Climate Change Impacts and Adaptation Strategies in Trans-Himalaya Region of Nepal

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Abstract

Nepal is ranked as one of the highly climate vulnerable nations in the present global climate scenario. Multiple studies have been done across the regions, yet there lacks a detailed study on the impacts of climate change and adaptation practices in mountainous areas such as Mustang region of Nepal. In this context, we aim to examine the impacts of climate change experienced locally and adaptation practices adopted in Muktinath valley of Mustang District, Nepal. A mixed-method approach was employed in gathering qualitative and quantitative data. The household surveys (N=60) were done using a simple random sampling followed by Key Informant Interviews (N=10) and Focus Group Discussions (N=2). The analysis of overall trend of mean annual maximum, minimum and average temperatures from 1985 to 2016 depicted an increment by 0.06℃/yr, 0.0369℃/yr and 0.0217℃/yr respectively. Agriculture, water resources, Non-Timber Forest Products and human health were extremely impacted due to the changing climate. Moreover, several natural hazards like landslide, avalanche, spread of invasive species, and increase in number of pests and flies were experienced. Construction of artificial pond, pest and weed control, change in plantation and harvesting time, and change in cropping pattern were the major adaptation practices adopted by the local people. Similarly, lack of technical and financial resources were the major constraints for adaptation practice. We recommend that the local and provincial governments should focus on local level policies to support the mountain livelihood and landscape.

Keywords: Adaptation measures, impacts, livelihood, mountains, policies

INTRODUCTION

Climate change is a major challenge that have utmost risks to both humans and ecosystems (Pachauri *et al*. 2015). The overuse and exploitation of resources and broadening of the industrial boundaries into agricultural and forest lands has resulted to increased production of greenhouse gas in the recent years that has explicitly increased the detrimental effects of climate change (IPCC 2014). And these effects are expected to dramatically increase in the future as well (Adger 2003; Marino and Ribot 2012; IPCC 2014). It has been argued that the countries that are dependent on agriculture and natural resources for their daily needs are more vulnerable to the impacts of climate change (Mertz *et al*. 2009; Adger 2010; Gentle and Maraseni 2012; Adhikari *et al*. 2018; Gentle *et al*. 2018; Khanal *et al*. 2019).

High mountain regions and people living in those areas are prone to adverse impacts of the changing climate compared to the lowlands of Nepal because the rate of rise in temperature is comparatively

more in the higher altitudinal zones (Xu *et al*. 2009; Gentle and Maraseni 2012; Sherpa 2014). In high mountains, increase in the temperature has been higher than the average global warming compared to past couple of decades (IPCC 2007a). The rate of warming in Nepal was dramatically escalating at an average annual rate of 0.06°C during the period from 1971 to 1994 (Shrestha *et al*. 2000). Rise in temperature has resulted to glacier recession, ice melting, erratic rainfall, snow melts in the mountain areas, and reduced productivity in the agricultural land that have altered functioning of mountain ecosystems in Nepal (Shrestha *et al*. 2000; World Bank 2009; Manandhar *et al*. 2011; Pandit *et al*. 2014; Gentle *et al*. 2018). Moreover, these changes have dramatic consequences on the mountain livelihood and ecosystem that has increased the vulnerability of downstream communities (Shrestha *et al*. 2000; World Bank 2009). Furthermore, climate change has exacerbated poverty, disaster risk, and food insecurity (Tiwari *et al*. 2014).

Multiple authors have argued that climate change is one of the greatest threats to sustainable agriculture production due to the increased drought, erratic rainfall, and decreasing seasonal precipitation (Bhatt *et al*. 2014; Chapagain *et al*. 2019; Adhikari *et al*. 2018; Khanal *et al*. 2019). The reduction in crop production, scarcity of water due to increased drought, increase in disease and pests are persistent due to rapid increase in temperature and fluctuatation in the rainfall pattern (Manandhar *et al*. 2011; Regmi *et al*. 2008; Khanal *et al*. 2019; Poudel 2020a), though some authors have shown positive aspects of adaptation practices to these changes in the mountains (Paudel *et al*. 2020). Diversifying crop species, rotating crops and seasons, best selection of seeds for the changing agricultural land properties, altering planting time, adopting chemical fertilizers, promoting mixed cropping system, investing to reduce livestock diseases are some of the adaptive measures practiced by farmers in Nepal (Aase and Chapagain 2017; CBS 2017). Moreover, Paudel *et al*. (2020) asserted that enriching education among farmers, adaptive management of changing social, agricultural and land tenure practices could be the future adaptation strategies. However, according to Tesfahunegn *et al*. (2016) and Uprety *et al*. (2017), the farmers are still unaware about the anticipated impacts of climate change in their livelihood and the economy. Therefore, detailed field-based studies on mountain farmers and landscape will help to clearly justify the impacts of climate change, minimise knowledge gaps for both farmers and policy practitioners, and possible adaptation strategies for the future.

