Impact of Climate Change on Farmer's Livelihoods and Their Adaptation Decisions in Mountain Agriculture: Evidence from Kinnaur, Himachal Pradesh, India

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Abstract: The literature review revealed that the Northwestern Himalayan region has experienced accelerated climatic changes, significantly impacting farmers' livelihoods in mountainous areas. This study examined climate change induced impacts on farmer's livelihoods, and their adaptations across three elevation zones through a field survey of 240 farm households from Kinnaur district, Himachal Pradesh, India, selected using multistage sampling and assessed through structured interviews and focus group discussions. Descriptive statistics and binary logit model (BLM) were employed to analyse the determinants of climate adaptation decisions. The findings revealed that climate change impacts on agricultural practices were substantial, with over 90% of farmers reported significant negative effects on crop yield, quality, and soil fertility. This includes early crop maturation (78.8% of farmers) and a decrease in water availability (70%). Farmers are struggling with increased threats, as nearly two-thirds reported a rise in pest attacks. To cope, 44.2% of farmers are using more pesticides, and over one-fifth are applying more fertilizers. These combined issues have resulted in financial hardship, with nearly half of the surveyed farmers witnessing income losses in the study area. Horticulture has been similarly affected, but with even greater severity due to disrupted chilling hours which are essential for temperate fruit crops. The study identified key adaptation strategies including slope management, crop diversification, modified tillage practices, adjusted fertilizer and pesticide application, seasonal crop timing adjustments, agroforestry integration, and altered irrigation patterns to mitigate climate change impacts. The binary logit model results demonstrated significant positive association between landholding size and various capital intensive adaptation measures. Model also revealed no significant relationship of farmer's education, their access to weather information and extension services, due to cost factors. The study recommends that the promotion of elevation-specific adaptive crop diversification schemes, establishment of climate-smart infrastructure including climate adaptation funds and area specific crop insurance schemes, thereby strengthening local farmers' capacity for implementing climate-smart adaptation strategies in the Northwestern Himalayan agricultural practices.

Keywords: Climate change; agricultural practices; livelihood changes; climate adaptation; cropping pattern; crop yield; pest attacks; water scarcity; crop diversification; fertilizer and pest management

Introduction

The world has been experiencing significant changes in climate patterns, particularly in temperature and rainfall variability (Sarker et al 2014). The rise in anthropogenic greenhouse gases (GHGs) emissions is one of the main drivers of the observed increase in global temperatures since the mid-20th

century (Stern 2014). It has been risen more rapidly since 1970 than during any other 50 years period in the past 2,000 years (IPCC 2023). Between 2001 and 2020, the global surface temperature was 0.99°C [0.84–1.10°C] higher than the 1850–1900 average. According to the United States Global Change Research Programme (USGCRP 2017), a global temperature rise of about 1.4°C above 1976–2005 levels is expected under all scenarios during 2021–2050. Continued rise in global surface temperature is projected to intensify the global water cycle, enhance its variability, increase global monsoon precipitation, and raise the frequency and severity of extreme weather events such as floods, droughts, and prolonged erratic seasons. Similarly, global land precipitation is projected to rise by up to 12.9 percent by the end of the century under high-emissions scenarios (IPCC 2023), while monsoon precipitation is expected to increase by about 1 percent per 1°C of global warming, with especially strong increases in parts of Asia (Wang et al 2021).

India, with its diverse geography and monsoon climate, shows wide variations in temperature and precipitation patterns. The average temperature of the country increased by approximately 0.7°C between 1901 and 2018 (Ravindra et al 2024). Projections reveal that average temperatures could rise by 4.4°C by the end of the 21st century compared to the 1976–2005 average (Krishnan et al 2020). Precipitation trends, however, vary considerably across the country. While no significant trend has been observed in total annual or monsoonal rainfall (Kumar et al 2010), heavy rainfall events in most parts of India have shown significant increases in both frequency and intensity since the mid-20th century (Varikoden et al 2025).

