Climate Change Observations of Indigenous Communities in the Indian Himalaya

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ABSTRACT: Mountains are important global sites for monitoring biological and socioecological responses to climate change, and the Himalaya has some of the world's most rapid and visible signs of climate change. The increased frequency and severity of climate anomalies in the region are expected to significantly affect livelihoods of indigenous communities in the region. This study documents the perceptions of indigenous communities of climate change in the western Himalaya of India. The study highlights the power of knowledge and understanding available to indigenous people as they observe and respond to climate change impacts. We conducted a field-based study in 14 villages that represent diverse socioecological features along an altitudinal range of 1000–3800 m MSL in the western Himalaya. Among the sampled population, most of the respondents (>95%) agreed that climate is changing. However, people residing at low- and high-altitude villages differ significantly in their perception, with more people at high altitudes believing in an overall warming trend. Instrumental temperature and rainfall from nearby meteorological stations also supported the perception of local inhabitants. The climate change perceptions in the region were largely determined by sociodemographic variables such as age, gender, and income as well as altitude. A logistic regression, which exhibited significant association of sociodemographic characteristics with climate change perceptions, further supported these findings. The study concluded that the climate change observations of local communities can be usefully utilized to develop adaptation strategies and mitigation planning in the Himalayan region.

KEYWORDS: Social Science; Climate variability; Adaptation; Local effects

1. Introduction

The Indian Himalayan Region represents a major Himalayan biodiversity hot spot, wherein richness, representativeness, and uniqueness of biodiversity components at gene, species, and ecosystem levels is well recognized (Rawal et al. 2013). This region has been considered to be vital for preserving the ecological security of India (Negi et al. 2019). However, the National Action Plan on Climate Change underlines the intense vulnerability of this region to climate change. With a warming rate greater than the global average, several studies have indicated greater vulnerability to climate change of the Himalaya as a whole (Hansen et al. 2006; Chaudhary and Bawa 2011; Shrestha et al. 2012; Tripathi and Singh 2013). This has resulted in various survival challenges for indigenous communities as has also been reported for communities of the Arctic and subarctic (Davydov and Mikhailova 2011; Herman-Mercer et al. 2016).

In general, the mountain regions including the Himalaya are considered more vulnerable to changing climate because (i) warming trends are more intense in these regions, and (ii) the impacts are magnified by the sharp change in altitude over small distances (Shrestha et al. 2012, 2019; Negi et al. 2019). This causes new threats to biodiversity and livelihoods of subsistence-oriented communities in the Himalaya (Chaudhary and Bawa 2011; Shrestha et al. 2012, 2019; Upadhyay et al. 2017; Reyes-García et al. 2019; Thakur et al. 2020). However, documentation of likely consequences and responses is inadequate. This gap calls for reliable data and information to assess the current state of climate change impacts and to make predictions to support relevant policy and practice in the region.

Despite the interventions made by various government agencies to maintain a sustained flow of ecosystem goods and services that improve people's livelihoods in the Himalaya, a lack of reliable data and information for long-term mitigation planning and policy formulation make this exercise futile. The IPCC (2007) referred the Himalayan region as a “white spot” on account of insufficient data and information on climate, hydrology, and meteorology. Most of the studies on global climate have excluded the Himalayan region because of its extreme and complex topography (Upadhyay et al. 2017; Nandi et al. 2020). The available information about climate change from the region is largely based on data collected from gridded and model-based projections (Nandi et al. 2020). While the spatial resolution of global climate models is improving, considerable uncertainty remains about the local and regional environmental consequences of changing climate (Savo et al. 2016). Both instrumental observations of climate and perception-based studies have mostly been confined to developed countries (Pandit et al. 2014; Roco et al. 2015).

Indigenous peoples, with only 4% of the world's population, manage 11% of the total forestlands and maintain 80% of the world's biodiversity (Sobrevila 2008). They can provide key information on climate change impacts (Pyhälä et al. 2016;
2019; Hosen et al. 2020), and their knowledge and experiences
are reported to have a significant role in combating climate
change (Funatsu et al. 2019; Hosen et al. 2020; Osaka and
Bellamy 2020). The observations and experiences of indigenous
peoples have helped scientists test specific hypotheses pertaining
to climate change mitigation and adaptation (Chaudhary and
Also, their knowledge is considered vital for the validation of
climate model predictions and for improving their geographic
sensitivity (Singh et al. 2018; Reyes-García et al. 2019). Most of
the impacts of climate change reported in scientific studies are
also observed and experienced by indigenous communities
(Chaudhary et al. 2011; Chaudhary and Bawa 2011; Alexander
et al. 2011; Adger et al. 2013; Ford et al. 2016); thus they play a
significant role in climate change adaptations (Reyes-García
et al. 2016, 2019; Chaudhary and Bawa 2011; Brugnach et al.
2017; Tripathi and Singh 2013; Sharma and Shrestha 2016; Negi

Realizing the above, this study is an attempt to document
indigenous peoples’ perceptions of climate change in the west
Himalayan region, with a focus on (i) understanding people’s
perceptions and observations on climate change along an altitudi-
unal gradient (1000–3800 m) and (ii) analyzing relationship between
sociodemographic variables and people’s climate perceptions.