Amidst the growing threats from climate change, Nepal has designed and implemented multiple adaptation plans and policies (Gentle *et al*. 2018; Ranabhat *et al*. 2018; Khanal *et al*. 2019). Adaptation plans and policies like Climate Change Policy, National Adaptation Programmes of Action (NAPA), Local Adaptation Plans for Action (LAPA), reducing emissions from deforestation and forest degradation (REDD+), and Forest Policy have been formulated and implemented overtime (Tiwari *et al*. 2014; Ojha *et al*. 2016; Ranabhat *et al*. 2018). Sustainable forest management has emerged as a promising adaptation strategy in Nepal. Many of these programmes have made remarkable changes in local level climate change adaptation. But there are several critiques that Nepal's adaptation strategies are often reactive and unplanned, resulting in ineffective adaptation and maladaptation outcomes due to lack of resources, adaptation options and knowledge, technology, economic structures, and lack of integration of multi-level institutions in adaptation governance (Bhatta *et al*. 2015, Adhikari *et al*. 2018; Ranabhat *et al*. 2018). Moreover, there still lacks policy coherence across diverse sectors like agriculture, forestry, wildlife, hydrology etc. that are directly and indirectly affected by climate change (Ranabhat *et al.* 2018). Furthermore, several adaptation programmes and policies lack indigenous, traditional, and place-based knowledge incorporated in it. These policies exclude the voice of local farmers and are authoritarian in nature

that hinder local level participation during policy planning and implementation (Regmi *et al*. 2008; Sharma *et al*. 2020; Ojha *et al*. 2016). In this regard, this paper aims to outline the perceived impacts of changing climate in mountain livelihood and agricultural practices and examine adaptation strategies adopted by the rural communities in Muktinath valley.

MATERIALS AND METHOD

Study Area

This study focuses on the mountain livelihood from the Muktinath valley, which lies in the Mustang district of Nepal. Muktinath is located in Lower Mustang zone situated at 83°35' east, 28°49' north, to the north-east of the great Annapurna Massif. Currently, Muktinath valley lies in Baragaun Muktichhetra Rural Municipality after the new political structure adopted in Nepal. Ranipauwa, Jharkot, Lubra and Khinga are the villages located in this valley. The Muktinath region hosts several types of vegetations that include dry alpine and subalpine vegetative covers. There is thin distribution of forest cover as this region is affected by heavy rain-shadow of the high mountain ranges such as Annapurna and Dhaulagiri (Fort 1987). The primary vegetation distributed in this area are Blue Pine (*Pinus wallichiana*), West Himalayan Fir *(Abies spectabilis*), and Juniper *(Juniperus indica).*

Data Collection

A mixed-method approach (Teddlie and Tashakkori 2003; Gentle *et al*. 2018) was employed to gather primary information for this study. Household surveys were conducted using a simple random sampling. There was a total of 166 households in Muktinath valley. From the total population, purposefully 36 per cent sampling intensity was taken and survey for 60 households was conducted, which represents all category

