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Implication of Climate Variability on Water Resources Availability and Management of Melamchi Municipality

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Abstract

This study examines the impact of climate change on water resources in Melamchi Municipality, Nepal, based on focus group discussions, interviews, and field observations. Thirty-one years (1990–2021) of temperature and precipitation data from DHM were analyzed using the Mann-Kendall test, Sen's slope, and autocorrelation analysis. The study assessed the community's vulnerability to climate change using the exposure, sensitivity, and adaptive capacity indicators. The result indicates rising temperature at all stations while precipitation records indicate a significant decreasing trend in eight of the twelve stations. Autocorrelation analysis and Box-Ljung test of Dubachaur station precipitation indicated that the rainfall in a specific year is strongly related to the rainfall in subsequent years, while the yearly temperature data of the Melamchi region exhibited no strong linear dependencies and confirmed the absence of significant autocorrelations. Vulnerability analysis revealed differential exposure, sensitivity, and adaptive capacity within municipality according to the availability of sources. To address the issue, the study highlights the urgent need for adaptive water management strategies that incorporate both scientific and traditional knowledge.

Keywords: climate, climate variability, water resource, management, Melamchi

Introduction

Climate change is a long-term change in an area's specific or average climate. In recent decades, industrial and human activities have resulted in gradually accelerating changes to the climate, including an incremental annual increase in the average surface temperature, defined as climate change (Santos & Bakhshoodeh, 2021). Compared to industrialized countries, the impacts of climate change are more damaging economically

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developing countries (Devkota, 2014), and thus, it has been recognized at many forums for the last few decades (Riaz, 2018).

Climate change is evident in the predicted or observed occurrences of increasingly frequent and severe heatwaves, droughts, rainfalls on a global scale (Ozerola et al., 2020), uneven precipitation distribution, decreasing snow cover owing to increased temperatures, droughts, and sea-level rise (Kareem et al., 2021). Ground and surface water systems are impacted by climate variability and change in two ways: directly through evaporation and recharge, and indirectly through changes in water demand (Kareem et al., 2021). It is making droughts more frequent and severe, making it more difficult to manage water resources (Silva et al., 2022).

Water availability and demand are out of balance in many parts of the world right now, and this situation is expected to worsen in many more shortly (Vörösmarty et al., 2000). Many people throughout Asia rely on the massive mountains in the HKH region for their water supply where crop irrigation accounts for between 70 and 90 percent of the freshwater resources (Gurung & Sherpa, 2014). Climate change can affect the availability of water directly through changed patterns of rainfall and indirectly through changing water areas, including groundwater, surface water, snow, and glaciers, which can be utilized for agricultural water deposits, such as livestock and irrigation (OECD, 2014). Droughts in some areas are making water scarcer, which has a detrimental effect on people's productivity and health (Kolladi., 2014).

Nepal is the tenth most affected nation during the past 20 years in terms of deaths, losses, and damages, according to the German watch Global Climate Risk Index for 2021. Nepal is extremely vulnerable to the impact of climate change due to its rough, mountainous terrain, severe weather, frequent natural disasters, the inability of its poor citizens to adopt adaptation measures, political instability, and governance challenges (Mainali & Pricope, 2017) and thus expected to warm more quickly than the rest of the region. Nepal's average annual maximum temperature increased by 2.4 °C (0.056 °C/y) over an average of 44 years and mean rainfall has significantly decreased on an average of 3.7 mm per month per decade (GoN, 2016). Compared to the baseline period of 1986-2005, Nepal is expected to warm by 1.2^{0}C to 4.2^{0}C by the 2080s under the most extreme emission scenario, RCP8.5 (WBG & ADB, 2021).

In Nepal, around 80% of the country's rainfall is received during the monsoon season, which is the primary source of groundwater recharge. Similarly, most agricultural activities depend on monsoon rainfall, and any difference in the temperature of the air can lead to changes in climatic conditions like changes in precipitation and weather conditions, which have a direct impact on agricultural and other daily activities (Urfels, et al., 2019).

As Nepal's hills and mountains are predicted to have significant climate change impacts, water resources will remain one of the most urgent environmental challenges, with the largest impact sector among other sectors (Agrawala et al., 2003). As water supplies contribute to river flow, changes in them will affect the water needs of small-scale water management systems (urban water supply, micro/small hydropower, small-scale irrigation systems, and small businesses) (MoFE, 2021). In many regions, water supply is becoming less predictable, and more frequent flooding threatens to destroy water points and sanitation infrastructure as well as contaminate water sources. Droughts in some areas are making water scarcer, which has a detrimental effect on people's productivity and health. Conflicting needs, population growth, urbanization, climate change, hazardous chemicals, and natural disasters make the management of water resources more difficult (Kolladi, 2014). Improved resource management and governance techniques should be the way to lasting solutions. Failure to do so might be accountable for the challenges concerning local water shortages (White & Haapala, 2019).