The Himalayan region, meanwhile, faces greater climate-related risks. Rising temperatures, erratic rainfall, rapid snowmelt, and glacier retreat have been evident in past decades (Kulkarni & Karyakarte 2014). The northwestern Himalayas, in particular, have witnessed consistent warming, often exceeding 0.2°C per decade, with faster warming at higher elevations and during winter months (Bhutiyani et al 2010; Dimri & Dash 2012; Rao 2016; & Ren et al 2017). Precipitation patterns on the other hand show a general decline in annual totals, especially during the summer monsoon and winter snowfall in high-altitude zones (Anand et al 2025 & Ren et al 2017).

Such climatic variations have severe implications for agriculture, a sector directly dependent on temperature and rainfall. Crop cycles (Raza et al 2021), yields and production (Sue et al 2021), and crop quality (DaMatta et al 2010) are increasingly affected. As a result, agricultural stability, food security, and farmer livelihoods are under growing threat (Mirzabaev et al.,2022). In the Himalayan region, research has identified major agricultural impacts such as declining yields, increased pest attacks, altered irrigation demands, the spread of farming into higher altitudes, and the introduction of new cereal and horticultural crops (Negi et al 2012; Batool et al 2019; Rai et al 2015; Lal et al 2018 & Kaur 2022). These challenges are especially apparent in the temperate high hill dry zone of Kinnaur district in Himachal Pradesh.

Adaptation strategies play a crucial role in addressing these impacts. Farmers and communities often engage in autonomous adaptation or spontaneous responses to mitigate climate-related risks (Rahman & Hickey 2019). In contrast, planned adaptation involves deliberate measures initiated by governments and institutions (Mersha & Van Laerhoven 2018). However, successful autonomous adaptation requires farmers to have a sound understanding of climate change and its farm-level consequences.

Recent literature shows a growing focus on farmer's perception of climate change, impact on agriculture and farmer's adaptation responses, both in developed and developing countries (Banerjee 2019; Ali & Rose 2021; Khan et al 2021 & Mu et al 2022). Perception and adaptation are interconnected as farmers adopt measures only when they recognize climatic risks (Mitter et al 2019). Additionally, socioeconomic conditions and farm-related characteristics play key roles in determining adaptation choices (Tagwi & Khoza 2024), and these determinants differ across agroecological regions (Bryan et al 2013). Empirical evidence on adaptations is thus essential for designing policy frameworks aimed at strengthening climate-resilient agriculture (Somda et al 2017).

Given these circumstances, the present study attempts to examine climate change impacts on agricultural livelihoods, and the climate change adaptations in the temperate high hill dry zone of Kinnaur district, Himachal Pradesh.

Objectives

This study examines the impact of climate change on farmer's livelihoods, and their adaptation decisions to climatic variations at the farm level in the Kinnaur district of the Himachal Himalayan region.

Data Sources and Methodology

The study is entirely based on primary data collected from farm households using a multi-staged stratified random sampling technique. Data collection was conducted through structured interview schedule and focus group discussions. Informed consent was obtained from all participating farmers prior to the interviews.