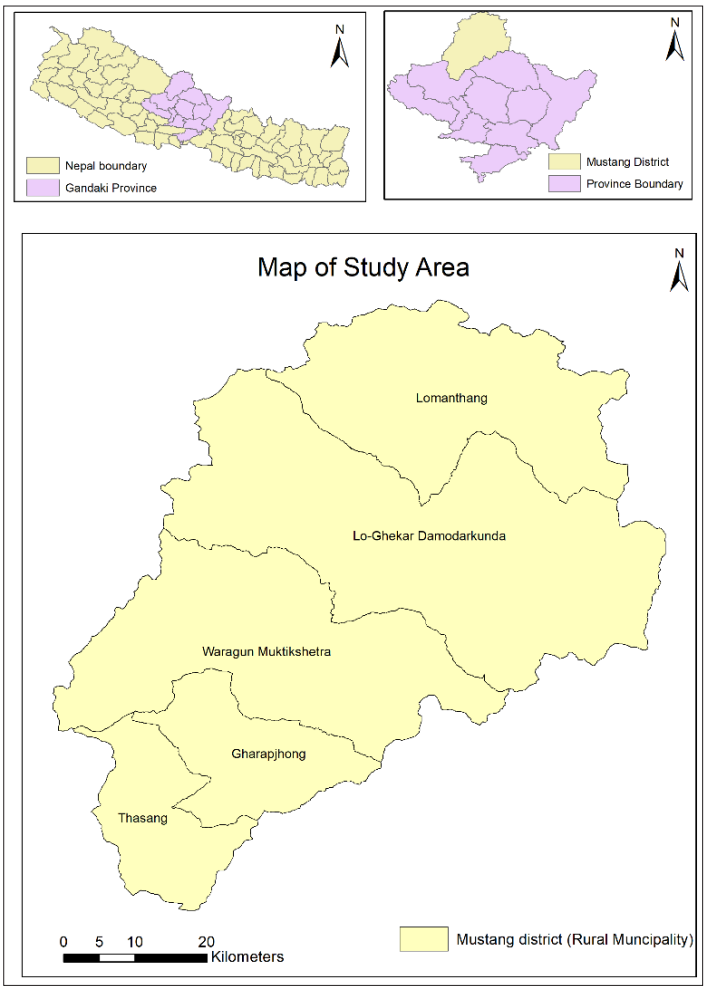

Figure 1: Map of Study Area

population. Key informant interviews (KII) were conducted with 10 key informants that include elderly individuals, local leaders, school teachers, social workers, local government officials, and non-government organisation such as Annapurna Conservation Area Project (ACAP) and other Non Governmental Organisations (NGOs) to explore the impacts of climate change and adaptation measures adopted in this area. The key informants were selected from multiple institutions based on their prior knowledge on climate change issues including impacts and adaptation strategies. We conducted two focus group discussions (FGDs) among the elite groups of Muktinath Valley. A set of semi-structured questionnaires were prepared for collecting data via FDGs. This helped us to gather data on different perception regarding impacts of climate change, community level adaptation strategies, and barriers in implementing adaptation strategies. In addition, FGDs were conducted to triangulate various information gathered from household survey, and KIIs.

Meteorological data (precipitation and temperature) for the past 30 years were collected from the Jomsom station, which is the nearest station to the study area. Data on minimum, maximum, and average temperature, and precipitation between 1985 and 2016 were collected and patterns of these variables were observed.

As secondary sources of information, we gathered relevant documents from the local governments (i.e., municipalities), ACAP, and Divisional Forest Office (DFO).

Data Analysis

The quantitative and qualitative data generated from the fieldwork were analysed separately. The quantitative data collected from household survey were coded, categorised and fed into the computers for further analysis using MS-Excel 2013 and Statistical Package for Social Science (SPSS) v.20. We designed and employed Likert scale to determine the people's perception on climate change impacts. Friedman test was done to analyse the ranking barriers to climate change adaptation strategies. Climatic data from meteorological station were analysed using linear regression model. To analyse the climatic data, we adopted least square curve fitting technique, which helped us to fit the linear trend in the data. The linear trend between the time series data(Y) and time (t) is presented in the equation below:

y=a+bt; "a" and "b" are the constant estimated by the principal of least square

RESULTS AND DISCUSSION

Characteristics of Respondents

Information on the social characteristics of the respondents involved in the household survey is presented in the table below (Table 1). Among total participants, majority of respondents were male participants (65.5%), while only a few (34.5%) were female. In terms of the age class, majority of the respondents belonged to middle age group i.e., of 40-55 years of age. Majority of the respondents involved in this research were illiterate (45%), followed by 35 per cent literate having school level education, and only 20 per cent of the respondents were educated who have a college level education.

Table 1: Socio-economic Characteristics of the Respondents

Characteristics		Percentage (%)
Gender	Male	65.5
	Female	34.5
Age categories (years)	Young (30-40)	7
	Middle (40-55)	60
	Old>55	33
Educational status	Illiterate	45
	Literate up to school	35
	Literate up to college	20
Land holding status	0-5 Ropani	20
	5-10 Ropani	60.5
	>10 Ropani	19.5
Main livelihood sources	Business/Hotel	34.5
	Agriculture & Livestock	30.5
	Apple farming	22
	Tourism	6
	Service/Job	7

The land holding status of the research participants shows that 60.5 per cent of the respondents hold 5-10 Ropanies of private land while 34.5 per cent of the respondents were involved in business and hotel as their livelihood sources. Mustang, being a religious touristic area where most of the respondents seemed to be attracted towards tourism business, hotel, and cash crops. However, about 30.5 per cent of the respondents were engaged in agriculture and livestock farming for their income sources. Apple farming and tourism are the major sources of income while few respondents (7%) were engaged in service/job for their earning.

General Understanding about Climate Change

Although Mustang has been badly affected by climate change, it was found that 27 per cent of the total respondents were totally unaware about the term climate change. We found that 37 per cent of the respondents had little knowledge and 36 per cent had just heard about the term, but did not have a good knowledge about it. Their understanding about climate change was limited to change in temperature only. Similar result has been reported by Sharma *et al*. 2020 where they found that 63 per cent of their respondents did not have basic knowledge about climate change while 37 per cent respondents had heard about it. Similarly, Bhattarai *et al.* (2020), Khanal *et al.* (2019), and Piya *et al.* (2013) reported that most of the respondents in their research did not have basic information about climate change while only few participants had basic ideas and perceived climate change as alterations in rainfall and temperature.

