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Full Length Article

How Himalayan communities are changing cultivation practices in the context of climate change

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ABSTRACT

Climate change can have significant impacts on crop yields and food security. This study assessed the linkages between climate change and crop yields to obtain a better understanding on the drivers of food security. The study was conducted in Pasagaun village of Lamjung District in Nepal, where household surveys and focus group discussions (FGDs) were used to collect data including crop cultivation, irrigation facilities, and adaptation strategies. Moreover, climate data (temperature and precipitation) from 1992 to 2020 were collected from the Khudi Bazar meteorological station and crop yield data were obtained from the Agri-Business Promotion and Statistics Division. Trend analysis of temperature and precipitation was conducted using Mann-Kendall trend test and Sen's Slope method, and the results showed an increase in the average temperature of approximately 0.02 °C/a and a decrease in the annual precipitation of 9.84 mm/a. The cultivation of traditional varieties of rice and foxtail millet (Kaguno) has vanished. Although, there was no significant impact of the maximum temperature on the yield of rice and maize, the regression analysis revealed that there are negative relationships between rice yield and annual minimum temperature ($r = -0.44$), between millet yield and annual precipitation ($r = -0.30$), and between maize yield and annual minimum temperature ($r = -0.31$) as well as positive relationship between rice yield and annual precipitation ($r = 0.16$). Moreover, average rice yield and millet yield have decreased by 27.0% and 57.0% in 2000–2020, respectively. Despite other reasons for the decrease in crop yield such as the lack of irrigation facilities, out-migration of farmer, and increased pest infestation, respondents have adopted adaptation strategies (for example, shifts in cultivation time and changes in crop types) to minimize the impacts of climate change. More investigation and community-based farming education are needed to understand and alleviate the harmful impacts of climate change on crop yield, as effective adaptation coping strategies are still insufficient. This study provides insights into the adaptation strategies that are necessary to keep food security in the face of climate change.

1. Introduction

The United Nations Framework Convention on Climate Change (UNFCCC) defines climate change as: "a change of climate which is attributed directly or indirectly to human activity that alters the composition of the global atmosphere and which is in addition to natural climate variability observed over comparable time periods" (UNFCCC, 2004). Nepal has been listed as one of the most affected countries by extreme weather events from 1999 to 2018 according to the Global Climate Risk Index (Sönke et al., 2020). This means that Nepal has experienced more than two decades of climate change-related disasters and extreme weather events, with negative

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consequences for people's lives and livelihoods, physical assets, and environments (Sönke et al., 2020). Moreover, the rate of increase in average temperature in the Himalayas is expected to be faster than the increase of global average temperature (IPCC, 2014). The Himalayan region is one of the world's most ecologically sensitive regions, particularly vulnerable to the impacts of climate change. This region is experiencing a range of climate change impacts, including the increase of temperature, variations of precipitation patterns, melting of glaciers, and changes in the frequency and intensity of extreme weather events (Xu et al., 2009). Previous studies have reported that the temperature rise is faster at higher elevations than at lower elevations (Immerzeel, 2007; Baidya et al., 2008). A rise in temperature from 1975 to 2006 by 1.80 °C (average increase of 0.06 °C/a) has been recorded in Nepal and the increase of temperature is predicted to continue in the future (Malla, 2009).

Many Himalayan communities contain indigenous and marginalized groups, who are especially vulnerable to the impacts of climate change due to their reliance on natural resources for their livelihoods. These communities are often located in remote and inaccessible areas, with limited access to basic services such as healthcare and infrastructure (Sujakhu et al., 2019), particularly in the ecologically vulnerable regions of mid-hills and mountains.

Cultivation practices in mountain ecosystems, including the Himalayas, are shaped by the unique local environmental conditions. Mountain agriculture is characterized by its high altitudes, steep slopes, and harsh weather conditions, which pose significant challenges for farmers (Sharma et al., 2009). Several studies have been conducted on the impacts of climate change on Himalayan communities and cultivation practices (Hussain et al., 2016; Dahal et al., 2023). For instance, the Government of Nepal has recently published a report explaining the climate change scenarios of Nepal (MoFE, 2019). Climate change has led to variations in crop yield, water availability, and agricultural practices in the Himalayas (Dahal et al., 2018, 2023; Arunrat et al., 2022; Yao et al., 2022).

The possible effect of climate change on food security in Nepal is critical to understand for two reasons: (1) Nepal has a low level of capital and technology, and the current food production system is highly sensitive to climate change; and (2) agriculture is the primary source of livelihood for 60.0% population in Nepal (Dahal et al., 2020). Furthermore, changes in temperature and precipitation would result in variations in the suitability of land for cultivation and crop yield. Farming operations generate nearly two-thirds of rural household income, 80.0% of agricultural workers are self-employed farmers, and agriculture is the only source of cash revenue for 90.0% of the poor population (Bhandari, 2018).

The increase in extreme weather events like droughts and floods clearly affects agricultural output. According to the Central Bureau of Statistics (CBS) of Nepal (CBS, 2004), climate-related events have affected about 3.08×10^4 hm^2 of land, which is owned by nearly 5.0% of households in the central part of the country and is uncultivable over the last decade. Most (76.0%) of the cultivated land is rain-fed, which has been affected by irregular precipitation patterns, droughts, flash floods, landslide, etc., over the years. The cultivable area in Nepal is approximately 4.00×10^6 hm^2, 34.0% of which is in the Terai, 8.0% in the Siwalik, 48.0% in the hill and mountain regions, and 10.0% in the high Himalayas (FAO, 2009). Due to the recent lack of sufficient precipitation, rice and wheat production in most region of the mid-hills of Nepal has decreased and farmers have diversified their crop types, such as planting fewer and favored crops (Gurung et al., 2010). Similarly, due to hailstones, hilly regions in Nepal such as Dailekh have lost roughly 80.0% of the main winter crops, which impacted maize production in Sankhuwasabha and Taplejung (WFP, 2013). Likewise in other hilly regions, droughts affected the livelihood of people as there was no water for irrigation or even drinking (Bashyal and Dhakal, 2015).