2. Material and methods

a. Study area

The study was conducted in the Indian part of the trans-
boundary Kailash Sacred Landscape (KSL) (Fig. 1), which is
well known for its cultural, geohydrological, and biological
diversity (Rawal et al. 2012). The forest (>26%) and high-
alitude grazing lands (>21%) form the major land cover in
the landscape. The landscape is largely inhabited by rela-
tively marginalized and indigenous peoples, who hold much
knowledge about traditional agriculture and animal hus-
bandry, which forms the major source of their livelihood.
Among others, the nomadic pastoralist Bhotiya tribal group,
mostly inhabiting high-altitude villages (>2500 m), is well
known for rich traditional knowledge and practices. Our
study was conducted in 14 villages, of which 7 fall in the
midaltitude zone of the Hatkalika watershed (1000–2200 m)
and the other 7 are Bhotiya migratory villages in the high-
alitude Byans Valley in the Kali watershed (2400–3800 m).

The criteria for selection of our study area and villages include
(i) wide representation of altitudinal range (1000–3800 m), (ii)
cultural and biodiversity values, and (iii) presence of natural-
resource-dependent indigenous communities. The livelihood of
these peoples largely depends on rainfed traditional agriculture,
animal husbandry, tourism, and trade of natural-resource-based
goods. The traditional agricultural and animal husbandry system in the area is closely linked with the forest and alpine ecosystems (e.g., high-altitude grazing lands). The indigenous communities have a wealth of ethno-biological knowledge, and their cultural identity has a symbiotic relationship with nature.

b. Household survey

Thirty households in each representative village were selected (14 villages; total of 420 households) for understanding people’s perceptions of climate change. Information on sociodemographic variables such as age, gender, education, landholding, and income were documented (Table 1). Following the published literature, a semistructured questionnaire on people’s perceptions about climate change was developed (Chaudhary and Bawa 2011; Tripathi and Singh 2013; Aryal et al. 2014; Sharma and Shrestha 2016; Tesfahunegn et al. 2016; Upreti et al. 2017) so as to document the climate change experiences and observations of local inhabitants. An equal number of respondents was selected in different age groups (i.e., <40, 40–60, and >60 years) and other sociodemographic variables, also ensuring representation of both genders. Data on perception, responses, and adaptations to climate change and local knowledge of climatic variability were generated using the questionnaire and a checklist of issues tailored to specific interview characteristics. The respondents were, however, asked a few common questions: (i) Do you agree that climate is changing? (ii) How do you know the climate is changing? (iii) Have you experienced, observed, or witnessed change in climate and can you provide examples in addition to those mentioned in the questionnaire? The adaptation measures adopted by the local community to cope with climate change impacts were also documented.

Key informants in each village such as the village head (i.e., head of the village council—Paradhan), chief of community forest (i.e., Sarpanch), traditional herbal healers (i.e., Vaidyas), and animal herders (i.e., shepherds in case of high-altitude villages) were also interviewed using the same semistructured questionnaire, followed by an open discussion to better document detailed information. Key informants were identified with the help of the head of each studied village. A total of 21 key respondents (3 in each village) from midaltitude villages and 28 respondents (4 in each village) from high-altitude villages were interviewed. Key informants provided information on major adaptation strategies adopted by the individual inhabitants and also by the village as a unit. Although English-language scientific terminology is used in the paper to discuss the perceptions of respondents, questions during interviews were asked in the regional dialect (Kumauni) or national language (Hindi).

c. Analysis of sociodemographic variables and climate data

Sociodemographic variables and a participant’s responses were summarized and are presented in percentages. A two-proportion Z test was performed to compare the perceived

