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Climate Vulnerability Assessment of Farming Systems in Himachal Pradesh, Indian Himalayas

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This study assessed the climate vulnerability of the agriculture, horticulture, and livestock sectors at the block scale in the Kullu district of Himachal Pradesh. This region exhibits the most conspicuous manifestations

of climate change. The study sites were selected to represent different elevation zones. A total of 108 indicators for the sectors were chosen to assess climate vulnerability as a methodological framework suitable for a mountain perspective. The net climate vulnerability in the agriculture sector was lowest in blocks that had greater accessibility to the road network, were nearer to markets, had high literacy and more institutions, and were shifting to

enterprises other than agriculture. The net vulnerability index (VI) for horticulture revealed that vulnerability was reduced by a shift toward off-season vegetable cultivation, productive soils for crops, and the establishment of new orchards. The net VI of the livestock sector was lower if there were fewer diseases and pests and they were quickly managed, if there was good access to veterinary facilities, if slopes were less steep, and if improved grassland was available. The composite net VI of all blocks in different sectors of this farming system revealed that the Naggar block, followed by Kullu and Nirmand, was the least vulnerable.

Keywords: climate adaptation strategies; mountain ecosystem; agriculture; horticulture; livestock.

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Introduction

Mountain ecosystems all over the world are considered among the most sensitive to climate change. About one fourth of the world's land surface is covered by mountains, which are home to 12% of the world's population. Mountain regions are diverse, rich in ethnicity and languages, and hotspots for the world's terrestrial biodiversity.

In mountain regions, including the Himalayas, the livelihoods of people are closely intertwined with natural resources. Mountains directly support human life, because they are sources of timber, hydroelectricity, niche products, mineral resources, recreation, and flood management (Sharma et al 2019). A recent analysis by the Food and Agriculture Organization of the United Nations (FAO) revealed that 39% of the population (both rural and urban) in mountains in developing countries were vulnerable to food insecurity in 2012 (FAO 2015). Most of the population depends on a farming system composed of agriculture, horticulture, and animal husbandry. The increasing trend of present and future losses and damage in mountain

agricultural systems necessitates a holistic understanding of the climate vulnerability of the agriculture, horticulture, and livestock sectors in mountains. The assessment of climate vulnerability provides tools for the adoption of suitable adaptations to climate change across geographical regions. The importance of this is compounded in Himalayan regions because of the high vulnerability of these ecosystems.

This study assessed climate vulnerability in the agriculture, horticulture, and livestock sectors at the block scale in the Kullu district in Himachal Pradesh (HP), India. This region exhibits the most conspicuous manifestations of climate change. An approach based on various indicators for the Himalaya of HP was used.

The impacts of changing climate and associated risks are insufficiently understood, which hinders the design and the implementation of adaptation measures. The long-term temperature trends in the Himachal Himalaya indicate an increase in annual maximum temperature at a rate of +0.06°C annually, and rainfall trends during the yearly and postmonsoon seasons have shown diminishing rates between 1991 and 2010. However, summer rains have shown

increasing trends (Rathore et al 2013). The evidence of climate change is highly visible in HP. There is a shifting and shortening of the *rabi* (October to May) crop season. Rainfall patterns are changing, and there is reduced snowfall in the Himalayas. Fewer apples are produced because the temperate fruit belt is receding to higher regions (Rana et al 2012). Furthermore, there has been a decrease in surface water resources during the past 3 decades in the mountains of HP (Rana et al 2014). These climatic changes affect agricultural production in the mountains, impacting food security. The Himalayan catchment area in the Kullu district of HP has been particularly affected in terms of economic activities such as agriculture, horticulture, and livestock. The present study examines the vulnerability of the agriculture, horticulture, and livestock sectors in the Kullu district.

Material and methods

Topography and land cover in the study area

The Kullu district in HP is situated between 31°20' and 32°24'N and 76°55' and 77°51'E. The elevation ranges from 850 to 6790 masl. The 2-dimensional geographical area is estimated from revenue records to be 5503 km² (Table S1, *Supplemental material*, <https://doi.org/10.1659/MRD-JOURNAL-D-20-00056.1.S1>). The district extends across a mountainous area with varied elevation and associated weather patterns. The climate of the Kullu district is characterized by warm, dry springs and autumns; subtropical monsoon; cool, snowy winters at higher elevations; and warm, wet monsoonal summers (Rana, Sood, et al 2013; ISRC 2016). The Kullu district is predominately covered by forest (41%), grass and shrubs (27%), and rocks and nonvegetation (15%). Agriculture is spread across 7% of the total area. Snow and clouds cover 9% and glaciers and water bodies cover 11.1% of the area. The shares of the various land cover classes are shown in Table S1 (*Supplemental material*, <https://doi.org/10.1659/MRD-JOURNAL-D-20-00056.1.S1>; Bhagat et al 2009: 33–34). According to the latest Forest Survey of India report (2019), the Kullu district has seen a decrease in forest area by 10.71% between late 2015 and late 2017. In late 2017, the Kullu district had 35.91% (1976.29 km²) of its total geographical area under forest cover.

According to the revenue records for HP of the Department of Land Records (DES 2019), the total area under agricultural use is 426 km² (8%), which is close to the mapped and estimated area. About 90% (4952 km²) of the total geographical area of the Kullu district is legally defined as forest area, but the forest cover data show a large discrepancy (50%) with revenue records.