Impacts of climate change on winter crops and apple farming can be observed due to the reduced snowfall and increased temperature (Gurung et al., 2010; Adhikari, 2018). Further, winter drought has caused a shortage of water for irrigation, which has a negative impact on people's livelihoods (Khatri, 2013; Bhandari, 2018). In contrast to negative impacts, it has also been reported that the influence of global warming in the mountainous regions could be beneficial to several crops, such as tomato, cauliflower, wheat, maize, and rice (Malla, 2009). Crop phenology is linked to climate change, which in turn can increase agricultural risks. Both temperature increase and erratic precipitation have a direct impact on the phenological stages of crop production. According to some research, temperature increase has shortened the overall growth period of wheat in China over the last few decades, while the growth periods of maize and rice were extended (e.g., Xiao et al., 2021). Thus, climate change does have an impact on food security by influencing crop growth, phenology, and yield.

As indicated, some research has been conducted on the impact of climate change on agriculture in Nepal, but there is a significant research gap in understanding the specific vulnerabilities and adaptation strategies of communities in the regions of mid-hills and mountains (WWF, 2021). This study selected Pasagaun village in Nepal as the study area based on its geographical location and climate change issues such as erratic precipitation. Pasagaun village is located in the mid-hills of Nepal, which is highly vulnerable to the impacts of climate change due to its complex topography and dependence on natural resources (IPCC, 2014).

Pasagaun village is a suitable representative location that can assess the vulnerability of similar and small rural communities to climate change by analysing the nexus among crop yield, temperature, and precipitation in the context of climate change. Additionally, the study aims to evaluate the changes in farming practices and the yields of major crops over the past two decades and provide insights into the adaptation strategies that are necessary to sustain agriculture in the face of climate change. The null hypothesis of the study is that there is no significant effect of temperature changes and irregular precipitation patterns on crop yield and farming practices. The alternative hypothesis is that there is a significant effect of temperature changes and irregular precipitation patterns on crop yield and (or) farming practices.

2. Materials and methods

2.1. Study area

The study was carried out in Pasagaun village (28°16′35″N, 84°13′46″E), Ward-6 of Kwholasothar Rural Municipality of Lamjung District (Fig. 1), which is located in the western part of Nepal's mid-hills spanning tropical to Himalayan geo-ecological belts. The annual average temperature and precipitation in Lamjung District are 21.00 °C and 1377.00 mm, respectively. The elevation varies between 300 and 6400 m. Pasagaun village covers an area of 1.01×10^3 hm^2 with 163 households and 711 population (Kwholasothar Rural Municipality, 2018). The village is approximately 27.0 km away from the district headquarter, Besishahar.

Pasagaun village is also a major agricultural area, and the livelihoods of the local communities heavily rely on subsistence agriculture (Lama and Devkota, 2009; Shrestha, 2014). Therefore, it is crucial to understand how climate change impacts the agricultural production in Pasagaun village and how local communities can adapt to these impacts.

2.2. Data sources

2.2.1. Secondary data sources

The following paragraph summarizes the information about the secondary data sources, contents, and application. The secondary data including temperature, precipitation, and crop yield were used to assist in testing the hypothesis and assessing the trends of temperature and precipitation, and examine the impact of temperature and precipitation on crop yield.

Khudi Bazar meteorological station in Lamjung District (13.5 km) provided data information about temperature and precipitation during the period of 1992–2020, while the crop yield data from 2003 to 2018 were obtained from the Agri-Business Promotion and Statistics Division.

2.2.2. Questionnaire survey and focus group discussions (FGDs)

To assess changes in farming practices and crop yield, we conducted a semi-structured questionnaire in April of 2021 to interview 50 randomly-selected households (31.0% of the total households in Pasagaun village). Those interviewed respondents included 59.0% males and 41.0% females, with the average age of 55 years old. The questions were pre-tested in the neighboring region with similar socio-economic conditions to ensure the suitability of the questionnaire. The questions were based on the following aspects: climate change; crop yield changes; food availability, accessibility, and consumption; water use; perception of local people on climate change; and adaptation strategies.

Two FGDs were conducted with a mixed group of male and female respondents. This is considered as an appropriate method to collect qualitative data on the population's understanding of climate change, irrigation facilities, crop yield changes, and the history of extreme weather events such as irregular precipitation, droughts, and floods. These interactive group discussions encouraged participants to share their perspectives and experiences and provided rich and detailed data. A mixed group including male and female respondents helped to ensure that the perspectives and experiences of both genders were captured in the study. The group size was chosen to be no more than 15 people to ensure that all participants had the opportunity to express their views and opinions.