Temperature and Precipitation Variability

Variation in Temperature

Study of the overall trend of temperature in Muktinath area showed that the pattern of mean annual maximum, minimum, and average temperature between thirty years of time (1985-2016) was increasing by 0.0067°C/yr, 0.0369°C/yr, and 0.0217°C/yr respectively. The result showing the trend of temperature in between 1985 and 2016 based on the data collected from Department of Hydrology and Meteorology (DHM) is presented in Figure 2. In terms of the summer temperature, results showed a decline in maximum temperature by 0.0246°C/yr. However, the average and minimum temperature increased by 0.0073°C/yr, and 0.0392°C/yr respectively. On the other hand, in terms of winter temperature, average maximum, average minimum, and mean temperature all followed the increasing trend by 0.0465°C/yr, 0.0585°C/yr, and 0.0525°C/yr respectively.

Based on the qualitative information, most of the respondents agreed that the temperature in the Muktinath region was in rising trend. Most of the respondents (85%) perceived that the summer temperature was rising while 15 per cent of them reported that the summer temperature was not changing. Similarly, 53 per cent of the respondents perceived that the winter temperature is also rising while 33 per cent said that the temperature remained unchanged and 15 per cent responded that the winter temperature has been decreasing over the decades. Local people were able to explain the changes in temperature and precipitation based on their experiences on the changes seen on agriculture crops planting and harvesting time, seasonal changes in flowering, variation of water amount in the local rivers, and quantity of snow cover in the mountains nearby. Most of the participants perceived that the overall temperature has been increasing in the Muktinath region. Data on increase in temperature in the region from DHM coincided with the perception of the local people.

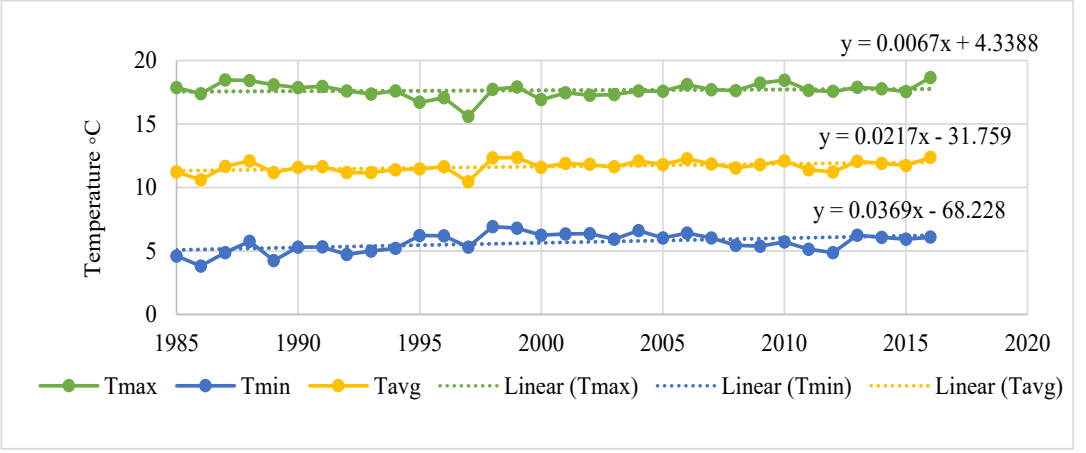

Figure 2: Annual Temperature Trend
Source: DHM Kathmandu (Jomsom station)

Multiple studies have reported similar results on rising trend of annual temperature (Shrestha *et al.* 1999; Gentle and Maraseni 2012; Shrestha *et al.* 2019). A recent study shows that Nepal faced significant fluctuations in temperature and precipitation between 1979-2016 with a large spatial variation (Shrestha *et al.* 2019). Between this period, Nepal observed an increase in mean annual temperature by 0.03 °C/year with an increase in maximum temperature by 0.02 °C/year and minimum temperature by 0.04 °C/year (Shrestha *et al.* 2019). Karki *et al.* (2019) reported that the temperature was rising at the rate of 0.0659°C/yr between 1985-2017 in Gorkha, Nepal. Moreover, Gentle and Maraseni (2012) also showed change in temperature; however, the average temperature was in an increasing trend in Jumla. The result further presented that the mean maximum temperature in Jumla ranged from 21.78 °C in 1999 to 19.6°C in 1997 while the highest mean minimum temperature was 6.1°C and lowest minimum temperature remained 2.13°C respectively (Gentle and Maraseni 2012). In addition, Khanal *et al.* (2019), and Chaudhary *et al.* (2011) reflected an increase in the summer temperature and a decreased winter temperature. Paudel and Andersen (2013) showed that the temperature increased in the summer and winter in the Trans-Himalayan region. Furthermore, Shrestha and Aryal (2011) reported that the climatic data and the perception of local people on increase in the temperature aligned.

