Farmers' perception of climate change and management strategies in the mid-Himalaya, India

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The Himalayan ecosystem is one of the most climate change-affected ecosystems in the world. The present study focuses on farmers' perceptions of climate risks and adaptation strategies in Uttarakhand, mid-Himalaya, India. Using district-level long-term climate data along with village-level surveys, we explored the major trends in climatic variables with farmers' perception and adaptation practices against climate change vagaries. Farmers noticed changes in the environment that were consistent with trends in the climate data. Farmers' adaptation measures included changes in crop varieties, reduced number of livestock, shifting to non-farm activities, shifting planting dates and changing the cultivable land size. Stronger extension services, use of mobile advisory for increasing extension contact, inexpensive credit, community-focused agricultural training were the most important factors for effective climate change adaptation behaviour. Farmers' perception was significantly influenced by number of crops grown, training experience and extension contact. This study emphasizes the need for policymakers to take into account local knowledge of climate change and strategies to speed up communities' shift towards resilience and the extension mechanism must adapt their strategies for promoting resilience based on locally constrained and unconstrained measures.

Keywords: Agriculture, adaptation, climate change, farmers' perception, management strategies, small landholdings.

THE term 'climate change' refers to the 'long-term changes and variability persisting for a considerably longer duration in weather conditions'[1]. The effects of climate change are multifaceted. A vast body of research exists on climate change as a global challenge affecting humans, their socio-economic activities, health and food security[2,3]. Consequently, climate change is bringing adverse changes to livelihoods as well. Communities that depend on farmlands are the most impacted because they must constantly adapt to weather changes. The situation becomes more precarious, especially in hilly areas, as a result of the confounding issues of low technical and infrastructure development, and high reliance on rainfed farmlands. The Himalayan mountain ecosystems despite being rich in biodiversity and traditional knowledge, are highly susceptible to natural hazards and climate change[4]. The fact that hill agriculture in Uttarakhand, India, is mainly rainfed (covering more than 80% of the area), makes it extremely vulnerable to climate vagaries[5]. Agricultural and subsistence-based communities are disproportionately vulnerable to the consequences of climate change[6]. However, in many Himalayan regions where agriculture is largely rainfed, climate change adaptation efforts are sporadic, limited and poorly coordinated, and lack the inclusion of farmers' perspectives. A climate risk adaptation plan is effective when the farmers of a region experience a change in climate, which is adversely affecting their agriculture and livelihoods. Analysing farmers' perception of climate change is essential for framing appropriate adaptation and mitigation strategies related to timely decision-making in agricultural practices[7]. Farmers' perception of climate variability and change, coupled with indigenous knowledge leads to an advanced understanding of climate change and its effect on agricultural output. The knowledge of how farmers perceive climate helps in framing strategies for adaptation at the local level, which are well accepted by them due to the feasible nature of such strategies. There are several studies on changing trends in climate and its impact on agriculture based on real-time data, but only a few studies explore farmers' understanding of these changes, who are being affected by climate change. There are several studies that state that farmers perceive the trend accurately, and there are some that show a lack of congruence between farmers' perceptions and climatic trend data. This emphasizes the need for locale-specific climate-risk perception across regions so that specific programmes and policies can be framed for effective adaptation against climate-induced hazards.

Research on farm-level climate change adaptation reveals that there is a lack of consensus in the literature on the adequacy of rural farmers' awareness about climate change and their strategies for reliable adaptation[8]. Studies carried out in the hill agro-ecosystem have also stressed incorporating the awareness of local people about climate-induced changes along with other stressors. Personal experiences and risk perceptions have an impact on how people adapt to climate change[9]. Communities may not adopt effective adaptation measures without accurate perceptions[10,11]. Perceptions change with locations and communities. Studies on perception have been conducted in the Himalayan region of Garhwal, North Eastern region and farming areas of the Ethiopian highlands[11], where farmers noticed a trend of rising temperatures and decreasing rainfall. The output and productivity of presently grown crops will be adversely impacted by decreased rainfall and increasing temperature, and a region's continuing shift in temperature and rainfall

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pattern will have significant effects on food security. Nearly all farmers in Nepal's mid-hills mentioned that summers were getting hotter and longer, while 81% of those surveyed mentioned that winters were getting warmer and shorter[12]. A study on farmers' perceptions towards climate change in Ghana considered the vulnerabilities of farm location to the incidence of droughts and floods and indicated that drought conditions on farms in lowlands and hills have been relatively high[13]. Instead of examining the factors that determine 'risk perception', the majority of these studies only describe it[14]. Local community-specific perception of climate change and its determinants not only provide real-time data on climatic changes but also provide a blueprint for planning suitable location-specific climate adaptation strategies that may work in an area. The programmes and policies that largely depend on the empirical data and neglect local perceptions and knowledge can be useful for adaptation planning at the regional level but often fail at local scales[15].

Interdisciplinary and multi-stakeholder evaluations are increasingly incorporating local knowledge and vulnerabilities[6]. According to the Intergovernmental Panel on Climate Change, adaptation to climate change is the modification of natural or human systems in reaction to real or anticipated climatic cues or their effects, which mitigates damage or capitalizes on advantageous opportunities. Smallholder farmers can adjust on their own (autonomous adaptation) or through Government programmes that promote suitable and successful adaptation measures (planned adaptation). However, in order to execute suitable interventions, it is necessary to comprehend location-specific possibilities, challenges and important drivers of adaptation.