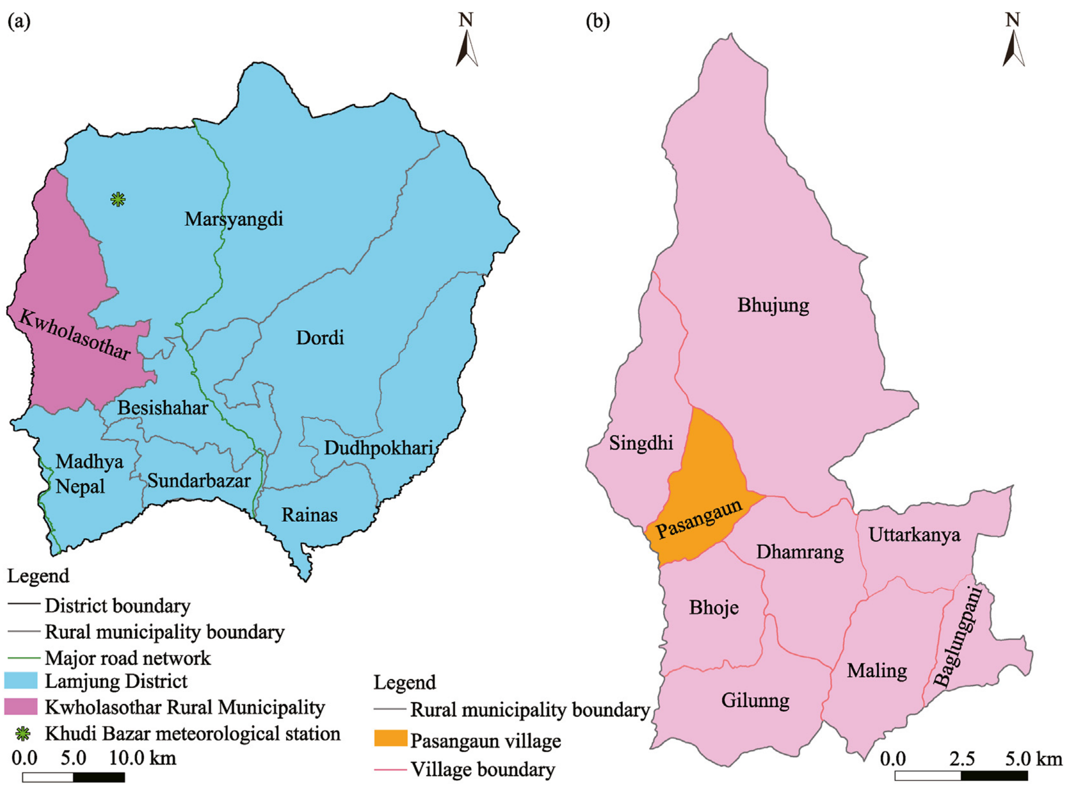

Fig. 1. Location of Kwholasothar Rural Municipality in Lamjung District of Nepal (a) and Pasagaun village in Kwholasothar Rural Municipality.

2.3. Data analysis

Data collected from the questionnaire surveys were coded and computed in Microsoft-Excel (Microsoft Corporation, Redmond Washington, the USA), and descriptive statistics such as mean and standard deviation were calculated. To analyze the rate of changes in crop yield, mainly for rice, millet, and maize, we performed multiple comparisons of means using one-way Analysis of Variance (ANOVA) and post-hoc tests. The one-way ANOVA test was used to compare the means of the different crop yields, and the post-hoc test was applied to determine which groups were significantly different from others (Ostertagova and Ostertag, 2013). The significance level was set at $P < 0.05$, and a 95% confidence interval was used for descriptive statistics. Simple correlation was used to examine the impacts of temperature and precipitation on crop yield. Data analysis was carried out using IBM Corporation SPSS (version 22.0) (IBM Corporation, Armonk, the USA).

The seasonal and annual trends of temperature and precipitation were analyzed using the Mann-Kendall trend test, which is widely used in climate change studies and has been recommended by the Intergovernmental Panel on Climate Change (IPCC) as a standard method for trend detection (Hamed, 2008). The significance level was set at $P < 0.05$, and a 95% confidence interval was used. We further used the Sen's slope method to quantify the trend in climate data (Sen, 1968); this method is widely used in hydrological and climate change studies and is robust to outliers and non-normality (Mendes et al., 2022). A trend analysis of crop yield and its association with temperature and precipitation was also carried out.

3. Results

3.1. Climate change and crop yields

3.1.1. Changes in temperature and precipitation

The annual average and maximum temperatures increased by 0.02 °C/a and 0.16 °C/a from 1992 to 2020 in Lamjung District, respectively, while the minimum temperature decreased by 0.13 °C/a during this period (Fig. 2). Results of Sen's slope analysis revealed that the annual average, maximum, and minimum temperatures all have changed significantly over time ($P < 0.05$).

The average annual temperature over the years of 1992–2020 was 21.47 °C, with the maximum and minimum temperatures recorded in 2015 (30.12 °C) and 2018 (13.79 °C), respectively (Fig. 2). The seasonal temperature showed a decreasing trend in spring (−0.01 °C/a) and an increasing trend in summer (0.01 °C/a), autumn (0.03 °C/a), and winter (0.05 °C/a). Sen's slope analysis indicated that the average temperature in autumn, summer, and winter changed significantly over time ($P < 0.05$), but it was not significant ($P > 0.05$) in spring, as shown in Fig. 2.

The total average precipitation in Lamjung District was 3311.00 mm during the period of 1992–2020. From 1992 to 2020, the annual precipitation showed a decreasing trend (−9.84 mm/a) ($P < 0.05$), with the maximum precipitation in 2020 (4711.00 mm) and the minimum precipitation in 2015 (2278.00 mm) (Fig. 3).

Even though precipitation appeared to exhibit an increasing trend in spring and autumn and a decreasing trend in summer and winter, these changes were not significant (Fig. 4). Approximately 67.0% of precipitation occurred during the monsoons. In summer, the maximum precipitation was observed in 2020 (4049.8.00 mm) and the minimum precipitation was in 2015 (1446.00 mm). However, in winter, the average precipitation was 89.03 mm from 1992 to 2020, with the maximum precipitation in 1997 (272.00 mm) and the minimum precipitation in 2009 (14.90 mm).

