Regional Sustainability 3 (2022) 122–132

Contents lists available at ScienceDirect

Regional Sustainability

journal homepage: www.keaipublishing.com/en/journals/regional-sustainability

Impact of climate change on agricultural production: A case of Rasuwa District, Nepal

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ARTICLE INFO

Keywords:
Mountainous areas
Climate change
Temperature
Precipitation
Agriculture production
Nepal

ABSTRACT

Climate change is expected to threaten the developing countries the most. Nepal is considered one of the five countries most vulnerable to climate change in the world. The mountainous area such as Rasuwa District in Nepal is more vulnerable due to complex topography, human activity (tourism), and climate change. In this context, we carried out this study to assess the climate change and its impact on agriculture production as well as people's perceptions on the impact of climate change. The long-term (1980–2014) observed climate data (temperature and precipitation) and field-based survey data on people's perceptions were analyzed. Mann-Kendall trend test and Sen's slope estimation were used to analyze the temperature and precipitation trends. Furthermore, key informant interviews (KIIs) and focal group discussions (FGDs) were conducted to understand people's perceptions of the impact of climate change on agricultural production. Further, ERA5 and APHRODITE datasets were used to compare the *in situ* climate data. The maximum temperature and total precipitation in summer monsoon (June–September) were found increasing significantly at rates of 0.07°C/a and 19.89 mm/a, respectively. But the minimum winter temperature and winter precipitation were found decrease by 0.05°C/a and 4.89 mm/a, respectively. Moreover, a large number of respondents reported a decrease in millet and wheat productions while an increase in potato production over the considered time duration (1990–2014). It is noteworthy that the respondents from the mid-elevation regions perceived an increasing trend in crop production compared to those from the low elevation regions. In recent years, people living in the high elevation regions of Rasuwa District have started to shift their cropping calendar to increase agricultural production. This study will provide useful information for policy-makers in formulating adaptation strategies in mountainous areas of Nepal.

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https://doi.org/10.1016/j.regsus.2022.07.002
Received 28 December 2021; Received in revised form 20 June 2022; Accepted 8 July 2022

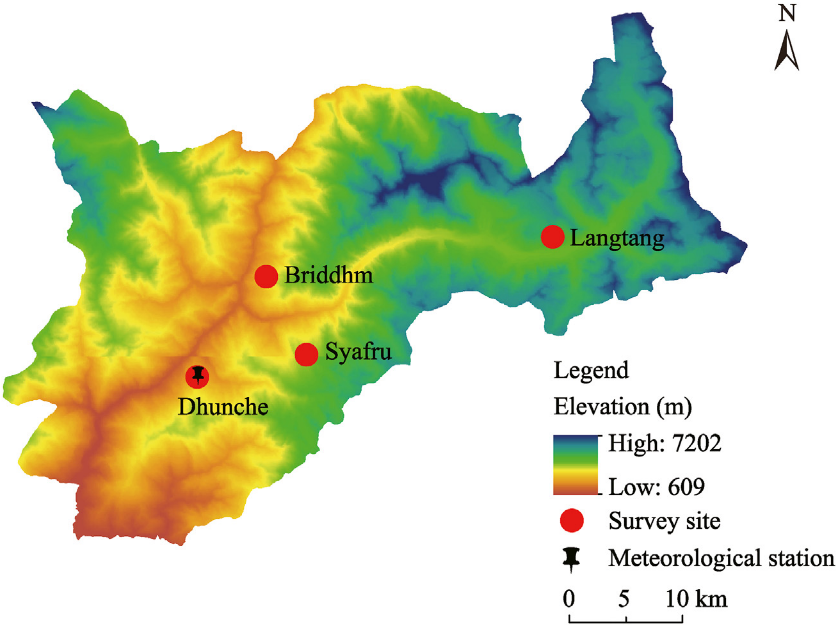

Fig. 1. Overview of the study area as well as the distribution of the selected survey sites.

1. Introduction

Climate change is expected to adversely impact the agriculture sector of the developing countries due to the associated damage and huge adaptation costs. The Intergovernmental Panel on Climate Change (IPCC) announced in the Sixth Assessment Report that the global average temperature has rose by 1.10 °C in the recent decade (2011–2020) while it is projected to increase by about 1.30°C–5.70 °C by the end of the century corresponding to the low-emissions and very high-emissions scenarios (IPCC, 2021). These warming scenarios impose a greater risk on South Asia, especially in the sectors of agriculture, land use, energy, biodiversity, health, and water resources (Food and Agriculture Organization of the United Nations, 2019). Nepal is considered one of the five countries most vulnerable to climate change in the world (Nepal Disaster Report, 2015). Moreover, low-income people from rural areas of Nepal are more vulnerable because of their high dependence on the agricultural sector (Department of Hydrology and Meteorology, Government of Nepal, 2017).

