

Climate change perception and adaptation strategies across socio ecological gradients in the Indian western Himalaya

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Abstract

Climate change presents an escalating global crisis, with its repercussions intensifying in ecologically fragile mountain systems. In the Western Himalaya, particularly Uttarakhand, projected warming rates surpass global averages, yet comprehensive long-term climate datasets remain fragmented due to limited meteorological coverage. To fill this empirical void, the present study systematically captures climate change perceptions from local communities distributed across an altitudinal transect (1000–3800 m) spanning multiple valleys. An overwhelming majority of respondents reported acute environmental disruptions: increasing temperatures (82.7%), unpredictable rainfall patterns (87.5%), shifting phenological events (63.5%), declining natural resources (65.9%), drying springs and water sources (73.0%), diminishing agricultural productivity (80.7%), emergence of novel pests and diseases (69.9%), and biological invasions by alien species (67.2%). These impacts have disproportionately strained agrarian livelihoods in isolated and underserved regions. Despite significant institutional and technological barriers, local populations are innovating through time-tested, traditional ecological knowledge systems, revealing a dynamic but constrained adaptation landscape. These findings substantiate community-observed climate stressors, highlighting an urgent need for region-specific, inclusive policy frameworks that recognize and integrate indigenous knowledge to fortify resilience and sustainability in Himalayan socio-ecological systems.

1. Introduction

Climate change is one of the most emerging environmental challenges of the twenty-first century, with mountain ecosystems experiencing its impacts more rapidly and intensely than many lowland regions (IPCC, 2023; Acharya et al., 2024). The Hindu Kush Himalayan (HKH) region has been identified as a global climate hotspot, showing warming rates higher than the global average, leading to an increase in glacier retreat, altered hydrological regimes, and an increase in the frequency of extreme climate events such as floods, droughts, and landslides (Chaudhary et al., 2024). Recent studies from the Western Himalayan region report a consistent rise in mean annual temperature and an erratic rainfall pattern, posing serious threats to the region's ecosystems and local communities (Upadhyaya et al., 2023; Rahim et al., 2023; Kumar et al., 2025). Indigenous and ethnic communities inhabiting the Himalayan region depend heavily on rain-fed agriculture, pastoralism, forest resources and natural water resources, making them sensitive to climate variability (Negi et al., 2017; Sati, 2024).

Furthermore, among socio-ecological groups, they play a crucial role in shaping how communities respond and adapt. Research from the Himalayan context shows that socio-ecological groups can detect and interpret climate shift, such as a decrease in snowfall, changes in rainfall time, and an increase in temperature- through lived experience and local indicators embedded in traditional ecological knowledge (Macchi et al., 2015; Pandey et al., 2018; Das, 2024). These perceptions often align with observed meteorological trends, reinforcing the validity of local climate understanding. Despite this, much of the existing knowledge on climate change in the Himalaya has been dominated by physical science and a natural hazards perspective (Mukherjee et al., 2016). However, there is a lack of literature

on climate change perceptions and adaptation strategies among local communities in the western Himalayan region (Negi et al., 2017; Thakur et al., 2021). Adaptation strategies require a reliable comprehension of the vulnerability events and actual ground realities, and also how the local communities withstand these events, which enables them to cope with extreme weather and environmental change over decades (Negi et al., 2017; Maikhuri et al., 2019). The studies on climate change adaptation have increasingly recognized that effective adaptation strategies must be grounded in local realities and community perceptions. Indigenous and traditional knowledge systems contribute to resilience by offering context-specific adaptation practices, such as modifications in sowing times, crop diversification, water conservation, and grazing patterns shaped by multi-generational observations of environmental variability (Tolulope et al., 2025). Recent global studies confirm that indigenous knowledge enhances adaptive capacity and resilience among low-population groups, including those in mountain regions (Dorji et al., 2024; Witharana et al., 2025). However, an important knowledge gap remains in the western Himalayan region. Studies focusing especially on how local communities perceive climate change and the socio-ecological factors that shape people's adaptation strategies are few and fragmented. Where such studies exist, they often document perception and validate it against limited climate datasets, with less emphasis on systematic analytic frameworks that unpack the drivers of adaptation choices and how these vary by age, gender, livelihood, or community networks (Negi et al., 2017).

Keeping on mind these key gap areas in western Himalayan region, present study adopts a mixed method research design that combines household survey, focus group discussion and statistical validation of perception data against regional climate trends this approach enables a robust analysis of how different demographic groups within ethnic communities interpret climate shifts and chose adaptation strategies and how these perception of local communities translate into concrete coping mechanisms. The present study comes under the political ecology of climate change, drawing on interdisciplinary research that examines climate perception and adaptation as socially and culturally mediated processes rather than purely biophysical responses (Nightingale, 2017). Following the work published in the Himalayan region, which falls under the political ecology of climate change on climate perception, Gargan (2015), Sherpa et al. (2019), and Negi et al. (2019) are understood as embedded in livelihood practices and a local knowledge-based system. By analyzing climate change perceptions across four valleys of the western Himalaya, the present study engages with indigenous and local knowledge while contributing empirical insights into how different social sectors interpret climate impacts and adopt adaptation strategies under region-specific socio-ecological conditions. Furthermore, in this study, Traditional ecological knowledge (TEK) is understood as place-based, intergenerational knowledge developed through long-term interaction of local communities with their environment. It includes climate observations, seasonal indicators, farming and forest use practices, and adaptive livelihood responses. The use of TEK is justified because the knowledge is orally transmitted, practice-oriented, and embedded in everyday socio-ecological decision-making rather than in short-term individual perceptions.

2. Climate change impacts and adaptations

2.1 Study area

The study was carried out in four different valleys i.e. Byans, Chaudas (29°35' N to 30°18' N 80°30' E to 80°45' E) in district Pithoragarh; upper Bhagirathi Valley (30°43' N to 31°02' N 78°25' E to 79°02' E) in district Uttarakashi, and Barora valley (29°35' N to 29°51' N 79°30' E to 79°38' E) in Almora district of Uttarakhand state (Fig. 1). Uttarakhand state represents a politically and ecologically complex mountain region shaped by its colonial forest history, post-independence development trajectories and ongoing plains- mountains political dynamics, all which have profoundly influenced land use, livelihoods, and human environment relation (Pathak, 2004). Seven villages were randomly selected from each valley to document local people's perception with respect to climate change and adaptation strategies. A major section of inhabitants of these valleys were farmers with few irrigation opportunities and mostly terrace farming is in practice. These valleys are not differentiated by altitude and ecological configurations. The Barora Valley, located at lower elevation, is characterized by relatively good market connectivity, mixed land use, better forest and water resources, and stronger linkages to nearby urban areas. The upper Bhagirathi valley represents a mid-altitude landscape where agriculture, seasonal migration, and hydropower projects increasingly intersect, particularly following the expansion of large infrastructure projects in the Bhagirathi basin (Baghel & Nusser, 2010; Kuniyal et al., 2024). The high altitude Byans and Chaudas valleys, located near international borders, are shaped by pastoral agricultural livelihoods, restricted mobility due to border securitization, and long-standing male outmigration for military and other livelihood options, resulting in feminization of agriculture and changing adaptation practices (Negi et al., 2017). Across all valleys, villages are embedded within forested landscapes historically influenced by colonial and post-colonial forest governance, including the expansion of *Pinus roxburghii* Sarg. that have altered fire regimes, fodder availability, and local perception of ecological change in forest resources (Singh et al., 2014). In study regions agriculture remains largely rainfed, with limited irrigation facilities, and terraced farming is the dominant practice. The villages were surrounded by good forest cover that in turn facilitates various goods and services to the local communities. The villages were divided into three different elevation range, low altitude (1000–1500 m)-Barora valley, middle altitude (1600–2500 m)- Upper Bhagirathi valley and high altitude (2600–3800 m)- Byans and Chaudas valley based on the altitude (Fig. 1).

2.2 Demography of study areas

Uttarakhand, the 27th state of India, was established on 9 November 2000. It ranks as the 18th largest in terms of land area, encompassing approximately 53,483 km². Geographically, it shares borders with Tibet to the north, Nepal to the east, Himachal Pradesh to the northwest, and the plains of Uttar Pradesh to the south. The state is composed of two major hilly regions, Garhwal and Kumaon, linked by the fertile Terai belt at the foothills. Uttarakhand spans latitudes from 28°43' N to 31°27' N and longitudes from 77°04' E to 81°01' E. The residents, commonly referred to as Uttarakhandis, are further distinguished by regional identities as Garhwali or Kumaoni, depending on their ancestral origins. As per the 2011 Census

of India, the state had a total population of 1,0,116,752, placing it 19th in population ranking nationally. Ecologically, Uttarakhand is notable for its rich biodiversity, harboring around 175 rare species of aromatic and medicinal plants. Its varied topography supports a spectrum of climatic zones, facilitating commercial viability across horticulture, floriculture, and agriculture sectors.

The state's diverse terrain also offers significant tourism potential across religious, adventure, and eco-tourism domains. Key attractions include the Char Dham pilgrimage circuit (Badrinath, Kedarnath, Gangotri, and Yamunotri), the sacred Kailash Mansarovar route, and natural destinations such as Nainital Lake and Mussoorie. A summary of the demographic attributes across key districts is presented (Table 1).

2.3 Positionality and Ethical consideration

The present study recognizes that social science knowledge is produced through relationships shaped by power, positionality, and context, and that researchers do not occupy a neutral “view from nowhere”. The research team is institutionally based within an Indian academic system and shares regional and cultural familiarity with the North Himalayan context, which facilitated access, trust building, and communication during fieldwork. At the same time, differences in caste, gender, education, and socio-economic positioning between researchers and participants influenced interactions in uneven ways across four study valleys. In addition, all participants were informed of the study's objective, the voluntary nature of participation, and their right to withdraw at any time. Verbal informed consent was obtained prior to interviews and surveys, given the local literacy contexts.

Table 1
Demographic profile of the study area, in Western Himalaya

Parameter	District Almora	District Pithoragarh	District Uttarkashi
Features pertaining to the Valley			
Total Geographical area (km ²)	3144 km ²	7090 km ²	8016 km ²
Geo-coordinates	29°35' N to 29°51' N 79°30' E to 79°38' E	29°35' N to 30°18' N 80°30' E to 80°45' E	30°43' N to 31°02' N 78°25' E to 79°02' E
Elevation	1000–1500	1500–3800	500–2200
Population density (per km ²)	198 Km ²	68 Km ²	41 Km ²
Decadal population growth	Decreasing (-1.67%)	Increasing (4.58%)	increase11.89
Total forest area (%)	50.43	57.92	88.8%
Total sown area (%)	19.2	45.9	3.62
Average annual temperature (°C) (Min.-Max.)	04-33.6	-1.7-30.3	1.6–34.4
Average annual rainfall (cm) (Months)	96.1	129.66	170.6
Average annual Relative humidity (%) (Min. - Max.)	54–69	58–73	54–67
Literacy rate	80.47	82.25	75.81
Average size of farm (ha)	0.48	0.5	0.8
Average size of farm with small farmers (ha)	0.02	0.01	0.04
Total sown area with irrigation facility (%)	11.3	8.2	6.084
Total urban area (%)	10.01	14.4	0.44
Total rural area (%)	89.99	85.6	99.66
Irrigated agriculture land (%)	21.34	8.45	12.67
Livestock per thousand population	2182.3	1087.2	710
Percent of workers as farmer	69.62	63.44	71

2.4 Preliminary survey and data collection

The study adopted a cross-sectional household-based survey design across the selected 4 valleys of the western Himalayan region. Seven villages were randomly selected in each valley, for a total of 28. Households within each village were selected using proportionate sampling, with approximately 30% of households per village included. Although an equal sample across valleys was initially targeted, the final sample reflected actual settlement sizes, resulting in 188 households from Barora Valley, 388 from Byans & Chaudas Valley, and 288 from Bhaghitrathi Valley, for a total of 862 households surveyed. Data was collected through a semi-structured questionnaire administered to one adult per household, with the household serving as the primary unit of analysis. Site selection was guided by a combined assessment of exposure to climate-related stressors (such as recurrent droughts, water scarcity, and localized flooding) and demographic dynamics, particularly seasonal and long-term out-migration. These regions have experienced recurrent climatic disturbances, primarily prolonged droughts, acute water scarcity, and episodic flooding which have affected agricultural viability through interactions with land use practices, livelihood strategies, and local resource governance. Rather than attempting to delineate fine scale climatic variability methodological challenging at the valleys scale the study conceptualizes climate impact through lived exposure and vulnerability, shaped by interacting environmental, and institutional factors. Selection of the study sites was informed by consultations with climate and environmental experts, migration and population specialists, and government officials. It also incorporated insights from existing datasets and reports detailing regional climate trends and displacement patterns. Additional logistical factors, including geographic remoteness and localized security challenges, also shaped the final choice of survey locations. Primary data were collected across four valleys through a semi structured questionnaire survey (n = 862), including by focus group discussion to capture shared experience and community level perspectives. Secondary literature and publicly available datasets on climate trends, agriculture, and migration were used only to contextualize the field findings and refine survey design. This stepwise approach ensured coherence between different data sources while maintain the household survey as the core empirical foundation of the study.