Keeping in mind that successful adaptation is dependent on the merging of both science trends and farming perceptions[16], the present study attempts to answer four research questions: (i) how do farmers perceive climate variability and change compared with historical climatological data in the study area? (ii) What measures do hill farmers adopt to reduce climate-induced changes in their crops? (iii) What constraints do hill farmers face in adopting strategies for climate adaptation? (iv) Which factor(s) influence hill farmers' perception of the changing climate in the study area? The study analysed farmers' cropping system adaptation strategies and several barriers to climate change adaptation. The perception of farmers was also compared with the meteorological data to examine the congruence between farmers' perceived and actual climate trends.

The three main objectives of this study were to: (i) evaluate farmers' perception of and adaptation to climate change in the mid-hill region; (ii) examine the factors that influence farmers' perception of climate change and (iii) analyse the adaptation strategies used by farmers towards climate change and the constraints they typically perceive in adapting climate-smart practices. There is a dearth of empirical information regarding the indicated gaps in knowledge.

This study was conducted in Uttarakhand, situated in the Northwestern Himalayan region of India (Figure 1). It is one of the hill states, most vulnerable to climate change in the area, where the situation is exacerbated by the interaction of numerous stresses caused by rainfed agriculture. The hill regions are particularly vulnerable because of their ecological fragility and institutional weakness, now aggravated by climate change. The main crops grown in the region during the season are maize, millets, paddy, legumes, and vegetables. The average elevation of the study sites ranges from 1604 m amsl in Almora to 2084 m amsl in Nainital.

The long-term climate data (1977–2016) of three districts in Uttarakhand, i.e. Almora, Nainital and Dehradun under the Indian mid-Himalayan region were collected from India Meteorological Department (IMD), Pune for ascertaining climatic trends of rainfall and temperature[17]. A survey on farmers' perceptions and adaptation strategies was conducted in the hill farming communities of the above districts using a multistage sampling technique with a sample of 100 farmers. A list of all homes was obtained, and a sample size of 100 was calculated based on a 95% confidence level and a margin of error of 5% from the total households. While the arable land is heavily used for rice and wheat farming systems, it is severely impacted by climatic and environmental stressors such as drought and falling groundwater levels, as well as a rise in pests and market risks. We assessed if there was a link between farmers' perceptions of climate change and periodic changes in climatic factors since 1980. To ascertain farmers' views, each respondent was asked if he/she had noticed any differences in rainfall patterns and daylight hours and temperature at night during the three seasons of agriculture (spring, monsoon and winter) over the last 20 years. Farmers in the age group of 35–65 years were interviewed, as they may have witnessed and recollected changes in weather parameters, if any, during their lives. They were instructed to select one out of three situations in their responses: declined (coded as –1), unchanged (coded as 0) and increased (coded as 1). Further, constraints experienced by farmers in practising adaptation measures were also assessed. The farmers were interviewed about the demographics of their families, the farming practices they used, the observed changes in the environment, particularly

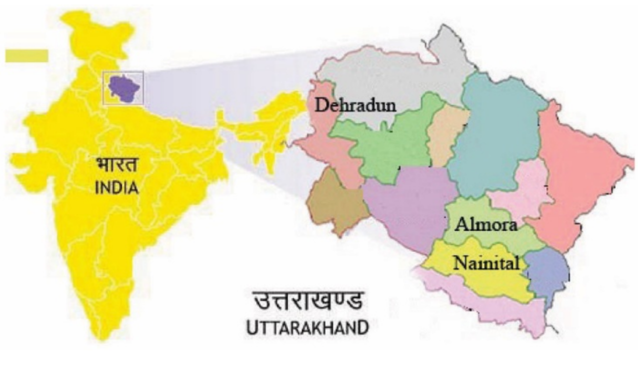

Figure 1. Study areas in Uttarakhand, India.

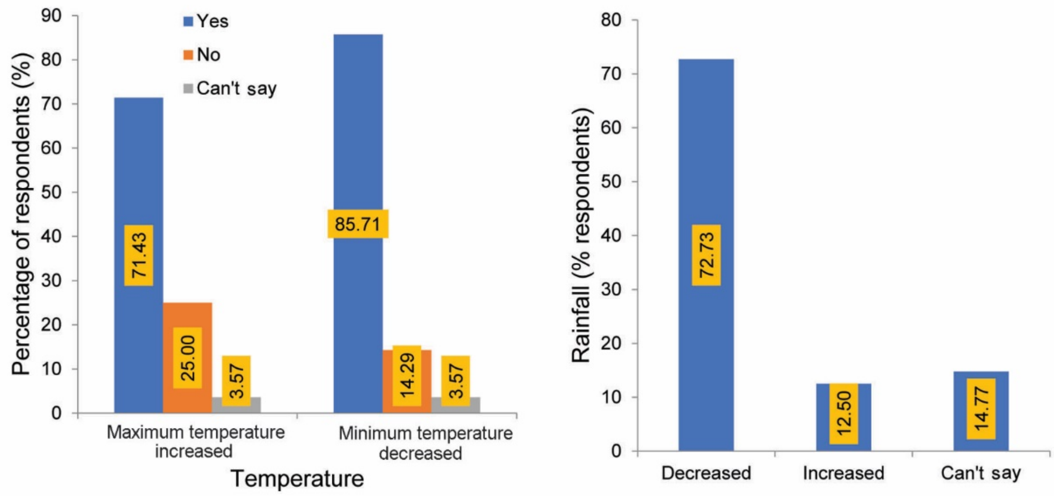

Figure 2. Farmers' perception of climate change during the past 40 years.