In context of Nepal, water transfer from rural to urban areas presents challenging issues of public policy, especially when addressing the interests of various stakeholders. In most instances, climate change is overlooked in policies and water resource management. Mitigation of water stress has become a pressing issue for local governments, which have the mandate to ensure access to water for every household. Current community-level interventions are still not sufficient in actually managing water resources and reducing water stress. Local governments have to utilize inherent capacities, seek the assistance of development partners and communities, and implement effective disaster management actions to mitigate these concerns (Gartaula et al., 2008). In this scenario, this study has been carried out to examine the impact of climate change on water resources in Melamchi Municipality.

Methods

The research was conducted in Melamchi, municipality of Sindhupalchok District, located in the Bagmati Province of central Nepal. The study area spans elevations from 755 to 1568 meters above mean sea level and includes three wards: Duwachaur (Ward 7), Kyaurani (Ward 8), representing upstream areas, and Fatakshila (Ward 13), representing downstream areas. The weather in the region is subtropical and humid, with an average temperature of 18°C. June is the warmest month, with an average temperature of 22°C, while January is the coldest, averaging 12°C. The annual rainfall is 1,999 millimeters. July is the wettest month, receiving 466 millimeters of rain, whereas November is the driest. Duwachour and Kyureni together have 1,375 households and a population of 5,713 people, comprising 2,940 females and 2,773 males. Fatakshila has 894 households with a total population of 4,286, consisting of 2,148 females and 2,138 males (CBS, 2021). The region's water resources are critical for agricultural and domestic use, making it a suitable case for examining the impacts of climate change.

In order to connect quantitative and qualitative data and produce integrated results, this study used an ordered explanatory mixed-methods model, which involves collecting and analyzing quantitative (climate data) and qualitative (FGD/Key informant interview) data in two successive phases (Ivankova et al., 2006). A total of 11 stakeholders from Melamchi municipality were chosen as key informants, and they provided insightful information about how water is distributed, how natural resources are used, and how weather and rainfall patterns have evolved. They also discussed the community's capacity for adaptation and problem-solving. In addition to relevant groups, these informants represented a variety of categories, including caste, ethnic communities, and gender.

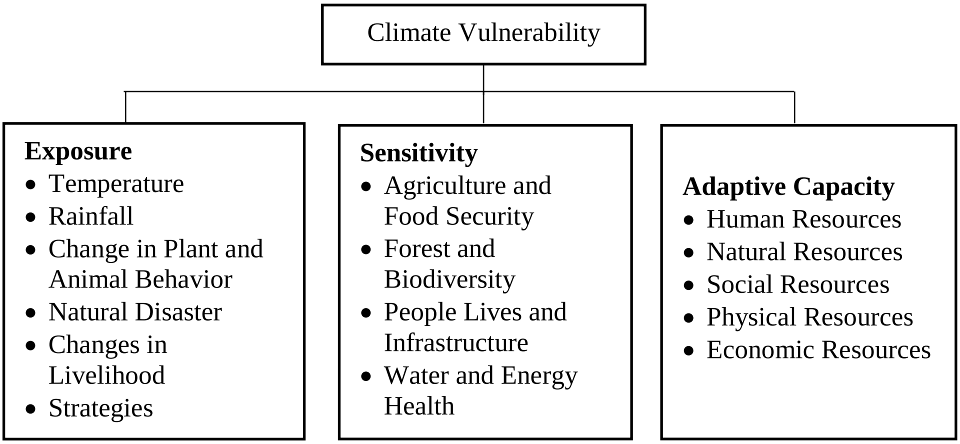
Further, a focus group discussion was conducted in a particular community. Before that, climate change sensitization sessions were performed to ensure participants were informed and engaged. FGDs were held with members of the community reflecting a range of genders, indigenous peoples, ethnic and caste groups, as well as members of water user associations and agricultural cooperatives, to gather primary data. There were 7-12 participants in each session who shared their perspectives and experiences in a comfortable and informal setting. Climate change-related stress, its impact on people’s livelihood, water management, resource allocation, people’s vulnerability, and associated conflicts were the topic of discussion. A total of 22 focal communities were involved in the discussion. Field observations were carried out to assess climatic hazards and vulnerability issues.

To analyze the temperature and precipitation time-series pattern, climate data from various sources were used. The major source was the Department of Hydrology and Meteorology (DHM), which provides data from the nearest weather station. In particular, annual and monthly precipitation measurement data were gathered from 12 meteorological stations across the Sindhupalchok district. To analyze temperature trend along with DHM’s station data, data from the NASA POWER gridded database were utilized. This database, provided by the National Aeronautics and Space Administration/Prediction of Worldwide Energy Resources (NASA/POWER), provides detailed weather data with an associated horizontal resolution of ½° x ⅝° in terms of latitude and longitude. The data was extracted based on a specific geographic location with the coordinates 27.94456111 latitude and 85.59513611 longitude, situated at an elevation of 2909.05 meters.