Table 2
Preliminary survey and data collection from the Western Himalaya

Items	Alternatives	Counts		
		Barora valley (188)	Byans & Chaudas Valley (384)	Bhaghitrathi Valley (288)
		M/F	M/F	M/F
Age	below 30	15/31	42/17	25/21
	31–40	16/17	46/21	38/14
	41–50	22/12	56/26	43/17
	51–60	24/14	63/28	59/22
	60–70	18/8	42/16	23/11
	71 and above	11/2	19/8	9/6
Residence	Rural	78/68	231/101	149/52
	Urban	28/16	37/15	48/39
Education status	Illiterate	7/1	15/19	6/4
	Primary (1–5)	11/19	83/44	61/36
	Secondary (6–8)	15/22	69/21	53/23
	Higher Secondary (9–12)	39/26	57/12	43/14
	Graduation (Bachelors)	21/12	38/14	23/11
	Post-graduation (Masters)	13/4	6/6	11/3

2.4. Accuracy and data precision

A comprehensive rural appraisal survey was conducted across three highland districts (Almora, Pithoragarh, and Uttarkashi) of Uttarakhand encompassing a total sample of 862 individuals. The survey aimed to document community perceptions of climate change (CC) and adaptive practices along altitudinal gradients, with responses reported as percentages of the total participants interviewed. Approximately 30% of the population from each selected village contributed, enabling broad representativeness across socio-ecological zones. Data collection employed semi-structured questionnaires and in-depth interviews with diverse community stakeholders. These included village heads (Pradhans), household decision-makers, traditional herbal practitioners (Vaidyas), and residents spanning five defined age brackets (< 25, 26–40, 41–55, 56–70, > 70 years). Caste and ethnic identities (including Scheduled tribes) were acknowledged as important dimensions of social differentiation in the

Himalayan context but were not treated as independent analytical variables due to sensitivity surrounding identity disclosure and uneven representation across study sites. Instead, socio-ecological vulnerability was examined through livelihood dependence, land-use practices, and migration patterns. Respondents reflected on climate-related changes by reconstructing historical scenarios through generational memory and by comparing perceived past conditions with current climatic and ecological realities. To ensure linguistic accessibility and cultural relevance, surveys and interviews were conducted in the local dialect. The inquiry addressed multiple facets of village ecosystem dynamics, climate variability, resource availability, changes in agricultural and livestock productivity, pest outbreaks, incidence of climate-sensitive diseases, and broader impacts on human health and social resilience. In parallel, documentation focused on traditional knowledge systems, particularly concerning the use and observed phenological shifts of high-value medicinal plant species. Insights into the deterioration of traditional healthcare practices linked to ecological disruptions were also synthesized (Table 2). To corroborate community-based observations on medicinal plant phenology and ecological shifts, published botanical literature and regional floristic records were consulted (Naithani, 1984; Gaira et al. 2014; Singh et al., 2015). The adaptation strategies were further analyzed at the household and community levels, encompassing responses from both genders across age groups. Local barriers to climate adaptation, ranging from institutional constraints to resource limitations, were explicitly documented based on respondent testimonies.

3. Results

3.1 Community Perception of Climate Change and Agroecological Shifts

An overwhelming majority of respondents (91.74%) expressed acute awareness and concern regarding the adverse impacts of climate change in their respective valleys (Fig. 2). The key indicators cited include rising ambient temperatures (82.77%), increasing frequency of drought events (73.02%), declining consistency and predictability of rainfall (91.37%), reduced rainfall frequency (87.52%), diminished snowfall (72.63%), and observable shifts in plant phenology (63.53%) (Fig. 3). A significant proportion (83.3%) of respondents reported a substantial decline in the yields of traditional crops such as *Hordeum vulgare* L., *Eleusine coracana* (L.) Gaertn., *Fagopyrum esculentum* Moench, *F. tataricum* (L.) Gaertn., *Amaranthus paniculatus* L., *Setaria italica* (L.) P. Beauv., *Sesamum indicum* L., and *Sorghum vulgare* Pers. etc. In response, communities have increasingly adopted climate-resilient and market-oriented crop alternatives including cash crops (*Pisum sativum* L., *Phaseolus vulgaris* L., *Zingiber officinale* Roscoe), vegetables (*Brassica oleracea* L., *Solanum tuberosum* L., *S. melongena* L., *Lycopersicon esculentum* Mill.), and fruits (*Pyrus malus* L., *Carica papaya* L., *Mangifera indica* L., *Citrus maxima* (Burm.) Merr.), particularly in mid-altitude zones (1500–2500 m) and selected higher elevation sites (2600–3800 m). The alarmingly, 69.85% of respondents indicated an increase in the prevalence of crop diseases and insect-pest infestations, which have further contributed to yield decline. Across mid and lower elevations areas, the emergence of novel pest species and fungal infections, including leaf spot, stem rot, floral

blight, and leaf bloom distortion, has become increasingly common. Respondents also highlighted the rapid spread of invasive species and a marked reduction in the availability of culturally and nutritionally important wild edibles. These include flowers (*Rhododendron arboreum* Sm.), fruits (*Myrica esculenta* Buch.-Ham. ex D. Don, *Pyracantha crenulata* (D. Don) M. Roem, *Embllica officinalis* Gaertn.), and vegetables (*Diplazium esculentum* (Retz.) Sw. *Bauhinia variegata* L, *Morchella esculenta*, *Chenopodium album* L, *Phytolacca acinosa* Roxb.), with 65.97% of respondents reporting significant declines in their accessibility and abundance (Fig. 2).

Low alt- Low Altitude (Barora Valley; 1000-1500m asl), Mid alt-Middle Altitude (Chaundas Valley; 1501-2501m asl), High alt- High Altitude (Byans Valley; 2501-3800m asl)

In mid- and high-altitude villages, respondents consistently reported pronounced alterations in rainfall and snowfall patterns, which have had severe repercussions on horticultural fruit yields, most notably, apple production. Apple cultivation represents a cornerstone of livelihood and agro-economic stability in the upper Bhagirathi valley; however, climatic irregularities have significantly undermined its net productivity. Among the most cited stressors was the increasing frequency of intense hailstorms during the critical fruit-setting phase, identified as the primary cause behind the precipitous decline in apple yields. Beyond horticulture, a range of other sectors, including agriculture, livestock management, and access to wild food resources, have also experienced negative impacts due to climate variability and warming trends. A summary of these cross-sectoral disruptions is detailed in (Fig. 2).

In mid and high-altitude villages, people reported that change in rainfall and snowfall has impacted the yield of horticultural fruits particularly of apple production. Apple cultivation and production is the prime livelihood activity in the upper Bhagirathi valley of Uttarkashi also has negative impacts with climate warming and variability as revealed by local inhabitants. Respondents reported that heavy hailstorm during initial growth of fruits is the most vital reason for declining apple production. Besides above, they have cited various examples of climate warming and variability (Fig. 2). About 76.23% in middle altitude and 63.46% respondents in high altitude expressed that CC also impacted phenophases (flowering and fruiting) of some important medicinal plant species. Local *Vadiyas* of high-altitude villages observed 15–30 days earlier flowering and fruiting in many medicinal plants of alpine meadows namely *Picrorhiza kurrooa* Royle, *Saussurea costus* (Falc.) Lipsch., *Angelica glauca* Edgew. *Allium humile* Kunth., *A. stracheyi* Baker., *Rheum emodi* Wall., and many more. One of the important changes has been observed in the availability of Yarsha gambu (*Cordyceps sinensis*), a fungus of highly medicinal value and source of livelihood to tribal inhabitants of the region, that was not reported in earlier studies (Negi et al., 2006; 2014).

3.2. Climatic Variability and Its Impacts on Horticultural and Medicinal Flora

Residents of mid- and high-altitude villages consistently reported that shifts in precipitation regimes, particularly erratic patterns of rainfall and declining snowfall, have critically affected horticultural

productivity, with apple cultivation being most severely impacted. Apple farming constitutes the principal livelihood source in the upper Bhagirathi valley of Uttarkashi, where climate warming and variability have posed tangible threats to both yield and economic stability. According to local observations, the increasing incidence of heavy hailstorms during the early fruit development stages was identified as the predominant factor contributing to the decline in apple production. Beyond horticulture, respondents offered diverse examples of climate-induced perturbations affecting ecological and livelihood systems (Fig. 2). Notably, 76.23% of middle-altitude and 63.46% of high-altitude respondents noted that climate change has disrupted the phenophases, flowering and fruiting patterns, of several key medicinal plant species (Fig. 2). Traditional herbal practitioners (Vadiyas) from alpine villages reported that species such as *Picrorhiza kurrooa* Royle, *Saussurea costus* (Falc.) Lipsch. *Angelica glauca* Edgew., *Allium humile* Kunth., *A. stracheyi* Baker., *Rheum emodi* Wall., and others are now exhibiting flowering and fruiting 15–30 days earlier than previously recorded. A particularly significant change has been observed in the availability of Yarsha gambu (*Cordyceps sinensis*), a fungus of high medicinal value and critical economic importance for tribal communities in the region. Its emergence in recent years, as highlighted by local stakeholders, marks a new ecological and socioeconomic shift not documented in earlier studies (Negi et al., 2006; 2014).

3.3 Indigenous Adaptation Strategies in Response to Climate Variability

To address increasing climatic instability and erratic weather patterns, local communities in mid- and high-altitude regions have actively implemented a suite of indigenous, experience-driven adaptation strategies (Tables 3a & 3b). These interventions are deeply rooted in traditional ecological knowledge and reflect a pragmatic response to emerging environmental stresses. Key measures include: (i) construction of rainwater harvesting tanks, gully stabilization structures, and infiltration trenches to combat spring desiccation; (ii) excavation and maintenance of community ponds positioned strategically near homesteads and farm edges to ensure water availability; (iii) adoption of improved composting techniques to enhance soil fertility and crop productivity; (iv) modification of seed sowing calendars to align with shifting climatic windows; and (v) targeted replanting and gap-filling using heat- and water-resilient seedlings, coupled with increased crop rotation, diversification, and selective use of agrochemicals (Table 3a). These measures have evolved alongside a marked decline in the cultivation of traditional crops, driven by both socio-economic transitions and climate-induced constraints, posing novel challenges to mountain farming systems. Consequently, many villages have shifted towards agroforestry models, integrating multiple crop types within spatially optimized layouts to ensure resilient and harmonious production. Farmers increasingly employing organic inputs, such as vermicompost and bio-compost, alongside high-yielding hybrid varieties to bolster productivity. Additionally, seasonal and short-duration crops, such as maize, turmeric, ginger, and leafy vegetables, are cultivated year-round to diversify livelihood options and reduce vulnerability. A notable recent adaptation involves the introduction of new horticultural cultivars, particularly high-yielding apple varieties like *Actinidia deliciosa* (A. Chev.) C.F. Liang & A.R. Ferguson, across mid-altitude zones in the western Himalaya. In several high-altitude settlements, traditional staples such as *Hordeum vulgare* L. and *Fagopyrum esculentum* Moench,

are being systematically replaced by apple orchards, reflecting a strategic pivot toward climate-resilient agricultural practices and market-aligned crop systems. The Adaptation strategies from Tables 3a-3b (e.g., rainwater harvesting, crop diversification, herd reduction, sacred groves) will be clustered into four domains: water management, cropping systems, livestock management, and land/housing practices. Barriers (e.g., lack of early warnings, extension services, and seed access).