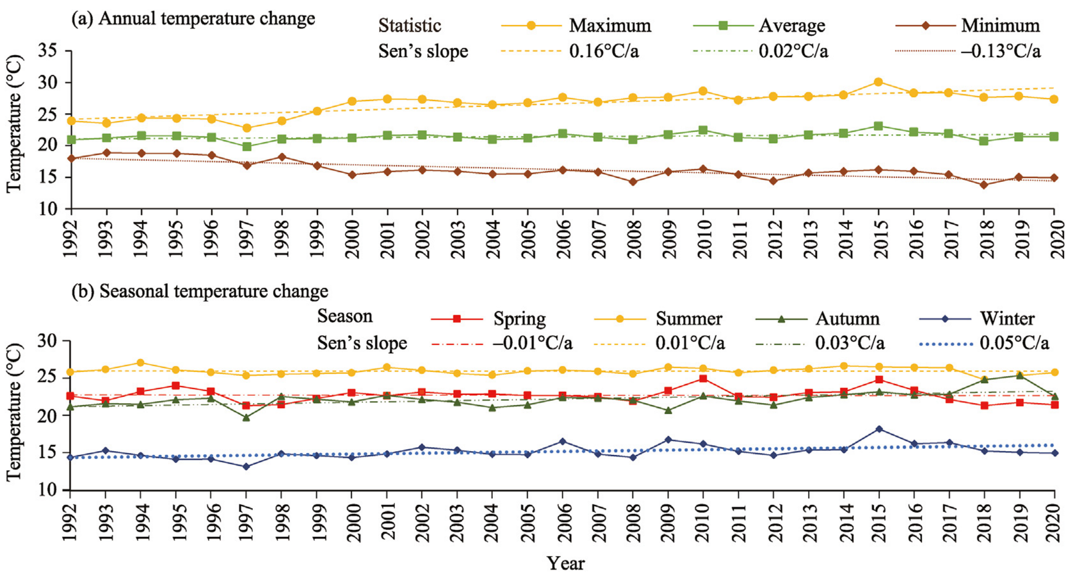

Fig. 2. Annual (a) and seasonal (b) temperature changes in Lamjung District.

3.1.2. Changes in cereal crop yields

Fig. 5 shows the yields of cereal crop (maize, wheat, millet, cardamom, and rice) from 2003 to 2018 in Lamjung District. The total yield of rice in 2003 was 1709.00 kg/hm^2, while it was 2410.00 kg/hm^2 in 2018. Rice yield has increased by 48.0% during the period of 2003–2018 (Table 1). Similarly, the total yield of cardamom in 2003 was 300.00 kg/hm^2, and it was 160.00 kg/hm^2 in 2018.

Table 1 shows the change rates of the yields of cereal crops during the different periods (2008–2018 and 2003–2018) in Lamjung District. The average change rates of rice and maize yields have increased during 2003–2018, while those of wheat and cardamom yields have decreased during 2003–2018, as shown in Table 1. There were significant changes in the yields of maize, wheat, cardamom and rice in Lamjung District during the period of 2003–2018.

3.1.3. Relationship between climate factors and cereal crop yields

Rice yield and annual minimum temperature had a negative correlation ($r = -0.44$), but there was no significant effect of annual maximum temperature on rice yield ($r = 0.05$). Moreover, annual precipitation had a positive effect on rice yield ($r = 0.16$). Millet yield showed a positive correlation with annual maximum temperature ($r = 0.20$), and a negative relationship with annual minimum temperature ($r = -0.20$). Annual precipitation also had a significant negative effect on millet yield ($r = -0.30$). Similarly, there was a negative correlation between maize yield and annual minimum temperature ($r = -0.31$), while annual maximum temperature ($r = 0.06$) and precipitation ($r = -0.08$) exhibited no significant effect on maize yield.

3.2. Historical and recent changes in farming practices

3.2.1. Income source and food dependence

Crop yields provided income to a majority of the respondents (45.0% of the total), followed by remittances (18.4%). Some respondents were cultivating for self-sufficiency (29.0%), whereas only 16.0% of respondents produced commercial production. Similarly, most respondents (55.0%) relied on market-available food, while 45.0% of respondents relied on their own crops.

3.2.2. Changes in crop types

There are three main types of cultivated land. Specifically, Khet land is an area with crisscrossing terraces; Bari land means an area with rain-fed upland levelled or sloping terraces; and Pakho land refers to rain-fed upland sloping terraces with poor soil quality. The average landholding sizes used for cultivation were 0.47 hm^2 for Khet land, 0.15 hm^2 for Bari land, and 0.54 hm^2 for Pakho land.

Respondents in Pasagaun village reported rice, millet, and maize as their major crops, but they also cultivated potatoes, vegetables, and cardamom. About 10–12 years ago, respondents grew mustard, barley, and wheat; however, they no longer cultivate these grains due to the lack of market value. Another reason for the decline in mustard cultivation is drought. Potatoes were introduced around 10 years ago from the neighboring ward of Pasagaun village after respondents shifted their cultivation from mustard, barley, and wheat. Cauliflower, cabbage, and beans are the most popular vegetables introduced by respondents in recent years. The reason for these shifts from cereal crops to vegetables is that respondents believe that vegetable production requires less manpower, consumes less water, and provides better economic returns than cereal crop cultivation. Further, from the FGDs, it was reported that there was an increase in the production of rice in recent years due to the introduction of high-yielding varieties. In contrast, the cultivation of millet, potatoes, and maize have declined recently due to erratic precipitation. It was also revealed that increased pest infestation has resulted in a decline in the production of cardamom.

Foxtail millet (Kaguno) is an ancient grain, a type of millet, which is considered as the first domesticated variety of millet. It was the most grown species of millet in Pasagaun village in 2000. Kaguno is also an important crop because of its health and medical benefits, such as lowering blood glucose levels and cholesterol control in both normal and diabetic patients (Yadav et al., 2018). This crop can grow well in dry conditions and is considered as a famine food. However, no one grows Kaguno in Pasagaun village currently, and many young respondents are unaware of this ancient crop. According to the FGDs, one of the reasons for declining the cultivation of this ancient crop is the time and effort required for weeding and post-harvest processing. More labor-intensive agricultural products with limited pre-existing markets are being abandoned as a result of labor shortage and increased youth out-migration, as well as hailstorms in winter.