As Nepal lies on the southern slopes of the central Himalayas, summer monsoon (June–September) is the major rainy season that contributes about 80.00% of the total annual precipitation (Shrestha, 2000). The high precipitation pocket areas are distributed in the range of 1600–2600 m a.s.l., and the elevations from north to south change obviously (Fujita et al., 2006). Many studies reported that recent climate change is responsible for the variability and alteration in the spatial distribution of both the annual and seasonal patterns of precipitation across Nepal (Dhar and Nandargi, 2005; Department of Hydrology and Meteorology, Government of Nepal, 2017; Talchabhadel et al., 2018). Except for Terai (the southern plains of Nepal), all the geographical regions show a decreasing trend in annual precipitation with the highest reduction rate of 3.17 mm/a (Department of Hydrology and Meteorology, Government of Nepal, 2017). Also, annual and seasonal precipitation values (except for summer monsoon) are in decreasing trends throughout the country (Dhital and Kayastha, 2013; Dhital et al., 2013). Furthermore, the number of wet days is decreasing with increasing drought period and precipitation extremes in Nepal (Sigdel and Ikeda, 2010; Karki et al., 2017; Sigdel and Ma, 2017). Significant changes in temperature patterns were also observed in most regions of the country. Seasonal and annual minimum temperatures show positive trends in lower elevations and negative trends in higher elevations. Annual maximum temperature exhibits a significant increasing trend in all the seasons, except for Terai in winter and pre-monsoon, and Siwaliks in winter (Department of Hydrology and Meteorology, Government of Nepal, 2017). Using data from mountains and high elevation stations, studies have also revealed that the warming trend is resulted from the increasing maximum temperature (Kattel and Yao, 2013; Kattel et al., 2013; Thakuri et al., 2019; Dawadi et al., 2020).

In addition to quantification of the varying observed climatic variables, people's perception is a supplementary method for the assessment of climate change and its impact. A global survey in 2019 showed that there are rising public concerns about recent climate change, and most people believed that this is a major global threat (Fagan and Huang, 2019). Studies in Nepal show results similar to the global scale with observed rising cases of drought events, landslides and soil erosion in the mountainous areas, and flooding and inundation in Terai (Nepal Disaster Report, 2015; Sapkota and Rijal, 2016; Devkota et al., 2020). Research has shown that grass growth, medicinal plants, and other local agricultural products have declined due to the low amount of snowfall in the Himalayan region (Tiwari et al., 2010).

About 60.00% of Nepal's workforce is involved in agriculture, accounting for one-fourth (25.00%) of the gross domestic product (GDP) (Central Bureau of Statistics, 2019). Over the past decade, demand for the summer crop “corn” and winter crop “wheat” has

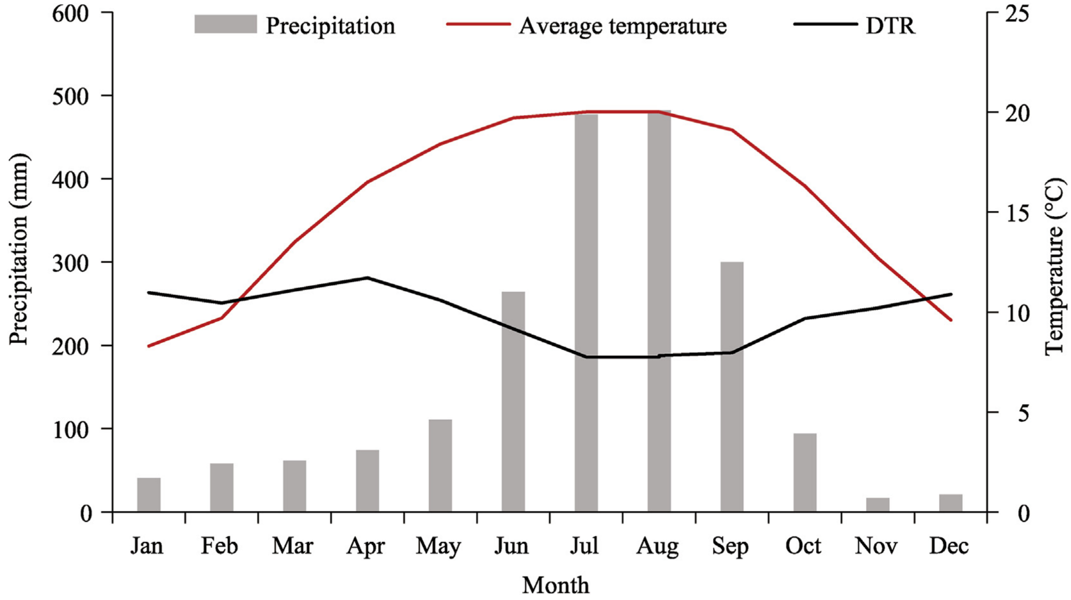

Fig. 2. Monthly climatology (precipitation and temperature) of Dhunche in Rasuwa District. DTR, diurnal temperature range.

increased by more than 5.00% (Sapkota and Pokhrel, 2010). Due to the existing tedious and labor-intensive agronomic practices, people are losing interest in millet cultivation though its demand is high (Devkota et al., 2016). Agriculture products have been both negatively and positively impacted by climate change. However, the rising problems perceived by a majority of people in previous studies are the increase in pests and diseases, insects, and invasive species in their farms with increasing climatic variability (Tiwari et al., 2010; Joshi and Joshi, 2016; Food and Agriculture Organization of the United Nations, 2019; Neupane et al., 2019).

In recent years, Rasuwa District of Nepal is becoming more popular for tourism rather than agriculture. In addition to the rapid climate change, its impact on agricultural production in this district is also pronounced. Based on the report of the Ministry of Environment (2010), Rasuwa is one of the most vulnerable districts to recent climatic variability in Nepal. However, the linkage between climate and agriculture production is still unknown amongst the local people from the rural areas of Nepal. Thus, this study was carried out with the objective of evaluating the climatic variability using observed climate data as well as people's perceptions of the impact of climate change on agricultural production. Despite the study area is relatively small; the methodology could be applied in other high mountainous areas with the similar socioeconomic conditions to help in planning and formulation adaptation strategies to cope with climate change.