Table 3

a. Climate change impacts and community-based adaptations at local level in Western Himalaya

Climate change impacts	Adaptation Strategies	Studies sites		
		LA	MA	HA
Drying up of water streams and springs	Rainwater harvesting tank, gully structure and trenches	✓	✓	
Declining soil moisture and soil erosion	Covering soil with litter/ mulching	✓	✓	✓
	Using vermi-compost and organic fertilizers	✓	✓	
Mortality of seedlings and saplings	Planting seedlings for gap filling area	✓	✓	
	Used bamboo stick to protect seedlings and saplings from wind breaks		✓	
Restoration of flash flood area	Construction of chek-dam, planting of broad leaf species (<i>Alnus nepalensis</i> D.Don, <i>Quercus leucotrichophora</i> A.Camus, <i>Grewia optiva</i> J.R. Drumm. ex Burret. <i>Bauhinia variegata</i> L. etc.).	✓	✓	
Expansion of invasive species	Removal of invasive species through regular cleaning	✓	✓	✓
Human diseases have increased (allergies, skin, dysentery and diarrhea)	Adoption of traditional health care system		✓	✓
Change in growing season and decline in agriculture productivity	Change in seed sowing and planting time, preference short rotational crop varieties	✓	✓	
Pest attacks and disease incidences in agri-horti crops	Planting short rotational crops, diversification, using pesticide	✓	✓	
Decline in availability of medicinal plants	Promoted cultivation and conservation of medicinal plants through development of Medicinal Plant Conservation Areas		✓	✓
High incidents of landslides and flood	Construction of protection wall and plantation of soil stabilizing species	✓	✓	✓
Decline in availability of non-Timber Forest Products (NTFPs)	Promotion to agro-forestry and plantation of multifarious species	✓	✓	
Crop failure and economic loss	Alternate source of livelihood (Handicrafts business)		✓	✓

Climate change impacts	Adaptation Strategies	Studies sites		
		LA	MA	HA
Decline fuelwood energy resources	Using efficient cooking stove, and non-preferred tree and shrub species for fuelwood energy	√	√	

Table 3

b. People perception (n = 862) on various examples of climate change in Western Himalaya

Low altitude (1000–1500)	Middle altitude (1501–2500)	High altitude (2501–3800)
Adoption of LPG and kerosene chullah to meet the fuel wood requirement	Depending on fuel wood, harvested from nearby forest	Dependent on fuel wood from forest and pasture
Harvesting of tree species (<i>Pinus roxburghii</i> Sarg, <i>Shorea robusta</i> Roth, <i>Myrica esculenta</i> Buch.-Ham. ex D.Don, <i>Quercus leucotrichophora</i> A.Camus etc) for fuel wood requirement	Harvesting of trees (<i>Pinus roxburghii</i> Sarg, <i>Pinus wallichiana</i> A.B.Jacks., <i>Alnus nepalensis</i> D.Don, <i>Rhododendron arboreum</i> Sm. etc) species for fuel wood.	Harvesting of unique and threatened shrub (<i>Juniperus</i> spp.) and tree (<i>Abies pindrow</i> (Royle ex D.Don) Royle, <i>Pinus wallichiana</i> A.B. Jacks., <i>Betula utilis</i> D.Don <i>Juniperus indica</i> , Bertol. <i>Juniperus communis</i> L.) species for fuel wood.
Livestock population is high due to adequate availability of fodder.	Reduce the quantity of livestock due to scarcity of fodder.	Reduce the quantity of livestock due carrying capacity of pasture land, scarcity of fodder
Major fodder demand met from agriculture and partial from forest. Also cultivate fodder species in the farmland	Dependent on forest for fodder requirements and also left the cattle in the forest for grazing	Left livestock for long period in the forest and alpine pasture for grazing
Migrate to the urban area for employment and livelihood.	Highly engaged in the collection of high value medicinal plants for income generation (i.e. <i>Cordyceps sinensis</i> , <i>Allium</i> spp.)	Engaged in the collection of high value medicinal plants for income generation
Cultivation of few medicinal plants	Cultivation of few medicinal plants i.e. <i>Swertia chirata</i> Buch.-Ham. ex Wall. <i>Allium stracheyi</i> Baker, <i>Picrorhiza kurrooa</i> Royle, <i>Origanum vulgare</i> L., etc.	Cultivation of few high valued medicinal plants i.e. <i>Podophyllum hexandrum</i> Royle, <i>Picrorhiza kurrooa</i> Royle, <i>Carum carvi</i> L., <i>Saussurea costus</i> (Falc.) Lipsch.
Increased homestead biodiversity with multifarious species and vegetables cultivation	Cultivation of apple Awanla at middle altitude villages and	Engaged in cultivation of cash crops.
Low alt- Low Altitude (Barora Valley; 1000-1500m asl), Mid alt-Middle Altitude (Chaundas Valley; 1501-2501m asl), High alt- High Altitude (Byans Valley; 2501-3800m asl)		

Low altitude (1000–1500)	Middle altitude (1501–2500)	High altitude (2501–3800)
	cash crops (Potato & Kidney bean)	
Regular working of <i>Van panchyat</i> and sustainable harvesting of forest resources at community decision	Regular working of <i>Van panchyat</i> and sustainable harvesting of forest resources at community decision	Regular working of <i>Van panchyat</i> and sustainable harvesting of forest resources at community decision
Conservation of unique forest as Sacred groves by taking account of cultural and spiritual values	Conservation of unique forests by taking account cultural and spiritual values	Conservation of unique forest by taking account cultural and spiritual values
Shortening of maturity period of winter crops, increased warmer period and pest infestation.	Shortening of maturity period of winter crops, increased pest infestation.	Decline in snowfall period, depth and persistence, decline in apple yield, success of cabbage/pea/tomato cultivation in high elevations in recent years
Damage to rainy season crops when they are close to maturity, increased frequency of rainfall.	Damage to rainy season crops when they are close to maturity, increased frequency and severity of landslides.	Large-scale mortality, abandonment of <i>Panicum miliaceum</i> L in rain fed area, declining yields of <i>Amaranthus</i> .
	Delayed sowing of winter crops, decline in barley and wheat yields in mid altitude.	Delayed sowing of winter crops, because increase temperature in high altitude.
	Use of hybrid varieties and high-yielding varieties of upper apple in Bhagirathi valley	Initiation of apple cultivation in most of the villages (i.e Gunji, Garbiyang, Bhudhi of Pithoragarh district)
	Replacement of apple cultivation by the vegetable (i.e. <i>Lycopersicon esculentum</i> Mill.) and other horticulture crops (i.e <i>Actinidia deliciosa</i> (A.Chev.)	Replacement of traditional crops (i.e <i>Hordeum vulgare</i> L. and <i>Fagopyrum esculentum</i> Moench) by apple cultivation
Low alt- Low Altitude (Barora Valley; 1000-1500m asl), Mid alt-Middle Altitude (Chaundas Valley; 1501-2501m asl), High alt- High Altitude (Byans Valley; 2501-3800m asl)		

3.3. Community-Driven Adaptations in Energy, Livelihood, and Land Use Systems

In response to mounting pressure from climate-induced resource constraints, inhabitants of mid- and high-altitude villages have initiated diverse adaptive measures in household energy use, land management, and livelihood diversification (Table 3b). To address the depletion of forest biomass and fuelwood resources, many households have transitioned to cleaner cooking alternatives, including liquefied petroleum gas (LPG) and kerosene. Additionally, communities have begun favoring fast-growing shrub species for fuelwood collection, reducing reliance on ecologically sensitive forest zones. The livestock management strategies have also undergone substantial shifts. Households at higher altitudes have reduced herd sizes due to dwindling fodder availability and the declining carrying capacity of alpine pastures. In contrast, farmers at lower elevations have responded by cultivating *Pennisetum purpureum* Schumach. (Napier grass), a high-yielding fodder crop capable of mitigating forage scarcity. Several villages, particularly those at mid and higher elevations, have adopted rotational conservation practices by designating sacred groves to protect endemic forest species. These groves serve as ecological reservoirs, supporting sustainable extraction of fuelwood and fodder within culturally regulated frameworks.

In parallel, high-altitude farming communities have begun cultivating select medicinal plant species, including *Allium stracheyi* Baker., *Picrorhiza kurrooa*, *Saussurea costus* (Falc.) Lipsch. *Angelica glauca* Edgew., and *Podophyllum hexandrum* Royle, as supplementary income sources and ecological buffers. These species, traditionally harvested from wild alpine meadows, are now increasingly integrated into farm-based conservation plots to support household resilience. The architectural adaptations were also observed, with communities modifying traditional housing designs to improve thermal insulation, material efficiency, and climate responsiveness. These structures, often built using locally sourced materials and passive solar principles, reflect the evolving intersection of indigenous knowledge and contemporary climate challenges. The Assessments emphasize macro-level gaps, recommending sectoral studies, stakeholder consultations, and State Action Plan revisions for resilience-building. Longitudinal data from Kashmir shows increasing vulnerability from urbanization, deforestation, and water disputes amid heatwaves/droughts.

Table 3

b. Adaptation of mountain communities to cope up with the climate change impact across elevation gradient of Western

Low altitude (1000–1500)	Middle altitude (1501–2500)	High altitude (2501–3800)
Adoption of LPG and kerosene chullah to meet the fuel wood requirement	Depending on fuel wood, harvested from nearby forest	Dependent on fuel wood from forest and pasture
Harvesting of tree species (<i>Pinus roxburghii</i> Sarg, <i>Shorea robusta</i> Roth, <i>Myrica esculenta</i> Buch.-Ham. ex D. Don, <i>Quercus leucotrichophora</i> A.Camus etc) for fuel wood requirement	Harvesting of trees (<i>Pinus roxburghii</i> Sarg, <i>Pinus wallichiana</i> A.B.Jacks., <i>Alnus nepalensis</i> D.Don, <i>Rhododendron arboreum</i> Sm. etc) species for fuel wood.	Harvesting of unique and threatened shrub (<i>Juniperus</i> spp.) and tree (<i>Abies pindrow</i> (Royle ex D.Don) Royle, <i>Pinus wallichiana</i> A.B. Jacks., <i>Betula utilis</i> D.Don <i>Juniperus indica</i> , Bertol. <i>Juniperus communis</i> L.) species for fuel wood.
Livestock population is high due to adequate availability of fodder.	Reduce the quantity of livestock due to scarcity of fodder.	Reduce the quantity of livestock due carrying capacity of pasture land, scarcity of fodder
Major fodder demand met from agriculture and partial from forest. Also cultivate fodder species in the farmland	Dependent on forest for fodder requirements and also left the cattle in the forest for grazing	Left livestock for long period in the forest and alpine pasture for grazing
Migrate to the urban area for employment and livelihood.	Highly engaged in the collection of high value medicinal plants for income generation (i.e. <i>Cordyceps sinensis</i> , <i>Allium</i> spp.)	Engaged in the collection of high value medicinal plants for income generation
Cultivation of few medicinal plants	Cultivation of few medicinal plants i.e. <i>Swertia chirata</i> Buch.-Ham. ex Wall. <i>Allium stracheyi</i> Baker, <i>Picrorhiza kurrooa</i> Royle, <i>Origanum vulgare</i> L., etc.	Cultivation of few high valued medicinal plants i.e. <i>Podophyllum hexandrum</i> Royle, <i>Picrorhiza kurrooa</i> Royle, <i>Carum carvi</i> L., <i>Saussurea costus</i> (Falc.) Lipsch.
Increased homestead biodiversity with multifarious species and vegetables cultivation	Cultivation of apple Awanla at middle altitude villages and cash crops (Potato & Kidney bean)	Engaged in cultivation of cash crops.