The study region is exclusively within the Kullu district and is further divided into blocks or *tehsils* representing different elevation zones. Block- or *tehsil*-scale data are used as a secondary source. The primary database was also divided into 5 blocks for the calculation of vulnerability indices (VIs) to enable comparison and the development of a composite VI for the district level. Figure 1 shows the land cover of the Kullu district and the 5 blocks and situates Kullu within HP and India.

Data collection

Primary data were collected using a well-structured and pretested interview conducted for 2 periods: a recent year

(period 1) 2014–2015 and the past 10–20 years (period 2). This allowed changes in climatic and agricultural patterns perceived by the farmers to be compared (see Tables 1, 2). Secondary data were collected from block headquarters and meteorological stations located in the Kullu district for different periods (1980 to 2010) to measure the accuracy of the farmers' perceptions. There were thus 2 types of data: primary data sourced from the farmers' survey and secondary data sourced from the government revenue records and, for the weather data, from recording stations of the India Meteorological Department and from the Bajaura research station of the Chaudhary Sarwan Kumar Himachal Pradesh Krishi Vishwavidyalaya (Kullu). These vulnerability indicators were further categorized into exposure, sensitivity, and adaptive capacity to calculate the VI.

A total of 108 indicators were used to understand demographics, exposure, sensitivity, and adaptation in the agriculture, horticulture, and livestock sectors and the sectors' vulnerability in the context of climate change. The study was carried out across different blocks of the Kullu district (HP) at different elevations. After initial surveillance, we conducted field visits to the district and discussions with key farmers, informants, and stakeholders in different areas of the district. The study villages in the 5 blocks of the district were identified as suitable based on the criterion that the impact of climate change was particularly pronounced there. In the first stage of sampling, the block data were chosen. In the second stage of sampling, clusters of 2–4 study villages were drawn from each of the selected blocks for the final selection of farmers for interviewing. In the last stage of sampling, 50 households were selected from the study villages in each block, making a total sample size of 250 households from 5 blocks of the district. The households were classified into 3 categories based on their landholdings: marginal (those owning less than 1 ha), small (those owning 1–2 ha), and large (those owning more than 2 ha).

Vulnerability indices

According to the Third Intergovernmental Panel on Climate Change Assessment Report (McCarthy et al 2001), vulnerability is a function of the magnitude, character, and rate of climate variation to which a system is exposed, the system's sensitivity, and its adaptive capacity. A VI is thus a measure of the exposure of a population to a given hazard.

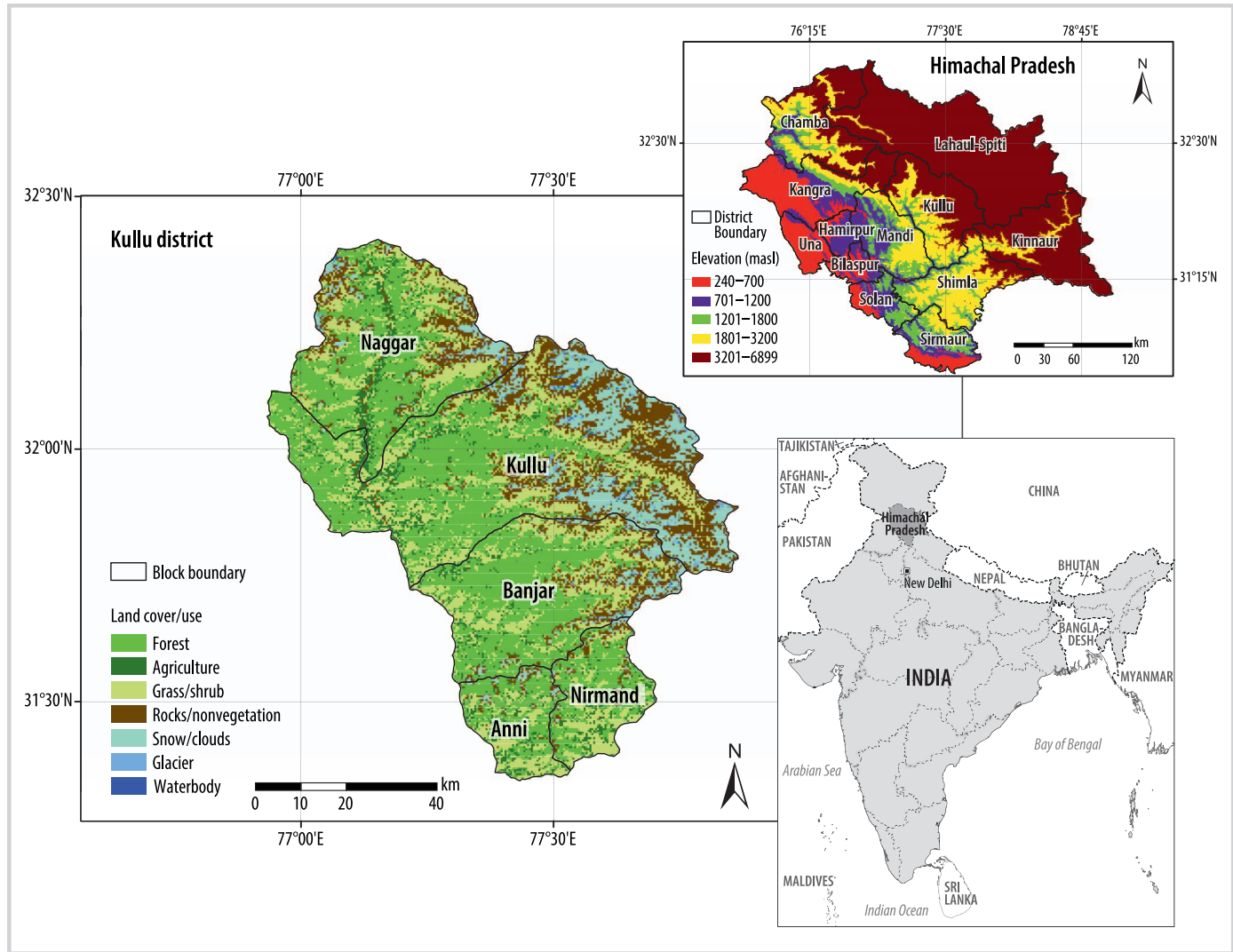
The climate change VI is used to evaluate the vulnerability of humankind to extreme climate events and variations in climate over the next 3 decades. Kumari and Bharti (2017) identified the 3 important components of vulnerability:

- Exposure, or the nature and extent of changes in climatic variables (eg precipitation, temperature, and extreme weather events) of a region;
- Sensitivity, or the environmental and human conditions that can aggravate the hazard;
- Adaptive capacity, or the potential to implement adaptation measures that could help avert potential impacts.

Thus, vulnerability is potential impact (exposure plus sensitivity) minus adaptive capacity:

$$V = f(I - AC)$$

FIGURE 1 Land cover of the Kullu district and its 5 blocks, location of the Kullu district within HP with topographical information, and location of HP within India.



where V is vulnerability, I is potential impact (exposure plus sensitivity), and AC is adaptive capacity.

The climate change VI includes exposure to climate extremes and changes, the current sensitivity of humans to such climate stresses, and their capacity to adapt to the impacts of climate change. The climate change VI is thus a numerical rating based on exposure to climate change, sensitivity, and adaptive capacity. It is used to calculate risks from future climate change (Rana, Sood, et al 2013).

Normalization (for each indicator)

The following equation is used for normalization. X_{ij} is computed when vulnerability indicators have an increasing functional relationship with vulnerability:

$$X_{ij} = \left(X_{ij} - \min_i(X_{ij}) \right) / \left(\max_i(X_{ij}) - \min_i(X_{ij}) \right)$$

$$\text{actual}X_I = (\text{actual}X_I - \min X_I) / (\max X_I - \min X_I)$$

where X is the set of the observed minimum and maximum values of the dataset. X_{ij} is the index for indicator j corresponding to region i , X_i is the i th value in the dataset,

$\min X$ is the minimum value in the dataset, and $\max X$ is the maximum value in the dataset.

The index scores lie between 0 and 1. The value 1 corresponds to the region with the maximum value, and 0 corresponds to the region with the minimum value.

Y_{ij} is computed when vulnerability indicators have a decreasing functional relationship with vulnerability:

$$Y_{ij} = (\max_i(X_{ij}) - X_{ij}) / (\max_i(X_{ij}) - \min(X_{ij}))$$

$$\text{actual}X_I = (\max X_i - \text{actual}X_I) / (\max X_I - \min X_i)$$

where Y_{ij} is the index for indicator j corresponding to region i , X_i is the i th value in the dataset, $\min X$ is the minimum value in the dataset, and $\max X$ is the maximum value in the dataset. This can be checked easily:

$$X_{ij} + Y_{ij} = 1$$

so that Y_{ij} can be calculated as

$$Y_{ij} - 1 = X_{ij}$$

When there are equal weights, a simple average of all normalized scores is found to construct the VI:

TABLE 1 Exposure and sensitivity indicators and their functional relationship with the VI.

Type of indicator	Serial no.	Name of indicator	Relationship	Data type
Exposure indicator	1	Change in rainfall	Negative	Primary data and secondary data from India Meteorological Department
	2	Change in maximum temperature	Negative	
	3	Change in minimum temperature	Negative	
	4	Snowfall decrease	Negative	
	5	Change in southwest monsoon	Negative	
	6	Drought probability	Negative	
Sensitivity indicator	1	Total population	Positive	Secondary data
	2	Male population	Positive	
	3	Female population	Positive	
	4	Literacy (total)	Positive	
	5	Literacy of males	Positive	
	6	Literacy of females	Positive	
	7	Agriculturists	Positive	
	8	Agricultural labor	Positive	
	9	Shift of agricultural labor	Negative	Primary data

$$VI = \sum_j X_{ij} + \sum_j Y_{ij} / K$$

where X is the set of the observed minimum and maximum values of the dataset, i is the region (called the block in our study), j is the vulnerability indicator, Y is the set of the observed minimum and maximum values of the dataset, and K is the total number of indicators.

Finally, the calculated VIs are used to rank the various regions based on their vulnerability. The higher the VI, the more vulnerable that particular region is and the higher the assigned rank. To calculate the weight of each component, the standard deviation or variance is calculated and the value divided by the standard deviation is the weight of the component. The indices (agriculture, horticulture, and livestock) explain the climate vulnerability of the specific sectors. The composite VI is the best index to assess the climate sensitivity of the entire farming system.