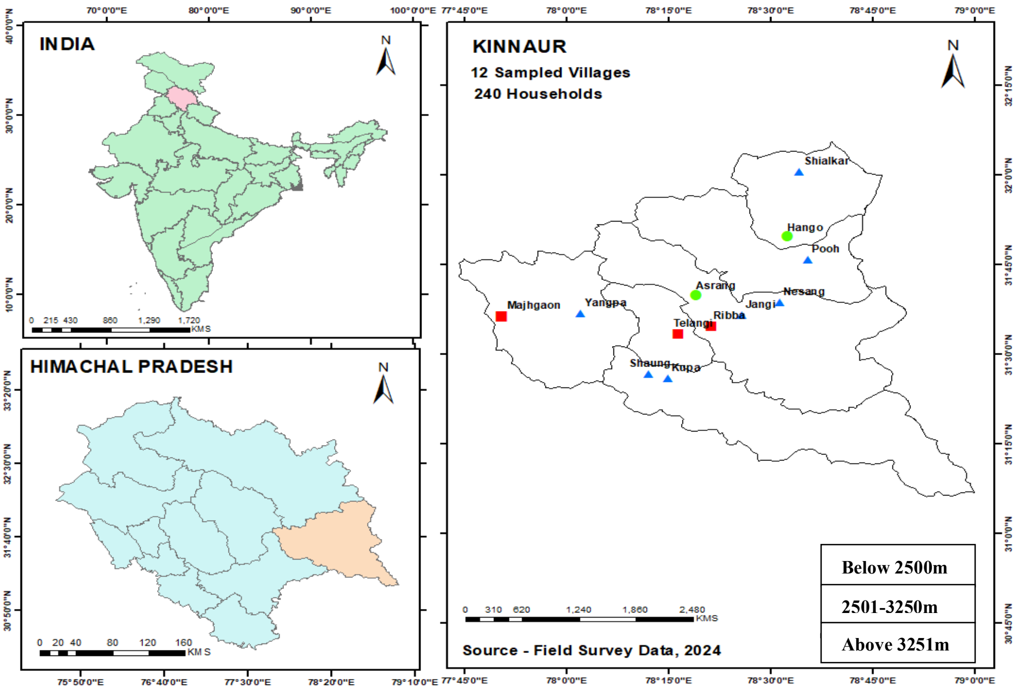

Fig 1: Map of the Study Area

A total sample of 240 farmers was selected from four categories of farm households, defined by landholding size: Marginal (below 2.5 acres), Small (2.5–5 acres), Medium (5–25 acres), and Large (above 25 acres). These farmers were chosen from three elevation zones: below 2500 meters (m), 2501–3250 m, and above 3251 m. Field surveys were conducted between April to November, 2024.

Impacts of climate change on agricultural practices over the past 10–15 years were assessed. The adaptation strategies to these perceived changes were also investigated. (Fig 1: Map of Study area)

Data analysis involved descriptive statistics and a binary logit model. The binary logit model was employed to study the combination of adaptation strategies, examine correlations among dependent variables, and reduce bias. Farmers' socio-economic characteristics, farm attributes, and institutional factors served as independent explanatory variables influencing adaptation decisions. The results are presented through tables, graphs, and maps.

The formula for the binary logit model used in the analysis is as follows:

$$\mathrm{logit}(p) = \log\left(\frac{\mathrm{p}}{1-\mathrm{p}}\right) = \beta_0 + \beta_1 x_1 + \beta_2 x_2 + \dots + \beta_m x_m$$

p is the probability that the outcome *Y=1*

- $\frac{\mathrm{p}}{1-\mathrm{p}}$ is the odds of the event occurring
- β_0 is the intercept
- $\beta_1, \beta_2, \dots, \beta_m$ are coefficients for predictors $x_1, x_2, \dots, x_m$

Results and Discussion

The first section of the paper identifies the major impacts of climate change on crop farming and horticulture in the Kinnaur district. It also discusses various adaptation strategies employed by farmers to mitigate the negative effects of climate change on agricultural practices and their livelihoods. The second section presents the results of the analysis on the relationship between key determinant factors and farmers' adaptation measures, using a binary logit model. It explores how factors such as education, landholding size, access to weather information, and extension services influence adaptation decisions. The third section discussed conclusions and recommendations based on the findings of the study.

Impact of Climate Change on Crop and Horticulture Farming

Impact on Crop Farming

The data analysis shows that climatic changes have profoundly impacted crop farming in Kinnaur, with farmers orienting towards change in their practices across all zones (Figure 2). The most noticeable finding is that 100 percent of farmers reported changes in cropping patterns, indicating a shift from traditional agricultural practices due to climate variability. Over 90 percent of the farmers experienced significant losses in crop yield (93.8 percent), crop quality (94.6 percent), and soil fertility (93.8 percent), while nearly half (47.1 percent) reported substantial income losses from the changing climatic conditions. Farmers of Kinnaur witnessed lower crop yields and shrinking kernel size of crops namely ogla, fafra, cheena, kodo, barley, and wheat; and shortened rabi growing season because of increasing temperature particularly winter temperature. The increasing temperature has accelerated crop maturation cycles, with 78.8 percent farmers reporting early crop maturation, especially in winter crops (barley and wheat) maturing ten to twenty days earlier due to warmer springs disrupting conventional crop cultivation cycles (Bento et al 2021). Moreover, the crops like rajma and peas are now becoming commercial and lucrative for farmers in the slightly warmer and favourable season in higher elevation zone of Kinnaur.