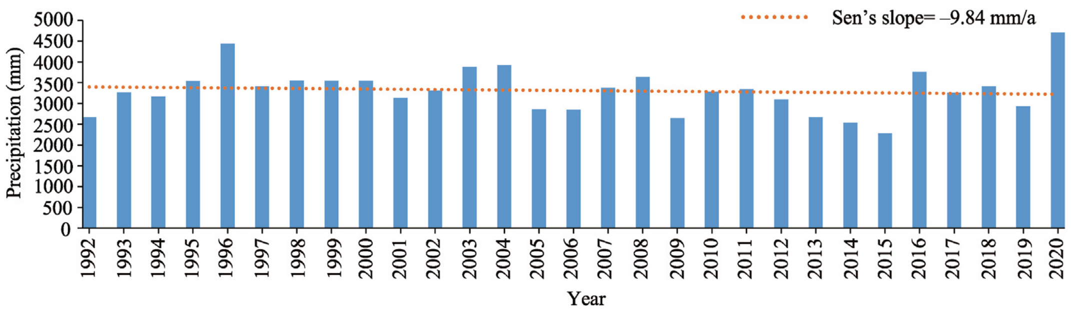

Fig. 3. Total nnnual precipitation change in Lamjung District.

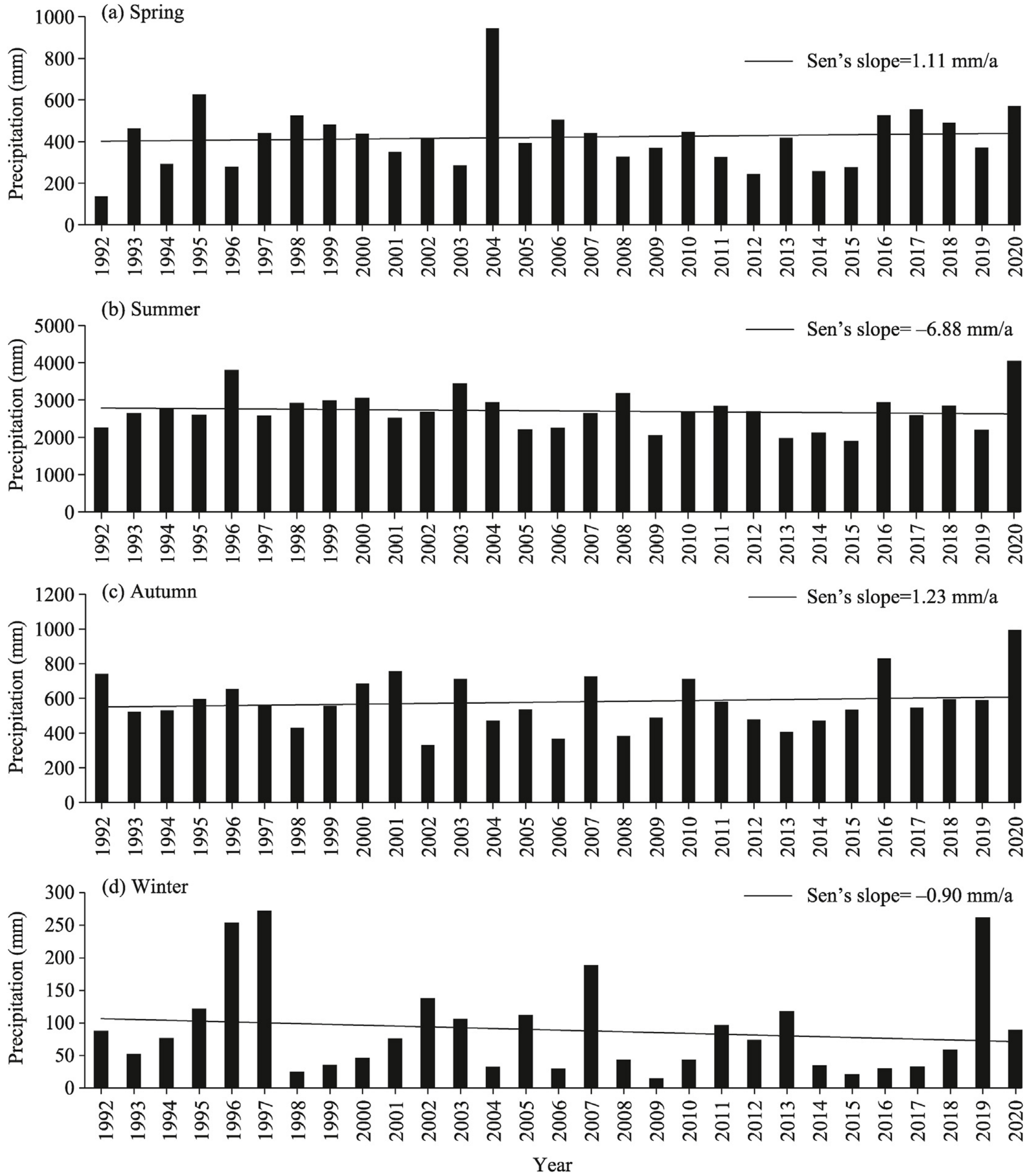

Fig. 4. Seasonal precipitation changes in Lamjung District. (a), spring; (b), summer; (c), autumn; (d), winter.

3.2.3. Changes in irrigation facilities

Most of local respondents did not have access to adequate irrigation facilities, using precipitation as the primary source of irrigation. They sometimes relied on tap water that comes from springs, and only a few local respondents depended on canals from the Kamro River to irrigate their cultivated land. However, with the help of the district development committee, Pasagaun village has begun to build irrigation canals. Previously, this village relied on spring canals (Kulo) for irrigation, but all of these springs have dried up in the last decade. Furthermore, the number of times local respondents irrigated cultivated land has decreased by 29.0% from 2000 to 2020 due to a decrease in available water.

3.2.4. Changes in crop yields

This study examined the cultivation shifts of different cereal crops (rice, millet, and maize) in Pasagaun village based on household surveys. The average rice yield decreased by 27.0% during 2000–2020. The average rice yields in 2000, 2010, and 2020 were 160.93, 146.06, and 117.67 kg/hm^2, respectively. The average millet yield has also decreased by 57.0% during the period of 2000–2020. The average millet yields in 2000, 2010, and 2020 were 113.65, 91.81, and 68.01 kg/hm^2, respectively. The average maize yield, has likewise, decreased by 59.0% from 2000 to 2020. The average maize yield in 2000, 2010, and 2020 were 147.74, 122.86, and 77.42 kg/hm^2, respectively.