The data were analyzed using rank-based non-parametric Mann-Kendall (MK) statistical test, which is one of the widely used test to identify significant trend in hydro-meteorological time series. Sen's slope estimator was used to calculate the true slope of hydro-meteorological time series data. Along with autocorrelation, the study run data for vulnerability test. The study follows the IPCC's definition as presented in Figure 1.

Figure 1

Grouping of Vulnerability Components



For this study, vulnerability is defined as the condition of high risk and limited capacity to recover, often marked by the state of helplessness, the risk of injury, death, loss, or livelihood disruption, and challenges to recovery during extreme events (Wisner et al., 2014).

Exposure is assessed through temperature, rainfall, risks, proxy indicators (plants and animals), and physical changes over the last 30 years. Sensitivity is the impact of local climate change and related hazards on biophysical and socioeconomic systems. Adaptive Capacity is the ability of a system to adapt to climate change to mitigate potential damages, capitalize on opportunities, or cope with consequences.

Exposure, sensitivity, and adaptation were assessed on a scale of 1 to 4, with 1 being a low perception of the community, 2 a moderate perception, 3 a strong perception, and 4 a very high perception (PAC, 2010). As a result, the vulnerability could only have a maximum value of 16 [(V=E*S*1/A) = (4*4*1/1)]. The lowest value that could be achieved was 0.25 [(V=E*S*1/A) = (1*1*1/4)]. There are 64 different V combinations in the range of 0.25 to 16.00 when the values of E, S, and A are all whole numbers. The value of V was further divided into 4 categories, with index 0.25-1 denoting low value, 1-2 denoting medium value, 2-4 denoting high value, and 4-16 denoting very high value (LAPA, 2011).

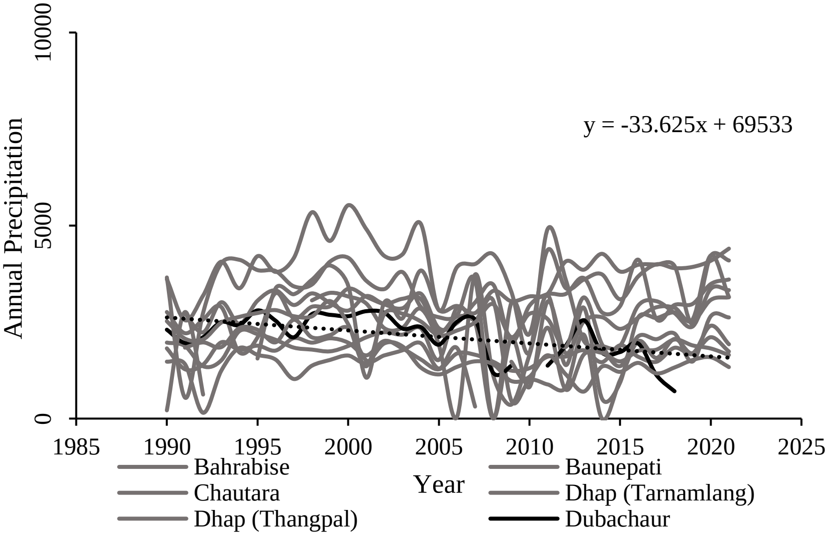
Results

Precipitation Analysis of Sindhupalchowk District

A trend analysis was carried out using 31 years (1990-2021) rainfall data from the Department of Hydrology and Meteorology (DHM) across twelve stations in Sindupalchowk district. The highest annual precipitation during this period was recorded at the Gumthang station in 2000, with a total of 5526.7 mm. Average annual precipitation ranged from 1,352.16 mm in Sangachok to 3,590.81 mm in Gumthang. Among the twelve stations, eight showed a decreasing trend, and four showed an increasing trend in annual precipitation, with only four stations showing statistically significant changes, while the remaining trends were not significant.

Figure 2

Annual Precipitation trend of all 12 stations



These findings are consistent with Pradhan et al. (2015), who reported a similar kind of fluctuation and mostly insignificant trend in the Indrawati river basin. They revealed a shift toward fewer but more intense rainfall events, suggesting a tendency for more irregular rainfall patterns and an increase in extreme events. Similarly, Karki et al. (2017) found a decreased but insignificant trend in seasonal precipitation across high ranges and the Himalayas from 1971 to 2014, with worsening extreme events.

The Mann-Kendall test results (Table 1) indicate that eight out of twelve stations show no significant trend in annual precipitation (p-value > 0.05), while four stations (Dhap Tarnamlang, Dhap Thangpal, Duwachaur, and Sarmathang) exhibit statistically significant trends. Sen's slope analysis reveals that eight stations have a decreasing trend and four stations show an upward trend.