Variation in Precipitation

Muktinath region witnessed an increasing trend in the annual precipitation between 1985-2016 (Figure 3). The annual precipitation increased at the rate of 3.18 mm/year in the study area. In addition, the highest amount of rainfall (432.1mm) was recorded during the year 1995 and the lowest amount of rainfall (116.1 mm) during 1988. Majority of the respondents (65%) during the household survey reported that the precipitation was increasing, while only 17 per cent respondents claimed that precipitation was declining. Similarly, 18 per cent of the respondents perceived that there was no change in the amount and duration of rainfall in this region.

Gautam *et al.* (2019) had the similar result showing an increasing trend of precipitation in the winter and monsoon season in the Pokhara valley. Moreover, the average annual rainfall was found to be increased by 2.11mm between 1987-2016 in Chitwan district, however, there was a decreasing trend of rainfall in the Mustang district (Khanal *et al.* 2019). This might be because of erratic nature of rainfall and differences in physiographic zones

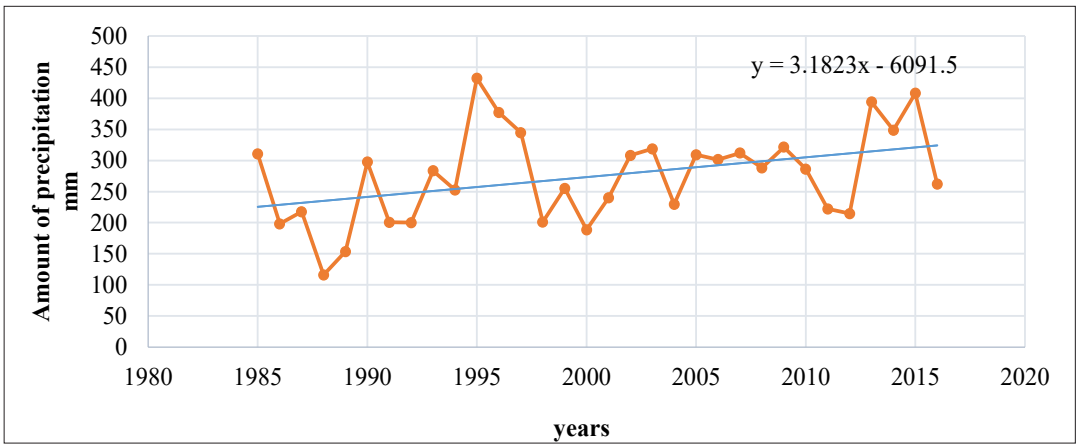

Figure 3: Annual Precipitation Trend

Source: DHM Kathmandu (Jomsom station)

of the study areas. Gentle and Maraseni (2012) found an erratic nature of precipitation in the study conducted in 2012 in Jumla district, Nepal. They observed that the mean annual precipitation of winter, pre-monsoon and post-monsoon followed a decreasing trend. Between 1979 and 2016, the annual precipitation increased at the rate of 8.7 mm/year with rise in monsoonal rainfall by 7.67 mm/year (Shrestha *et al.* 2019). Moreover, Shrestha *et al.* (2019) found that the trend of annual precipitation was continuously decreasing before 2000, whereas beyond that there has been a slight increase in the precipitation. Similarly, Bhatta *et al*. (2015) also reported that there was an increasing trend in rainfall pattern in high altitudes of the Himalaya.

Impacts of Climate Change in Muktinath Area

The impacts of climate change were observed in several sectors including agriculture, forests, livelihood, economy, and hydrological cycle. Agriculture was found to have the most adverse impact due to climate change. Non-timber Forest Products (NTFPs) reduction, crop disease, and reduced water sources were explicitly observed in the study area. Farmers in the area experienced an exponential decline in yarshagumba *(Ophiocordyceps sinensis)* production due to decline in snowfall. Yarshagumba collection and trading is the major economic surplus for the communities living in mountain regions of Nepal. People in this area also felt the increase in the occurrence of mosquito. Mosquitos are generally habituated in lower land of Nepal but due to the increase in temperature in the higher mountains, the problem has been experienced in the recent years. In addition, the respondents also claimed that there was increase in beetles and other insects in the forest crops, which reduced the quality of the major forest species such as *Pinus wallichiana and Abies species* in the area.