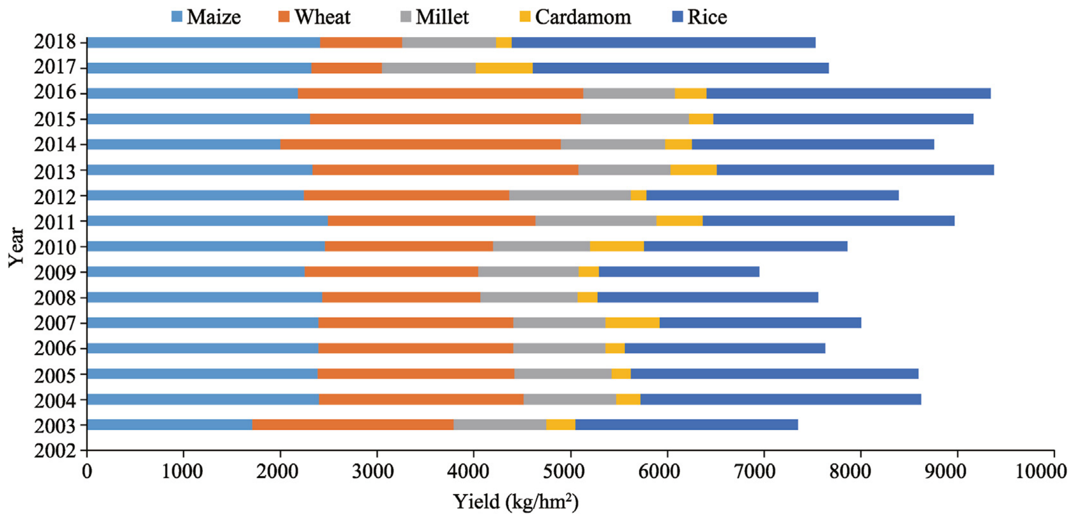

Fig. 5. Yields of cereal crops in Lamjung District.

Table 1
Change rate of cereal crop yield during different periods in Lamjung District.

Cereal crop	Period	Change rate (%)
Maize	2008–2018	36.0
	2003–2018	41.0
Wheat	2008–2018	32.0
	2003–2018	−59.0
Millet	2008–2018	−1.0
	2003–2018	1.5
Cardamom	2008–2018	71.0
	2003–2018	−43.0
Rice	2008–2018	25.0
	2003–2018	48.0

Respondents reported that the decreases in rice, millet, and maize yields were primarily due to the out-migration of farmers and irrigation problems. Moreover, according to the statement of some respondents, winter drought, particularly in 2015, and erratic precipitation in 2018 and 2020 were the primary causes of the decline in millet and maize yields. Despite the fact that rice yield has decreased overall during 2010–2020, it showed an increasing trend in the last three years due to the introduction of hybrid and high-yielding crop varieties by the Department of Agriculture. Hailstorms are another reason for the decreases of maize and potato yields. Besides erratic precipitation and drought, the respondents in the study area usually did not have good quality seeds and chemical fertilizers. Most of respondents used organic fertilizers, and few of them applied urea for millet and maize cultivation (mostly in 2000–2010). These all might be the reasons for the overall decrease in crop yield in Pasagaun village.

A few of the primary respondents (1.5% of the total respondents) had differing perspectives on crop yield changes during the period of 2000–2020 as they claimed that crop yield had increased over previous years. Also, several respondents were growing new types of vegetables (such as cauliflower) that were previously difficult to grow.

Multiple comparisons of mean difference revealed a significant difference in the average yields of maize and millet from 2000 to 2020 ($P < 0.05$), as shown in Table 2, based on data obtained from household surveys ($n = 50$). Similarly, multiple comparisons of mean difference indicated no significant difference in the average yields of rice maize, and millet during 2000–2020 ($P > 0.05$).

Table 2
Multiple comparisons of average yields of major crops during 2000–2020 at 95% confidence level.

Crop	Period	Mean difference (%)
Rice	2010–2020	−46
	2000–2020	−52
Millet	2010–2020	−19
	2000–2020	−6
Maize	2010–2020	−45
	2000–2020	−12

3.2.5. Fertilizer use

Most of respondents (77.6% of the total) indicated that they used both organic fertilizers (e.g., manure) and urea fertilizers for millet and maize cultivation after 2013 (Fig. 6). There was a significant increase in the proportion of respondents using both organic and urea fertilizers between 2000 and 2010 and an even more significant increase from 2010 to 2020. However, the proportion of respondents using of only organic fertilizers kept a declining trend from 2000 to 2020 (Fig. 6). Urea fertilizers were introduced in Pasagaun village by an agro-technician.

3.3. Linkages between climate change and crop yield

Over the past 12 years (2008–2020), respondents have observed an increase in strong precipitation events, notably from May to July. They also reported that precipitation is usually up to one month early or late in monsoons. From 2010 to 2020, respondents have found a significant increase in temperature, particularly in summer. As per the FGDs, the summer season has extended over the past ten years, and there has been a reduction in the number of cold days. The hailstorms have also become increasingly common in Pasagaun village, mainly in winter. Moreover, respondents claimed that 25 years ago, the village had snowfall every year in December, but now they can only see very few snowfall events in mid-March or April.

The primary sources of water in Pasagaun village are two springs: an old spring (Purano muhan) and a new spring (Naya muhan). People used to rely on the old spring about 20 years ago; however, they now only rely on the new spring water. The reason for this shift is that the water quantity of the old spring has decreased significantly, resulting in less water for drinking and irrigation. So, they shifted towards the new spring around 2002. Furthermore, the results of FGDs revealed that the 2015 earthquake altered the water flow of the old spring (groundwater), leading to a shortage of water. Most respondents are unaware of climate change; however, they have noticed a change in precipitation pattern, with more frequent untimely and heavy precipitation events, as well as winter drought and its impact on crop yield and water availability. During 2017–2019, summer precipitation, according to respondents, was more severe than that in previous years (before 2015). Very few respondents (about 1.0% of the total) reported taking adaptation strategies to mitigate the changes they have observed. These few respondents are changing planting time and using new crop varieties, such as hybrid rice.