<table>
<thead>
<tr>
<th>Variables</th>
<th>No.</th>
<th>Percentage</th>
</tr>
</thead>
<tbody>
<tr>
<td>Age (yr)</td>
<td></td>
<td></td>
</tr>
<tr>
<td>&lt;40</td>
<td>91</td>
<td>21.66</td>
</tr>
<tr>
<td>40–60</td>
<td>108</td>
<td>25.72</td>
</tr>
<tr>
<td>&gt;60</td>
<td>201</td>
<td>52.62</td>
</tr>
<tr>
<td>Gender</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Male</td>
<td>230</td>
<td>54.76</td>
</tr>
<tr>
<td>Female</td>
<td>190</td>
<td>45.24</td>
</tr>
<tr>
<td>Education</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Educated</td>
<td>164</td>
<td>39.04</td>
</tr>
<tr>
<td>Uneducated</td>
<td>256</td>
<td>60.96</td>
</tr>
<tr>
<td>Altitude (m)</td>
<td></td>
<td></td>
</tr>
<tr>
<td>&lt;2000</td>
<td>160</td>
<td>50</td>
</tr>
<tr>
<td>&gt;2000</td>
<td>160</td>
<td>50</td>
</tr>
<tr>
<td>Landholding (ha)</td>
<td></td>
<td></td>
</tr>
<tr>
<td>&lt;0.2</td>
<td>285</td>
<td>67.85</td>
</tr>
<tr>
<td>&gt;0.2</td>
<td>135</td>
<td>32.15</td>
</tr>
<tr>
<td>Income (rupees)</td>
<td></td>
<td></td>
</tr>
<tr>
<td>&lt;6,000</td>
<td>178</td>
<td>42.38</td>
</tr>
<tr>
<td>6,000–10,000</td>
<td>167</td>
<td>39.76</td>
</tr>
<tr>
<td>&gt;10,000</td>
<td>75</td>
<td>17.86</td>
</tr>
</tbody>
</table>

Table 2. Description of explanatory variables used in the logistic regression model.

<table>
<thead>
<tr>
<th>Explanatory variable</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>Increase in temperature</td>
<td>Local people are more likely to perceive change in temperature and warming</td>
</tr>
<tr>
<td>Decline in crop yield</td>
<td>Crop yield indicates lack of availability of sufficient irrigation or rainfall</td>
</tr>
<tr>
<td>Change in rainfall</td>
<td>Farmers are more likely to perceive change in rainfall as an indicator of climate change</td>
</tr>
<tr>
<td>Decline in snowfall</td>
<td>The traditional transhumance communities, particularly shepherds, spend more time in the upper rangelands and thus have better observations of climate change and its impacts</td>
</tr>
<tr>
<td>Drying up of springs</td>
<td>Increase in temperature and decrease in rainfall are reasons for springs drying up, according to people’s perception</td>
</tr>
<tr>
<td>Age</td>
<td>Age influences local people’s exposure to changes in different systems, and thus a higher farmer age is positively correlated with perception of climate change</td>
</tr>
<tr>
<td>Education</td>
<td>Education increases perception of climate change, and thus its effect is hypothesized to be positive</td>
</tr>
<tr>
<td>Landholding</td>
<td>Increase in land size encourages farmers to test different agricultural practices and enhances their perception</td>
</tr>
<tr>
<td>Altitude</td>
<td>People at high altitudes experience greater change from climate change than those at low altitudes</td>
</tr>
<tr>
<td>Gender</td>
<td>A male head of household positively influences perception of climate change</td>
</tr>
<tr>
<td>Income</td>
<td>The lower-income group has better understanding and observations of climate change because of their dependency on natural resources</td>
</tr>
</tbody>
</table>
climate indicators of the respondents from lower- and higher-altitude villages. In addition, a binary logistic regression model was employed to explore possible effects of each explanatory variable on climate change perception (Tables 2 and 3). In this study, the dependent variable is a dichotomous/binary variable with value 1 (for perceived change) or 0 (for no perceived change). The binary logistic regression function estimates the likelihood of the effects of the independent/explanatory variables on the dependent variable (Retherford and Choe 2011). The goodness of fit of the logistic model was estimated by Nagelkerke’s $R^2$, which is defined as 1 minus the proportion of variance not explained in the dependent variable (Nagelkerke 1991). Before the logistic regression model was run, a multicollinearity test was performed using variance inflation factor (VIF) to check colinearity among the explanatory variables. The final selection of variables was based on a VIF threshold <2.5, which is indicative of no colinearity among the explanatory variables (Johnston et al. 2018). The statistical analysis was done using R statistical software with package “aod,” and data visualization was performed using the package “ggplot2” (RStudio Team 2020).

Since there was no meteorological station in the study area, the nearest meteorological data on temperature and rainfall during the period 1980–2015 from the Indian Meteorological Department (IMD), Mukteswar, Uttarakhand, were used to validate local perceptions of climate change (Table S1 and Fig. S1 in the online supplemental material). Trend analysis of climate data was done using the Mann–Kendall test (Mann 1945; Kendall 1975; Gilbert 1987). In this test, the measure of correlation [Kendall’s tau ($\tau$)] shows the relationship between two variables. The numbers of rainy days ($\geq2.5$ mm) and dry spells were calculated according to the IMD definition (https://www.imdpune.gov.in/Weather/Reports/glossary.pdf).