Table 1

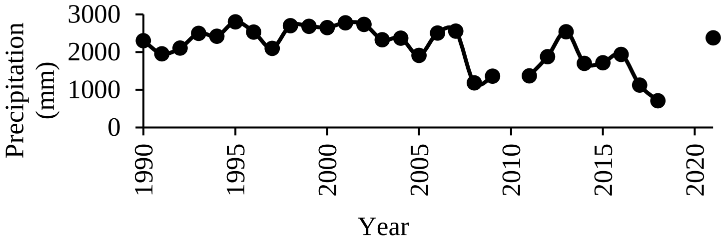
Statistical Results of Precipitation Data From 12 Stations

S. N	Station Name	Mann-Kendall Statistics (S)	Kendall's Tau	Var(S)	P value (two-tailed)	alpha	Sen's Slope
1	Bahrabise	-41	-0.088	3461.667	0.497	0.05	-6.362
2	Baunepati	-56	-0.113	3802.667	0.372	0.05	-4.593
3	Chautara	-18	-0.036	3802.667	0.783	0.05	-4.502
4	Dhap (Tarnamlang)	172	0.347	3802.667	0.006	0.05	24.923
5	Dhap (Thangpal)	168	0.349	3737.333	0.006	0.05	64.844
6	Duwachaur	-193	-0.390	3799.000	0.002	0.05	-43.635
7	Gumthang	-120	-0.242	3802.667	0.054	0.05	-43.732
8	Nawalpur	-70	-0.141	3802.667	0.263	0.05	-8.778
9	Sangachok	-56	-0.113	3802.667	0.372	0.05	-4.465
10	Sarmathang	251	0.507	3801.667	<0.0001	0.05	81.908
11	Tarke Ghyang	68	0.137	3802.667	0.277	0.05	12.883
12	Thokarpa	-109	-0.234	3461.667	0.066	0.05	-14.6

Annual Precipitation Changes in Duwachaur Station During 1990-2021. The current study used 31 years of precipitation data (1991-2021) from the Duwachaur station using the Mann-Kendall test and Sen's Slope Estimator. The analysis shows that the highest annual rainfall was 2801.7 mm in 1995, and the lowest was 708.7 mm in 2018, with an average annual rainfall of 1936 mm. The results indicated a significant decreasing trend in precipitation, with a Mann-Kendall p-value of 0.002 and a Sen's slope of -43.635, confirming a decline in rainfall over the study period.

Figure 3

Annual Precipitation of Duwachaur Station



Seasonal Precipitation of Duwachaur Station. A significant trend in precipitation was observed during the monsoon, spring, and autumn, with no significant trend in winter. Monsoon (June-August) was the wettest season, averaging 1,354 mm with the highest annual rainfall of 2,071 mm in 1995 and the lowest at 336.5 mm in 2018. Winter (December-February) was the driest season, averaging 47 mm, peaking at 129.4 mm in 2003 and declining to 2 mm in 2012, with an initial downward trend followed by high variability. Spring (March-May) and autumn (September-November) also showed substantial year-to-year variation, with precipitation ranging from 35.2 mm to 574.6 mm in spring, and 35 mm to 624.97 mm in autumn. These patterns align with broader national trends, where monsoon dominates annual rainfall and winter precipitation is influenced by western disturbances, particularly in high-altitude areas (Pokharel & Hallett, 2015).

Figure 5

Seasonal Precipitation trend of Duwachaur station

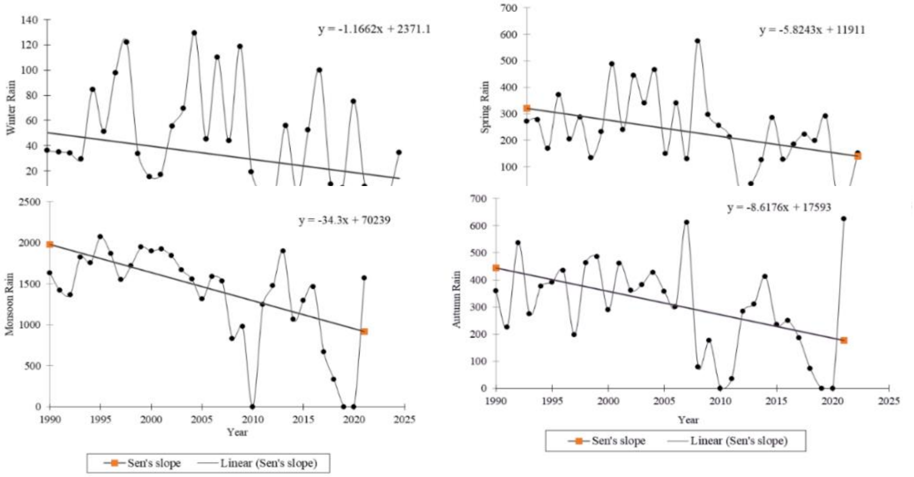


Table 2 shows no significant winter trend (p = 0.082, Sen’s slope = -1.17 mm/year), while spring (p = 0.027, slope = -5.82 mm/year), monsoon (p = 0.000), and autumn (p = 0.018, slope = -8.61 mm/year) exhibit significant decreasing rainfall trends.