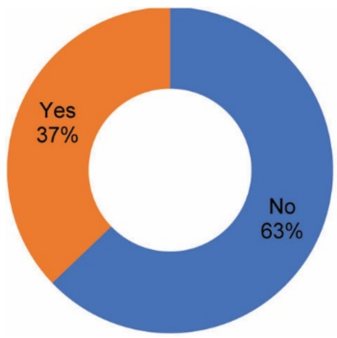

Figure 3. Distribution of respondents based on adaptation of farming practices.

Table 1. Farmers' perception of climate change, i.e. rainfall and temperature ($n = 100$)

Category	Increased	Decreased	Can't say
Rainfall amount	13	72	15
Maximum temperature	72	25	4
Minimum temperature	14	86	4

X^2 (2, 100) = 113.36, $P = 0.00001$, significant at 5% significance level.

Table 2. Farmers' perception of indicators of climate change ($N = 100$)

Category	Yes	No	Chi square value	*P*-value
Change in weather cycle	87.5	12.50	31.72	0.00
Less winter rainfall	90.91	9.09	39.92	0.00
Late rainfall in winter	78.41	21.59	17.01	0.00
Less snowfall	97.73	2.27	54.32	0.00
Reduced frost	48.28	51.72	0.08^{NS}	0.78
Reduced winter intensity	71.76	28.24	10.17	0.00
Reduced winter months	69.32	30.68	7.49	0.01
Late winters	90.91	9.09	40.41	0.00
Summer is reduced	9.09	90.91	40.41	0.00
Dry spell reduced	12.50	87.50	31.72	0.00
Rainfall has decreased	72.41	27.59	10.17	0.00
Rainfall is uncertain	76.14	23.86	14.50	0.00

rainfall and temperature, the effects felt over time, the adaptation strategies they used and the challenges they faced in adapting such strategies. The responses from the questionnaire were triangulated using information from concentrated group talks and interviews.

The IMD website was used to gather meteorological information. To study rainfall variations, we used the rainfall anomaly index. The following method was used to determine the rainfall and temperature standardized anomalous indices (SAI):

$$\mathrm{SAI} = \frac{(X - \bar{x})}{\sigma},$$

where X is the actual value of climate data, $\bar{x}$ the mean and σ is the standard deviation.

Farmers' statistics on rainfall variability were compared with the calculated standardized anomaly index for rainfall. We examined the trend in the highest (T_{max}) and lowest (T_{min}) temperatures to study temperature variations. The dependent variable in this study was 'farmers' perception of climate change. Explanatory factors were chosen based on the traits of the surveyed farms and the available literature[18,19]. Binary logistic regression analysis and descriptive (frequency, proportion, weighted mean) statistics were used. Using STATA, binary logistic regression was used to calculate the variables influencing the farmers' perspectives.

In the last 20 years, farmers have noticed changes in the environment. Many of the farms noticed changes in rainfall and temperature trends as a result of the changing environment (Figure 2). The majority of the farmers (72%) mentioned that rainfall had decreased, while the remaining mentioned that rainfall had increased (13%), or that they had not noticed any difference (15%). Additionally, a statistically significant difference between the proportion of