### 3. Results

#### a. Climate change perceptions of local communities

Analysis of data obtained from the questionnaire survey reveals that the majority of respondents (>97%) of all age groups have perceived notable changes in local climatic conditions during last three decades. In both mid- and high altitudes, an increase in the temperature and a growing trend of untimely and erratic rainfall were the most common cited examples of climate change. The instrumental climate data further validated the information obtained from the questionnaire survey, exhibiting a significant increase in maximum and minimum annual temperature during 1980–2015 (Table S2 and Figs. S1a,b in the online supplemental material). Major examples cited by local people (including perceptions of key informants) are provided in the online supplemental material (Table S2). The results of key informants also validated the data obtained from the questionnaire survey. For instance, 100% of the key informants agreed that climate is changing and cited examples of increasing temperature and erratic rainfall. Those in the <40 age group gave descriptive narrations of past events that they have obviously not experienced personally but had learned from their grandparents. Respondents of age group 40–60 cited many examples of climate change in their surroundings, while respondents >60 years of age narrated the details of differences between past and present conditions.

A slightly greater majority (96.4%) of respondents in the higher-altitude regions perceived an increase in temperature compared to midaltitude villages (94.5%), but the difference was not significant ($z = 0.36, df = 1, p = 0.644$). The people of midaltitude villages perceived significantly more erratic rainfall when compared with those in high-altitude villages ($z = 6.14, df = 1, p < 0.0001$). High-altitude villages still experience snowfall, and the respondents from these villages did not perceive a reduction in snowfall as was the case with midaltitude respondents; the difference was significant ($z = 2.48, df = 1, p = 0.01$). Significantly more people in midaltitude villages reported drying in spring as compared with respondents from higher altitude ($z = 8.38, df = 1, p < 0.0001$). The proportion test also confirmed significant differences in crop yield between mid- and high-altitude regions, that is, midaltitude villages have experienced significant declines in crop yield as compared with higher-altitude villages ($z = 7.64, df = 1, p < 0.0001$). A larger proportion of people in midaltitude villages reported an increase in pests and
diseases as compared with respondents from higher altitudes ($z = 7.33, df = 1, and p < 0.0001$). Significant differences ($z = 12.33, df = 1, and p < 0.0001$) in drought incidences were perceived by the mid- and high-altitude respondents.

b. Local observations of climate change in midaltitude villages

Local inhabitants, including key informants of midaltitude villages, cited various examples of climate change (Fig. 2a; see also Table S2 in the online supplemental material). They observed shifting of certain horticultural plant species toward higher altitudes, for example, cultivation of *Mangifera indica*, *Carica papaya*, and *Musa paradisiaca* is now possible up to 1000-m altitude. Most of the respondents observed that there were no mosquitoes in the past, but the increase in temperatures has created favorable condition for mosquitoes and many other pest and insects during past decades. The majority of respondents (>90%) perceived a decline in crop yield due to drought and uneven rainfall events. An increase in drought incidents (85%) also resulted in lower crop yields. These observations were in agreement with trend data of extreme events over the last 30 years (see Fig. S2 in the online supplemental material). The number of rainy days has significantly ($p < 0.05$) decreased (Fig. S2a), and there has been a significant increase in the number of dry spells ($p < 0.05$) during spring, summer, and autumn (Fig. S2b). Respondents perceived decreasing water availability, which has impacted farming and enhanced the drudgery of women in the region. Decreases or uneven patterns in snowfall were perceived by majority of respondents in the midaltitude villages. Respondents reported declines in the yield of apples and a shortening of the maturity period of winter crops. On the other hand, they reported an increase in the production of vegetables such as potatoes, peas, and cabbages. Most of the respondents felt that the monsoon as well as rainfall is now delayed by 20–30 days, and winter rainfall by 15–20 days. Many respondents also perceived an increase in sporadic rainfall events and incidents of cloudbursts and landslides. The majority of the farmers expressed their confusion in defining the date of sowing and harvesting of crops due to the unpredictable nature of rainfall. This has affected their traditional cropping calendar. Respondents also observed large-scale mortality and damage to maturing rainy season crops.

![Graph](https://via.placeholder.com/150)

**Fig. 2.** People’s perceptions of climate change in (a) midaltitude and (b) high-altitude villages in the western Himalaya.
due to changes in the rainfall pattern. For example, *Hordeum vulgare* and *Triticum aestivum* production was severely affected due to precipitation in the months of January and February. The harvesting time of many legume crops (i.e., *Cajanus cajan*, *Macrotyloma uniflorum*, *Phaseolus vulgaris*, *Pisum sativum*) has advanced by 20 days depending on the rainfall. Likewise, harvesting of *Oryza sativa* (paddy) and *Brassica campestris* (mustard) has advanced by 15–20 days in midaltitude areas.