2. Materials and methods

2.1. Study area

Rasuwa District, situated at 27°58′–28°23′N and 85°08′–85°47′E, is a rugged, high mountainous area in central Nepal, covering an area of 1500 km^2 (Fig. 1). It has an elevation difference from 609 to 7202 m a.s.l. Elevation in more than half of the district is over 3000 m a.s.l., and most areas have no access to roads. We selected Dhunche, Syafru, Langtang, and Briddhim in Rasuwa District as the study sites based on the climatic vulnerability reported by previous studies (MoE, 2010; Joshi and Joshi, 2016). Additionally, they were chosen because that they would spatially well-represent the different elevation ranges within the district. The elevations of Dhunchhe, Briddhim, Syafru, and Langtang are 1950, 2700, 2100, and 3200 m a.s.l., respectively.

Due to the lack of long-term observations in the other meteorological stations, we selected Dhunche meteorological station for the current study. It has a long historical time-series observed data, which can be a strong reference to compare with the people's perceptions of climate change.

Rasuwa District has diverse climatic conditions, ranging from temperate climate of the low-lands in the south to the polar tundra climate of the high elevation belt in the north (Karki et al., 2016). Data show that July and August (core summer monsoon months) receive maximum precipitation (880.00 mm), while November and December (winter months) receive minimum precipitation (20.00 mm) (Fig. 2). In this high elevation region, the high moisturized monsoon air and corresponding orographic effect cause a high summer monsoon precipitation (Boos and Kuang, 2010), while dry and cold winter air that mostly prevails over the study area is responsible for the low precipitation records. The minimum mean temperature was recorded in January (8.00°C) while the maximum mean temperature was recorded in July (20.00°C). The diurnal temperature range (DTR) shows a contrasting monthly pattern with average temperature distribution, where the lowest records were observed in July and August and comparatively high records were reported in the winter months. The normal precipitation and temperature of the station were 1985 mm and 15.00°C, respectively. It is also important to

Table 1
Mann−Kendall trend test and Sen's slope estimation statistics of precipitation (1980–2014), temperature (1990–2014), and agricultural production (1990–2014).

Variable	Season	Sen's slope	Kendall's tau	Kendall' *P*-value	Auto-correlation	Linear trend	Intercept	Mean	SD
P	Winter	−4.89	−0.29	0.03	0.09	−5.90	179.01	121.70	104.47
P	Pre-monsoon	−3.30	−0.10	0.49	0.35	−5.28	268.10	245.84	139.96
P	Monsoon	19.89	0.32	0.02	−0.17	22.19	1156.25	1509.78	431.39
P	Post-monsoon	−4.71	−0.31	0.03	0.06	−5.72	160.08	111.19	91.31
P	Annual	7.44	0.16	0.22	−0.16	6.39	1831.43	1985.38	436.96
Tmax	Winter	−0.14	−0.09	0.62	0.29	−0.06	17.77	14.55	1.74
Tmin	Winter	−0.05	0.11	0.53	0.35	−0.11	4.22	3.70	1.52
DTR	Winter	−0.04	−0.24	0.16	0.65	0.03	11.62	10.85	2.01
Tavg	Winter	−0.08	−0.19	0.26	0.05	−0.09	10.85	9.32	1.35
Tmax	Pre-monsoon	0.01	−0.06	0.74	−0.06	0.03	21.47	21.75	1.22
Tmin	Pre-monsoon	0.01	0.06	0.74	−0.14	0.04	10.68	10.62	1.60
DTR	Pre-monsoon	0.01	−0.14	0.38	−0.18	−0.01	10.86	11.10	1.61
Tavg	Pre-monsoon	0.03	0.03	0.83	−0.07	0.03	15.56	16.18	1.18
Tmax	Monsoon	0.07	0.29	0.08	0.21	0.07	22.47	23.97	0.75
Tmin	Monsoon	0.00	0.018	0.94	0.31	−0.01	15.85	15.78	0.63
DTR	Monsoon	0.08	0.17	0.33	0.15	0.08	6.60	8.19	0.95
Tavg	Monsoon	0.03	0.25	0.14	0.34	0.03	19.24	19.87	0.51
Tmax	Post-monsoon	−0.02	−0.15	0.38	0.09	0.02	19.75	19.61	1.37
Tmin	Post-monsoon	−0.01	−0.02	0.92	0.05	−0.01	9.81	9.60	0.76
DTR	Post-monsoon	0.01	−0.09	0.58	0.19	0.03	9.29	10.01	1.87
Tavg	Post-monsoon	−0.01	−0.09	0.58	−0.23	0.00	14.59	14.61	0.59
Tmax	Annual	0.01	0.02	0.92	0.20	0.02	19.78	20.17	0.99
Tmin	Annual	−0.04	−0.21	0.21	0.08	−0.05	11.17	10.52	0.77
Tavg	Annual	−0.01	0.00	1.00	−0.16	−0.01	15.59	15.36	0.64
DTR	Annual	0.06	0.00	1.00	0.55	0.07	8.21	9.66	1.24
Maize	Annual	43.26	0.38	0.01	0.08	50.30	2986.64	3624.92	647.37
Millet	Annual	−6.83	−0.22	0.14	0.23	−9.84	1185.25	1127.55	248.85
Wheat	Annual	21.66	0.27	0.07	0.37	20.30	1059.28	1297.02	290.34
Potato	Annual	690.68	0.41	0.01	0.68	821.93	15,801.89	24,279.03	7429.86

Note: P, precipitation; Tmax, maximum temperature; Tmin, minimum temperature; Tavg, average temperature; DTR, diurnal temperature range; SD, standard deviation.

note that the precipitation in summer monsoon contributes 76.00% of the annual total precipitation while precipitation in the winter monsoon contributes only 6.00% of the annual total precipitation.