Irrigation related challenges were prominent, with 70 percent of farmers noted decrease in water availability, due to shift in timing, intensity of both rainfall and snowfall, and thus leading to changes in the irrigation patterns of 43.3 percent of the farmers. Additionally, unpredictable rainfall affected grain quality and led to harvest loses in the study area. Nearly two third of the farmers (63.3 percent) reported an increase in pest attacks due to rising hot and humid conditions. In response to the climate variability challenges, 44.2 percent of the farmers have increased their reliance on the use of pesticides. Further, over one fifth (22.9 percent) farmers are now using more fertilizers in crops to compensate the decline in soil fertility as reported by 93.8 percent of the farmers.

The farmers of zone above 3251 m were severely affected as 100 percent of the surveyed farmers responded with yes on being asked about negative impacts of climate change on crop farming. The findings highlight the high vulnerability of crop farming to climatic changes happening in this north-western Himalayan region over the past few decades.

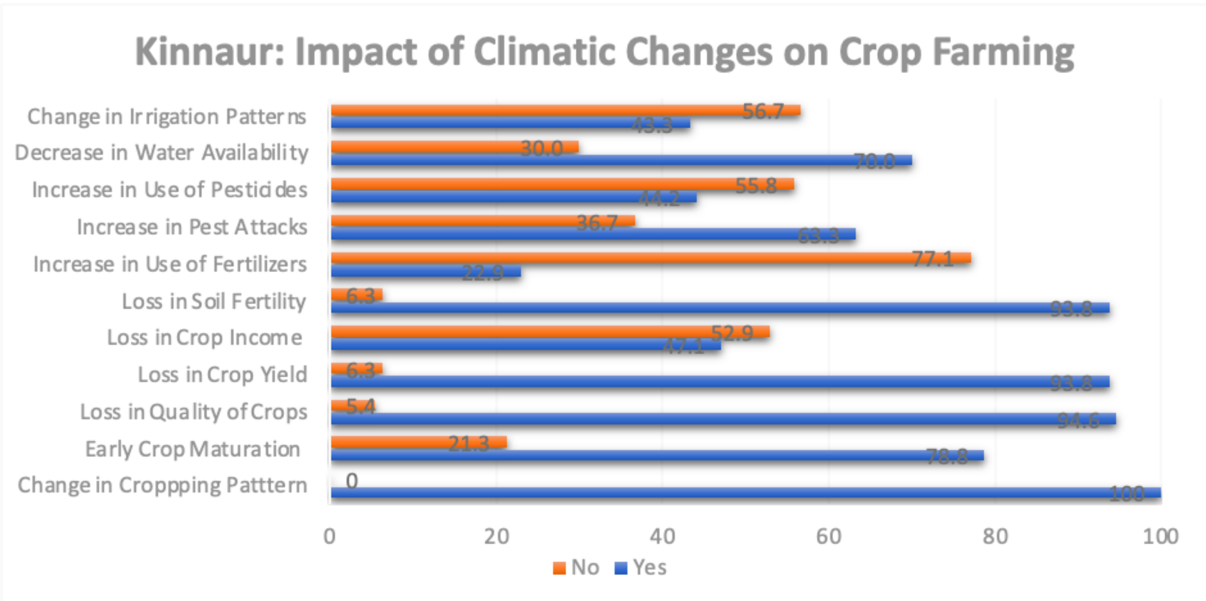

Fig 2: Impact of Climate change on crop farming in Kinnaur (Source: Calculated & Compiled from Field Survey Data, 2024)