Low altitude (1000–1500)	Middle altitude (1501–2500)	High altitude (2501–3800)
Regular working of <i>Van panchyat</i> and sustainable harvesting of forest resources at community decision	Regular working of <i>Van panchyat</i> and sustainable harvesting of forest resources at community decision	Regular working of <i>Van panchyat</i> and sustainable harvesting of forest resources at community decision
Conservation of unique forest as Sacred groves by taking account of cultural and spiritual values	Conservation of unique forests by taking account cultural and spiritual values	Conservation of unique forest by taking account cultural and spiritual values
Shortening of maturity period of winter crops, increased warmer period and pest infestation.	Shortening of maturity period of winter crops, increased pest infestation.	Decline in snowfall period, depth and persistence, decline in apple yield, success of cabbage/pea/tomato cultivation in high elevations in recent years
Damage to rainy season crops when they are close to maturity, increased frequency of rainfall.	Damage to rainy season crops when they are close to maturity, increased frequency and severity of landslides.	Large-scale mortality, abandonment of <i>Panicum miliaceum</i> L, in rain fed area, declining yields of <i>Amaranthus</i> .
	Delayed sowing of winter crops, decline in barley and wheat yields in mid altitude.	Delayed sowing of winter crops, because increase temperature in high altitude.
	Use of hybrid varieties and high-yielding varieties of upper apple in Bhagirathi valley	Initiation of apple cultivation in most of the villages (i.e Gunji, Garbiyang, Bhudhi of Pithoragarh district)
	Replacement of apple cultivation by the vegetable (i.e. <i>Lycopersicon esculentum</i> Mill.) and other horticulture crops (i.e <i>Actinidia deliciosa</i> (A.Chev.)	Replacement of traditional crops (i.e <i>Hordeum vulgare</i> L. and <i>Fagopyrum esculentum</i> Moench) by apple cultivation

3.4 Barriers to Climate Change Adaptation

The household-level constraints continue to inhibit effective implementation of climate change adaptation strategies across the Western Himalaya (Fig. 4). The absence of reliable early warning

systems emerged as the most critical barrier, identified by 85.84% of respondents. This lack of timely alerts undermines community preparedness and hinders proactive risk mitigation. The financial limitations also pose a formidable challenge, approximately 61.4% of households reported that the high cost of innovative techniques restricts adoption, particularly in the context of low per capita income and limited access to market-based resources. These economic barriers compound the difficulty of transitioning to resilient agricultural and infrastructural practices. The technical constraints further aggravate adaptation gaps. The respondents cited insufficient technical expertise (61.4%) and lack of access to appropriate technology (64.1%) as key deterrents to adopting climate-resilient solutions. Additionally, the perceived ineffectiveness of certain indigenous practices (72.3%) suggests a need to strengthen the interface between traditional knowledge systems and emerging scientific interventions. The institutional support remains inadequate, only 38.2% of respondents reported access to extension services, underscoring a persistent disconnect between state-led programs and local implementation. Moreover, the limited availability of improved crop varieties and seeds (76.2%) constrains agricultural diversification and productivity under changing climatic conditions. These barriers highlight the urgent need for integrated policy frameworks that couple technological advancement with locally tailored capacity building, financial inclusion, and institutional outreach.

We have substantially sharpened the conceptual framing by integrating the IPCC vulnerability model (exposure–sensitivity–adaptive capacity) with a novel TEK co-production pathway, rigorously hypothesizing that validated climate perceptions (e.g., 87.5% erratic rainfall, 82.7% temperature rise) trigger clustered adaptation strategies (water/cropping/livestock/land) whose efficacy is moderated by informational (85.8% lack early warnings), institutional (76.2% extension gaps), and financial barriers (small landholdings) across our strategically designed 1000–3800 m altitudinal transect, revealing critical socio-ecological gradients from market-connected lowlands (Barora) to remote pastoral highlands (Byans/Chaudas), thus establishing testable pathways from ethnic/valley-specific TEK activation to empirically reduced vulnerability.

3.5. Policy Implications for Climate Change Adaptation

In the above all, future climate adaptation policies in the Western Himalaya must prioritize decentralized, community-driven frameworks that enable inclusive participation and strengthen ecological resilience. The barriers identified, ranging from economic constraints to lack of technical access, underscore the critical need for targeted investment in early warning systems, climate-smart technologies, and tailored extension services (Agrawal, 2008; Mehta et al., 2019).

The integrating indigenous ecological knowledge with formal scientific approaches should be institutionalized through co-designed capacity-building programs and localized innovation hubs (Pandey et al., 2016). Additionally, adaptive agricultural inputs such as improved crop varieties and region-specific fodder species require broader dissemination through publicly funded seed banks and community nursery networks (Venkateswarlu & Shanker, 2009).

The policies must also account for altitudinal variability in socio-ecological systems by establishing differentiated adaptation incentives that reflect the unique constraints of highland versus midland communities. Moreover, rotational forest-use models and sacred grove conservation, rooted in cultural norms, should be recognized as viable pathways for sustainable resource governance and incorporated into mainstream land-use planning (Berkes et al., 2012). In essence, effective policy design demands a pluralistic and multi-scale approach that bridges administrative support with grassroots innovation, ensuring that adaptation is both ecologically sound and socially just.

4. Discussion

The present study demonstrates that climate change in the western Himalaya is predominantly understood and experienced through changes in the daily livelihood system. Across the study region, local inhabitants consistently perceived rising temperatures, erratic rainfall and snowfall patterns, and drying of springs. Similar findings also reported in perception-based studies from different parts of the Himalayan region (Saxena & Rao, 2009; Chaudhary and Bawa, 2011; Negi et al., 2012; Tripathi and Singh, 2013; Rahman and Alam, 2016; Negi et al., 2017). Perceived climate impacts were strongly mediated by altitude-specific resource dependence. In the present study, we reported that high-altitude communities have observed declining snowfall, reduced snow cover duration, and phenological shifts in forest and medicinal plant species. These findings align with the ecological perspective, suggesting that vulnerability in the mountain system is shaped less by elevation alone and more by interaction among climate stress, land use, livelihood strategies, and access to resources (Nightingale, 2015; Ojha et al., 2016). Uttarakhand survey and validated datasets. The claim "perceptions align with global findings of a 1.5°C regional temperature rise" has been revised to "community perceptions of temperature increases (82.7%) align with observed Western Himalayan warming of 0.16°C/ decade (1985–2020; Kumar et al., 2025).

Furthermore, local people in each valley strongly perceived multipurpose forest species and medicinal plants as critical indicators of climate change. Early flowering, altered fruiting periods, and reduced availability of medicinal flora were consistently reported by older respondents and traditional healers. Similar findings have also been reported by previous researchers across different parts of the Himalayan region (Gaira et al., 2014; Negi et al., 2017; Tiwari et al., 2025). At the same time, the present study consciously avoids a reductionist interpretation of socio-ecological change. Several processes perceived by respondents, such as increasing forest fire incidents, declining agricultural productivity, and shifts towards horticulture-based livelihoods, cannot be causally attributed solely to climate variability. In addition, forest fire in the western Himalayan region, forest instance, are widely recognized as co-produced phenomena, shaped by forest composition (notably pine expansion), institutional forest governance, human ignition sources, and land use practices, with climate acting primarily as an amplifying rather than originating factor (Singh et al., 2023; Sharma & Kumar, 2025). Furthermore, many livelihood changes are reported by respondents, particularly the transition toward commercial horticulture and market-dependent farming, reflecting broader political-economic transformation rather than climate adaptation. A recent publication from the Himalayan region cautions against farming

transitions solely as climate responses, noting that they are often driven by industrialization of mountain economies, demographic change, and shifting state priorities (Bhatta et al., 2019; Chakraborty, 2021; Hussain et al., 2024).

In addition, local people perceived a reduction in cultivated areas, abandonment of traditional crops, adoption of cash crops, and increasing reliance on remittances and seasonal migration. Although these responses provide short-term income stability, they also accelerate agrobiodiversity loss and heighten long-term vulnerability, a pattern observed across the Himalayan region (Maikhuri et al., 2003; Negi et al., 2017; Kumar et al., 2025). Similarly, the apple growing region of the study area reported declining productivity linked to insufficient chilling, pest proliferation, and phenological changes, reinforcing concerns about a climate-sensitive monoculture system at mid to high altitude (Vedwan and Rhoades, 2001; Rana et al., 2011; Das, 2022). In addition, forest-dependent livelihoods were further constrained by declining availability of fuelwood, fodder, and non-timber forest products, compounded by increased forest fire incidence in the pine-dominated region (Chakraborty et al., 2018). While forest fires are often attributed to climatic factors, respondents emphasized the role of forest management practices and human activities (Sharma and Pant, 2017; Sharma et al., 2025). Overall, the study contributes to Himalayan climate scholarship by foregrounding community perception as an analytical lens that captures how climate change is embedded within livelihood transitions, ecological change, and social differentiation.

Furthermore, Persistent adaptation barriers, such as the absence of early warning systems (85.84%), limited access to improved seeds (76.2%), and low household incomes, continue to undermine climate resilience in Himalayan communities (Becker et al., 2012; UNFCCC, 2025). These constraints are particularly acute in high-altitude regions, where ecological fragility and infrastructural deficits compound vulnerability. Robust investments in climate information services, decentralized seed banks, and rural extension systems are essential to overcome these barriers and foster anticipatory action (IIED, 2018). The community-based early warning systems, such as those deployed in the Jiadhal and Singora river basins, have demonstrated life-saving potential by integrating real-time weather monitoring with localized alerts and grassroots mobilization (UNFCCC, 2025). These systems exemplify how technological innovation, when embedded in local governance structures, can enhance adaptive capacity and reduce disaster risk. Similarly, participatory seed conservation and farmer-led varietal trials have enabled the revival of traditional crops and improved food security under shifting climatic regimes (IIED, 2018; Kathayat & Kattel, 2024). In Byans Valley and other high-altitude apple-growing zones, reduced snowfall and early pest outbreaks, such as leaf-boring caterpillars, are disrupting phenological cycles and diminishing yields (Gaira et al., 2014; Harwood & Koirala, 2025; Pharswan & Kuniyal, 2026). These impacts underscore the need for localized climate monitoring, pest forecasting, and adaptive horticultural practices. The loss of winter snow, once a natural pest suppressant, has allowed pests to overwinter and emerge earlier, intensifying crop damage (ICIMOD, 2019; Chawla et al., 2021). Integrating local health practices, diversified income strategies, and indigenous ecological knowledge into formal adaptation planning can further strengthen resilience. For instance, agro-ecological innovations and community-led monitoring in Mustang and Jumla have helped mitigate livelihood risks and reduce

outmigration (Kathayat & Kattel, 2024; Gupta and Chanjta, 2025). Bridging institutional innovations with community knowledge, through inclusive governance, capacity-building, and co-designed interventions, offers a pathway to long-term sustainability across the fragile Himalayan landscape (Ladon, 2025; NITI Aayog, 2018).

5. Conclusions

The Indian Himalayan Region faces a confluence of ecological fragility, climate-induced stressors, and socio-economic vulnerabilities, magnified across its altitudinal zones. This manuscript underscores the urgent need for transdisciplinary strategies that integrate science, policy, and indigenous knowledge to foster climate resilience in high-altitude communities. Addressing water stress through spring shed, restoration, rainwater harvesting, and micro-irrigation, tailored to hydro-ecological contexts and traditional stewardship, offers a robust pathway for revitalizing drying water sources and securing livelihoods. The conservation of forest ecosystems and climate-sensitive medicinal flora demands embedded community-led governance mechanisms, such as Van Panchayats and sacred grove protection, alongside the strategic promotion of agroforestry and invasive species control. The adaptive capacity must be strengthened through decentralized climate information services, improved access to seed diversity, and inclusive rural extension systems. The empirical vulnerabilities, such as phenological disruptions in apple orchards and insufficient early warning systems, highlight the need for localized monitoring, pest forecasting, and diversified livelihood strategies. These findings advocate for a paradigm shift in Himalayan adaptation planning, one that is participatory, ecosystem-specific, and cognizant of biocultural resilience, bridging institutional innovation with community knowledge and placing ecological restoration at the heart of development, sustainable futures for mountain societies are not only imaginable, but they are also actionable.