Table 2

Mann-Kendall Statistics of precipitation of Duwachaur Station

S.N	Seasons	Mann-Kendall Statistics (S)	Kendall's Tau	Var(S)	P value (two-tailed)	alpha	Sen's Slope
1	Winter	-0.219	-108	3794	0.082	0.05	-1.166
2	Spring	-0.277	-137	3799	0.027	0.05	-5.824
3	Monsoon	-0.447	-221	3799	0	0.05	-34.3
4	Autumn	-0.297	-147	3799	0.018	0.05	-8.618

Autocorrelation Function. The autocorrelation function for Duwachaur station was estimated for lags 1 to 10. The Box-Ljung test was used to determine the overall statistical significance of these autocorrelations up to lag 10 (Table 3). The data was assumed to represent a white noise process, indicating independence.

Table 3

Autocorrelation Function

Lag	Autocorrelation	Box-Ljung Statistic		
		Value	Df	Sig.[b]
1	.495	7.852	1	.005
2	.231	9.630	2	.008
3	.289	12.522	3	.006
4	.149	13.323	4	.010
5	.218	15.111	5	.010
6	.276	18.088	6	.006
7	.147	18.968	7	.008
8	.158	20.032	8	.010
9	-.031	20.073	9	.017
10	-.288	24.011	10	.008

a. The underlying process assumed is independence (white noise).

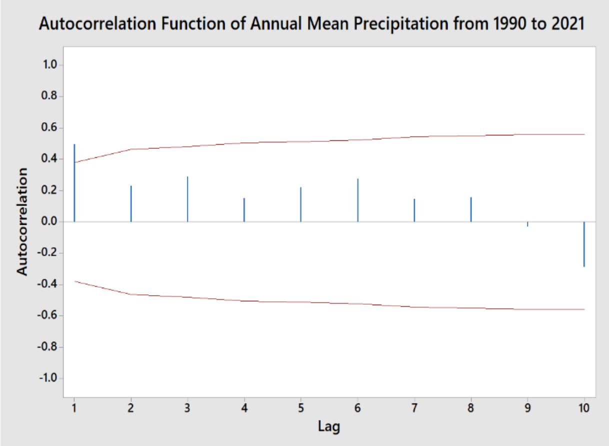
b. Based on the asymptotic chi-square approximation.

The autocorrelation analysis showed significant positive autocorrelations at lags 1 and 2 (0.495 and 0.231), indicating strong short-term persistence. This means higher rainfall in one year is likely followed by higher rainfall in the next year or two. The autocorrelations slowly decreased with increasing lags, reaching -0.031 at lag 9. The

Box-Ljung test confirmed significant autocorrelations up to lag 10, rejecting the hypothesis of zero autocorrelation and indicating that the rainfall data is not random but connected over time, suggesting potential for time series forecasting.

Figure 6

Correlogram (Autocorrelation Plot) of Rainfall Data of Duwachaur Station



Temperature Changes in Sindhupalchowk District During 1990-2021

Annual Temperature. A temperature trend analysis was conducted using eleven years (2011–2021) of data from Bahrabise, Chautara, and Sarmathang stations. Sen’s slope estimator and the Mann-Kendall test were applied to determine trends.

Table 4

Average Value of Kendall's tau

S.N.	Station Name		Kendall's tau	Alpha	Var (S)	P-value	Sen's slope
1	Bahrabise	Min	-0.273	0.05	165	0.276	-0.225
		Max	0.382	0.05	165	0.119	0.129
2	Chautara	Min	-0.611	0.05	92	0.028	-0.228
		Max	-0.166	0.05	92	0.783	0.121
3	Sarmathang	Min	-0.066	0.05	125	0.858	-0.010
		Max	-0.466	0.05	125	0.073	-0.233

From Mann-Kendall analysis, it is found that the minimum average temperature at Bahrabise showed a downward trend, but a trend that was not statistically significant (Kendall's tau = -0.273, p = 0.276; Sen's slope = -0.225). There was a non-significant upward trend in the highest average temperature (tau = 0.382, p = 0.119; Sen's slope =

0.129). There was a non-significant negative trend (tau = -0.166, p = 0.783) with a little positive Sen's slope (0.121) at Chautara, while the minimum average temperature exhibited a significant declining trend (tau = -0.611, p = 0.028; Sen's slope = -0.228). The minimum average temperature at Sarmathang showed no obvious pattern (tau = -0.066, p = 0.858; Sen's slope = -0.010). Nearing statistical significance, the maximum average temperature showed a declining trend (tau = -0.466, p = 0.073; Sen's slope = -0.233).