2.2. Data collection and analysis

2.2.1. Climatic factors and agricultural production

The monthly maximum and minimum temperature values of Dhunche meteorological station for the period of 1990–2014 and the monthly precipitation records from 1980 to 2014 were collected from the Department of Hydrology and Meteorology for this study. Precipitation data showed missing records from May 1990 to September 1994. In the case of temperature, the missing records were from August 1991 to September 1994 and the whole year of 1998. Further, APHRODITE (http://aphrodite.st.hirosaki-u.ac.jp/products.html) and ERA5 (https://cds.climate.copernicus.eu/cdsapp#!/dataset/reanalysis-era5-land?tab=overview) datasets of precipitation and temperature were used to compare with the observed data. ERA5 datasets cover the Earth on a 30 km grid and resolve the atmosphere using 137 levels from the surface up to a height of 80 km. Further, we used a new version of 0.25° × 0.25° gridded APHRODITE dataset, which is based on gridded datasets developed from the dense network of hydrometeorological stations in conjunction with other pre-compiled datasets.

Agricultural production data were not available at the local community level, so the annual total production at the district level for the period from 1990 to 2014 was used in this study. These agriculture production data were collected from the Ministry of Agriculture Development, Nepal.

Mann-Kendall trend test is a widely accepted non-parametric method used for the detection of the statistical significance of a trend in the time series variables like temperature and precipitation (Mann, 1945; Kendall, 1975). This method is applicable in cases of missing, extremes, and non-normal distributed data series (Zhang et al., 2000). Sen's slope estimation (Sen, 1968) is also a nonparametric method used particularly for computing the true slope of the existing trend of the time series data. We applied the Mann-Kendall trend test and Sen's slope estimation method to assess the trends of temperature and precipitation in the study area. Here, the annual crop production data were also run for trend tests under the above-mentioned test methods.

2.2.2. Household survey

A stratified probability sampling (Arkin and Colton, 1963) was applied to collect household information in a field survey. A total of 312 households were selected with an equal proportional allocation considering every 3 homogeneous strata (clustering Briddhm and

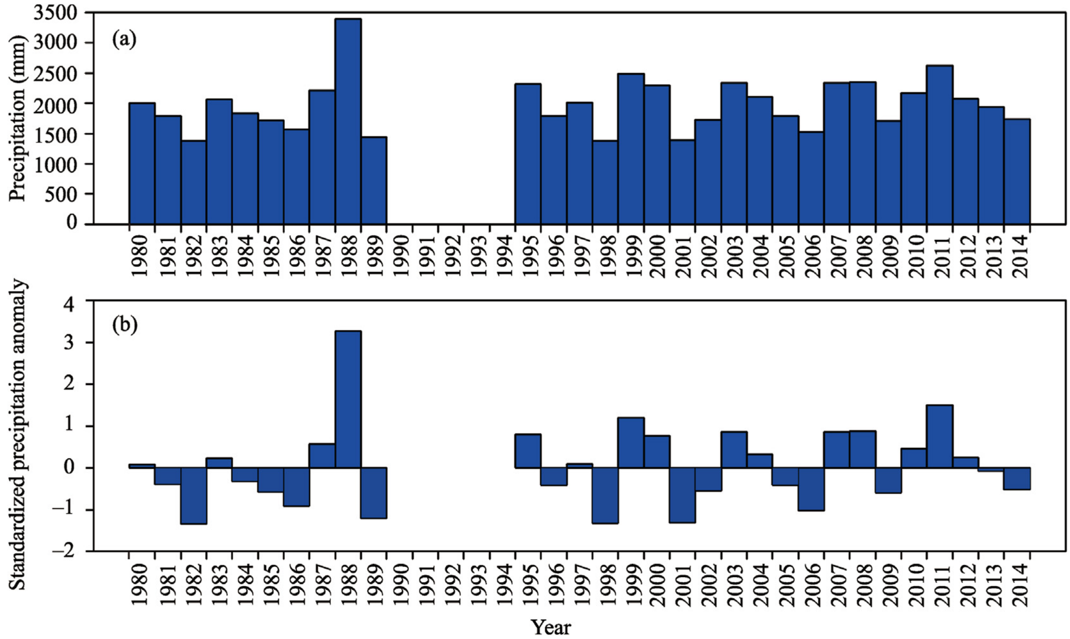

Fig. 3. Annual precipitation (a) and standardized precipitation anomaly (b) for the period from 1980 to 2014. Precipitation data showed missing records from May 1990 to September 1994.

Syafru with a single stratum and Lantang and Dhuche as a separate stratum). The desired degree of precision was set at alpha value and error limit while ensuring optimal sample size. The sample size for the household survey was determined by the formula given in Equation (1).

$$n = \frac{NZ^2 p(1-p)}{Nd^2 + Z^2 p(1-p)} \quad (1)$$

where n is the sample size ($n = 312$); N is the total number of households (population) ($N = 1648$); Z is the confidence level at 95% ($Z = 1.96$); p is the estimated population proportion ($p = 0.05$); and d is the error limit of 5% ($d = 0.05$).

2.2.3. Key informant interview (KII) and focus group discussion (FGD)

A total of 25 KIIs were conducted with respondents who had lived in the study area for a long period and individuals affiliated with national/international Non-Governmental Organizations, community forest user groups, women's group, and governmental officials. A total of six FGDs (two each in Dhunche and Langtang, and one each in Syafru and Briddhim) was conducted among local people about past and present climatic stress and its impact on agriculture. KIIs and FGDs were used to identify crop calendars and understand people's perceptions of climate change and its impact on agricultural production.