Methods with equal weights

Simple average of the scores: For major components like agriculture, horticulture, livestock, and demographics, the simple average of the scores is used:

$$VI = \frac{\sum_j X_{ij} + \sum_j Y_{ij}}{K}$$

After normalization, the average index (AI) for each sector is worked out, and then the overall VI is computed using the following equation:

$$VI = \left[\sum_{i=1}^n (AI_i)^\alpha \right]^{1/\alpha}$$

$$\sum_j X_{ij} + \sum_j Y_{ij}$$

where n is the number of sectors and $\alpha = n$.

Methods with unequal weights

Method of Patnaik and Narayanan (2009): The AI for each source of vulnerability (in our study, each sector) is calculated after normalization. Then, the overall VI is estimated by the following equations: Assuming M regions or blocks, K indicators of vulnerability, and X_{ij} , $i = 1, 2, \dots, M$ and $j = 1, 2, \dots, K$ as the normalized scores. The level or stage of development of the i th zone, Y_i , is assumed to be a linear sum of X_{ij} as follows:

$$Y_i = \sum_{j=1}^K W_j X_{ij}$$

where W is the weight and

$$W' S (0 < W < 1) \text{ and } \sum_{i=1}^K W_j = 1$$

Iyengar and Sudarshan's method (1982): The weights vary inversely with the variance over the regions in the respective indicators of vulnerability. The weight W_j is determined by the following equation:

$$W_j = c / \sqrt{\text{var}(X_{ij})}$$

where c is a normalizing constant.

The unequal weights method was chosen to assign the weights to different climate change indicators for calculating

TABLE 2 Adaptive capacity indicators by sector and their functional relationship with the VI. (Table continued in next column.)

Sector	Serial no.	Name of indicator	Relationship
Agriculture (<i>n</i> = 20)	1	Permanent water resources available	Positive
	2	>3 pesticide applications	Negative
	3	Market accessibility for sale	Positive
	4	Weather-based agroadvisory services	Positive
	5	Institutional support	Positive
	6	Road accessibility	Positive
	7	Disease/insect control measures	Positive
	8	No control measures	Negative
	9	Diversification	Positive
	10	Adoption of organic agriculture	Positive
	11	Glacier water irrigation sources	Positive
	12	Soil fertility (weight age: low, 40; medium, 70; high, 100)	Positive
	13	Cultivable waste	Positive
	14	Total fertilizer use	Positive
	15	Fertilizer use per hectare of cultivated area	Positive
	16	Organic use (farmyard manures, vermicompost)	Positive
	17	Organics per hectare of cultivated area	Positive
	18	Organic carbon status	Positive
	19	NPK status	Positive
	20	Micronutrient status	Positive

the VI because simple averages give equal importance to all indicators, whereas they do not all contribute with a similar magnitude.

A total of 108 indicators and variables of vulnerability were analyzed for this study (Tables 1–3). The sensitivity indicators for demographic vulnerability contribute to climate change (Table 1) and to potential adaptive capacity to the impacts of climate change. Thus, the demographic VI was used to calculate the composite VI. The indicators selected contribute significantly to the adoption of climate adaptation strategies and understanding the impacts of climate change.

TABLE 2 Continued. (First part of Table 2 in previous column.) (Table continued on next page.)

Sector	Serial no.	Name of indicator	Relationship
Horticulture (<i>n</i> = 22)	1	Permanent water resources available	Positive
	2	>3 pesticide applications	Negative
	3	Market accessibility for sale	Positive
	4	Weather-based agroadvisory services	Positive
	5	Institutional support	Positive
	6	Road accessibility	Positive
	7	Disease/insect control measures	Positive
	8	No control measures	Negative
	9	Sufficient honeybees	Positive
	10	Insufficient honeybees	Negative
	11	Diversification	Positive
	12	Adoption of organic agriculture	Positive
	13	Glacier water irrigation sources	Positive
	14	Soil fertility (weight age: low, 40; medium, 70; high, 100)	Positive
	15	Cultivable waste	Positive
	16	Total fertilizer use	Positive
	17	Fertilizer use per hectare of cultivated area	Positive
	18	Organic use (farmyard manures, vermicompost)	Positive
	19	Organics per hectare of cultivated area	Positive
	20	Organic carbon status	Positive
	21	NPK status	Positive
	22	Micronutrient status	Positive

Results and discussion

The data for the past 45 years indicated significant changes during the *kharif* (June to September) crop season for minimum and diurnal temperatures, whereas the *rabi* crop season showed significant changes in minimum temperature and rainy days. Table S2 (*Supplemental material*, <https://doi.org/10.1659/MRD-JOURNAL-D-20-00056.1.S1>) shows the results of a Mann–Kendall test at a 95% confidence level for

TABLE 2 Continued. (Previous part of Table 2 on previous page.)