Impact of climate change was also observed in agricultural crop production including buckwheat in Muktinath area. This happened due to increasing drought triggered by reduction in water sources and decline in snowfall. Furthermore, this area lacks proper irrigation facility. The changes in the valuable forest and agricultural crops, NTFPs, forest fires, invasive species, and insects due to climate change are tabulated below (Table 2). Respondents in the study area revealed that the production of yarshagumba, agricultural production, NTFPs, and water sources has decreased. Similarly, there has been an increase in forest fire incidents, agricultural diseases, mosquitoes and other insects, and invasive species has dramatically increased in the recent decades. As agriculture and livestock are the major sources of livelihood and income generation among the local people, the decrease in the production of agricultural crops have negetively impacted the economy of the people in this region.

Some forms of climate induced natural disasters in the study area witnessed by the residents are floods, landslides, forest fires, and avalanche (Table 3). Approximately 66 per cent of the respondents said that they experienced landslide three times in the last 30 years, while 37.7 per cent of the participants reported that they faced high floods in the last 30 years. In addition, 37.7 per cent of respondents reported that they faced large forest fire once in the study area and approximately 2 per cent of the respondents claimed the occurrence of forest fire three times in the last 30 years. The increase in forest fire and avalanche were highly prevalent in the study area due to increase in temperature and reduction in snowfall.

Table 2: Impacts of Climate Change

Parameters of impact of CC	Condition comparison to 30 years ago					
	Highly increased (1)	Slightly increased (2)	Same as before (3)	Slightly decreased (4)	Highly decreased (5)	Weighted mean
Yarshagumba collection	0	0	7	16	37	4.5
Agriculture production	0	0	17	35	8	3.85
NTFPs production	0	0	13	13	34	4.35
Human injury	3	13	29	15	0	2.93
Forest fire	8	18	21	13	0	2.65
Mosquitos, beetles and other insects	8	34	15	3	0	2.22
Crop disease	19	35	6	0	0	1.78
Invasive species	0	17	24	19	0	3.03
Water resource	0	0	11	23	26	4.25

Several studies on climate change in Nepal have revealed high impacts of climate change in agricultural crops (Shrestha *et al*. 2000; Manandhar *et al*. 2011; Gentle and Maraseni 2012; Li *et al*. 2013; Machhi *et al*. 2014; Gentle *et al*. 2014; Adhikari *et al*. 2018; Khanal *et al*. 2019; Paudel *et al*. 2020). Gentle and Maraseni (2012) reported reduction in the cultivation and production of local rice in Western Nepal. People used to plant the rice species thrice in a year but now they have dropped it to 1 or 2 times in a year. Li *et al*. (2013) claimed that the pests and insects remain active in warm temperature while they remain inactive in low temperatures. The increasing temperature in the study area might have enhanced the habitat for invasive species and other insect species. Similarly,

Table 3: Impact of Climate Change on Weather Related Disaster

Natural disaster	One time (%)	Two times (%)	Three times (%)	Not faced (%)
Flood	11.32	37.7	28.57	23.08
Forest fire	37.74	27.87	2.86	24.18
Landslide	9.43	14.75	65.71	25.27
Avalanche	41.51	19.67	2.86	27.47

Shrestha and Bawa (2015) claimed that the impacts of climate change have dramatically declined the habitat of medicinal species like yarshagumba (*Ophiocordyceps sinensis).* However, Manandhar *et al*. (2011) found an increase in some species of fruits and agricultural crops in the higher altitudinal zones compared to the lower planes.

In the high lands of Nepal, *Nessella neesiana* have invaded the pastureland and grassland biodiversity (Bourdot *et al.* 2012). Shrestha *et al*. (2015) show that in the high mountainous areas the increase in *Parthenium hysterophorus* detrimentally affected the forest ecosystem and biodiversity. Similarly, Hobbs and Mooney (2005) also revealed the spreading of the habitat of different invasive species due to changing climate. Furthermore, multiple invasive species like *Mikania micrantha, Lantana camara, Parthenium hysterophorus,* and *Chromolaena odorata* have covered forest lands that have negative impacts on biodiversity and forest ecosystems (Lamsal *et al.* 2017). However, Khanal *et al.* (2019) reported that there was decline in forest fire incidents which might be due to the successful community level awareness programmes. Several studies (Piya *et al.* 2013; Gentle *et al.* 2014; Piya *et al.* 2016) have found that disasters like soil erosion, landslide, and flood are the major impacts of climate change occurring every year in different parts of the country. In addition, other studies have also provided evidences of natural hazards like forest fire, landslide, and flood occurred due to climate change (Chaudhary and Bawa 2011; Manandhar *et al*. 2011; Gentle and Maraseni 2012; Gentle *et al*. 2018). In contrary, scholars argue that the impacts of climate change should not be limited within the periphery of changes seen in temperature and precipitation and the impacts that are observed due to these changes, but it should also be considered from the social perspective which gives holistic understanding of impacts of climate change in human livelihood and ecological systems (Sherpa 2014; Poudel 2020a; and Poudel 2020b)