Figure 7

Maximum Average Temperature of Bahrabise, Chautara and Sarmathang Station

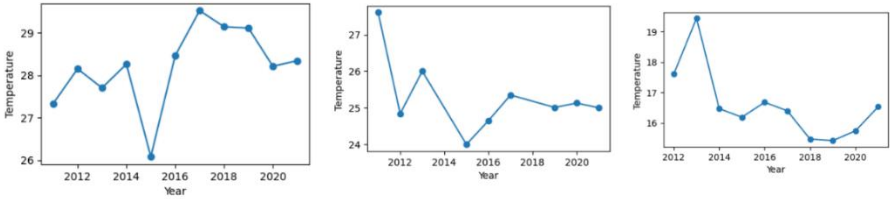


Figure 8

Minimum Average Temperature of Bahrabise, Chautara and Sarmathang Station

Table 5

Descriptive Results

S. N	Station Name	Temperature (^{0}C)	Min	Max	Mean	Std. Dev.
1	Bahrabise	Min Average	12.249	16.667	14.376	1.167
		Max Average	26.076	29.523	28.11	1.03
2	Chautara	Min Average	12.25	14.68	14.09	0.83
		Max Average	24.00	27.614	19.66	0.96
3	Sarmathang	Min Average	6.92	8.10	7.46	0.53
		Max Average	15.42	19.44	16.83	1.166

The analysis showed that at Bahrabise station, the highest average maximum temperature was 29.52 °C in 2017 and the lowest was 26.07 °C in 2015. At Chautara, it was highest at 27.61 °C in 2011 and lowest at 24.65 °C in 2016. Sarmathang recorded the highest in 2013 (19.44 °C) and lowest in 2019 (15.42 °C). For minimum average temperatures, Bahrabise had the highest at 16.67 °C in 2011 and the lowest at 12.25 °C in 2015. Chautara's minimum was highest in 2013 (14.68 °C) and lowest in 2019 (12.25 °C). Sarmathang's minimum was highest in 2013 (8.10 °C) and lowest in 2018 (6.92 °C).

In 2017, the Nepalese Department of Hydrology and Meteorology (DHM) published research that used non-parametric Mann-Kendall and Sen's Slope algorithms on daily temperature data from 93 sites to analyze climatic changes from 1971 to 2014. With an annual maximum temperature increase of 0.056°C, the results showed a notable rise in Nepal's maximum temperature. The monsoon season was the only time when the minimum temperature had a trend to rise, with a modest annual increase of 0.002°C. Throughout the research period, precipitation trends did not significantly change.

Seasonal Temperature.

Table 6

Average Temperature at Different Stations and Seasons

SN	Station Name	Seasons	Maximum Average Temperature		Minimum Average Temperature	
			Sen's Slope	p- value	Sen's Slope	p- value
1	Bahrabise	Winter	0.159	0.02	-0.176	0.119
		Spring	-0.12	0.21	-0.238	0.02
		Monsoon	0.055	0.876	-0.067	0.161
		Autumn	0.29	0.043	0.007	0.876
2	Chautara	Winter	0.255	0.68	0.226	0.492
		Spring	0.081	0.631	0	0.873
		Monsoon	-0.01	0.938	-0.055	0.938
		Autumn	0.107	0.386	0.001	0.813
3	Sarmathang	Winter	0.518	0.304	0.063	0.304
		Spring	-0.245	0.213	-0.078	0.755
		Monsoon	-0.086	0.276	0.124	0.013
		Autumn	0.2	0.062	0.54	0.003

Table 6 showed the highest mean temperature at the Bahrabise station records significant rising trends in winter and autumn, with insignificant trends in spring (declining) and monsoon (rising). Chautara station shows no significant trends for any season but has a slight decline in monsoon and rising trends in other seasons. In Sarmathang, the trend is rising in autumn, while winter (rising), spring, and monsoon (both declining) show no significant trends. For the minimum average temperature, Bahrabise station shows a significant decreasing trend in spring ($p < 0.05$), while winter, monsoon, and autumn exhibit non-significant trends ($p > 0.05$), with winter and monsoon decreasing slightly and autumn increasing slightly. Chautara station exhibits non-significant trends for all seasons, with winter increasing slightly, monsoon decreasing slightly, and no significant trend for spring and autumn. Sarmathang station shows significant increasing trends in autumn and monsoon ($p<0.05$) and no significant trends in winter (increasing) and spring (slight decreasing).

Autocorrelation Function of Annual Average Temperature. The National Aeronautics and Space Administration/Prediction of World-Wide Energy Resources (NASA/POWER) gridded database of annual average temperature from 1981 to 2021 were analyzed to assess the autocorrelation function, and the Ljung-Box test statistic is a statistical test used to evaluate the presence of autocorrelation in time series data of annual mean temperature.