3. Results and discussion

3.1. Changes in temperature and precipitation

In this study, we found that there were obvious changes in temperature and precipitation. According to the Mann-Kendall trend test and Sen's slope estimation, the maximum temperature and precipitation increased significantly during the summer monsoon (Table 1). The annual maximum temperature was in an increasing trend (0.01°C/a), however, the annual temperature was in a decreasing trend (0.04°C/a). Consequently, the annual average DTR for the study period showed a positive trend of 0.07°C/a (Fig. 3; Table 1) along with the linear trend of the winter and summer monsoon periods, even though the results were statistically insignificant. Previous studies (Kattel and Yao, 2013; Department of Hydrology and Meteorology, Government of Nepal, 2017; Nayava et al., 2017) also reported that in Nepal, the minimum temperature trend at the mountain meteorological stations exhibited larger variability even with a negative trend, however, the maximum temperature trend possessed a higher positive trend. The annual mean maximum temperature has increased at a higher rate than the annual mean minimum temperature. Previous research also found similar trends of maximum and minimum temperatures and also highlighted the significant increasing characteristic of DTR (Thakuri et al., 2019). In addition to the large-scale synoptic phenomena, the topographic factors (You et al., 2010) and microclimatic factors (Gouvas et al., 2011; Kattel and Yao, 2013) of the high elevation regions are likely to ascribe the unevenly distributed temperature. Another evidence is that both the minimum temperature and precipitation in winter (December–February) decreased significantly by 0.05°C/a and 4.89 mm/a

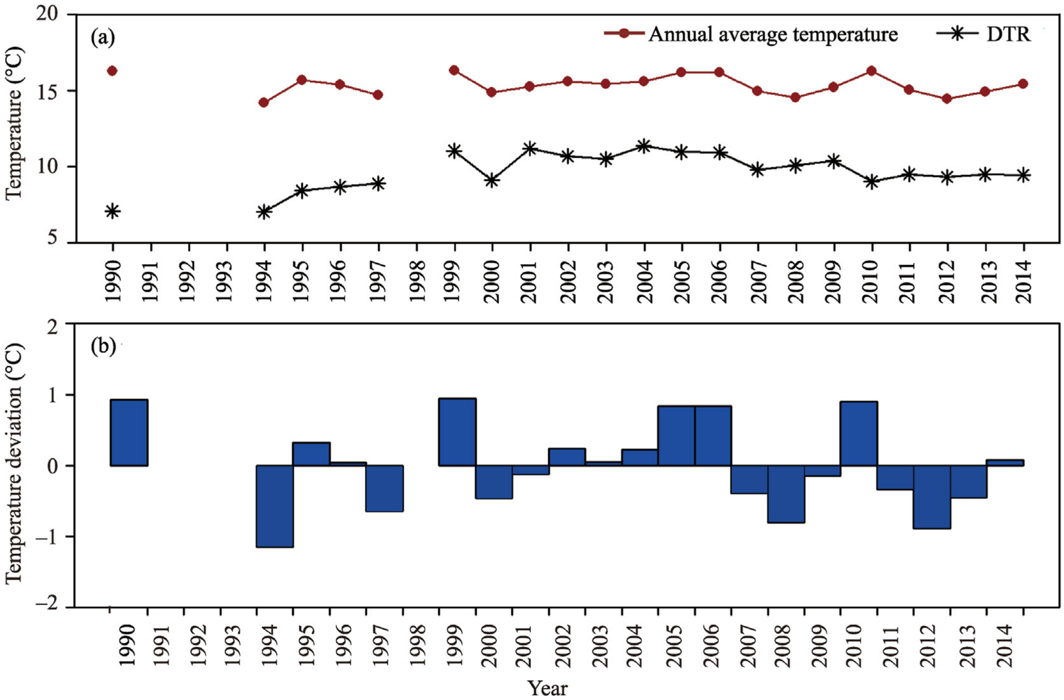

Fig. 4. Annual average temperature and annual average DTR (a) and annual distribution of temperature deviation (b) from 1990 to 2014. Temperature records were missing from August 1991 to September 1994 and the whole year of 1998.

respectively but an increasing trend of DTR (0.03°C/a) was observed. These indicated that the cold and dry winter months were experiencing decreasing number of rainy days and reduced cloudiness. Figs. 3a and 4a showed that the annual variations of precipitation and temperature are in the ranges of 1382–3396.00 mm and 14.20°C–16.30°C with standard deviations of 437.00 mm and 0.64°C, respectively. The increasing trend of precipitation was not significant (7.44 mm/a). Fujita et al. (2006) also suggested that the precipitation trend was increasing at a higher rate in the altitudinal range of 1600–2600 m a.s.l. in central Nepal. Fig. 3b revealed the annual variation of standardized precipitation anomaly. A similar analysis was also conducted for both the winter and summer monsoon seasons. Here, the total duration of positive and negative anomalies represented the change in temperature, and the severity represented the algebraic sum of respective negative and positive anomalies over such periods. The standardized annual precipitation anomaly showed the same duration of positive and negative anomalies, but the positive severity index (12) was higher than the negative severity index (10) in magnitude (Fig. 3b). On the other hand, for the summer monsoon, the duration of positive anomalies was 45.00% of the total but the positive severity index was greater than the negative severity index in magnitude. Furthermore, only 35.00% of the total duration resembled positive anomalies in winter. These findings clearly implied that the duration of annual positive anomalies is decreasing but the positive severity level is increasing. In other words, the intensity of precipitation seems to be high. It was thus clear that the number of wet years decreased and led to an increase in drought and related precipitation extremes due to the intense precipitation during these years (Sigdel and Ikeda, 2010; Karki et al., 2017; Fagan and Huang, 2019).