Most of the respondents perceived (80%) that water springs and seasonal streams in the villages have dried due to uneven rainfall and increasing temperature. This was in agreement with trend data of extreme events over the last 30 year (see Figs. S1 and S2 in the online supplemental material). Farmers perceived that soil has dried and hardened, making plowing of fields more difficult in recent decades. Hailstorms have become more common compared with past decades. This impacts the yield of agrihorticultural crops. Due to increasing temperature (94.5% respondents) and low snowfall in midelevations (>90.4% respondents), the yield of many fruits (such as apples and oranges) has declined. Respondents cited more frequent attacks of insects and diseases resulting in reduced crop yield. Change in flowering and fruiting time was perceived (72.4%) by the respondents for many tree species (i.e., *Rhododendron arboreum*, *Myrica esculenta*, *Pruus cerasoides*, *Pyrus Pashia*, *Bauhinia variegata*, etc.) and shrubs (i.e., *Rosa macropylla*, *Rosa sericea*, *Princsepa utilis*, *Pyracantha crenulata*, etc.). Among others, *Rubodendron arboreum*, which used to attain peak flowering stage in February/March, now flowers in January/February due to warming.

A large group of people perceived a decline in the availability of forest resources such as fuelwood, fodder, leaf litter, and nontimber forest products (NTFPs). Among these, a drastic reduction in the availability of NTFPs (wild edibles and medicinal plants) was reported, which has severely impacted alternative food supplements and local-enterprise-based livelihoods in the region. Changes in the regeneration of forest tree species were reported by forest guards and the head of the Community Forest Council. This includes better regeneration of *Shorea robusta*, and seedlings of emergence of *Pinus roxburghi* in *Quercus leucotrichophora* forests. A considerable increase of invasive alien species has been seen (i.e., *Ageratina adenophora*, *Parthenium hysterophorus*, *Lantana camara*, and *Ageratum conyzoides*) in abandoned fields, barren land, and forest gaps. An increase in frequency of forest fires in last few decades due to prolong drought periods was experienced by most of the respondents. This has caused a decline in the availability of forest resources. Key informants of midaltitude villages provided similar observations, although they were more focused on the drying of water springs, new diseases in agriculture crops, increasing intensity of forest fire, and alien invasive species due to climate change. Herbal practitioners (Vaidyas) from these villages mostly described declining wild populations of medicinal plants (MPs).

c. Local observations to climate change in high-altitude villages

Local inhabitants including key informants of high-altitude villages also cited various examples of climate change (Fig. 2b; see also Table S2 in the online supplemental material), such as an increase in temperature (96.4%) and warmer summers (82.5%). Analysis of climate data reveals that spring mean temperature increased significantly by 0.031°C yr⁻¹ (t = 0.198, with p = 0.048; Fig. S1c), while summer mean temperature increased significantly (t = 0.428, with p < 0.001; Fig. S1d) by 0.039°C yr⁻¹. Indigenous communities of the Byans Valley (high-altitude areas), engaged in pastoral activities for many years, are highly dependent on ecosystem goods for their survival. While comparing with the past, key respondents reported changes in pastoral activities (71.65%) such as (i) increased stay duration in summer settlements at high altitude, (ii) early movement from permanent lower settlements to summer settlements, (iii) change in grazing period/time in alpine pastures, and (iv) reduced size of sheep or goat herds. Respondents cited examples of climate change such as reduction in snow cover area (68%) and changes in the time of snowfall (>80%); this influences water discharge and vegetation composition in the alpine areas. Extreme heat and scorching in summer season were reported by many respondents. Shepherds were especially keen observer of climate change and its impacts. They reported changes in the composition of vegetation in alpine meadows. The respondents of high-altitude villages Kutu and Gunji reported a shift in frequency of precipitation from snowfall to rainfall. Key informants and respondents in the >60 age group reported (i) an increase in rainfall and cloudburst events resulting in more frequent occurrence of flash floods, soil erosion, and landslides, which were not common phenomena before three decades ago; (ii) faster melting of glaciers and snow in the nearby peaks during summer in last few decades; and (iii) decreased snow accumulation during winter.

Changes in the pattern of snowfall and snowmelt were considered to have impacts on timing of flowering and other phenophases of certain plant species. A large proportion of respondents (68.6%) observed that changes in climate have impacted phenological aspects of vegetation in the alpine, subalpine, and timberline zone. Local herbal healers (key respondents) reported changes in vegetation composition and reduced availability of MPs in alpine pastures. An early flowering (15–20 days) was cited for many MPs (e.g., *Podophyllum hexandrum*, *Allium stracheyi*, *Angelica glauca*, *Saussurea obvallata*, *Picrorhiza kurroa*, *Aconitum violaceum*, etc.), which are in frequent use in traditional herbal system in the region. Herbal healers indicated that in earlier times they used to walk for 1–2 km from their villages to nearby alpine meadows to collect desired MPs but now even a walk of 2–3 km fails to get the desired species. This indicates a shifting of MP distributions at high altitudes and a decline in density and availability in alpine meadows. Reduced availability of MPs has affected traditional herbal system of medicine in the high-altitude villages.