3.4. Crop calendar

The crop calendar showing different activities associated with cereal crop cultivation, as shown in Table 3. The shift in the crop calendar was observed only for rice cultivation. Respondents have advanced the seeding time of rice 2–3 weeks compared to the seeding time for the period of 2005–2020. The high precipitation is the primary cause of this shift that the village experienced from mid-May to mid-June. Weeding and harvesting have been pushed back a few weeks due to the shift in the seeding period for rice cultivation. New varieties of rice (hybrids) that can be cultivated at any month and have a shorter lifespan than traditional varieties have been adapted to the Terai regions of Nepal (Dahal et al., 2018).

4. Discussion

Effects of warming can be seen more clearly in the regions of mid-hills and mountains than in plains. Climate change is projected to continue to alter precipitation patterns, potentially affecting Nepal's current agricultural production. This study found that temperatures

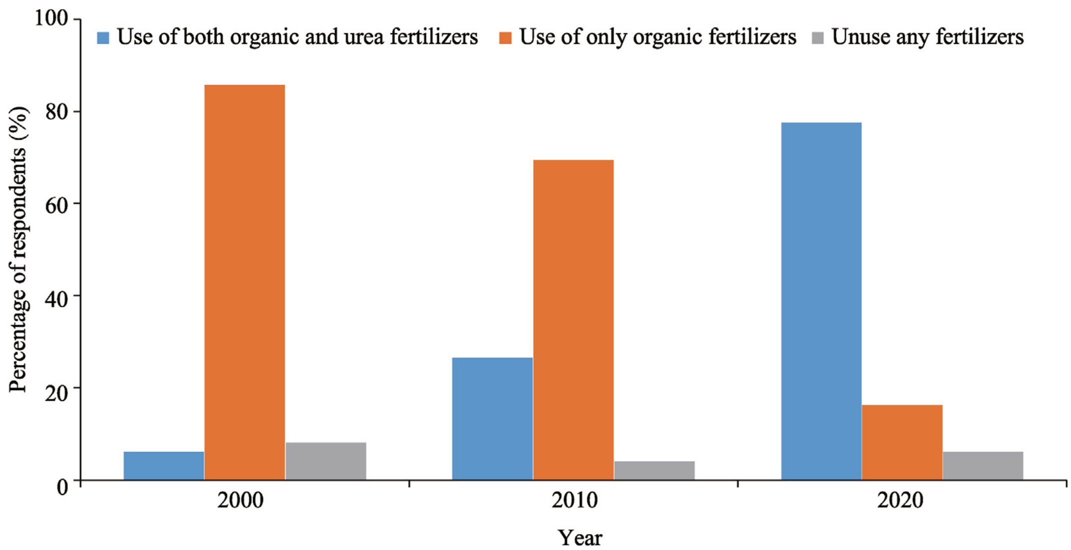

Fig. 6. Changes in the use of fertilizers from 2000 to 2020 in Pasagaun village.

Table 3
Crop calendar in the study area showing timing shift in some crops.

Crop	Activity	January				February				March				April				May				June				July				August				September				October				November				December			
		1st	2nd	3rd	4th	1st	2nd	3rd	4th	1st	2nd	3rd	4th	1st	2nd	3rd	4th	1st	2nd	3rd	4th	1st	2nd	3rd	4th	1st	2nd	3rd	4th	1st	2nd	3rd	4th	1st	2nd	3rd	4th	1st	2nd	3rd	4th	1st	2nd	3rd	4th	1st	2nd	3rd	4th
Rice	Seeding							✓	✓	✓	✓																																						
	Seeding (N)			✓	✓	✓	✓																																										
	Planting									✓	✓	✓																																					
	Planting (N)							✓	✓	✓																																							
	Weeding														✓	✓																																	
	Weeding (N)													✓	✓																																		
	Harvesting																											✓	✓	✓																			
	Harvesting (N)																									✓	✓	✓																					
Maize	Seeding																																												✓	✓	✓	✓	✓
	Weeding (+)				✓	✓	✓	✓																																									
	Harvesting (+)								✓	✓	✓	✓																																					
Millet	Seeding																																												✓	✓	✓	✓	✓
	Weeding (+)				✓	✓	✓	✓																																									
	Harvesting (+)								✓	✓	✓	✓																																					

Note: 1st, the first week of one month; 2nd, the second week of one month; 3rd, the third week of one month; 4th, the fourth week of one month. √, the week and month in which different crop activities take place; N, a shift in crop calendar; +, the activity in the following year (example of millet: seeding is done mostly in the last months of a year, so weeding and harvesting are conducted in the following year).

have increased in Lamjung District from 1992 to 2020. This is consistent with other studies that there is a rising trend in the maximum temperature in the entire country (Marahatta et al., 2009), and the maximum temperature has increased since 1978, based on the investigation of 47 meteorological stations across Nepal from 1971 to 1994 (Shrestha et al., 1999). Additionally, according to the results of FGDs, the frequencies of precipitation have decreased and precipitation time has shifted from December to March–April in Pasagaun village from 2000 to 2020. The duration of summer time has increased during the past 10 years, and the number of cold days has decreased. These observations support the findings of various regional studies conducted in Central and Western Nepal (Poudel and Shaw, 2016; Maharjan et al., 2018).