Impact on Horticulture Farming

A closure looks at Figure 3 reveal that the farmers observed significant increase in pest attacks (100 percent), loss in soil fertility (100 percent), decreased water availability for fruit crops (99.2 percent), changes in horticultural practices (97.5 percent), decline in fruit quality (96.3 percent), loss in fruit yield (66.3 percent), and loss in horticulture income (75.4 percent), due to climatic irregularities. The results of the present study correspond to the effects of climatic changes on horticultural farming (Datta 2013 & Bharti et al 2024). Furthermore, 77 percent of farmers reported early fruit maturation, due to reduction in chilling hours caused by rising temperatures, which is critical for temperate fruits and nuts such as apples, apricots, and almonds (Fernandez et al 2020). Changes in chill hours are associated with non-uniform flowering, delayed bud formation, reduced fruit set, and declining yields. The above figures on negative impacts indicate that horticultural farming has been more severely affected than crop farming in the study area. All horticulture farmers (100 percent) started using pesticides to lessen the pest attacks from rising hot and humid climate. Over 90 percent farmers have increased their dependence on more fertilizers in horticulture to enhance the declining in soil fertility. In response to change in irrigation patterns from declining water availability, only 40 percent of the farmers responded with yes for using micro and lift irrigation methods, because of Kinnaur's difficult terrain and limited resources of the local farmers.

The study noticed that the temperature rise has also led to horticulture expansion to higher altitudes. This shift has benefited the zone above 3251 m, where semi-arid areas with sparse vegetation have become suitable for apple orchards over the past few decades. It has also been observed that the farmers below 2500 m have now been transitioning to tropical fruits such as bananas and Mediterranean fruits, including lemons, oranges, figs, prunes, and pomegranates due to favourable warmer climatic conditions. This zone used to have prominence of cool temperate climate horticultural crops. The analysis of the data across three elevation zones showed that only a small minority of farmers reported no negative effects of the changing climatic conditions.

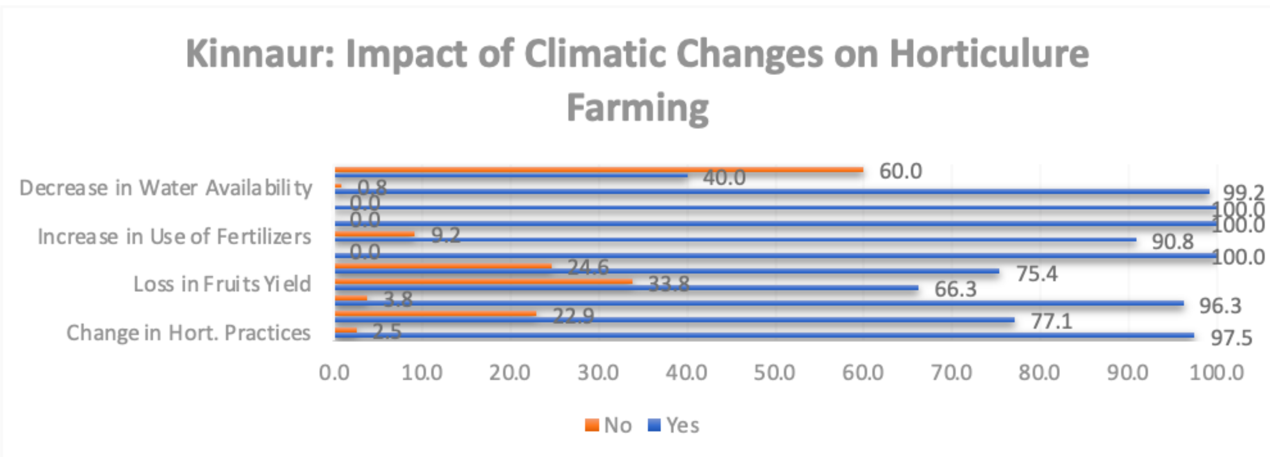

Fig 3: Impact of Climate change on horticulture farming in Kinnaur

Farmer's Adaptation to Climatic Changes

In response to the climatic variations and their impacts on farming, the farmers across all three elevation zones in Kinnaur implemented various adaptations (Figure 4) which are strongly influenced by farmers perceived adaptive capacity.