Declarations

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Author Contributions

Dalbeer Singh Pharswan led the investigation, conducted the formal analysis, and prepared the original draft of the manuscript. Dalbeer Singh Pharswan, Deep Chandra Tiwari, and Indra Dutt Bhatt jointly contributed to the conceptualisation and design of the study, as well as to the development of the methodology. All authors contributed to data interpretation and to the critical review and revision of the manuscript for important intellectual content. Indra Dutt Bhatt, Jagdish Chandra Kuniyal, and Shyamal

Kumar Nandi provided supervision and guidance throughout the research process. All authors read and approved the final manuscript, and agree to be accountable for all aspects of the work.

Data Availability Statement

The datasets generated and/or analysed during the current study are available from the corresponding author on reasonable request. The data are subject to appropriate measures to protect the privacy and confidentiality of the study participants.

Consent to Participate

Informed consent to participate in the study was obtained verbally from all adult participants prior to the interviews and questionnaire surveys. Participants were informed about the purpose and nature of the study, the voluntary nature of their participation, and their right to decline to answer any question or withdraw from the study at any time without providing a reason. Verbal consent was considered appropriate given the local literacy context and was obtained before data collection.

Ethics Statement

The Institutional Ethics Committee of G.B. Pant National Institute of Himalayan Environment (GBPNiHE), Kosi-Katarmal, Almora, Uttarakhand, granted a waiver of approval for this study. The research was conducted in accordance with the committee's policies and the ICMR National Ethical Guidelines for Biomedical and Health Research Involving Human Participants (2017), as well as the Declaration of Helsinki (2013). Written informed consent was obtained from all participants; appropriate measures were implemented to protect data privacy and participant confidentiality.

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Figures

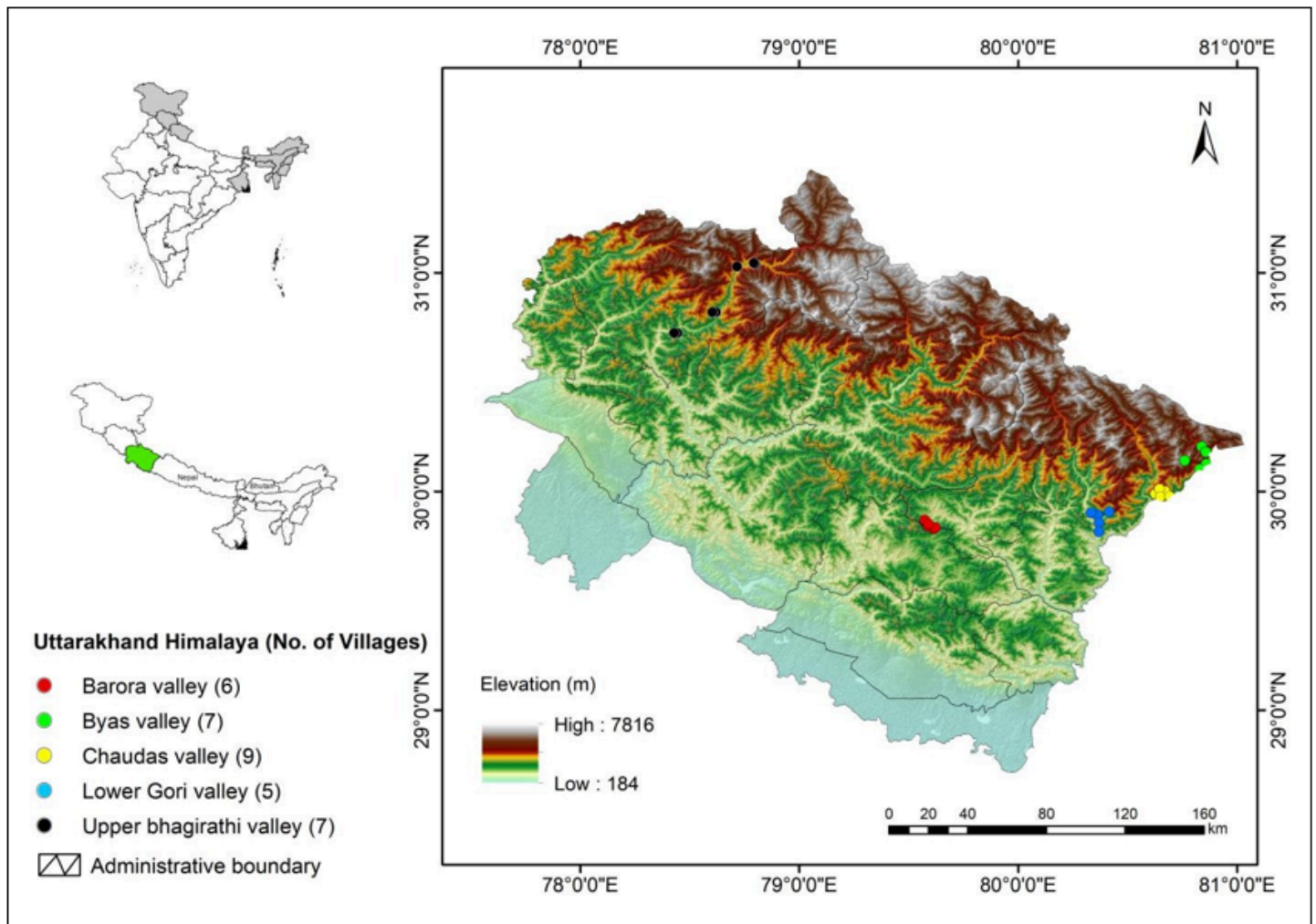


Figure 1

Study area map: different valleys in the Western Himalaya

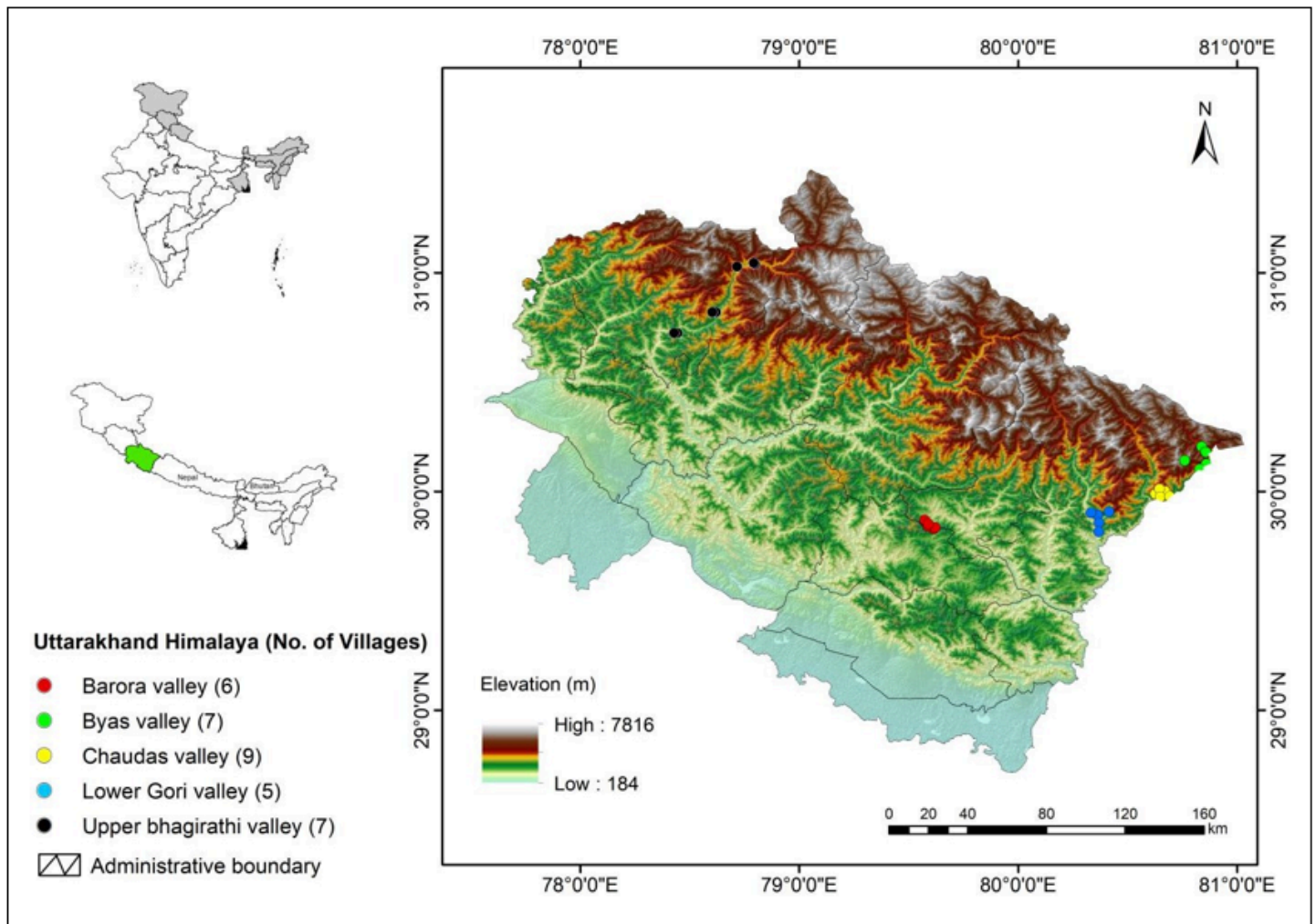


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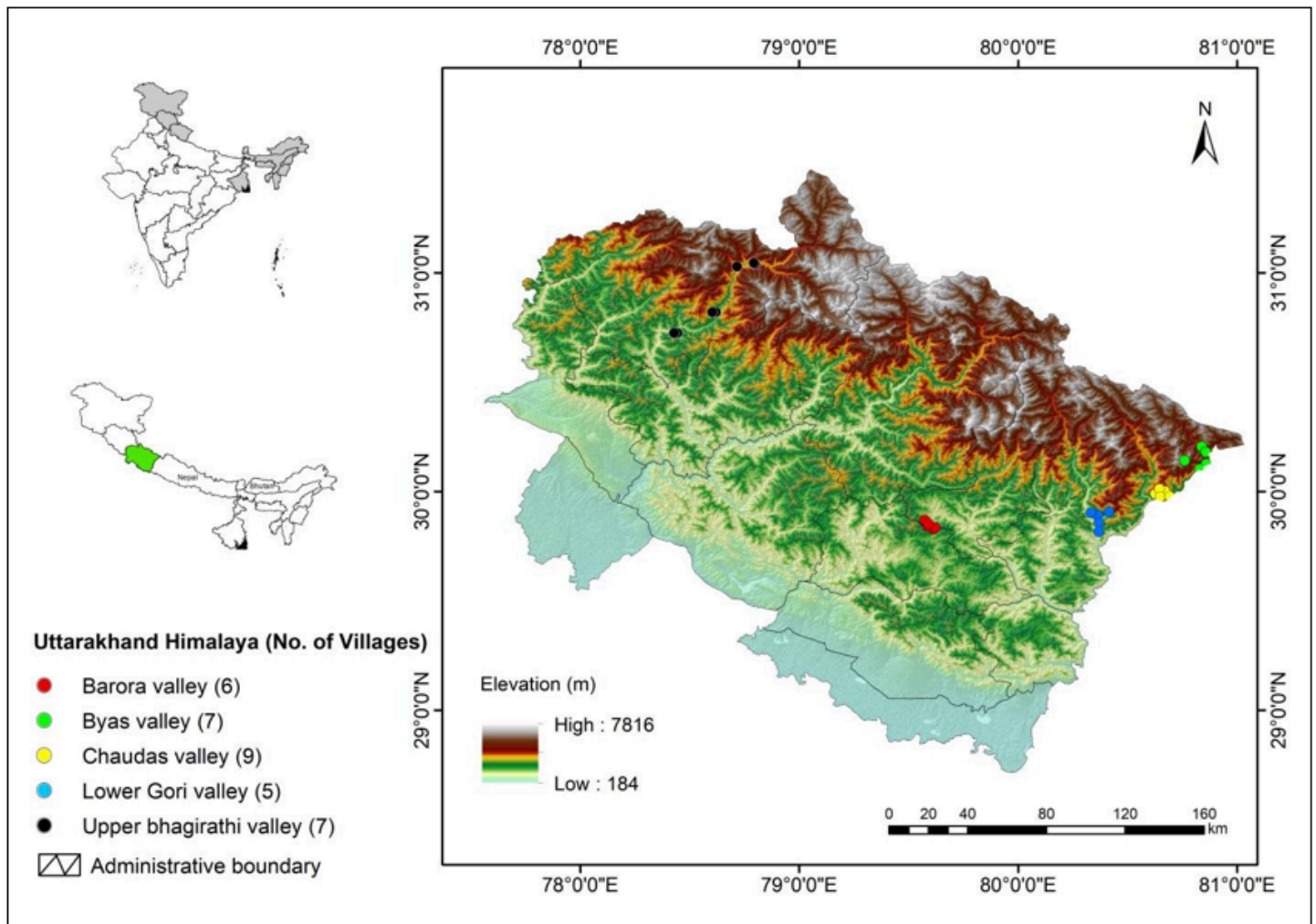