Sector	Serial no.	Name of indicator	Relationship
Livestock (<i>n</i> = 13)	1	Permanent water resources available	Positive
	2	Institutional support	Positive
	3	Access to agroadvisory services	Positive
	4	Market accessibility for sale of milk	Positive
	5	Road accessibility	Positive
	6	Disease/insect control measures	Positive
	7	No control measures	Negative
	8	Diversification	Positive
	9	Cultivable waste	Positive
	10	Grassland and pasture availability	Positive
	11	Fodder and concentrate availability	Positive
	12	Veterinary hospital	Positive
	13	Veterinary clinic/center	Positive

Note: NPK, nitrogen, phosphorus, and potassium.

minimum, maximum, and diurnal temperature, as well as rainfall for the period 1971–2016. The minimum temperature during the *kharif* season rises by 0.02°C annually. The minimum temperature was higher than the long-term average except for 2009 and 2012, indicating an overall warming trend after 2005. The diurnal temperature exhibited a declining trend of 0.02°C annually after 1997 except during 2001, 2002, 2008, 2011, 2013, and 2016. A steady trend for maximum temperatures and increasing minimum temperatures resulted in a narrowing range for diurnal temperatures during the *kharif* season. Rainfall and rainy days did not show significant variation from 1970 to 2016. During the *rabi* crop season, minimum temperature varied significantly, increasing at 0.02°C annually in the Kullu district. However, contrary to findings on the entire Himachal Himalaya, the maximum and diurnal temperatures and rainfall in our study did not show substantial changes from 1971–2016. Significant results were observed for rainy day variation during the *rabi* crop season, signifying a decline of 0.07 rainy days.

Perceptions on climate change

Worldwide climate change has shown that variations in climatic variables, such as precipitation and temperature, significantly increase the vulnerability of food production systems and security (Glantz and Wigley 1986). Recent research suggests crop yields have already been affected and are projected to decrease under future climate conditions (Ray et al 2019). Farmers acknowledged that there was a definite change in the climate over a period at Kullu. The

locally idealized traditional weather cycles were compared with changed weather cycles because of perceived climate change. The results were evaluated and correlated for the different blocks of the Kullu district. Farmers observed prolonged summers, rising summer temperatures, and delayed onset and uneven distribution of the southwest monsoon. The onset of winter was also delayed; therefore, winter was shorter and winter temperatures were warmer, with decreased and delayed snowfall and spells of low temperature at high elevations. Unpredictable rainfall and an increase in the number of foggy and cloudy days were also reported by farmers across the blocks (Figure 2). Farmers' perceptions of climate change are presented in Table S3 (*Supplemental material*, <https://doi.org/10.1659/MRD-JOURNAL-D-20-00056.1.S1>). These show that most indigenous farmers perceived climate change as a reality that affected local weather patterns. Most farmers also observed a trend of increasing dry spells for 6–8 months in all study villages. Furthermore, most farmers described changes in crop phenology. These included the advance of flowering and fruit setting by 7–10 days because of warming trends (Table S4, *Supplemental material*, <https://doi.org/10.1659/MRD-JOURNAL-D-20-00056.1.S1>).

Rana, Sood, et al (2013) also reported that Kullu farmers described climate change as a temporal displacement of weather cycles, reflected in changes in crops grown and livelihood options. The high-intensity rainfall and flood threat was perceived to be lower in Banjar, Anni, and Nirmand. Kullu and Banjar are more vulnerable to threats of floods, whereas Kullu, Anni, and Nirmand were seen as most prone to mudslides. More than 97% of farmers in Nirmand, along with Banjar and Kullu farmers, reported decreased rains during the southwest monsoon (ISRC 2016).

Perceptions on phenology of crops

Climate change significantly affects key flowering processes. Temperature and carbon dioxide concentration are major determinants of the timing and duration of the key developmental phases of flowering (Bahuguna and Jagadish 2015) and plant growth (Craufurd and Wheeler 2009), respectively. Farmers of different blocks realized that flowering and fruiting of horticultural crops, and the reproductive phase and maturity of other crops, had advanced by 7–10 days. This was reflected in shortened cropping periods and caused a reduction in yield. The Kullu block was ranked first in such vulnerability, followed by Banjar, Anni, and Nirmand (Table 4). The Kullu and Banjar areas were observed to have higher frequencies of dry spells for 6 to 8 months and were shifting to vegetable crops.

VI assessment in different blocks

The VI assessments for various blocks based on different indicators were categorized on the basis of exposure, sensitivity, and adaptive capacity. Assessment of vulnerability, when carried out holistically, is an important guide for the planning process, can help to make decisions on resource allocation at various levels, and can help to raise public awareness of risks (UNEP 2002). The vulnerability components were segregated into agriculture, horticulture, and livestock sectors, as well as demographics. The composite VI was calculated as an average of the VI of each

TABLE 3 Sensitivity indicators by sector and their functional relationship with the VI. (Table continued in next column.)

Sector	Serial no.	Name of indicator	Relation
Agriculture (<i>n</i> = 21)	1	Total cultivable area	Positive
	2	Rainfed area	Negative
	3	Total irrigated area (ha)	Positive
	4	Percentage of irrigated areas	Positive
	5	Lift irrigated area (ha)	Positive
	6	Flow irrigated area (ha)	Positive
	7	Tank and pond area (ha)	Positive
	8	Area of maize (ha)	Positive
	9	Area of rice (ha)	Positive
	10	Area of wheat (ha)	Positive
	11	Area of pulses (ha)	Positive
	12	Area of oilseeds (ha)	Positive
	13	Area of vegetables (ha)	Positive
	14	Productivity of maize	Positive
	15	Productivity of rice	Positive
	16	Productivity of wheat	Positive
	17	Productivity of pulses	Positive
	18	Productivity of oilseeds	Positive
	19	Productivity of vegetables	Positive
	20	Disease/insect spread	Negative
	21	New disease/insect appearance	Negative

component. The VIs of individual sectors in different blocks of Kullu are shown in Table 4.