Among these, the most widely practiced adaptations include changing tillage methods (100 percent), slope management (98 percent), fertilizer and pest management (91 percent), and adjusting cultivation dates (80 percent). Farmers also relied on diversification (63 percent), agroforestry (63 percent), cultivation of short-duration varieties (58 percent), micro-irrigation (32.5 percent), and indigenous pest management (20 percent) as secondary adaptation strategies. During the field survey, it was found that farmers were replacing their traditional large-scale ploughing practices, such as ploughing with yak, zo, and ox, with machine tillers and small-scale hand ploughing, or were shifting towards zero tillage. These changes were made to conserve soil moisture in response to rising temperatures. To control soil erosion from erratic and intense rainfall, farmers managed slopes by using contour bunds and terraces, particularly in the two higher elevation zones (2501-3250 m and above 3251 m) where trees like Changma, Chuli, and Juniper are used as contours. Cultivation dates were adjusted, with changes to sowing, planting, and harvesting times specially in winter crops like barley and wheat. Farmers are now sowing and harvesting winter crops 10-15 days in advance. This was in response to the shortening winter season, the early onset of summer, erratic and intense rainfall, and declining snow cover. Farmers have also adapted to fertilizer and pest management methods by using various types of fertilizers and pesticides, including natural, organic, and chemical ones. The amount, frequency, and timing of fertilizer and pesticide use are also changing in response to shifting temperature and rainfall patterns. To lessen the negative impacts of heat stress and water scarcity, farmers favoured diversification and agroforestry. They planted various heat-tolerant, water-efficient, and climate-resilient varieties of crops and trees on the same farms. Farmers shared that they have now been planting short-duration varieties of peas and apples for early harvests, while older, higher-input varieties have seen declining yields due to rising temperatures and their low adaptability to climatic shocks. Due to water scarcity and the high irrigation requirements for farming (caused by rising temperatures, erratic rainfall, and melting snow cover), one-third of the farmers are now conserving and using rainwater and melted snow as micro-irrigation methods such as, drip and sprinkler along with Kuhl irrigation, a traditional community based diversion of stream water or snow melt into gravity fed canals . Interestingly, one-fifth of the farmers used 'Sur' making smoke from dry juniper leaves, barley, and clarified butter as an indigenous pest management adaptation to control the increasing pest attacks from hot and humid summer conditions.

The study found significant variations in adaptation strategies across different elevation zones. In the zone below 2500 meters, the predominant adaptation measures were changing tillage practices, slope management, and fertilizer/pest management, which were adopted by all farmers (100 percent). This was followed by crop and horticultural diversification, adopted by 91.7 percent of farmers. In the 2501–3250 m zone, changing tillage practices was the most favoured adaptation to cope with the impacts of heat stress on soil health. Farmers in the zone above 3251 m adopted a more comprehensive set of adaptations. All farmers (100 percent) in this high-elevation zone implemented six major strategies: changing tillage practices, slope management, fertilizer/pest management, adjustment of harvesting dates, agroforestry, and the cultivation of short-duration crop varieties. The use of micro-irrigation and indigenous pest management methods were also prominent adaptations among farmers in this zone. The findings highlight that farmers in the zone above 3251 meters are the most severely impacted by climate change, forcing them to implement the maximum number of adaptations.

As a whole, these results indicate that farmers in Kinnaur are autonomously adapting to climate change by employing both modern and indigenous practices to mitigate its adverse effects.

Factors Determining Different Adaptations

This section quantifies the impact of various factors influencing farmers' decisions to undertake different adaptation measures under climatic variations. For this purpose, binary logit model was applied to the selected adaptation measures (Table 1).

Farmer's age is an important element in the decision-making process. However, the results of the binary logit model show that age has no significant relationship with any of the variables, indicating little or no evidence that it affects the odds of adopting any adaptation practices in the study area. This finding is supported by Ewulo et al. (2025), who also reported that farmers' age showed no significant relation to the adoption of most climate-smart agriculture (CSA) practices.