Table 7

Autocorrelation Function of Annual Average Temperature Data of Melamchi Region

Lag	Autocorrelation	Std. Error[a]	Box-Ljung Statistic		
			Value	df	Sig.[b]
1	.194	.151	1.658	1	.198
2	-.120	.149	2.304	2	.316
3	.085	.147	2.642	3	.450
4	-.013	.145	2.650	4	.618
5	-.056	.143	2.801	5	.731
6	-.132	.141	3.679	6	.720
7	.169	.139	5.161	7	.640
8	.226	.137	7.901	8	.443
9	-.154	.135	9.204	9	.419
10	-.060	.133	9.410	10	.494

a. The underlying process assumed is independence (white noise).

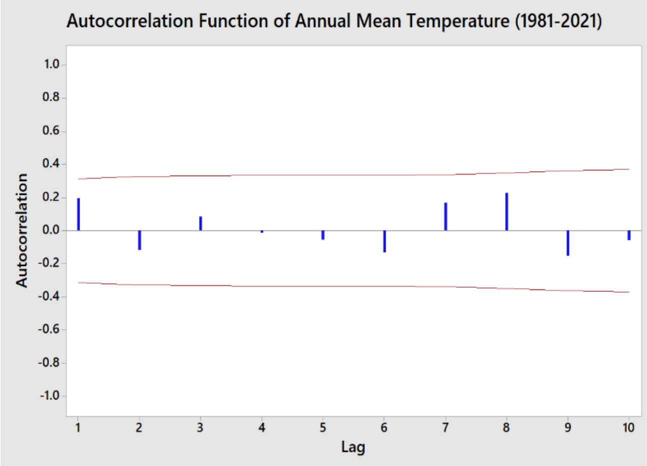
b. Based on the asymptotic chi-square approximation.

The sample autocorrelation function was computed for lags 1 to 10 to assess temperature persistence over time. Results showed low magnitude autocorrelations, with the highest at 0.226 observed at lag 8. None of these autocorrelations were statistically significant at the 5% level, as indicated by the high p-values from the Box-Ljung test. The first-order autocorrelation is 0.194, indicating some degree of short-term persistence from year to year; however, this is insignificant ($p = 0.198$). As the lag increases, the autocorrelations fluctuate in positive and negative signs. This suggests there are no consistent cyclical patterns or periodicity in the data.

The lack of significant autocorrelations implies that the annual temperature process does not exhibit statistically meaningful linear dependence over time. Therefore, the analysis indicates the absence of strong persistence or cyclical dynamics in the annual temperature data. This has implications for forecasting, suggesting temperatures may be difficult to predict solely from past values. Overall, the absence of statistically significant autocorrelations suggests that annual temperature observations are relatively independent from year to year, without strong linear dependencies or predictable patterns. This implies challenges in forecasting temperatures based solely on historical data, as there is no clear evidence of long-term trends or seasonal cycles in the dataset.

Figure 9

Correlogram of Annual Average Temperature of Melamchi Region



Community Perception on Climate Change

A total of 173 participants from 22 different communities participated in focus group discussions. Of this, that 54% were female and 46% were male reflects a higher representation of female participants due to the relative unavailability of male participants due to out-migration for work during the focus group discussions. Educational levels varied: 34.7% had no formal education, 30.6% had primary education, 20.8% had secondary education, while 13.9% had higher secondary education. Occupations were mainly agricultural (54%), with others engaged in mixed (28%) or non-agricultural (18%) livelihoods. Labor migration is often driven by climate-induced disasters like floods and landslides, and is a significant social outcome in Nepal (Jaquet et al., 2019; Kaczan & Orgill-Meyer, 2020).

Perception on Change temperature and rainfall. Communities, as discussed in key informant interviews and focus group discussions, reported facing increasing temperatures and shifting rainfall patterns. Nearly all participants noted an increase in local temperatures and a decrease in rainfall frequency, attributing these changes to irregular monsoons and altered rainfall patterns. Similar findings were noted by Pradhan et al. (2010) in the Indrawati River Basin, where most respondents observed increasing temperatures and changes in rainfall patterns, including delayed and unpredictable rains. A similar study by Pradhan et al. (2010) found that 97% of respondents noticed a change in average temperatures over the past decade, with 46% observing slightly higher temperatures and 19% believing winters had grown colder. In terms of precipitation, 74% noticed changes, with 72% of these reporting a decline. Nearly all respondents (99%) observed changes in precipitation patterns, 53% recognized a delay in the arrival of rains, and 27% thought rainfall had become more unpredictable.