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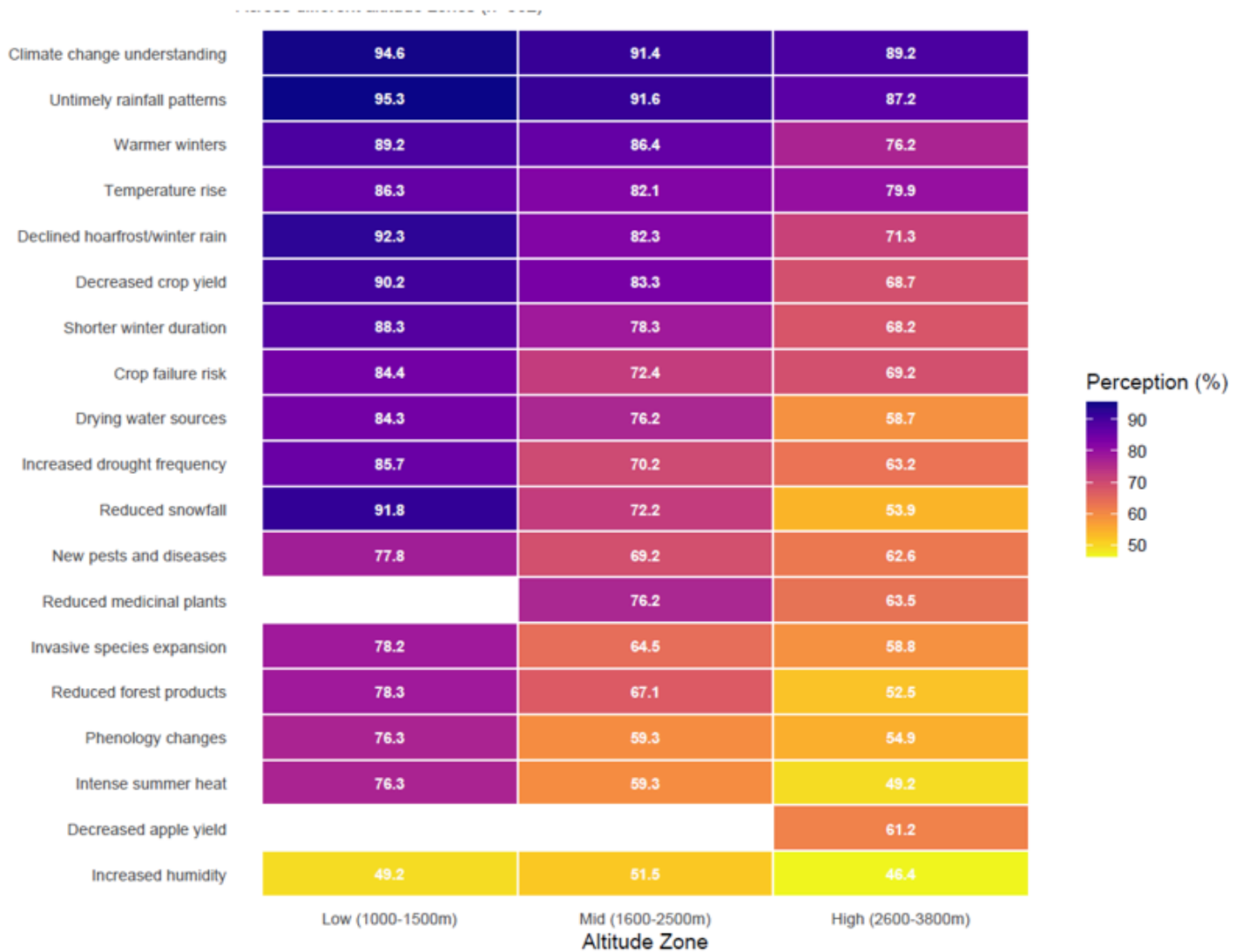


Figure 2

People perception (n=862) on various examples of climate change in Western Himalaya

Low alt- Low Altitude (Barora Valley; 1000-1500m asl), Mid alt-Middle Altitude (Chaundas Valley; 1501-2501m asl), High alt- High Altitude (Byans Valley; 2501-3800m asl)

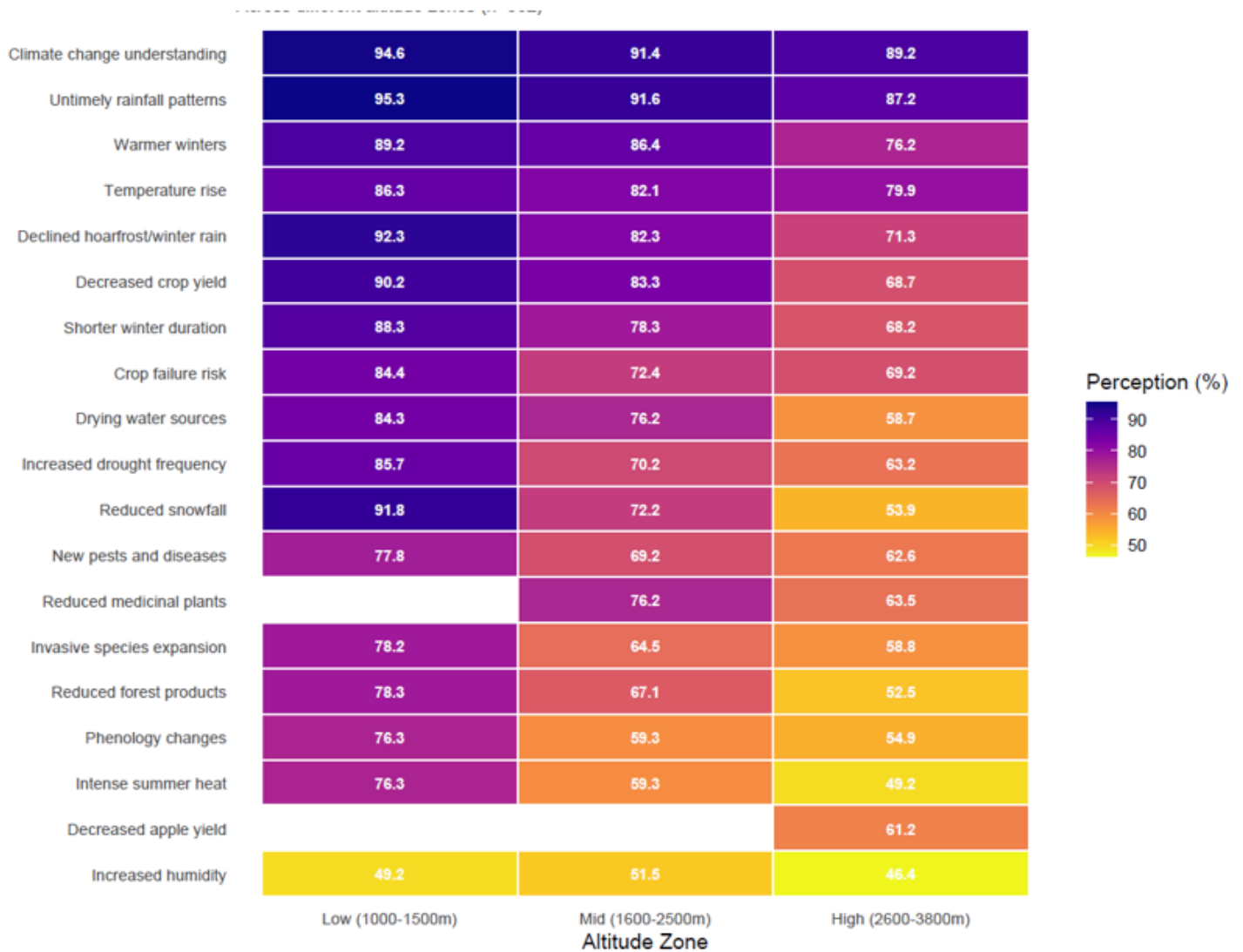


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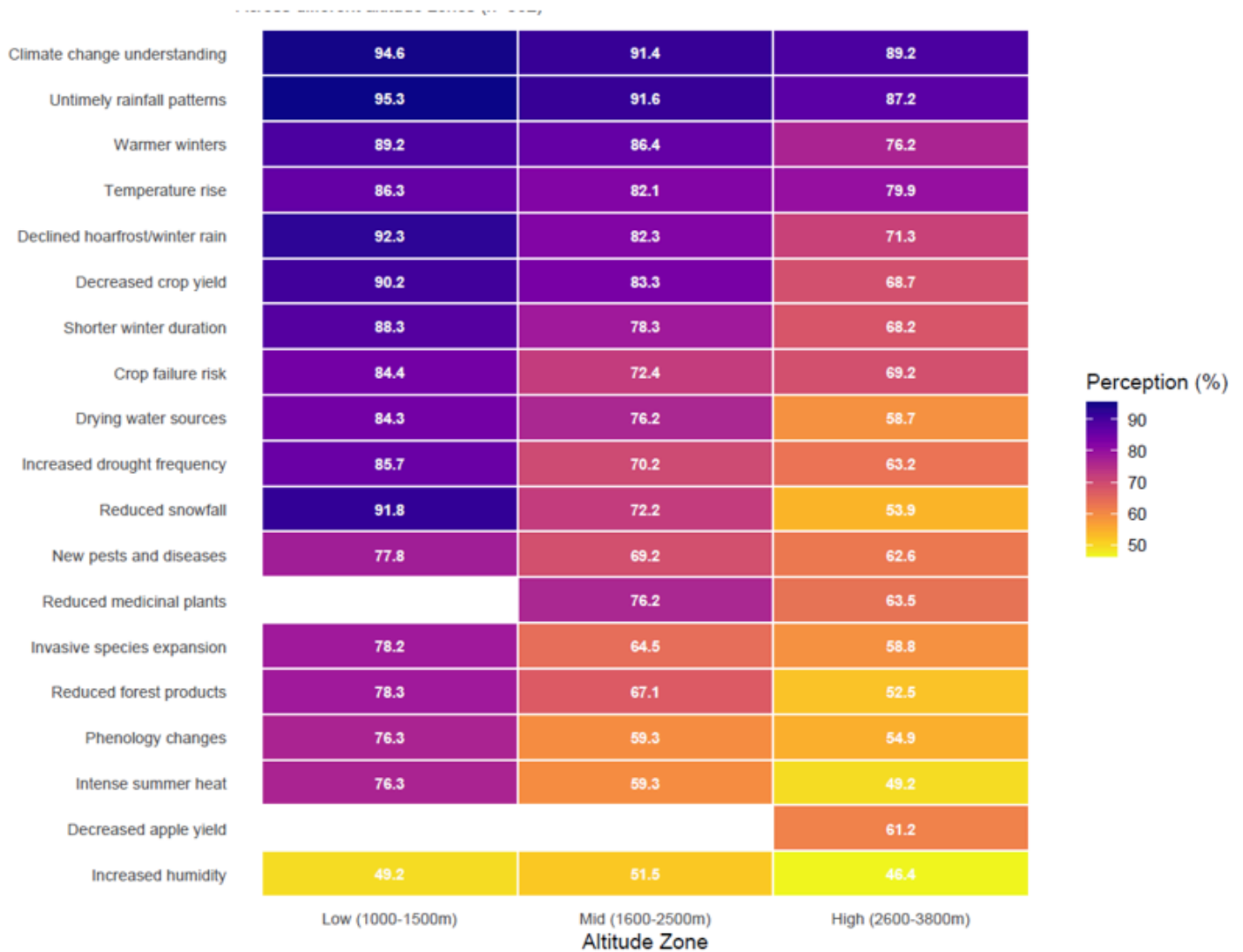