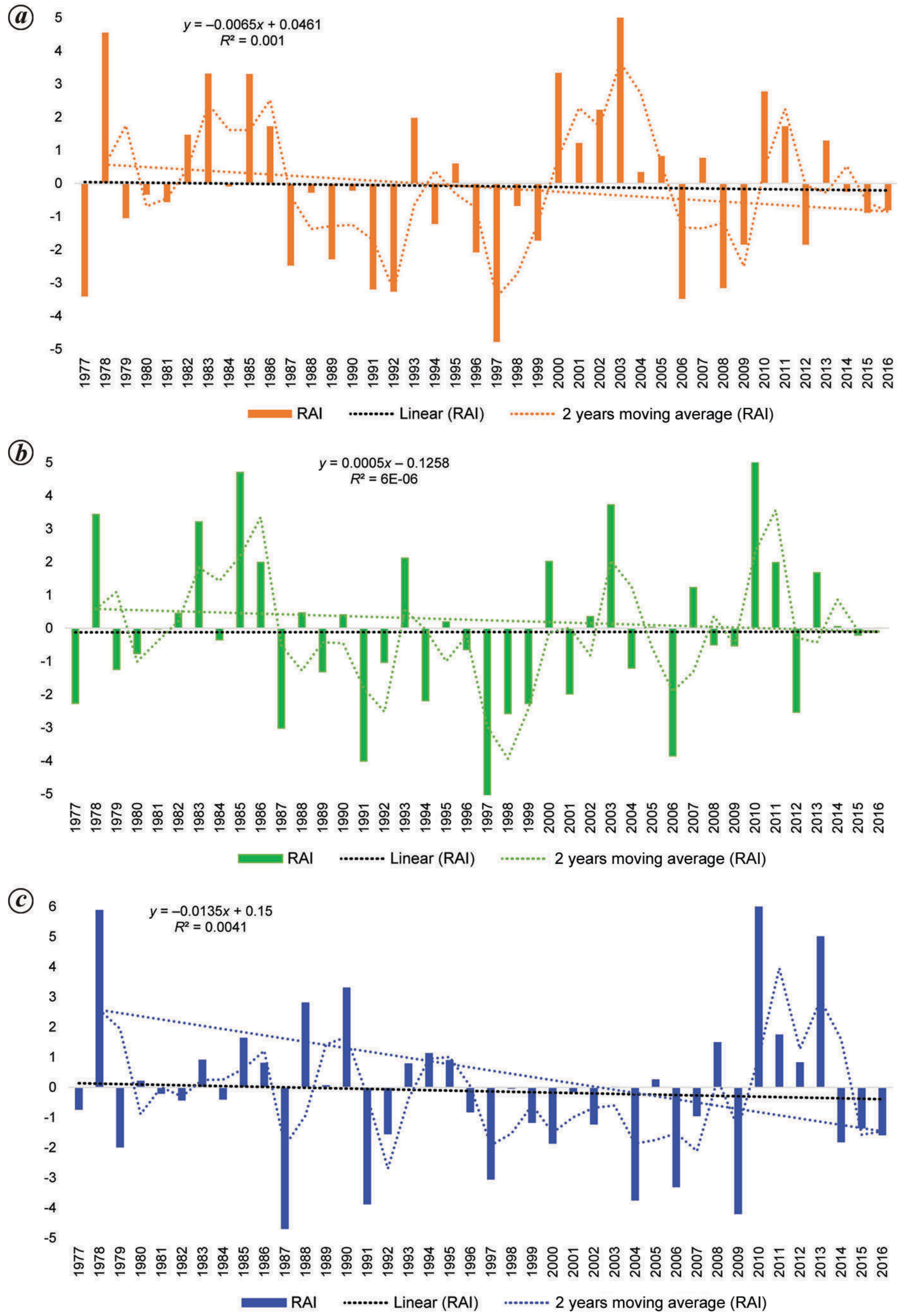

Figure 4. Rainfall anomaly index (RAI) and moving average of rainfall (MAR) of (***a***) Almora district (1977–2016), (***b***) Nainital district (1977–2016) and Dehradun district (1977–2016) in Uttarakhand (source: India Meteorological Department (IMD), Pune).

respondents who observed patterns in climate change indicators was revealed by the chi-square test (Table 1). Studies done in the central Himalayan region have shown that over 25 years, the intensity of rainfall has decreased while the range of maximum temperatures has increased and the rate of precipitation has decreased. Most farmers mentioned that rainfall has decreased throughout the year, particularly during the winter (Figure 3).

The trend of parameters of climate change was documented in general by farmers using dichotomic responses as ‘yes’ or ‘no’ (Figure 3). For instance, 87.5% of respondents agreed that there was a change in the weather cycle. The results of the chi-square test revealed a statistically significant difference between the respondents’ views of the different study environment variables (Table 2). The farmers perceived that rainfall had reduced in magnitude (91%) and had an erratic pattern (76%). Researchers have also reported that the majority of farmers perceived a decreasing trend in rainfall[13,20,21]. Farmers mentioned that winters were late (90%) and that there was less snowfall (98%).