Among high-altitude villages, the inhabitants of Budi and Garbiyang are engaged in seasonal collection and marketing of *Ophiocordyceps sinensis*; a rare combination of a caterpillar moth and fungus, which is highly expensive in international markets, and is one of the major sources of income and livelihood to the highlanders. Changed temperatures and low snowfall or early melting of ice have affected the availability of *O. sinensis* in the past five years and have thereby impacted the
livelihoods and socioeconomic status of inhabitants. Key respondents (forest guard, Sarpanch) cited good regeneration of birch (Betula utilis), kail (Pinus wallichiana), and silver fir (Abies spectabilis) in recent times. However, the majority of respondents reported a decline in fuelwood availability and forage production in high-altitude villages (>3000 m). Key informants (shepherd and traditional herbal healers) observed an expansion of invasive alien species (e.g., *Convolvulus arvensis* and *Verbacum thapsus*) as well as native species (i.e., *Rumex nepalensis, Polygonum polystachyum, Impatiens spp.*) in the alpine ecosystem. In the agriculture system, respondents cited declines in the yield of traditional varieties of crops as well as an increase in the yields of a few vegetables such as *Pisum sativum* (pea), *Brassica oleracea var. capitata* (cabbage), and *Rahpanus sativus var. radicula* (radish) due to increased temperature and longer growing season at higher altitudes.

Inhabitants in mid-altitude villages, following their traditional knowledge and experiences, have adapted to the impacts of climate change by way of (i) digging trenches and building water harvesting tanks upstream of water bodies to recharge the water table and springs, (ii) changes in sowing and harvesting time of many crops, (iii) improved methods of composting and organic farming to increase yield from farms, (iv) shifting of main crops (e.g., cultivation of peas over buckwheat), (v) offering forest patches to the local deity to ensure protection, (vi) ensuring periodic harvest of forests, and (vii) promotion of agroforestry through plantation of multipurpose tree species to meet leaf fodder and fuelwood requirements.

d. Determinants of climate perception

The multicollinearity test showed that except for the variable decline in snowfall, the variables have VIF < 2.5 indicating no collinearity among the explanatory variables. The logistic regression model showed a statistically significant relationship between the sets of explanatory variables and the dependent variable “people’s perception on climate change” (Table 4), for which $R^2 = 0.92$ (Nagelkerke) indicating satisfactory model performance. Estimation of the logistic regression model showed that among the different parameters of age, gender, altitude, and income, an increase in temperature, drying up of water spring, and a decline in crop yield had a significant ($p < 0.05$) positive association with perceptions of climate change. The results reveal that the odds of having climate change perception was 1.09 times higher for old people (Fig. 3a). Compared with females, male respondents were more likely to perceive climate change ($\beta = 3.87$) (Fig. 3b). Altitude has a significant relationship with the awareness of local inhabitants to climate change. People in high-altitude villages were more aware of climate change ($\beta = 1.008$) compared with mid-altitude residents (Fig. 3c). The lower-income group were found more likely ($\beta = 1.001$) to perceive climate change than the higher-income group (Fig. 3d). The knowledge of temperature trend was found to correlate significantly with the awareness of climate change ($\beta = 4.52$, Fig. 3e), drying up of water springs ($\beta = 4.38$, Fig. 3f), and decline in the yield of crops ($\beta = 3.89$, Fig. 3g).

4. Discussion

Indigenous communities in the Himalaya, as elsewhere, are reported among the most vulnerable groups to the impacts of climate change (Chaudhary et al. 2011; Shrestha et al. 2012; Uprety et al. 2017). This is often attributed the fact that the livelihoods of indigenous communities are highly dependent on climate-sensitive natural resources and sectors (Savo et al. 2016; van Gevelt et al. 2019). The perceived increase in temperature and uneven pattern of rainfall by the majority of respondents in the study villages is in general agreement with earlier studies from other parts of the Himalaya (Maikhuri et al. 2003, 2009; Chaudhary and Bawa 2011; Tripathi and Singh 2013; Aryal et al. 2014; Sharma and Shrestha 2016; Negi et al. 2017; Uprety et al. 2017; Reyes-García et al. 2019). The perceived rapid increase in temperature in high-altitude villages is similar to earlier observations suggesting greater climate change vulnerability in the high-altitude Himalaya (Shrestha et al. 2012; Chaudhary and Bawa 2011; Chaudhary et al. 2011; Uprety et al. 2017; Huang et al. 2019). Our analysis of climate data shows a significantly increasing trend of annual mean minimum and maximum temperatures during the last 30 years, which matches the perceptions of local people in the present study, indicating the ability of inhabitants to accurately observe climate changes. Our findings and analysis of climate data are also supported by another study from the western Himalaya (Shekhar et al. 2010), exhibiting
FIG. 3. (a)–(g) Results of the logistic regression model showing the relationship between probability of perceiving climate change and the various explanatory variables.
seasonal mean, minimum, and maximum temperature increases by 2°, 1°, and 2.8°C, respectively. In a recent study, Shrestha et al. (2019) have reported significant changes in temperature and precipitation in the Himalaya. Studies based on temperature and precipitation trends have further exhibited that warming in the Himalaya is 3 times greater than the global average (Xu et al. 2009).