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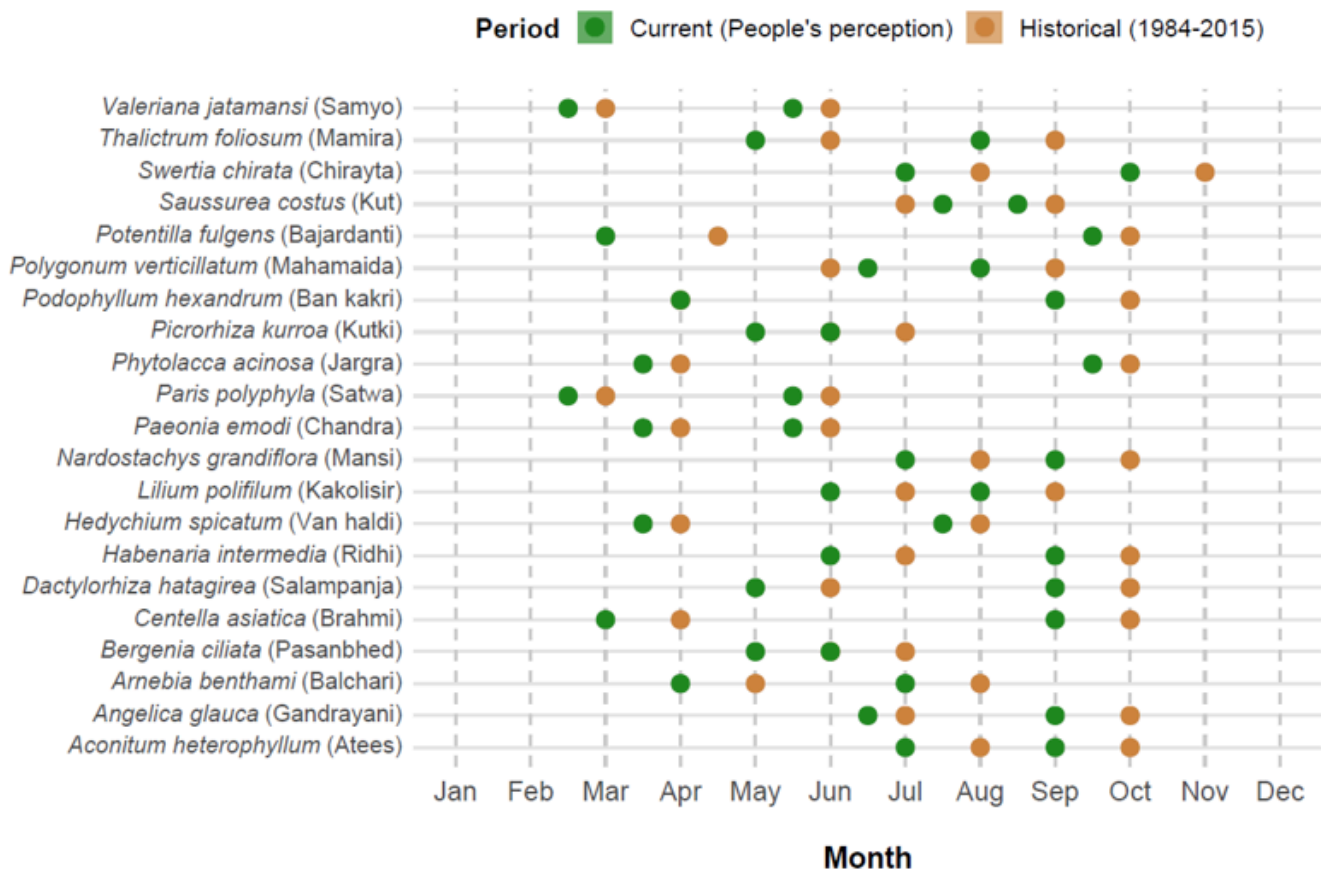


Figure 3

Impacts of climate change on phenology (flowering & fruiting) of some important medicinal plants

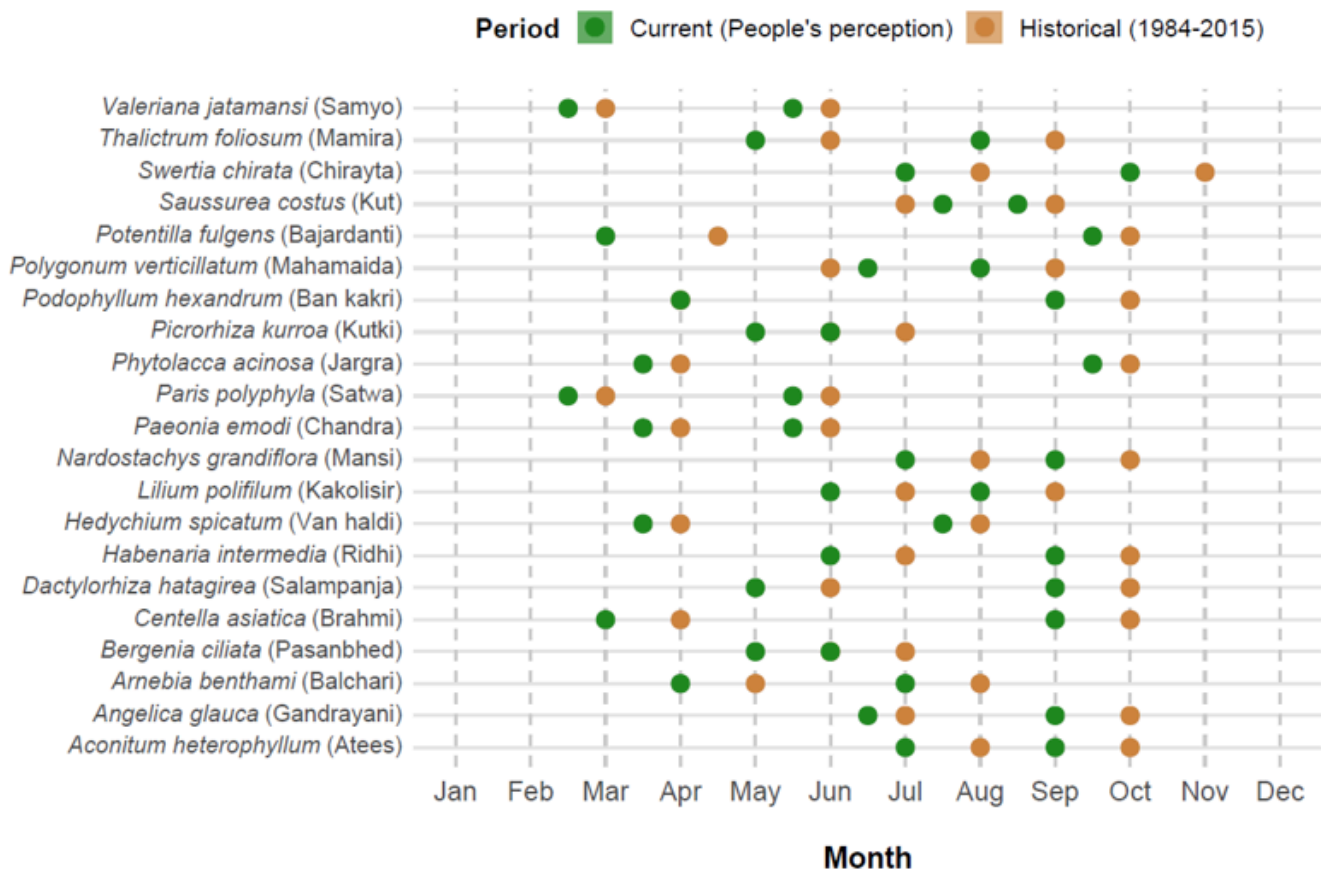


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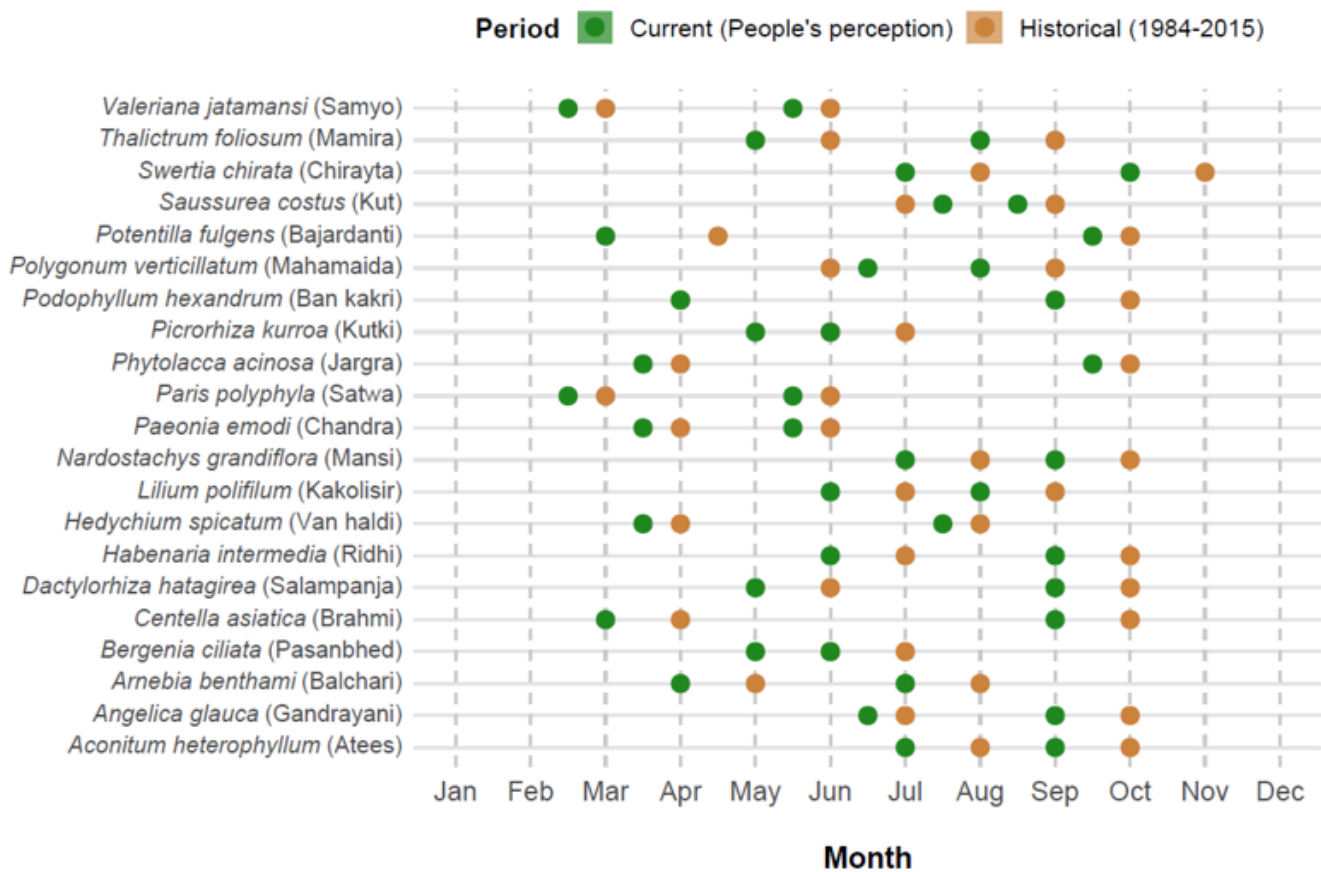