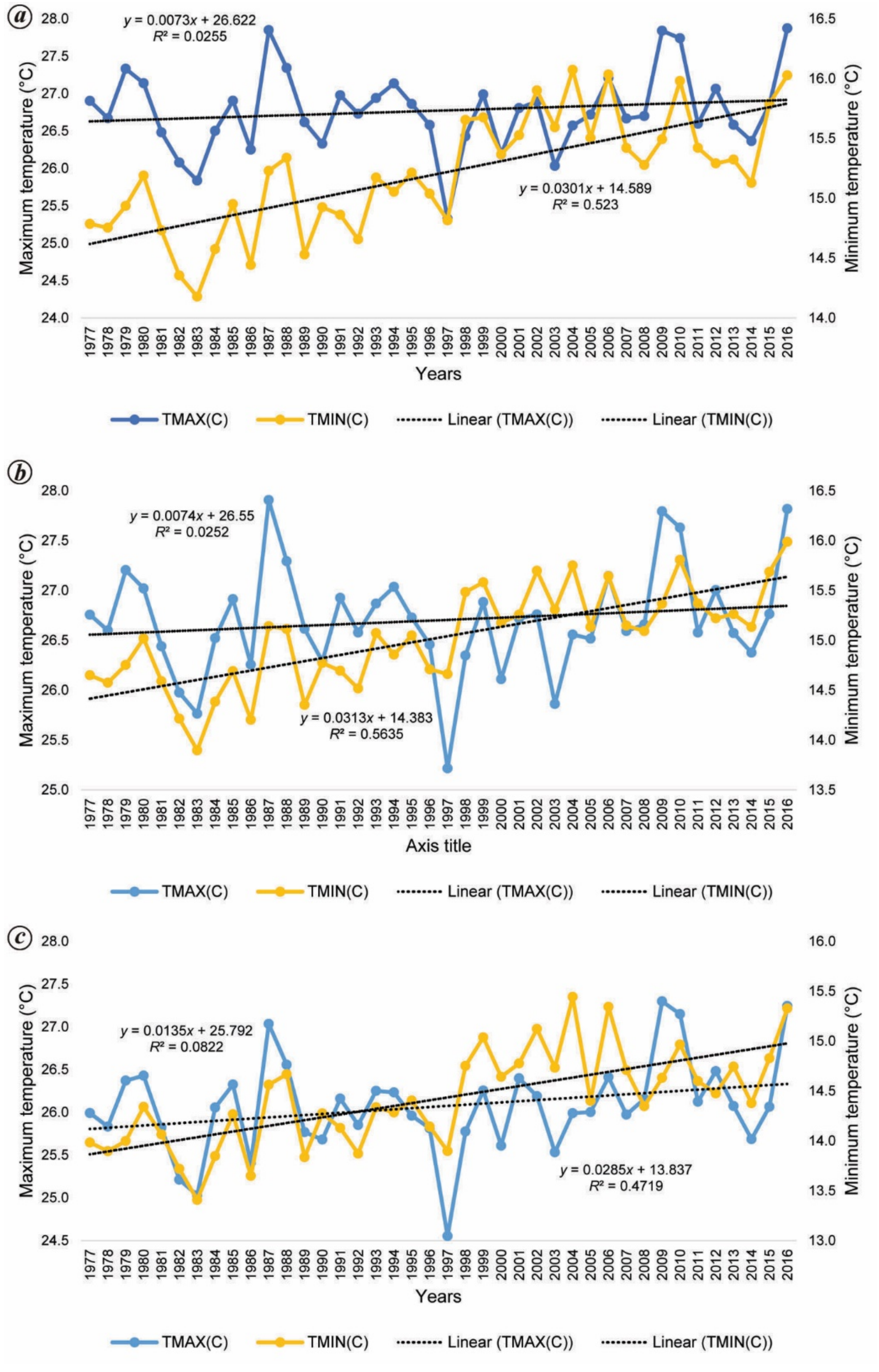

Figure 5. Trends of temperature variability in (***a***) Almora district (1977–2016), (***b***) Nainital district (1977–2016) and (***c***) Dehradun district (1977–2016) in Uttarakhand (source: IMD, Pune).

Farmers (72%) also perceived that winter intensity has reduced, which indicates that the minimum temperature has increased. Rainfall occurs late in winter (91%), which has adversely affected the *rabi* crops, especially wheat. In line with the findings of the present study on uneven rainfall as a sign of climate change, an earlier study cautioned about irregular rainfall in many emerging countries[19]. Researchers have documented a similar pattern of increasing maximum temperatures as an indicator of climate change[22,23]. Overall, it can be concluded that the farmers of the study area are aware of climate change and could accurately perceive the trend over the years. They gave affirmative responses to change in the weather cycle. They perceived that the rainfall pattern had changed erratically, with

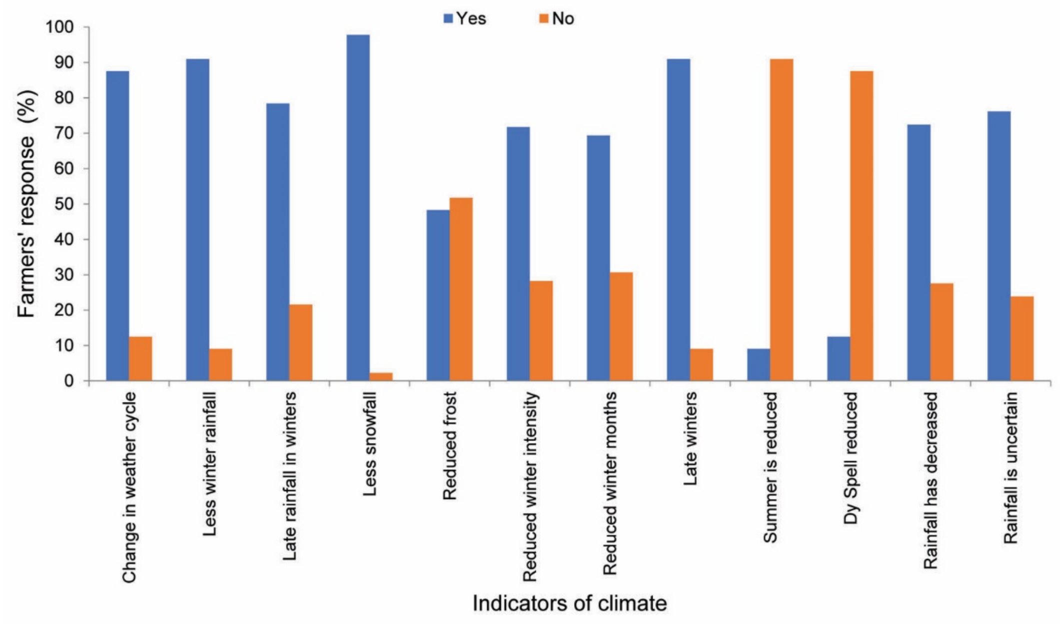

Figure 6. Farmers' perception of various parameters of climate change.

Table 3. Determinants of farmer's perception of climate change

Variable	Coefficient	Standard error	*z*	*P* > *z*
Age (yrs)	0.042	0.027	1.57	0.116
Gender (1 = male, 0 = female)	–0.057	0.830	–0.07	0.945
Education	0.623	1.037	0.60	0.548
Landholding (ha)	0.649	0.493	1.32	0.188
No. of crops grown	0.581	0.218	2.67	0.008*
Training experience (1 = yes, 0 = otherwise)	1.854	0.673	2.75	0.006*
Extension contact (1 = yes, 0 = otherwise)	1.399	0.599	2.34	0.020*
Constant	–5.768	2.053	–2.81	0.005

*Significant at 0.05 level of significance.

fewer spells of rainfall that also occurred later than expected. Farmers were of the view that not only the winter rainfall but also the annual rainfall had decreased, leading to a longer dry spell. Over the years, snowfall has also decreased, and the winters are less intense. The winter season has become relatively shorter. There was no consensus among farmers on the reduction in frost. The farmers have reduced the area of wheat because of the uncertainty of winter rainfall. Only a few farmers were neutral in their responses to climatic indicators and were probably unsure. Farmers also perceived significant changes in temperature. They have also reduced the cultivation of garden peas, which is a commercial crop, due to disease incidence which could be a result of climate change.