Considering the second-most-cited example of climate change, erratic or unpredicted rainfall, significant differences were revealed in the perception of mid- and high-altitude respondents, which is supported by climate datasets of the region. An increasing trend in rainfall for the western Himalaya has been reported (Krishnan et al. 2019). However, Singh and Goyal (2016) have reported decreasing trends in precipitation for the last 50 years, and they project erratic patterns in the near future for the eastern Himalaya. The observations of local inhabitants about the impacts of erratic rainfall on water resources and agricultural productivity were in agreement with previous studies from the region (Chaudhary and Bawa 2011; Shrestha et al. 2012; Saikia et al. 2013; Kumar and Jaswal 2016). Rainfall has been reported to have become more intense and sporadic in nature, particularly in the mid-altitude region. Earlier studies have reported heavy rainfall often accompanied by landslides and cloudbursts that aggravate flash flood risks (Maikhuri et al. 2009; Joshi et al. 2014). Our analysis of climate data shows a significant increase in number of dry spells during spring and summer. Warmer climate and an extended drought period contribute to drying of water springs that leads to water shortages for both farming and drinking (Chaudhary and Bawa 2011; Tambe et al. 2012; Pramanik and Bhaduri 2016; Singh et al. 2018). Glacier melting as a consequence of climate change is frequently reported in the Himalaya (Barnett et al. 2005; Immerzeel et al. 2010; Kaushik et al. 2020). The reported reduction in the coverage of snow and ice on the peaks in the present study is in general agreement with the findings of previous studies (Maikhuri et al. 2009; Bhutiyani et al. 2010; Chaudhary et al. 2011; Shukla et al. 2018). Decreases in snowfall have been reported to affect bud initiation, flowering, fruiting, and yields of horticultural crops, particularly apple and other crops in the mid-altitude area of the western Himalaya (Negi et al. 2012; Basannagari and Kala 2013; Mir et al. 2015).

The reported higher incidence of drought, which causes soil moisture deficits leading to yield declines in traditional crops (i.e., *Oryza sativa, Triticum aestivum, Eleusine coracana*), corresponds with studies from other parts of the Himalaya (Maikhuri et al. 2009; Rautela and Karki 2015; Negi et al. 2017; Isaac and Isaac 2017; Pandey et al. 2016). Therefore, with >85% of agricultural land depending on rainfall, agriculture in the region is one of the most vulnerable sectors to climate change. Further, the observed increase in pest and weed infestation with rising temperature and greater incidence of drought is in line with a study by Uprety et al. (2017) that reported that 79% of the residents of high mountain areas of west, central, and east Nepal believe that insect pests have increased in recent years. Likewise, Chaudhary et al. (2011) reported that more respondents report new crop pests (73.6%) and new weeds (54.2%). The perception that diseases like rust and blight have become frequent in cereals and potato is in agreement with previous studies (Vedwan and Rhoades 2001; Tripathi and Singh 2013; Paudel et al. 2014; Singh et al. 2018; Pandey et al. 2016). This phenomenon of climate change–induced increases in pests and diseases has compelled the farmers to use insecticides and pesticides, having long-term negative impacts on rainfed mountain agriculture. Many respondents stated, “we were dependent on the market only for salt, sugar, and oil before three decades ago, but now we are purchasing most food items including rice and wheat from the market,” and attributed this shift to a changing climate. However, climate change has enabled the process of crop diversification (Azhoni and Goyal 2018), as the high-altitude villages of the study area are successfully cultivating certain high-value medicinal plants, vegetables, and fruits in recent times.

As an indicator of climate change, changes in phenological events are frequently reported (Menzel et al. 2006). In this context, reported changes in flowering and fruiting time of many plant species from the study area are in general agreement with other studies from the western Himalaya (Maikhuri et al. 2009, 2018; Chaudhary et al. 2011; Gaira et al. 2014; Sharma and Shrestha 2016) and the Sikkim Himalaya (Joshi and Joshi 2011). The advancement of flowering phenology is further supported by our analysis of climatic data, which suggests a significant increase in the spring mean temperature. Such changes in phenology have implications for agriculture production and local livelihoods (e.g., pollination services). Advance in the flowering and fruiting of many MPs, as reported by herbal healers in high-altitude villages, would severely affect the harvesting calendar of herbal healers and their herbal practices in the region (Maikhuri et al. 2018). The reported decline in density of many MPs, and certain species becoming restricted to higher altitudes, is indicative of adverse impacts of climate change on MPs in the region. Similar observations of climate change impacts on medicinal plants have been made elsewhere (Applequist et al. 2020). The perceived increase in coverage of invasive alien species in mid-altitude, and expansion of selected native species in alpine ecosystems, has implications for overall biodiversity. The manifold increase in cover of *Ageratina adenophora* during past decade in mid-altitude has caused severe loss to the biodiversity-based resources in the region.