Figure 3

Impacts of climate change on phenology (flowering & fruiting) of some important medicinal plants

Household-Level Barriers to Climate Change Adaptation

Comparison across altitudinal zones

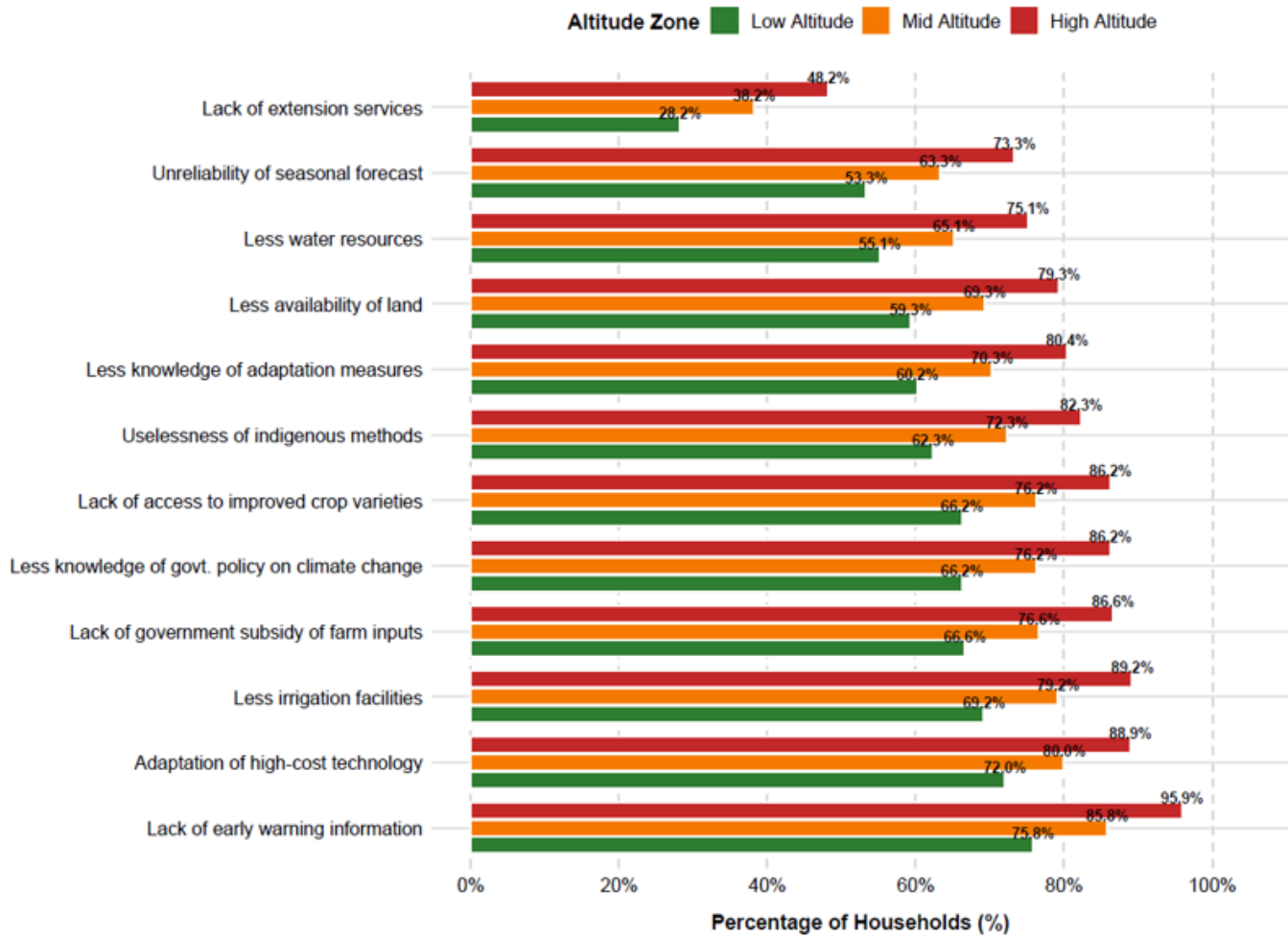


Figure 4

Household level barriers to climate change adaptation strategies in Western Himalaya

Household-Level Barriers to Climate Change Adaptation

Comparison across altitudinal zones

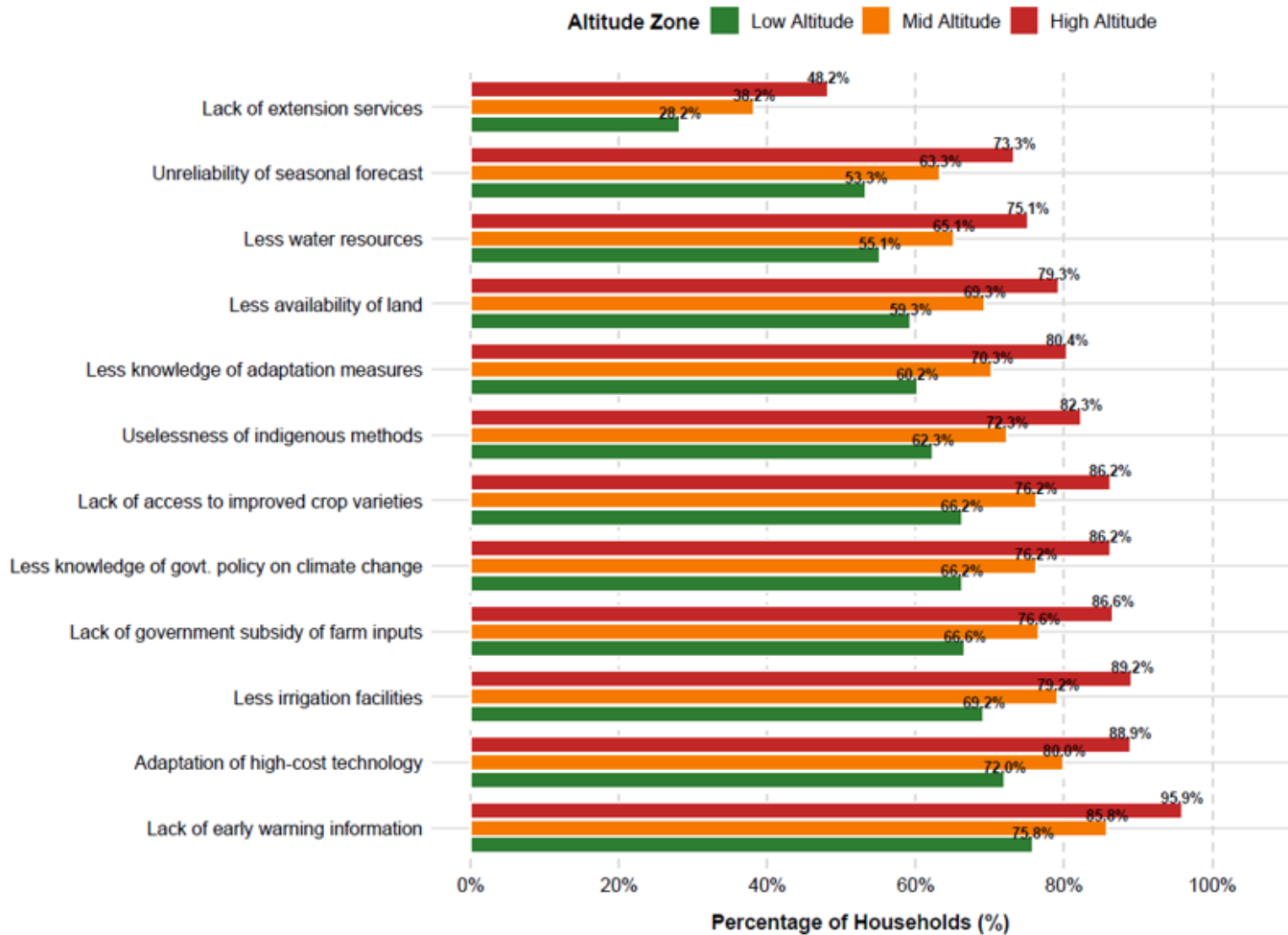


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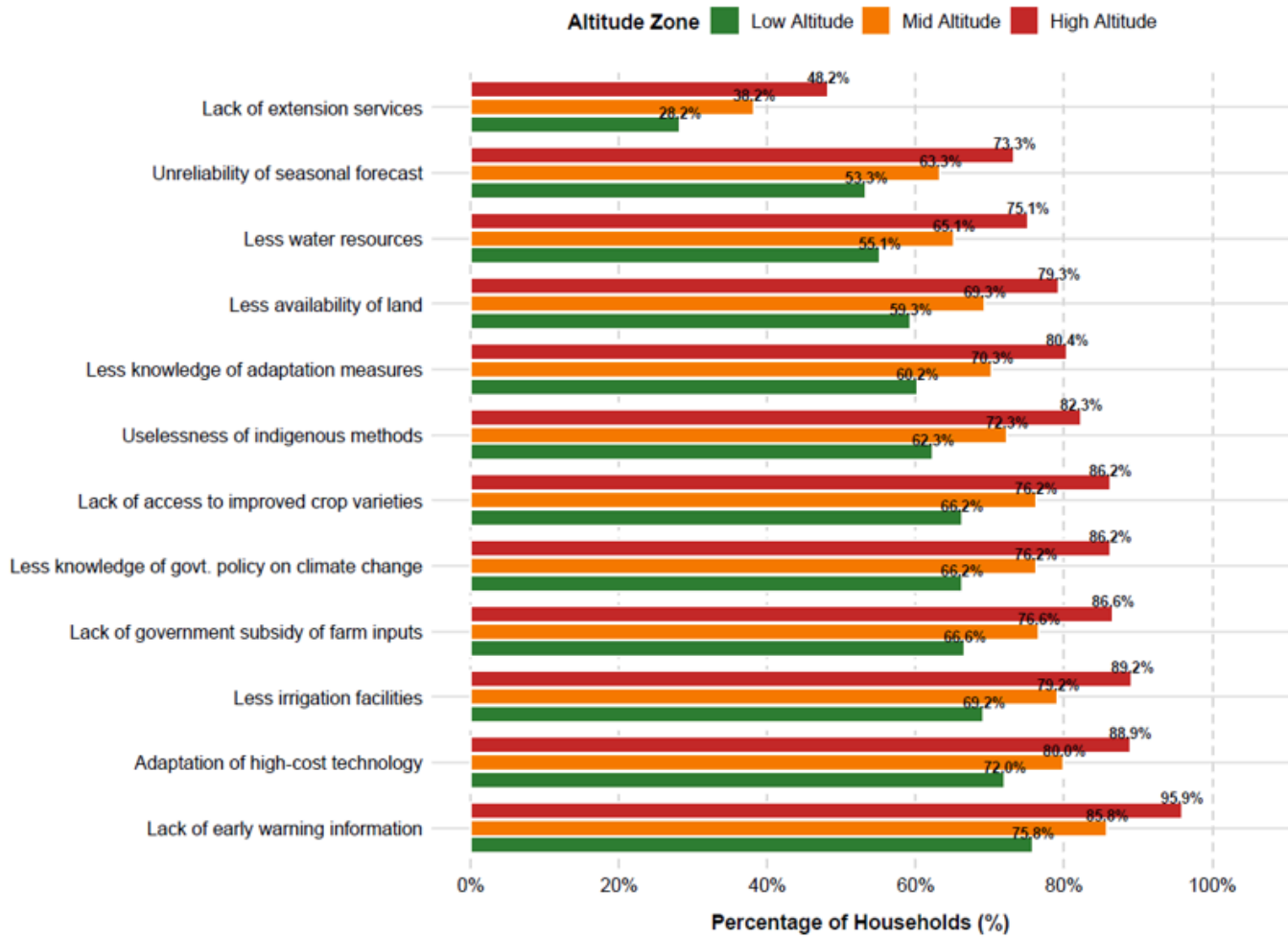


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