Adaptation Strategies to Climate Change

The local people in the community were adopting several adaptation strategies to cope with the impacts of climate change based on their own traditional knowledge and support from multiple organisations working in the area. We found that the Local Adaptation Plans of Action (LAPA) was implemented in the area, and people were supported with several adaptation strategies through small projects. Several adaptation strategies adopted by the community members are presented in Figure 4. Nearly half of the farmers (45%) altered their occupation from agriculture to business and cash crops production as a strategy to adapt with the climate change. Likewise, 13 per cent of the farmers changed their cropping pattern. They also reported that they changed crop species that are suitable to the changing climate. For example, they used to plant buckwheat and wheat in the past but now they have started mixing them with apples. This shows that they adopted agroforestry practices to adapt to the changing climate. In addition, they generated good amount of money from apple plantation to enrich their economic status and adopt multiple form of adaptation strategies locally.

Respondents also adopted rotational cropping system to prevent disease transmission and enhance crop productivity. They said that they have started to replace buckwheat with wheat to promote productivity. As the cases of drought and water scarcity is increasing every year, they adopted to wheat plantation that requires fewer water than buckwheat. Furthermore, 12 per cent of the participants reported that they have changed planting and harvesting time of the crops. Due to the change in rainfall pattern, they claimed that they faced slight change in planting and harvesting season and therefore had to adjust their planting and harvesting time. Similarly, 8 per cent of the farmers adopted chemical fertilizers and insecticides due to lower productivity and increase in pest infestation in the agricultural land. Moreover, they also adopted

mulching to safeguard the water in seedlings and cleaning practices to control weeds that supported agricultural productivity. A small number (5%) of respondents said they have installed artificial water tank for water harvesting and storage as an adaptation measure to water scarcity for household chores and livestock feeding. In response to the increased landslide, soil erosion and flood, the community has started constructing different engineering structures like check dams, gabion boxes, and embankments.

Several studies have shown similar findings. Manandhar *et al.* (2011) revealed crop diversification, irrigation canal systems, and small scale enterprise business to adapt to climate change. Moreover, they asserted that enrichment in traditional and indigenous knowledge helped in promoting long-term adaptation strategies. Promotion of cash crops, using hybrid seeds, promoting irrigation systems, bio engineering, intensifying fertilizers and strengthening soil conservation activities are major adaptation strategies (Regmi *et al.* 2008; Gentle and Maraseni 2012; Piya *et al.* 2013; Gentle *et al.* 2014; Adhikari *et al.* 2018; Khanal *et al.* 2018; Gentle *et al.* 2018; Khanal *et al.* 2019; Paudel *et al.* 2020; Dhungana *et al.* 2020). The adaptation strategies designed locally to enrich agricultural productivity in various parts of Nepal were short-term (Gentle *et al.* 2018; Khanal *et al.* 2018; Poudyal *et al.* 2021). Therefore, there is a need for a rather long-term adaptation strategies. Bhatta and Agrawal (2015) claimed that the local farmers are adjusting their cropping system according to their capacities rather than looking for financial loans, which could be economic burden in the future. Furthermore, Acharya (2021) argued for the need of promotion of renewable energy technologies such as hydropower, solar power, wind energy, and improved cooking systems in the mountainous country like Nepal to adapt with the changing climate. Sherpa (2014) and Poudel (2020a) have reported that defining and adopting adaptation based on the changes seen in temperature and precipitation are not enough as they do not incorporate the social perspective of adaptation, which require incorporation of the local understanding and voices in policy planning and implementation.