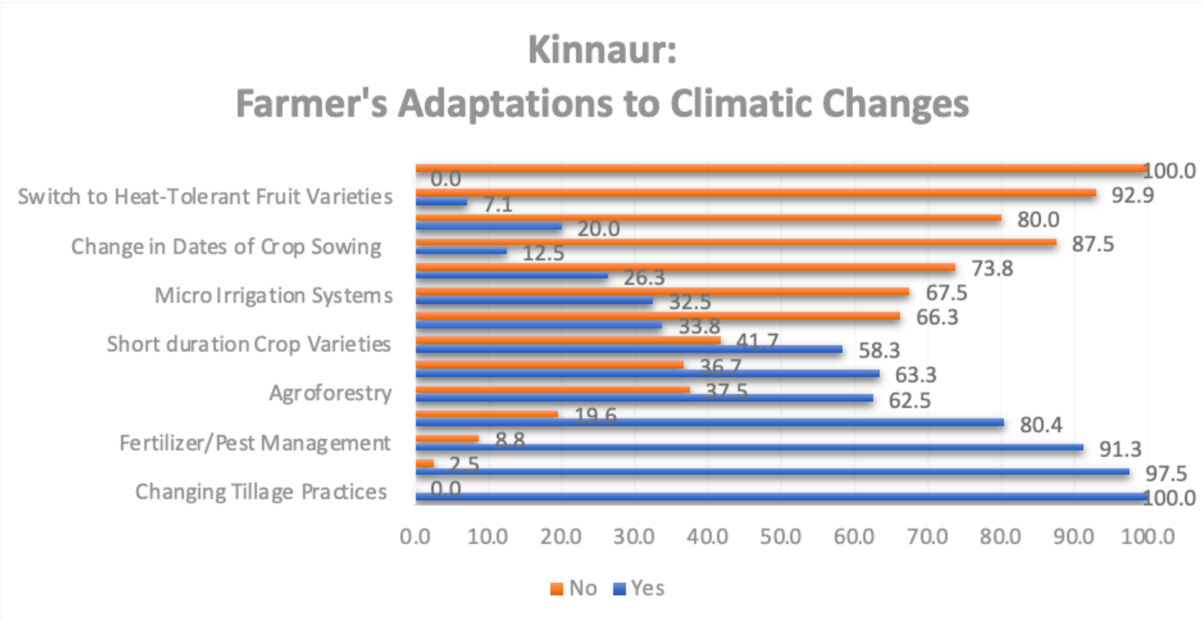

Fig 4: Farmer's adaptations to climate change (Source: Calculated & Compiled from Field Survey Data, 2024)

Table 1: Results of the Binary Logit Model on different Adaptation Measures

Predictor	Slope Management	Crop Diversification	Changing Tillage	Pesticide Use	Early Sowing	Agroforestry	Micro-irrigation
Age	-0.001 (0.986)	0.002 (0.882)	0.041 (0.655)	0.021 (0.613)	-0.020 (0.382)	0.025 (0.122)	0.002 (0.896)
Landholding Size	0.022 (0.514)	**0.027* (0.008)**	0.044 (0.480)	0.060 (0.106)	0.000 (0.979)	**0.019* (0.025)**	**0.019* (0.014)**
Education	-0.035 (0.907)	0.103 (0.270)	-0.155 (0.748)	-0.273 (0.168)	**-0.393* (0.006)**	-0.004 (0.967)	**-0.247* (0.012)**
Traditional Knowledge	0.147 (0.897)	-0.598 (0.083)	16.785 (0.998)	**-4.766* (0.000)**	-0.511 (0.341)	**1.172* (0.004)**	**-1.398* (0.004)**
Access to Weather Information	-17.015 (0.999)	0.269 (0.729)	-14.153 (0.999)	3.728 (0.070)	18.932 (0.999)	-0.385 (0.648)	-0.664 (0.411)
Access to Extension Services	-17.476 (0.998)	**-1.252* (0.035)**	-16.794 (0.998)	-17.563 (0.998)	19.536 (0.998)	-0.327 (0.486)	-0.791 (0.090)
Constant	37.968 (0.998)	0.657 (0.641)	33.040 (0.998)	18.103 (0.998)	-37.743 (0.998)	-0.767 (0.588)	1.187 (0.405)

Note: Numbers in table without bracket represents – Unstandardised Regression coefficient
Note: Numbers in table in bracket represents – p-Value of coefficient
Note: * indicate significance level at $p < 0.05$
Source: Calculated & Compiled from Field Survey Data, 2024

Landholding refers to the total area of land that a farmer or farming household cultivates or controls. Farmers with larger landholdings are generally more likely to adopt new agricultural practices due to their greater resource capacity and ability to manage risks. The results of this study indicate that larger landholding size significantly positively correlates with the adoption of crop diversification ($p < 0.05$), agroforestry ($p < 0.05$), and micro-irrigation ($p < 0.05$), as larger farms are generally better positioned to invest more in land, labour and capital assets for these adaptations in the study area. In line with the present study's findings, recent studies (Khan et al 2025; Malik & Khan 2024; Singh & Sharma 2025; Johnson & Lee 2025 Carter & Anderson 2024) have reported similar positive relationship between large landholdings and adaptions like crop diversification, improved irrigation methods, and other water-efficient techniques.