In general, the increase in alien species in the mountains is considered a serious threat to native biodiversity (Shrestha et al. 2018). Invasive species with distributions previously confined to foothills and midelevations (<2500 m) in the region have now been reported from higher altitudes, that is, up to 3000 m (Pathak et al. 2019). These changes will have implications for the unique and endemic plants in the alpine ecosystems. As also reported earlier in the region (Maikhuri et al. 2009; Saxena and Rao 2009; Huang et al. 2019), the changes in pastoral migration timing and the composition of alpine vegetation reported by the pastoral community in Byans Valley have adverse impacts on livestock rearing.

Under a warming climate, the distribution of species in high-altitude ecosystems is projected to shift higher (Schickhoff et al. 2015). In this context, better regeneration of certain species (i.e., *B. utilis, Abies spectabilis*) at the timberline zone...
in indicative of their upward movement. Shifting of *Abies spectabilis* 100–150 m above tree line has already been reported in Langtang, Nepal (Schickhoff et al. 2015). Likewise, the upward movement of *P. wallichiana* (at 14–19 m decade$^{-1}$) and *A. spectabilis* (at 2.6 m yr$^{-1}$) in India and Nepal is known (Dawadi et al. 2013; Dubey et al. 2003; Tiwari et al. 2017). Upward expansion of *P. wallichiana* on south-facing slopes has been reported from Nanda Devi National Park in the west Himalaya (Negi et al. 2018). The perceived decline in the availability of high-value caterpillar fungus (*Ophiocordyceps sinensis*) due to unusual snowfall and increasing temperature in recent years matches the International Union for Conservation of Nature’s reporting of a 30% decline in its population during last 15 years, thereby listing it as “vulnerable” (Negi et al. 2020). This decline will have definite consequences on the livelihoods of dependent high-altitude villages in the region.

The effects of climate change are translated into social and economic consequences through a range of different pathways (Gitz et al. 2016; Niles and Mueller 2016). The proportion of respondents identifying the causes of climate change was significantly higher those do not aware of climate change impacts. However, the age of respondents was closely related to their experience and knowledge of climatic change. For example, the old age group was able to perceive changes in climate more, which can be attributed to their experience as reported in other studies (Roco et al. 2015; Habtemariam et al. 2016). Similarly, poor households, being more exposed to impacts of climate change, have been reported to play a vital role in climate change adaptation in other mountain regions (Macchi et al. 2015; Shrestha et al. 2019) and south Ethiopia (Debela et al. 2015). Occupation is also known to play an important role in shaping perceptions (Tesfahunegn et al. 2016). For instance, being more exposed to day-to-day weather changes, the farmers are more likely to perceive climate change. Lower-income people perceived changes in climate more because of their grater engagement with agriculture. These people also had more knowledge on change in agriculture crops and fruits. Likewise, gender is significantly related to accuracy in climate perception (Yadav and Lal 2018). In present study, male respondents were found to be keen observers of happenings around them. This can, however, be attributed largely to the shyness of women and their lesser involvement in decision-making processes (Ishaya and Abaje 2008; Cook et al. 2019). The indigenous community of high-altitude villages are more exposed and vulnerable and thus perceived more climate change impacts (Chaudhary and Bawa 2011; Shrestha et al. 2012; Upreti et al. 2017). These people in such remote areas, as elsewhere in the world, have been testing new approaches or adaptation to climate change (Chaudhary and Bawa 2011; Savo et al. 2016; Reyes-Garcia et al. 2019; Hosen et al. 2020; Osaka and Bellamy 2020).

5. Conclusions

Considering that studies on short-term local weather changes involving indigenous communities are important to intensify the knowledge base and minimize uncertainty in adaptation planning, our study documents people’s perceptions in the west Himalaya, and provides detailed elaboration of complex interactions among physical and biological components of the environment under changing climate. The respondents were able to clearly describe impacts of a changing climate on water resources, biodiversity, agricultural production systems, and overall livelihoods in the region. Inhabitants were also able to associate drying of water springs, low agricultural production, declining population density of important species, changing phenology, and invasion of alien species as major impacts from climate change. Among wider impacts of increased warming, the study provided evidence of upward shifting of species and benefits of crop diversification by farmers at higher altitudes. We argue that climate perceptions of people vary significantly by location (i.e., village, altitude) and sociodemographic attributes of the respondents. Therefore, when interpreting perceptions of climate change, one needs to keep such characteristics in mind. We further argue that the information generated on adaptation strategies adopted by local inhabitants may have direct application value for planners and policy makers engaged in developing policies and strategies for resource management and biodiversity conservation to minimize the adverse effects of a changing climate in the Himalaya.

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