Farmers' perceptions were compared with long-term climate data for the selected districts. The majority of farmers stated unequivocally that temperatures have risen during the monsoon and spring seasons, while rainfall and wet days have decreased across all seasons.

Figures 4 and 5 show rainfall anomaly index (RAI) and trend in temperature variability results with a two-year moving average for Almora, Nainital and Dehradun districts of Uttarakhand respectively. Data on rainfall from 1977 to 2016 were analysed. RAI, with a two-year moving average, was calculated and matched with farmers' perception. Based on a two-year rolling average, consistent variation in the amount of rainfall was observed each year. Nearly half of the years within the study periods experienced annual rainfall below normal range. Farmers' view that lately there has been a shift in rainfall quantity and rainy days is supported by the clear climate data values. The results show that farmers' perceptions of rainfall match closely with the empirical observations. Most of the farmers confirmed increasing temperature trends and decreasing rainfall, which is in accordance with empirical climatology records.

Table 3 shows the empirical binary logistic regression model used to calculate the variables that affect the farmers' view of the surrounding region. A statistically significant correlation between the independent variable groups and farmers' perceptions of climate change was revealed by the logistic regression model. The respondent's perception of climate change is more significantly and favourably influenced by the variables in Table 3, with a high Wald coefficient number. Numerous commodities produced, training experience and extended interaction were among the explanatory variables examined that significantly influenced how well farmers perceived climate change. Studies done elsewhere also show consensus with the results that the dependent variable is influenced by a few socio-economic, institutional and farm-related factors[23].

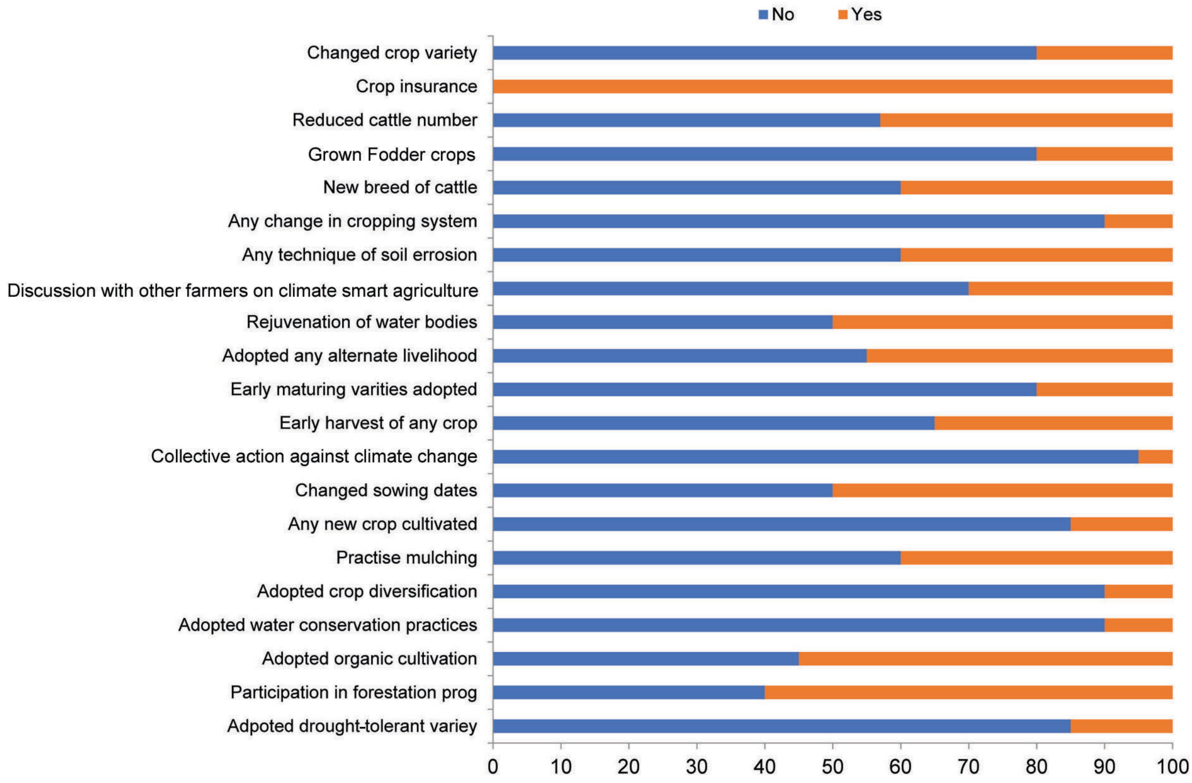

Figure 7. Type of adaptation strategies used by the farmers.