Education plays an important role in shaping farmers' knowledge and decision-making processes regarding agricultural practices. However, the findings of the logit model show that educated farmers of Kinnaur have significant negative relationship with adaptations i.e. early sowing of crops ($p < 0.05$) and micro-irrigation ($p < 0.05$). Farmers in the study area reported their reluctance to adopt these adaptation measures because of high initial installation and maintenance expenses of micro irrigation methods; and limited knowledge on agro-forecasting for changing their cultivation dates.

In the study area, the traditional knowledge of the farmers has a significant negative relationship with use of pesticides ($p < 0.05$) and micro-irrigation measures ($p < 0.05$). The aged farmers with greater traditional knowledge reported their reliance more on adopting natural farming methods and Kuhls (traditional irrigation channels) for agricultural operations. Further, the study found that the agroforestry is significantly positively correlated with higher levels of traditional knowledge of the Kinnaur farmers ($p < 0.05$).

The results show no significant positive relationship of access to information on weather and extension services with any adaptations of farmers because of the inability of Kinnaur farmers for capital intensive investments in utilising the weather information and extension services to make major changes in farm operations e.g. sowing, planting, irrigation, pest management, and harvesting as climate adaptations.

Conclusion and Recommendations

This comprehensive study of climate change impacts on agricultural practices in Kinnaur district reveals that farmers demonstrate exceptionally high climate awareness on rapid climatic changes and their impacts on agriculture in the Northwestern Himalayan region. The research conclusively establishes that climate change is severely undermining agricultural production across elevation zones as over 90 percent of farmers reported losses in crop yield, declining crop quality, and soil fertility; 78.8 percent farmers observing early crop maturation; 70 percent of farmers noted decrease in water availability; Nearly two third of the farmers reported an increase in pest attacks; nearly half of the surveyed farmers witnessed income losses; 44.2 percent of farmers used more pesticides; and over one fifth farmers are now using more fertilizers in crops due to changing climatic conditions. Similar negative impacts of climatic changes have been observed on horticulture farming as well. However, horticulture has been severely impacted than crop farming due to disrupted chilling hours affecting temperate fruits crops especially apples, apricots, and almonds. The worst affected zone includes above 3,251 meters villages where 100 percent of farmers reported early fruit maturation, increase in pest attacks, loss in fruit yield, decline in fruit quality, loss in horticulture income, loss in soil fertility, decreased water availability and changes in horticultural practices. Through binary logit model analysis, the study identifies education, landholding size, traditional agricultural knowledge, access to weather information and extension services as primary determinants of adaptation decisions. Results reveal that larger farms are significantly positively corelated with the adoption of capital intensive climate adaptations such as diversification, agroforestry and micro-irrigation. However, cost and complexity barriers of different adaptations led to their no significant relationship with education of farmers, access to weather information and extension services. The study observed that educated farmers paradoxically resist certain adaptations due to financials limitations, and farmers with traditional knowledge prefer indigenous methods over modern technologies. Despite these constraints, farmers have demonstrated remarkable autonomous adaptation capacity by universally adopting changed tillage practices (100 percent), implementing slope management (98 percent), adjusting fertiliser and pest management strategies (91 percent), modifying cultivation dates (80 percent), and pursuing crop diversification and agroforestry (63 percent), preferring short-duration varieties (58 percent), improving irrigation through micro schemes (32.5 percent), and picking up indigenous pest management (20 percent) as adaptation strategies. To address these challenges, the study recommends the promotion of elevation-specific adaptive crop diversification schemes, establishment of climate-smart infrastructure including govt funded water harvesting and soil conservation techniques, facilitated access to subsidized climate-resilient technologies with a focus on water-efficient varieties, establishment of climate adaptation funds and area specific crop insurance, thereby strengthening local farmers' capacity for implementing climate-smart adaptation strategies in the Northwestern Himalayan agricultural practices.

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