (2009). The linkages between land use change, land degradation and biodiversity across East Africa. A*frican Journal of Environmental Science and Technology*, 3(10).

Maroyi, A. (2013). Traditional use of medicinal plants in south-central Zimbabwe: review and perspectives. *Journal of ethnobiology and ethnomedicine*, 9(1), 31.

Malik, K., Ahmad, M., Zafar, M., Sultana, S., Tariq, A., & Rashid, N. (2019). Medicinal plants used for treatment of prevalent diseases in Northern Pakistan of Western Himalayas. In *Medicinal Plants-use in prevention and treatment of diseases*. IntechOpen. https://doi.org/10.5772/intechopen.89932

Mahara, A., & Ojha, N. (2024). Ethnobotanical Study of Medicinal Plants in Kepilasgadhi Rural Municipality of Khotang District, Nepal. *European Journal of Medicinal Plants,* 35 (6), 105-131.

Moore, P. D. (1994). Trials in bad taste. *Nature*, 372(6505).

Nautiyal, N., Singh, S., & Chatterjee, C. (2005). *Seed reserves of chickpea in relation to molybdenum supply. Journal of the Science of Food and Agriculture*, 85(5), 860-864. https://doi.org/10.1002/jsfa.1929.

Negi, H. S., Kumar, M., & Thakur, P. K. (2020). Climate variability and its ecological implications in Uttarakhand Himalaya. *Journal of Earth System Science*, 129(1), 1–13. https://doi.org/10.1007/s12040-020-1330-9.

Negi, H. S., Kumar, M., & Thakur, P. K. (2020). Climate variability and its ecological implications in Uttarakhand Himalaya. *Journal of Earth System Science*, 129, 1–13.

Olsen, C. S. (2005). Trade and conservation of Himalayan medicinal plants: Nardostachys grandiflora DC. and Neopicrorhiza scrophulariiflora (Pennell) Hong. *Biological Conservation*, 125(4), 505-514.

Pandey, S. K. (2017). Species composition and diversity of legumes in sal plantations of north-eastern Uttar Pradesh, India. *Annals of Plant Sciences*, 6(9), 1668-1675.

Paudyal, K., Putzel, L., Baral, H., Chaudhary, S., Sharma, R., Bhandari, S., ... & Keenan, R. J. (2017). From denuded to green mountains: process and motivating factors of forest landscape restoration in Phewa Lake watershed, Nepal. *International Forestry Review*, 19(4), 75-87.

Pirker, H., Haselmair, R., Kuhn, E., Schunko, C., & Vogl, C. R. (2012). Transformation of traditional knowledge of medicinal plants: the case of Tyroleans (Austria) who migrated to Australia, Brazil and Peru. *Journal of Ethnobiology and Ethnomedicine,* 8(1), 44.

Petruzzella, A., van Leeuwen, C. H., van Donk, E., & Bakker, E. S. (2020). Direct and indirect effects of native plants and herbivores on biotic resistance to alien aquatic plant invasions. *Journal of Ecology*, 108(4), 1487-1496.

Parviainen, M., Luoto, M., Ryttäri, T., & Heikkinen, R. K. (2008). Modelling the occurrence of threatened plant species in taiga landscapes: methodological and ecological perspectives. *Journal of Biogeography*, 35(10), 1888-1905.

Rodríguez, J. P., Brotons, L., Bustamante, J., & Seoane, J. (2007). The application of predictive modelling of species distribution to biodiversity conservation. *Diversity and Distributions*, 243-251

Rokaya, M. B., Münzbergová, Z., & Timsina, B. (2010). Ethnobotanical study of medicinal plants from the Humla district of western Nepal. *Journal of Ethnopharmacology*, 130(3), 485-504.https://doi.org/10.1016/j.jep.2010.05.036.

Samant, S. S., Dhar, U., & Palni, L. M. S. (1998). Medicinal plants of Indian Himalaya: Diversity distribution and potential values. Gyanodaya Prakashan, Nainital, India.

Shinwari, Z. K., & Gilani, S. S. (2003). Sustainable harvest of medicinal plants at Bulashbar Nullah, Astore (Northern Pakistan). *Journal of Ethnopharmacology*, 84(2–3), 289–298. https://doi.org/10.1016/S0378-8741(02)00312-1.

Sala, O. E., Stuart Chapin, F. I. I. I., Armesto, J. J., Berlow, E., Bloomfield, J., Dirzo, R., ... & Wall, D. H. (2000). Global biodiversity scenarios for the year 2100. *science*, 287(5459), 1770-1774. https://doi.org/10.1126/science.287.5459.1770.

Shrestha, A., Bishnu, K. C., & Thapa, C. B. (2004). Ethnomedicinal uses of plants among the Kumal community in Chirtungdhara, Palpa, Nepal. *Botanica Orientalis: Journal of Plant Science*, 4(1), 59-62. Retrieved from https://www.nepjol.info/index.php/BOTOR/article/view/544.

Singh, V., Shekhar, M., & Kumar, P. (2022). Changing precipitation patterns and extreme weather events in Uttarakhand Himalaya: A spatiotemporal analysis. *Current* Science, 122 (6), 678–685.

Shrestha, U. B., Gautam, S., & Bawa, K. S. (2012). Widespread climate change in the Himalayas and associated changes in local ecosystems. *PloS one*, 7(5), e36741.https://doi.org/10.1371/journal.pone.0036741.

Shrestha, A. B., Wake, C. P., Mayewski, P. A., & Dibb, J. E. (1999). Maximum temperature trends in the Himalaya and its vicinity: an analysis based on temperature records from Nepal for the period 1971–94. *Journal of climate,* 12(9), 2775-2786.

Tewari, A., Rawal, R. S., Upreti, N., & Bhatt, Y. D. (2013). Distribution pattern and indigenous uses of high value medicinal plants in Indian Himalayan Region. *Tropical Ecology, 54*(1), 121–134.

Tse-Ring, K., Sharma, E., Chettri, N., & Shrestha, A. (2012). *Climate change vulnerability of mountain ecosystems in the Eastern Himalayas* (No. id: 5000).

Thuiller, W. (2004). Patterns and uncertainties of species' range shifts under climate change. *Global change biology*, 10(12), 2020-2027.

Uddin, K., Shrestha, H. L., Gilani, H., Murthy, M. S. R., Wahid, S., & Zomer, R. J. (2015). Spatial assessment of forest degradation in the Hindu Kush Himalayas: A case study from the Kailash Sacred Landscape. *Applied Geography*, 62, 20–31. https://doi.org/10.1016/j.apgeog.2015.04.002

Uniyal, S. K., Singh, K. N., Jamwal, P., & Lal, B. (2006). Traditional use of medicinal plants among the tribal communities of Chhota Bhangal, Western Himalaya. *Journal of ethnobiology and ethnomedicine,* 2(1), 14.

Wester, P., Mishra, A., Mukherji, A., & Shrestha, A. B. (2019). The Hindu Kush Himalaya assessment: mountains, climate change, sustainability and people (p. 627). *Springer Nature*.