Demographic VI

The demographic average VI, comprising exposure and sensitivity, was highest in Anni, followed by Nirmand and Banjar, because of a shift of agricultural labor to other enterprises and lower literacy rates in the farming community. Naggar, followed by Kullu, had the lowest VI, reflecting less vulnerability to change in climatic conditions (Table 5).

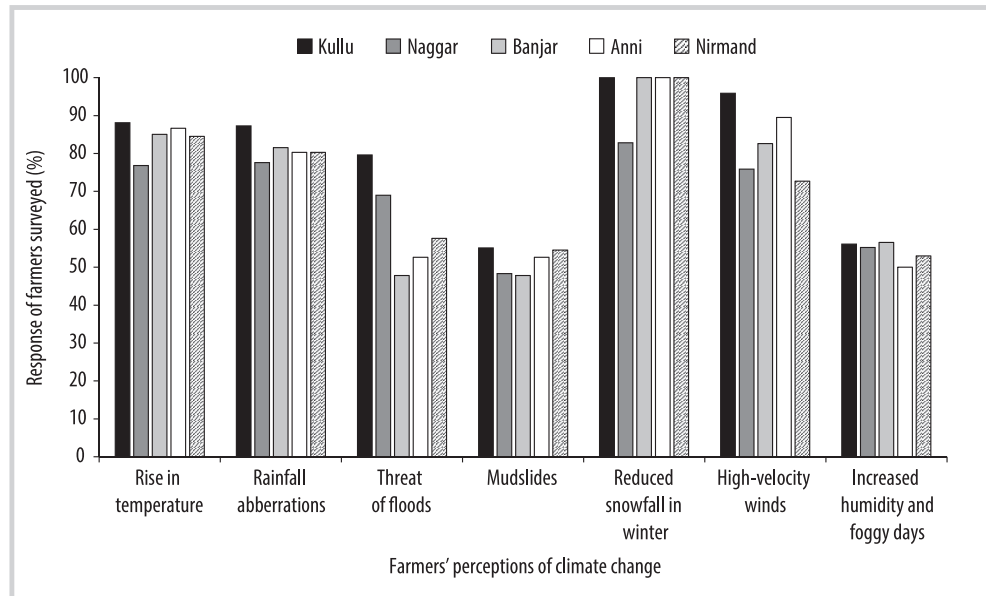
Agriculture sector: In the agriculture sector, Banjar had the highest VI for exposure vulnerability, followed by Anni and Kullu, because of a higher degree of changes in climatic conditions. The lowest VI was for Naggar, followed by Nirmand. Sensitivity VI was highest in Anni (0.643), followed by Naggar, and lowest (0.497) in Kullu (Table 6). The higher sensitivity index resulted from more rainfall, more diseases and insect or pest attacks, and their management using more

TABLE 3 Continued. (First part of Table 3 in previous column.)

Sector	Serial no.	Name of indicator	Relation
Horticulture (<i>n</i> = 11)	1	Area under fruit (total)	Positive
	2	Area under apple	Positive
	3	Area under stone fruit	Positive
	4	Area under pomegranate	Positive
	5	Area under other fruit	Positive
	6	Productivity of apple	Positive
	7	Productivity of stone fruit	Positive
	8	Productivity of pomegranate	Positive
	9	Productivity of other fruit	Positive
	10	Disease/insect spread	Negative
	11	New disease/insect appearance	Negative
Livestock (<i>n</i> = 6)	1	Animal population	Positive
	2	Sheep and goat population	Positive
	3	Others	Positive
	4	Poultry population	Positive
	5	Disease/insect spread	Negative
	6	New disease/insect appearance	Negative

than 3 sprayed pesticides. Villages without local institutions (self-help groups), with higher occupational dependence on agriculture, and with negligible infrastructure facilities had a relatively higher social vulnerability score (Shukla et al 2016).

Gallopín (2003) described sensitivity as the extent or degree to which a particular system would be modified or affected by an internal or external disturbance or change or a set of disturbances or changes. This measure reflects the responsiveness or changes of a system to climatic influences and is molded and shaped by ecological and socioeconomic conditions. It determines the degree to which a group would be affected by environmental stress (Gbetibouo and Ringler 2009; Fellmann 2012). However, it is difficult to directly predict crop yields under potential future climates on a decadal timescale (Challinor et al 2007). The adaptive capacity index among blocks revealed that Anni ranked first, followed by Banjar and Nirmand, indicating less adaptive capacity to ameliorate climate change impacts on agriculture. This results from limited management of insects and pests, less market and road accessibility, and poor institutional support and access to agroadvisory services. Naggar and Kullu had higher capacity to adapt to and mitigate the climate change impacts. This results from well-managed orchards with new spur varieties of apple that can withstand higher temperatures. The Kullu block alone has

FIGURE 2 Farmers' perceptions of climate change in the different blocks of the Kullu district.

recorded more than 55% of farmers shifting to vegetable crops from horticulture fruit orchards. Similarly, overall net vulnerability was highest in Banjar, followed by Anni and Kullu (Table 6). The lowest level was recorded in Naggar, followed by Nirmand. Banjar, Anni, and Kullu were more vulnerable to changes in climatic conditions on the agriculture sector.