Because of the short period of available temperature data, we analyzed the actual annual variation from the temperature deviation of its mean during the study period (Fig. 4b). It showed that the duration of positive deviation was lower than that of the negative deviation. This indicated that the cooling effect was increasing, and this might be a cause of crop failure (especially vegetables) in this region (Lobell, 2007).

Furthermore, we compared the observed data with APHRODITE and ERA5 datasets, but these datasets showed high variability with *in situ* data records. Both APHRODITE and ERA5 datasets consistently underestimated precipitation and temperature (Fig. 5). Sharma et al. (2020) and Chen et al. (2021) have found very similar results in the southern slope of the central Himalayas, especially in high elevation regions of Nepal.

3.2. Impact of climate change on agricultural production

The two major crop systems in the study area are the summer and winter crop systems. The summer crop system mainly includes maize, millet, and potato, while the winter crop system mainly comprises wheat. Agricultural production data were not available at the local level. So, the annual total production at the district level for the period from 1990 to 2014 was used in this study. The overall analysis of maize, wheat, and potato production showed a significant increasing trend throughout the study period, but millet production exhibited an insignificant decreasing trend (Table 1). Maize demand has grown by 5.00% over the last decade and the productivity of maize has been slowly and constantly increasing in Nepal since 1984 (Sapkota and Pokhrel, 2010). A previous study

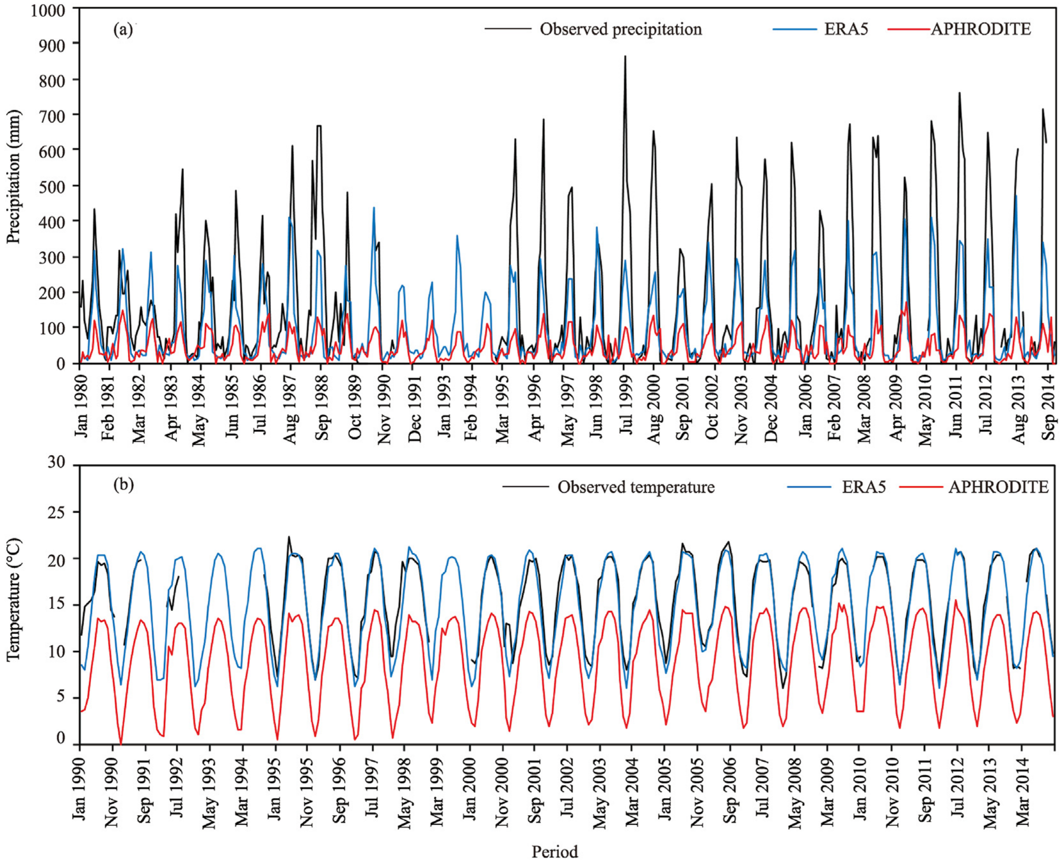

Fig. 5. Comparison of observed climate data with ERA5 and APHRODITE datasets for the period of 1990–2014. (a), precipitation; (b), temperature.