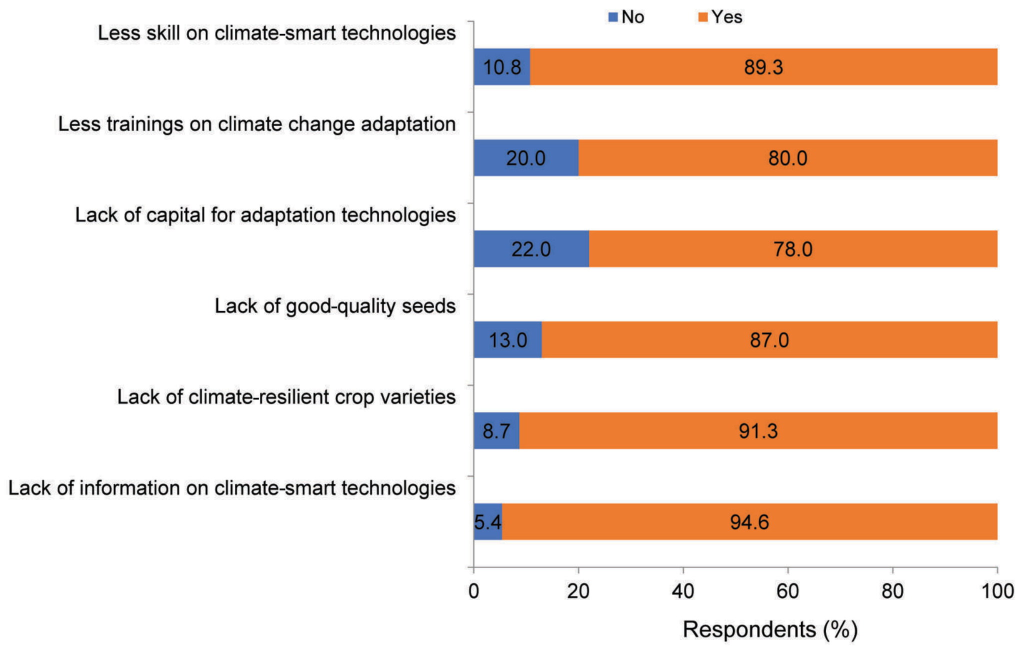

Figure 8. Barriers reported by farmers in adapting various strategies.

Farmers' strategies for overcoming the negative effects of climate change on crops were determined. According to the findings, the majority of the interviewees (63%) did not alter their farming practices to adapt to the effects of climate change, while 37% did make (some type of) modification (Figure 6). The proportion of farmer adaptation methods taken into account in the research is shown in Figure 7. Although farmers were conscious of climate change and how it affected agriculture, they were unaware of the technologies that could help them adjust to it. However, the adaptation made by them was not adequate to mitigate climate change effects on agriculture.

Figure 7 illustrates that the majority of hill farmers (80%) had changed their crop varieties due to lower production but were unaware that these were drought-tolerant varieties. A few farmers (15%) had cultivated less water-requiring varieties of *rabi* crops provided by the State Department of Agriculture. Forty-three per cent of the respondents reduced their number of livestock as a coping strategy due to lack of water and fodder, and 25% had changed their cattle breeds. For *rabi* crops, farmers (50%) had changed their date of sowing wheat to avoid the adverse impact of climate change due to of less winter rainfall. The area under wheat has also reduced (43.80%). Other adjustments reported by the farmers were diversification of crop types and varieties (15%), implementation of soil conservation schemes like mulching (40%) especially for nursery-raising, diversification of livestock types and breeds (25%), and diversification from farming to non-farming activity (45%). Most male members were working in the hotel industry outside Uttarakhand. Only 10% of the respondents had built water-harvesting structures to meet the irrigation demands, but they were non-functional, while the rest of the farmers wanted to get poly tanks, but could not afford it. None of the respondents used crop insurance to protect their crops from the adverse impact of climatic conditions. The farmers were uncertain and not assured of the claim settlements made under crop insurance programme.

Farmers were sensitive towards climate change as they had participated in afforestation programmes (60% of the respondents) and water bodies' rejuvenation programmes (50% of the respondents). Thus, it can be concluded that the majority of farmers in the study area has changed crop types, decrease in the number of livestock, move away from farming, alteration in planting dates, and variation in the amount of land under cultivation as the main adaptation practices. Additionally, they used a variety of adaptation techniques. This choice suggests that a mix of strategies is probably more successful than a single strategy in adapting to the effects of climate variability and change.

Farmers claimed to have altered grain varieties and cropping patterns in reaction to animal threats and market demands, but it is possible that they were quietly implementing these climate change adaptation measures. For example, farmers used to grow garden peas, which had a high market demand, but they eventually stopped producing them. Though they mentioned animal menace as the reason for the same, the lack of irrigation facilities in the village indicates that it was a climate-induced decision as well. Similar was the case with transplanted paddy. Over the years, the area under transplanted, irrigated paddy has decreased because of the lack of irrigation facilities due to less rainfall, as these areas are rainfed.

Farmers' access to information on climate-smart activities was meagre, as there was no regular source of information pertaining to farming practices for adaptation to climate change. The farmers were willing to adapt technologies, but lack of appropriate awareness and capital were the main constraints. Perceived barriers to using various adaptation options have also been assessed from the empirical data (Figure 8). Lack of information on climate-smart technologies, lack of access to climate-resilient crop varieties, less skill on the part of the farmers in using technologies, lack of suitable good-quality seeds, and lack of capital and credit facilities were the main barriers to the adaptation mechanism. It was observed that perceptions were often not enough to motivate farmers to bring about any change in their farming practices over the last two decades. Piya *et al.*[11] studied the perception of hill farmers in Nepal's rural mid-hills. They stated that perceptions of rainfall changes, land tenure status, size of landholding, distance to the highway, access to useful credit, extension services, information and skill development training influenced households to deviate from traditional coping strategies and adopt appropriate practices towards climate vagaries.