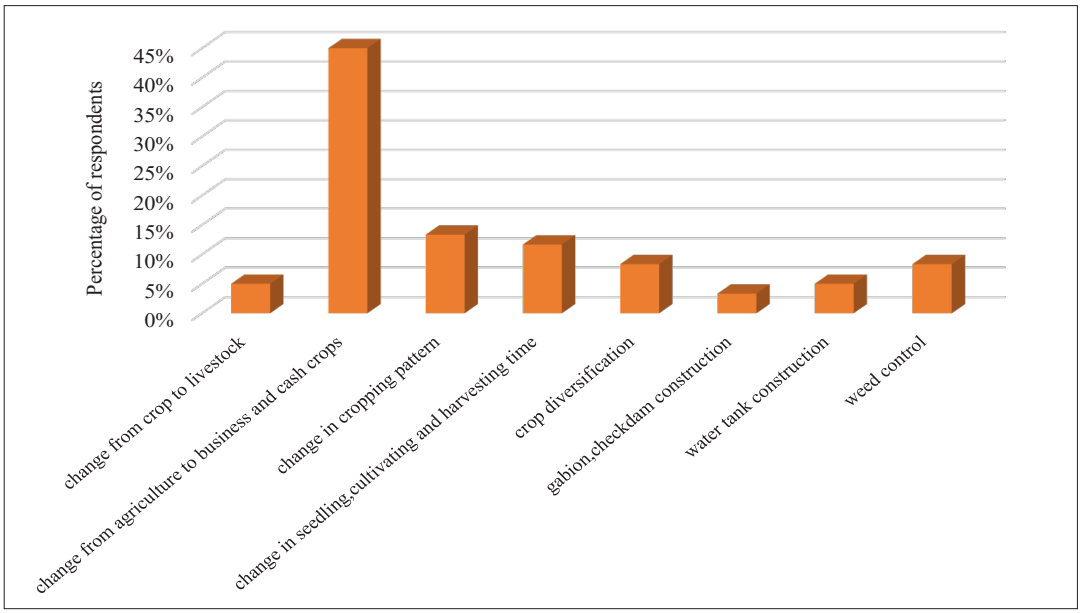

Figure 4: Various Adaptation Strategies Adopted by Local People

Barriers to Adaptation Strategies

Several barriers and challenges to climate change adaptation faced by the communities were identified in the study area. The barriers and challenges have been listed in a hierarchical rank (Table 4); starting from the highest to lowest priority based on respondents' opinions. A non-parametric Friedman test was employed to test the major barriers to climate change adaptation.

Table 4: Barriers to Adaptation Strategies

Ranks	
Ranking of barrier to:	**Mean Rank**
No access to money	(1)1.52
No access to water	(6)5.63
No access to land	(7)6.65
Shortage of labor	(2)1.97
Lack of knowledge on adaptation	(4)4.05
Poor infrastructure	(5)5.30
Lack of market	(3)2.88

Here, chi-square value=294.829, df(n-1)=6 Asymp. Sig (p) value is less than 0.01 i.e., different people significantly perceived the different barrier which was at 1 per cent level of significance. The major barriers and challenges were lack of access to money followed by labor shortage, lack of market, lack of knowledge on climate change and adaptation, poor infrastructure, lack of access to water and land. Very few farmers had little knowledge on adaptation and were adopting short-term and reactive adaptation strategies. Moreover, their financial status was weak to adopt modern techniques in agricultural adaptation. Most of the farmers had migrated to nearby urban areas like Pokhara or country's capital Kathmandu for employment and other income generation activities. Moreover, most of the youths in the village have migrated to India and other golf nations for foreign employment due to lack of quality education and employment in the village. The geography and landscape are fragile in Mustang district that has hindered market access to export the locally produced fruits and agriculture.

CONCLUSION

This paper highlights the change in the pattern of different climatic variable like temperature, and precipitation based on meteorological data and farmer's experience. This study also presented the impacts of climate change, adaptation strategies followed by the local communities, and barriers in adopting adaptation strategies in the mountain regions of Nepal. We conclude that the mountain regions are prone to the changing climate and are anticipated to have additional impacts in the coming years. The meteorological data and farmers' perception reveal that on an average, the annual temperature is rising, and precipitation is erratic in nature, that has negative impact on the mountain livelihood. We also conclude that there is lack of knowledge on climate change among farmers. Lack of agricultural and forest crops productivity, reduced NTFPs production, reduced Yarshagumba production, increased insects, pests, and mosquitoes, increase in natural hazards like flood, landslide, forest fire, increased occurrence of droughts were the major impacts seen due to climate change in Muktinath area. In response to these changes, farmers have been adopting diverse adaptation strategies based on their own locally available resources and traditional knowledge. Change in the crop species, cropping pattern and time, employing rotational cropping, adopting agro forestry practices, mulching, using insecticides and fertilizers, water harvesting and storage, construction of engineering designs like check dams, gabion boxes and embankments etc. are the major adaptation strategies practiced. We also found that lack of financial support, lack of knowledge, technical ideas, economic status, and lack of labors were major barriers and challenges to adopting adaption strategies.

These results suggests that the impacts of climate change are increasing rapidly but the current adaptation strategies are not sufficient to adapt with these changes. Most of the adaptation strategies were short-term, reactive, and based on farmer's weak knowledge. The policies and plans were not satisfactorily able to address the voice and need of the farmers. Thus, we recommend that the local level government should ensure the active participation and voices of local farmers in municipal level policy planning and implementation. The local level policies must mainstream climate change adaptation strategies into their annual plans. Moreover, the adaptation strategies should integrate environmental, socio-cultural, and economic aspects to ensure its effectiveness and better outcome. Finally, it is crucial to integrate farmers' traditional knowledge and modern technologies for the sustainable and effective outcomes in the long-run.

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