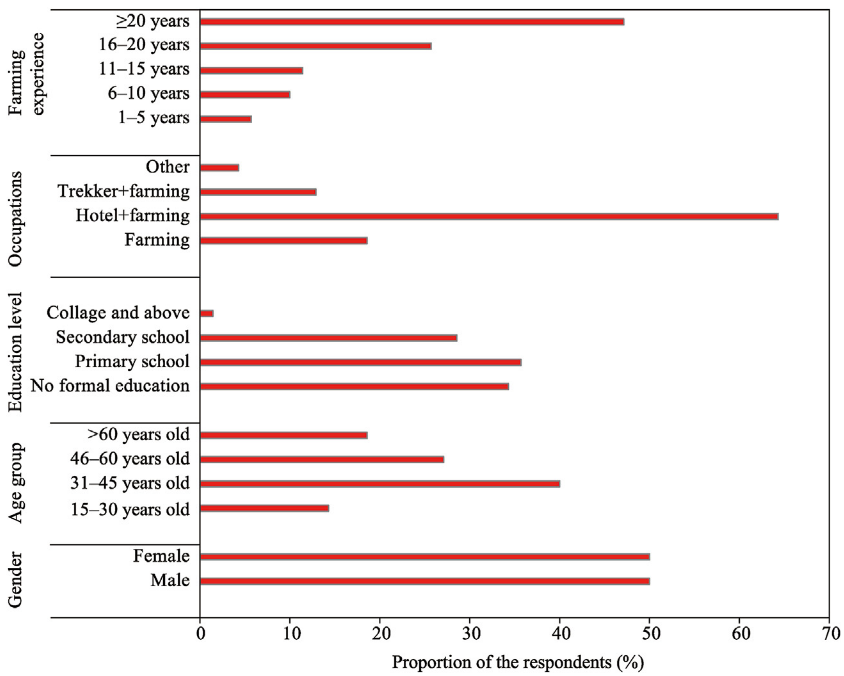

Fig. 6. Socioeconomic background of the respondents in the study area.

Table 2
Statistical analysis of people's perceptions of climate change on agriculture production.

Perceptions of climate change	Proportion of the respondents (%)	Proportion of the respondents by age group (%)			
		15–30 years old	30–45 years old	45–60 years old	>60 years old
Have not heard	62.86	50.00	64.29	63.16	61.54
Heard but not clear	30.00	30.00	32.14	36.84	23.08
Clear understanding	7.14	20.00	3.57	0.00	15.38

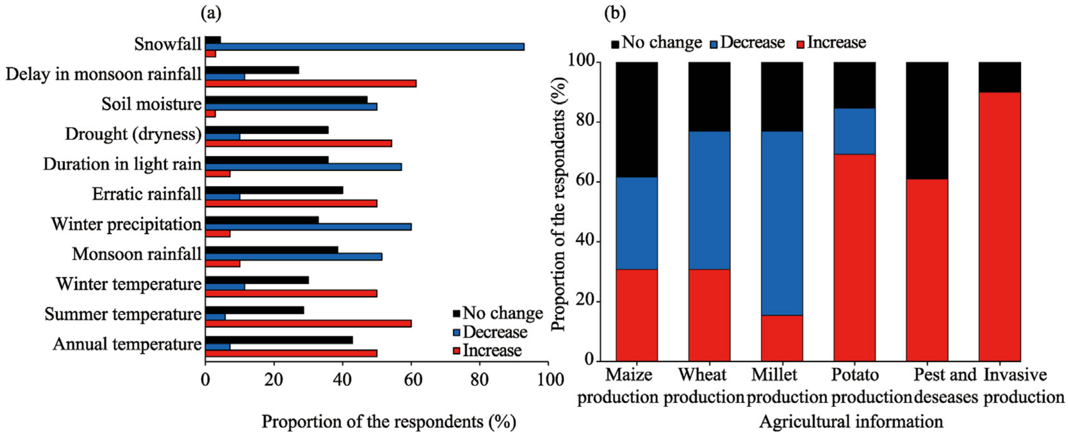

Fig. 7. People's perceptions of climate change (a) and people's perceptions of agricultural information (b).

conducted by Malla (2008) reported that both maize and wheat productions in the mountainous areas of Nepal were increasing with the increased warming effect, which was consistent with our findings.

Considering a decadal timestep, millet production in the first studied decade (1990–1999) showed a positive linear trend (3.21 kg/a), followed by a decreasing trend of 38.43 kg/a in the second studied decade (2000–2009) and 69.80 kg/a in the following years (2010–2014). The low production caused by climate change was one of the reasons why people were not interested in planting millet. Also, decreased in production created challenges in maintaining the cost for labor and other resources. In addition, the increased emphasis on income-generating crops, such as potatoes, may reduce the cultivation of other crops like millet. Furthermore, governmental agencies working on the agricultural sector generally neglected research on expansion of millet cultivation as it was perceived as low-status food (Devkota et al., 2017). On the other hand, the highest records of potato production in recent decades were due to high market value, the need for low human resources, and modern practices with recent and hybrid varieties. Due to specific station-based climate data and district-level agriculture production data, we did not find the correlation between these two parameters.

3.3. People's perceptions on the impact of climate change

Historical and current information was collected during the field survey to assess people's perceptions of climate change and its impacts on agriculture production in Dhunche, Syafru, Briddhim, and Langtang of Rasuwa District. Face-to-face survey was conducted with respondents from a wide range of farming experiences, occupation, education, gender, and age group (Fig. 6). Results revealed that most of the people have been living there for many years, with farming as the major occupation. Some of the respondents were partly engaged in hotels or as porters for trekking in the tourist seasons. Most respondents (62.86%) had lower than average perceptions of the impact of climate change on agriculture production were found to be lower than the average level (Table 2). However, local people have certainly experienced climate change. A significant proportion of the respondents (7.14%) were in the study area, including those who believe and understand that climate change has been occurring. On the other hand, 30.00% of the respondents were not likely to understand well or even skeptical of the evidences of climate change, while a considerable number of the respondents (62.86%) were completely unaware of climate change and its impact. Similar results were obtained by Devkota (2014) and Martin et al. (2022) in other geographically similar areas of Nepal with a comparable education levels.