The fertility status index based on 490 samples analyzed for 12 parameters (micro- and macronutrients) also indicated more vulnerability in Anni, followed by Kullu. The soil fertility VI was lower for the Banjar, Nirmand, and Naggar blocks of the Kullu district. Hiremath et al (2015) assessed the vulnerability of the drylands of Saurashtra to climatic change and reported that the agriculture sector was the main contributor to the overall vulnerability to climate change. Similarly, a study of the VIs for selected districts of Gujarat revealed that agricultural vulnerability variables were significant contributors to the overall vulnerability to climate change (Hiremath and Shiyani 2013). Raju et al (2016) studied agricultural vulnerability in Karnataka and concluded that agricultural VI indicators, such as commercial crop area, cropping intensity, and gross irrigated area, were major drivers in determining vulnerability.

Horticulture sector: The exposure VI was highest for Banjar, followed by Anni and Kullu, because of lower snowfall, reduced southwestern monsoon, and higher probability of drought. Naggar and Nirmand had low exposure to climatic parameters. The sensitivity VI was highest in Nirmand and Anni and lowest in Banjar, followed by Naggar, indicating a lower impact of climatic changes on horticultural crops. The adaptive capacity to ameliorate climate change impacts on the horticulture sector was highest in Anni, followed by Nirmand and Banjar. Naggar block ranked least vulnerable with more adaptive capacity because of the establishment of new orchards with spur variety, high snowfall in northern aspects compared with other blocks, and greater accessibility to markets and roads. The net VI for horticulture also revealed that Naggar was least vulnerable, followed by Nirmand and Kullu (Table 6). The horticulture sector in Anni and Banjar was most vulnerable because of poorer accessibility of roads, less institutional support, and older orchards with a nonspur variety. Chaturvedi et al (2011) concluded that the mountain forest regions (alpine and subalpine forest, Himalayan moist temperate forest, and Himalayan dry temperate forest) were more susceptible to the adverse effects of climate change, because climate change is projected to be greater for regions at higher elevations.

TABLE 4 VIs and block rankings by sector and across sectors.

Block	Agriculture		Demographic		Horticulture		Livestock		Composite	
	VI	Ranking	VI	Ranking	VI	Ranking	VI	Ranking	VI	Ranking
Kullu	0.676	3	0.443	2	0.767	3	0.131	2	0.504	2
Naggar	0.400	1	0.232	1	0.214	1	0.017	1	0.216	1
Banjar	0.909	5	0.679	3	0.791	4	0.579	4	0.740	4
Anni	0.738	4	0.725	5	0.934	5	0.879	5	0.819	5
Nirmand	0.492	2	0.692	4	0.726	2	0.184	3	0.524	3

TABLE 5 VIs and block rankings by exposure and sensitivity components individually and combined.

Block	Exposure		Sensitivity		Net VI	Net ranking
	VI	Ranking	VI	Ranking		
Kullu	0.576	3	0.309	1	0.443	2
Naggar	0.143	1	0.321	2	0.232	1
Banjar	0.876	5	0.483	3	0.679	3
Anni	0.841	4	0.609	4	0.725	5
Nirmand	0.456	2	0.927	5	0.692	4

Livestock sector: The exposure VI for the livestock sector among different blocks of the Kullu district was highest in Banjar (0.876), followed by Anni. Naggar was less vulnerable to climate change scenarios. Similarly, sensitivity VI was lowest in Kullu, indicating less vulnerability because of less disease or insect spread and their immediate management, whereas Anni and Banjar showed more vulnerability. The adaptive capacity index was highest in Banjar, meaning it was the most vulnerable, followed by Anni, because of fewer veterinary hospitals and clinics, steeper slopes, and poor-quality grassland. The net VI was lowest in Naggar, followed by Kullu, reflecting the least vulnerable blocks for the livestock sector. The highest VI was observed in Anni, followed by Banjar, indicating high vulnerability (Table 6).

Composite VI of blocks: Comparing the net VI for different blocks in all sectors revealed the Naggar block to be the least vulnerable, followed by Kullu and Nirmand. Overall, the VI

of Anni was highest, followed by Banjar, indicating that these were more vulnerable than other blocks. The Naggar block recorded the lowest VI value and was thus the least vulnerable, followed by Kullu. According to the Indo-Swiss Research Consortium (ISRC 2016), institutional support and timely control of disease, insects, and pests contribute to lower VI. The low vulnerability of the Naggar block (Table 6) could also be attributed to fertile soils, the establishment of new orchards, and a shift toward off-season vegetable production. Upgupta et al (2014) analyzed the impact of climate change and assessed the vulnerability of forests using remote sensing and geographic information system-based technology in the Indian Western Himalayan region. The results indicated that under the current scenario, the Mandi district (1.83), followed by Solan (1.75), and Bilaspur (1.74), was the most vulnerable district to climate change. They concluded that the districts of Chamba, Kullu, Shimla, Mandi, and Kangra of HP would be the most vulnerable districts by 2030. Loss of human lives, cultural heritage, ecosystem services, and social structure was not included in this vulnerability assessment approach.

Similar studies in different regions show the composite VI is a useful tool for decision makers and can assist in formulating efficient adaptation measures and developmental programs (Chaliha et al 2012). Allen et al (2018) developed an assessment framework for adaptation planning using insights from a pilot study of flood risk in HP.

Adaptation strategies

A case study identified adaptation strategies for the farming sector and outlined potential measures for addressing climate-related risks to agriculture, horticulture, and

TABLE 6 VIs and block rankings by exposure, adaptive capacity, and sensitivity components, as well as for the different sectors.