The results of the present study corroborate the evidence that temperatures are rising while rainfall is decreasing and becoming less predictable[24,25]. The erratic nature of rainfall in the hills during the *rabi* season (winter) is a matter of concern, which is affecting the production of wheat crops. Almost all of the farmers in the study region agree that there is climate change. They mentioned that in some years, rainfall comes early while in others, it arrives late, indicating an irregular pattern. Farmers were aware that the unpredictability of rainfall makes it difficult to forecast the planting dates of their crops, and that their output suffers as a result of either a late or early start or stoppage of rainfall. A comparable tendency and impact of climate change on crop production and food security were noticed among farmers in two districts of Uttarakhand[26]. Farmers' perception of rainfall and weather is typically based on their encounters with rainfall unpredictability, rising dry periods and changes in rainfall scheduling rather than real data. However, farmers did not agree on their views of changes in winter temperature which is confirmed by earlier research[27–30]. They considered that rainfall and temperature have changed during winter and that rainfall fluctuation has had a greater effect on crop output than temperature change.

The present study reveals that some passive adaptations were also reported by the farmers as a response to climate change, particularly discontinuing transplanted paddy, declining areas under pea cultivation, etc. Similar observations of passive adaptation among farmers in eastern Uttar Pradesh, India, have been reported[31].

Only three factors, namely the number of crops produced, training experience and extension contact, had a significant positive impact on farmers' perceptions of climate change. A positive relationship between farmers' perception of climate variability and agricultural extension contact suggests that increasing agricultural extension advisory through an efficient method is likely to increase farmers' knowledge of climate change. These results are supported by studies stressing the need for robust extension services and contact for farmers to promote climate-smart agriculture[21,31,32]. More attention must be given to enhanced access to smart-agro-climate training and extension contact. Farmers growing more crops perceived climate change precisely, pressing upon the need for crop diversification as one of the adaptation strategies. A farmer with better exposure through training is expected to perceive climate change more precisely. Thus, regular training programmes for farmers on climate-smart agricultural techniques need to be promoted. Information and communication technology (ICT) may also be used to reach farmers in remote locations. The development of promising adaptation methods that take into account the variables affecting farmers' perceptions of climate change is critical for effective and sustainable climate adaptation.

Farmers have been facing growing negative impacts on farming output and income over the last few decades as a result of natural stress and market volatility. Many farmers have undertaken a variety of farm and non-farm adaptation efforts to mitigate the possible impacts of adverse weather conditions and environmental challenges, as well as to improve their food and livelihood stability as a foundation for overall well-being. The present study uses both quantitative and qualitative methods to examine how smallholder farmers in India's mid-Himalayan area perceive climate change and contrast their views with past metrological data. Farmers primarily noticed shifts in temperature and rainfall trends. They observed an overall increase in yearly average temperature and a decline in annual average precipitation. Farmers can reliably detect trends because rainfall is easier to observe[33].

If policymakers and planners understand how farmers perceive climate-related factors, they can take appropriate measures to adapt to and mitigate recent or ongoing changes in climate. This understanding can guide the development of effective policies to address climatic variability and lessen the impact of climate change. Although there is currently limited evidence of farmers changing their practices in response to climate change, institutional support for adaptation strategies such as water harvesting may be necessary to ensure that even small-scale farmers can afford the costs involved in accessing climate-smart technologies.

Improving communication among Government officials, policymakers and other concerned parties regarding future changes in the weather, and the need to adapt farming practices should be the top priority. To help farmers choose the right crops and cropping patterns and avoid the negative effects of weather changes, the Government should provide them with timely and accurate information about climatic conditions. Access to such information would help farmers cope with uncertainty and increase productivity by taking appropriate measures to protect their crops. The findings of this study suggest that there is a need for farmers' capacity development programmes to enable them to cope with the changing climate. Climate education must be provided through ICT-based innovations. Text messages, along with voice messages, can be a viable option to reach the farmers. Such training programmes could include smart agro-climate training for farmers and extension agents as well. There is a need to build the capacity of agricultural extension systems. Crop diversification must be promoted as an adaptation intervention and gender concerns must be mainstreamed to enable farmers to adapt to climate change. Effective strategies for access to improved varieties, financial help for climate-smart technologies and land rights in the case of women farmers must be explored. In this study, we found that women farmers could not decide whether to use poly tanks in their fields, as men were the main decision-makers for land utilization, which affected the adaptation intervention. This study is limited to farmers in the mid-hills of three districts in Uttarakhand. More studies confirming the trend and farmers' attitudes towards climate resilience with respect to agriculture are required to confirm our findings.

Conflict of interest: The authors declare that there is no conflict of interest.

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Deriving fuel from pine needles through pyrolysis, charring and briquetting and their GHG emission potential

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The present communication presents an overview of generating renewable fuels from pine needles through pyrolysis and briquetting technology. Pine needles are the products of leaf shedding in the forests from pine trees and are considered potential fire hazards. Studies conducted in the last few years show that this biomass can be effectively utilized for the production of bio-oil, biochar and briquettes in an environment-friendly manner. Through pyrolysis, pine needles could be converted to 35% bio-oil with a calorific value of 28.52 MJ kg^{-1}, which can be a base material for other fuels and chemicals. The process also yields 25% biochar, which has a half-life of 600–1000 years and is a suitable material for soil carbon sequestration. The proposed pine needle-based energy centre can produce about 3.8 t briquettes, 1.2 t bio-oil, 1.6 t biochar and 1240 Nm^3 pyrolysis gas from 10 t pine needles, with an energy efficiency of 87.2%. Greenhouse gas emissions were found to be considerably lower for charring and pyrolysis routes compared to forest burning.

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