3.4. People's perceptions of temperature, precipitation, and agricultural production

Almost half of the respondents perceived that temperature is increasing (Fig. 7a). It was more visible over the last two decades. Especially, the increase of summer temperature was greater than that of winter temperature. About 30.00% of the respondents did not agree with the temperature change while the rest responded to the temperature decrease. Productivity of many crops has decreased due to heat stress, longer dry seasons, uncertain precipitation, and land degradation, resulting in adverse effects on food security and eroding livelihood assets of poor people, which made their livelihood more vulnerable to climate extremes (Devkota, 2013; Yiridomoh et al.,

Table 3
Crop calendar based on major changes in cropping time.

Crop	Earlier time periods		Recent years	
	Cropping time	Ripening time	Cropping time	Ripening time
Maize	3rd week of March	1st week of September	1st week of April	3rd week of August
Wheat	3rd week of September	3rd week of March	2nd week of September	2nd week of April
Millet	4th week of May	3rd week of November	4th week of June	1st week of November
Potato	1st week of February	3rd week of June	1st week of April	1st week of August
Soybean	3rd week of June	2nd week of November	4th week of June	1st week of November

2022) because of their low adaptive capacity. People's perceptions on summer monsoon and annual mean temperature matched the observed data, as shown in Table 1 and Fig. 4. But in the case of winter temperature, the observed trends were opposite. It was observed that the local people regarded the increased frequency of heavy precipitation as an indicator of climate change.

Fig. 7a showed that there was uniformity in people's perceptions, 52.00% of the respondents reported a decrease in precipitation and about 39.00% disagreed with the changes in both precipitation amount and time pattern. Similarly, more than half of the respondents (60.00%) agreed with the decrease in winter precipitation. People's perceptions of decreasing trends of precipitation were exactly in line with the observed data (Table 1) as well as a previous work accomplished by Joshi and Joshi (2016). More respondents from the Langtang area had the public opinion of erratic monsoon precipitation along the trekking route. It is important to note that the respondents with the age range of 45–60 years old agreed with the increasing trend of intense precipitation, but they informed that both rainy events and durations were decreasing, consisting with the finding of Devkota et al. (2020). About 20.00% of the total respondents also agreed with perceiving strong climatic variability, 61.43% reported delay in monsoon onset, 54.29% observed intermittent dryness, and 50.00% experienced decreasing of soil moisture. These factors have been identified as emerging problems for the cultivation of major crops. Information perceived on monsoon delay was also validated by Department of Hydrology and Meteorology, Government of Nepal (2021). Moreover, 92.87% of the respondents mentioned a decrease in snowfall in the study area (Fig. 7a).

The respondents had different perceptions about crop production trends (Fig. 7b). In the case of millet and wheat, more respondents reported a decrease in production, while a high proportion (69.23%) reported an increase in potato production. Maize production has increased by 38.46%. It is noteworthy that the respondents from the mid-elevation regions reported increasing trends of production compared to those from the lower elevation regions. People's perceptions on millet and potato production were consistent with the published production data for the Rasuwa District.

Each crop had a distinct cropping and ripening time depending on its cropping calendar (Table 3). Only a few of the respondents mentioned unchanged cropping time compared to the past, while the majority reported the shifting of cultivation time. Similar views were found during the FGDs and KIIs. Based on the views of FGDs and KIIs people were trying to shift their cropping and harvesting time as per their convenience with the implementation of certain local adaptation practices such as switching to improved varieties and using organic manure to cope with the rising climatic variability. Respondents reported that the harvest of summer crops such as maize, millet, potato, and soybean was one month earlier than in the past while the harvest of winter crop (wheat) was delayed by a month. For potatoes, the current harvesting time was about half a month earlier than in the past. Results from the surveys indicated that people's perceptions of the impact of climate change on agriculture was consistent with the trends shown by the observed climate data. As the agriculture sector is more susceptible to climate change, it can directly impact the subsistence livelihood of the local people.

4. Conclusions

The present study evaluated the climatic variability in rural area of Nepal and its association with agriculture production in order to support the agricultural practices and formulation of adaptation strategies to cope with climate change in the future. Historical climate data showed that during the summer monsoon, the maximum temperature and total precipitation increased significantly at rates of 0.07°C/a and 19.89 mm/a, respectively. About 60.00% of the respondents reported an increasing trend of summer temperature, but they have different perceptions of precipitation. In winter, more than half of the respondents (60.00%) agreed with the decrease in winter precipitation and mean temperature. People's perceptions on the changing agriculture production in general showed similar trends with the past official records, while the recorded wheat and maize production trends did not match with people's perceptions. It was noteworthy that this study revealed increasing trends in climatic variability and crop production in the mid-elevation and high elevation regions by comparison to the low elevation regions of the study area. This study will provide reference for future researchers and policy-makers to formulate new strategies and research priorities in the sector of climate change and its impact on agricultural production focused on the mountainous areas of Nepal.

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.

Acknowledgements

The authors express their sincere thanks to the scientists of the Asian Precipitation–Highly Resolved Observational Data Integration Towards Evaluation (APHRODITE) and European Centre for Medium-Range Weather Forecasts (ECMFW) for providing datasets. The Department of Hydrology and Meteorology, Government of Nepal, is also acknowledged for providing the observed climate data. We also would like to thank all the involved local communities and district administration offices in Rasuwa for providing agricultural production data and information. Dr. Utsav Bhattarai is highly acknowledged for his support for the English improvement. The authors would also like to thank anonymous reviewers for their insightful comments and suggestions, which helped to improve the quality of the manuscript.

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