Sector	Block	Exposure		Adaptive capacity		Sensitivity		Composite	
		VI	Ranking	VI	Ranking	VI	Ranking	VI	Ranking
Agriculture	Kullu	0.576	3	0.397	2	0.497	1	0.676	3
	Naggar	0.143	1	0.384	1	0.641	4	0.400	1
	Banjar	0.876	5	0.563	4	0.596	3	0.909	5
	Anni	0.841	4	0.746	5	0.643	5	0.738	4
	Nirmand	0.456	2	0.535	3	0.571	2	0.492	2
Horticulture	Kullu	0.635	3	0.349	2	0.481	3	0.767	3
	Naggar	0.123	1	0.329	1	0.420	2	0.214	1
	Banjar	0.874	5	0.395	3	0.312	1	0.791	4
	Anni	0.863	4	0.597	5	0.668	4	0.934	5
	Nirmand	0.532	2	0.529	4	0.723	5	0.726	2
Livestock	Kullu	0.576	3	0.445	1	0.000	1	0.131	2
	Naggar	0.143	1	0.691	2	0.565	2	0.017	1
	Banjar	0.876	5	0.998	5	0.701	4	0.579	4
	Anni	0.841	4	0.956	4	0.994	5	0.879	5
	Nirmand	0.456	2	0.881	3	0.609	3	0.184	3

livestock sectors for all small, marginal, and large households (ISRC 2016).

Agriculture and horticulture: In these sectors, we identified several adaptation strategies and potential measures. They can be grouped into three fields of activity:

- **Climate resilience practices:** Organic and biodiverse agriculture could help to provide climate resilience to extreme weather compared with traditional monocultures. Opting for varieties, species, and genotypes that are resilient to climatic changes can improve resilience against humidity, drought, pests, and diseases. Minimal plowing strategies can reduce the effects of intensive farming that lead to land erosion. Crop rotation and mixed cropping maintain soil fertility without the need for a fallow phase that leads to soil erosion. Practices such as mulching are helpful in reducing losses because of evaporation, pests, and diseases.
- **Diversification in agricultural sector:** Adoption of new technologies for vegetable production and growing off-season vegetables could mitigate against climate change. To address the shift in the apple-growing belt, apple orchards could be replaced with temperate stone fruit and pomegranate. Agriaquaculture involving diversification for small landholders by including fish farming, animal husbandry, mushroom cultivation, or beekeeping would improve food and water security.
- **Water conservation strategies:** Water budgeting and efficient irrigation methods will ensure irrigation water is available during drought conditions. Traditional irrigation strategies, using local traditional knowledge, can help to ensure fair and efficient water allocation. Harvesting and storage of rainwater in microreservoirs can improve water security for a region. Constructing permeable ponds to recharge local ground water reserves will help with the spring recharge.

Livestock: Strengthening the organized livestock sector through improved pastures using high-yielding fodder varieties, improved feed quality, value addition, effective marketing of livestock products, and prompt management of newly appearing disease are important adaptation measures. Development of heat and cold stress management through scientific housing plans can enhance climate resilience in the livestock sector.

Extension services support: Agrometeorological advisory services can help to provide timely information on adverse weather conditions. Climate-smart insurance could reduce financial losses because of extreme weather. Scientific capacity can be built by strengthening local institutions and universities through education. Community-based training, by means of exchange programs, joint research projects, and international networking, can enhance climate resilience among farmers. Strengthening of ground-level capacity-building measures by engaging local farming communities is key to the successful implementation of adaptation measures.

The agrometeorological advisories in the Himalayan region proved effective in reducing crop losses by using advance weather information (Rana, Bhagat, et al 2013). Tripathi (2014) showed that districts with well-developed infrastructure and economies were less vulnerable to climate

change and concluded that vulnerability to climate change and variability were correlated with social and economic development.

Conclusions

The impacts of climate change are particularly visible in mountain regions. Vulnerability assessment is a useful tool for policy planners to create effective adaptation measures to offset climate change. This vulnerability assessment study in a fragile mountain ecosystem clearly indicates varying degrees of climate vulnerability in the farming system at the block scale. Regions with a low VI have more institutional support and higher literacy, and farmers have the capacity to shift to enterprises other than agriculture. Environmental factors that contribute to a lower VI are fertile soils, improved grassland, better climate, and gentler slopes. New orchards, a shift toward off-season vegetable production, and lower spread and better control of diseases, insects, and pests also help lower the VI. In terms of infrastructure, regions with less climate vulnerability are nearer to markets, have access to road networks, and have a greater number of veterinary hospitals and clinics. Agroadvisory services with advance weather forecasts, SMS-based alerts for pest control, and disaster management were shown to be beneficial in increasing the profits of the farmers. The mountain ecosystem of the study regions warrants focus on adaptations involving agronomic manipulation, such as planting window adjustments, crop management practices, reduction of chemical usage, and balancing soil nutrient applications. Local farmers' participation in identification and implementation of adaptation measures to offset climate change can enhance climate resilience in mountain regions.

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Supplemental material

TABLE S1 Distribution of land cover classes for the Kullu district, HP.

TABLE S2 Climatic trends in the Kullu district.

TABLE S3 Farmers' perceptions of climate change in different blocks of the Kullu district.

TABLE S4 Farmers' perceptions of crop phenology in relation to climate change.

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