From 1992 to 2020), precipitation showed a decreasing trend (decrease of 9.84 mm/a), and approximately 67.0% of precipitation occurred in the monsoons. However, despite this overall decreasing trend, there is evidence of increasing precipitation in the study area, particularly in summer, according to the household surveys. This result is comparable to another study (Poudel and Shaw, 2016), which revealed that the precipitation trend is decreasing in Lamjung District, especially the Khudi Bazar meteorological station. Furthermore, the household surveys and FGDs also revealed that there is a large fluctuation in the precipitation patterns, indicating an increase in precipitation uncertainty.

Many studies have shown an increasing trend of precipitation in summer in different parts of Nepal (Adhikari and Mathema, 2023), but some of the studies also indicated a decrease in summer precipitation (Pokharel et al., 2019; Upadhayaya and Baral, 2020). Wang et al. (2013) and MoFE (2019) denoted a decrease of precipitation in winter in the western part of Nepal. It is clear that erratic and unpredictable precipitation patterns have negative influences on crop yield in many areas.

The major crops grown in the study area are rice, millet, and maize, but respondents also grow potatoes, vegetables, and cardamom. Around 2010, mustard, barley, Kaguno, and wheat were also planted. Similarly, cardamom yield has been declining in Panchthar District of Nepal and also in a few places in India (Rijal, 2014; Sharma et al., 2016). The factors responsible for this declining are untimely precipitation, reduced precipitation durations, shift in seasons, long dry spells lasting until flowering, drying springs, temperature rising, and increases in infections (both viral and fungal diseases), insects, or pests (Rijal, 2014; Sharma et al., 2016).

According to Pant (2013), rice and maize yields increased by 1.2% and 2.4%, respectively, across Nepal from 1990 to 2010. Likewise, Maharjan and Joshi (2013) discovered a significant upward trend in rice and maize yields. In addition to climate change, several relevant variables, such as the introduction of new seeds and agriculture technology, advanced irrigation facilities, and better crop management practices, may be responsible for the increase of crop yield (Regmi and Paudyal, 2009; Dahal et al., 2018). However, the yields of cardamom and wheat have decreased. Since wheat is grown in winter, a decrease in winter temperature in Lamjung District might reduce wheat yield, as the minimum optimal temperature threshold for wheat production is 20.00 °C, and temperatures below 19.00 °C can result in a significant decrease in wheat yield (Thapa-parajuli and Devkota, 2016).

Crop types has also changed in the study area due to climate change such as erratic precipitation and drought along with the decline in market value. In terms of rice, hybrid grains are introduced, and the traditional rice varieties are fading, with a few rice varieties now absent in some areas. The yield of barley has declined due to the lack of workers. Furthermore, Kaguno has disappeared from Pasagaun village. Various studies showed the reasons for the shrinking of Kaguno, mainly because of the lack of workers, out-migration of farmers, land use change, globalization, and depleting traditional knowledge (Gurung et al., 2016; Palikhey et al., 2016). However, farmers have also mentioned that excessive hailstorms and changes in food habits and taste are the main reasons for their shift from Kaguno to other crops. Increased temperatures have provided opportunities for the introduction of new crop varieties and vegetables, but they have also resulted in the loss of current diversity. This finding is also in accordance with the study of Parajuli and Upadhya (2016).

It is well known that both temperature and precipitation affect the yield of crops (Rahman et al., 2017; Liu et al., 2021). It is demonstrated that it is helpful to develop appropriate strategies to mitigate the impacts of climate change on agriculture in Nepal and other Asian countries by analyzing the often-complex relationships among temperature, precipitation and crop yield.

Various modeling studies have demonstrated that Nepal is highly vulnerable to climate change (Maharjan and Joshi, 2013; Chalise et al., 2015). If agricultural productivity in Nepal is affected as projected, it will have a substantial negative impact on economy, as agriculture is the country's main economic basis. Very few respondents have implemented coping strategies, such as adapting to the impacts of climate change with shifts in planting schedules or choosing new crop varieties (Dahal et al., 2018). Training and technical assistance could help farmers implement water conservation and management techniques (such as rainwater harvesting, irrigation, and water-efficient farming practices), and soil conservation and management techniques, e.g., conservation tillage, cover cropping, and integrated pest management (Ogunsola et al., 2021; Zhao and Boll, 2022).

Since the overall food security of the study area has deteriorated in 2005–2020, it is now commonly acknowledged that rural households of mid-hills and mountains are the most affected by extreme climate events. Besides, farming, remittances, small companies, and wage labors all contribute to protecting livelihoods and food security in the study area. Some respondents who did not work in agriculture stated that food accessibility and consumption patterns are improving in the study areas.

5. Conclusion and recommendations

This study accepts the alternative hypothesis (there is a significant effect of temperature changes and irregular precipitation patterns on crop yield and (or) farming practices) as there is sufficient evidence to reject the null hypothesis (there is no significant effect of temperature changes and irregular precipitation patterns on crop yield and farming practices), and concludes that there is significant impacts of temperature changes and irregular precipitation patterns on crop yield and farming practices. The research highlights the adverse impacts of temperature and precipitation on crop yield, with the decrease of precipitation and the increase of temperature significantly impacting the yields of various crops. This study also shows that the cultivation of traditional varieties of rice and foxtail millet has vanished, which may be due to the lack of market value and the time and effort required for harvesting and post-harvest processing. Farmers in the regions of mid-hills and mountains have already observed changes in pest infestations, crop planting seasons, and the cultivation of certain crops. However, there is still a lack of effective strategies to address climate change, emphasizing the need for more research and community-based farming education to better understand and mitigate the adverse impacts of climate change on crop yield. The findings also suggest that future research should consider crop prioritization, focusing on the most affected crops, such as barley and millet, to ensure food security in areas vulnerable of climate change.

Authorship contribution statement

Ashma Subedi: conceptualization, methodology, formal analysis, writing - original draft, writing-review and editing. Nani Raut: conceptualization, methodology, formal analysis, writing - review and editing. Smriti Gurung: conceptualization, formal analysis, writing - review and editing.

Ethics statement

Ethics approval was obtained from the participants of Pasagaun village, and they provided their informed consent to participant in this study.

Declaration of competing interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

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