Table 8

Perception of the Community Towards Changing Temperature and Rainfall

Perceptions	Temperature		Rainfall		
	Summer	Winter	Frequency	Intensity	Duration
Increased	✓			✓	
Decrease		✓	✓		✓

Climatic hazards and risk in the area. Community perceptions from focus group discussions and key informant interviews highlight significant climate risks in the area, with declining water resources and increased drought conditions identified as most pressing. Over 30 years, participants noticed worsening droughts that persist beyond monsoon months. Drought was identified as the most significant hazard, followed by drying up of water resources, landslide, flood, and forest fire (Table 9). Upper belt Communities face threats from landslides, soil erosion, and debris flows, while lower belt communities, particularly downstream, report, higher risk of flash floods, especially during the monsoon. Despite a piped water supply from the municipality, local water scarcity remains critical, forcing farmer to leave their farmland uncultivated/barren due to a lack of irrigation (Gentle et al., 2014).

Community perception from this study aligns with the national level findings reported by MoHA (2017), which states that almost 80% of Nepal's population lives in rural, hazard-prone areas that are susceptible to earthquakes, landslides, floods, droughts, very high temperatures, and GLOF. Consistent with (Hahn et al., 2009), this study also found that families led by women are among the most vulnerable, with less access to technology, education, skills, and financial resources.

Table 9

Major Climate Hazards Identified by Communities

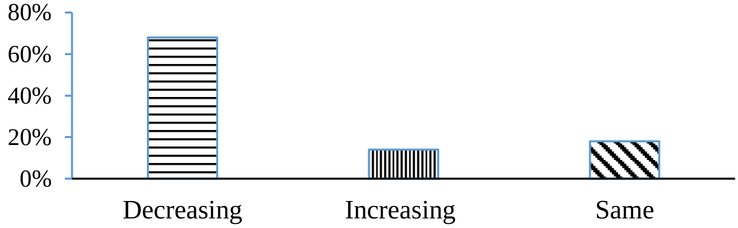
Hazards	Causes			Ranking
	Temperature	Rainfall	Both	
Flood		✓		4
Landslide		✓		3
Drying up of water resources			✓	2
Drought	✓			1
Forest Fire	✓		✓	5

According to Piya et al. (2012), local perceptions of climate change gathered through FGDs and KIIs often differ from scientific assessments. The existing literature is insufficient to fully capture the effects of climate change on locals and their responses. While global climate change is real, its impacts and the corresponding responses are inherently local. These findings highlight the need for localized, perception-based adaptation strategies grounded in community experiences.

Perception on Water Availability. A majority of respondents reported a decline in the quantity and availability of water in the study region, reflecting growing concern over water scarcity as a critical environmental issue exacerbated by climate change. According to community perception, 68% of participants reported a decrease in water availability, while 14% observed an increase, and 18% noted no change (Figure 10).

Figure 10

Perceptions on Water availability

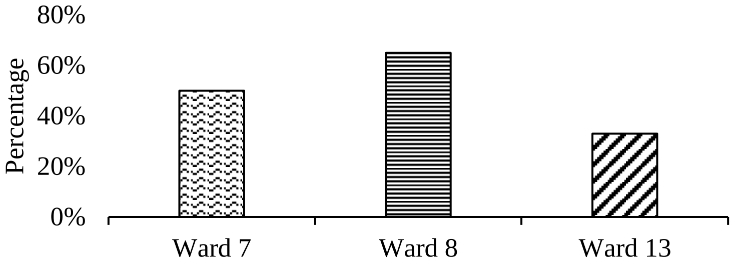


Existing Management Practices and Distribution of Drinking Water. In the study area, major water sources include surface water and groundwater, particularly in Ward 13 of Melamchi municipality. The municipality is implementing a "1 Ghar, 1 Dhara" program to provide household-level water access with community taps serving areas where this program has not yet reached. Figure 11 shows that 65% of households in

Ward 8 receive drinking water through a piped supply, followed by 50% in Ward 7, and only 33% in Ward 13.

Figure 11

Piped Water Supply in Households in the Selected Ward



Local levels will face challenges related to climate change impacts, ensuring inclusive and participatory decision-making, and meeting rising water needs for domestic, agricultural, and commercial uses (White and Haapala, 2019). Despite this, water resource issues have not received enough attention in climate change analyses and policy development. While piped water primarily meets drinking and basic household needs, irrigation depends on small streams, local water bodies, and springs. Challenges include insufficient irrigation infrastructure and the depletion of water resources, exacerbated by frequent climate hazards that damage irrigation canals. In the Indrawati river basin, no significant trend in annual water availability was observed between 1980 and 2008; however, 84% of farmers believed decreased water supply for irrigation and agriculture over the previous ten years (Pradhan et al., 2015). The most severe flood in recent decades occurred in 2021, causing significant loss of life and property. Most people noted changes in the climate, including higher temperatures, intense rain, prolonged floods, droughts, changes in the timing of rain, changes in the seasonal cycle, and increased lightning activity.

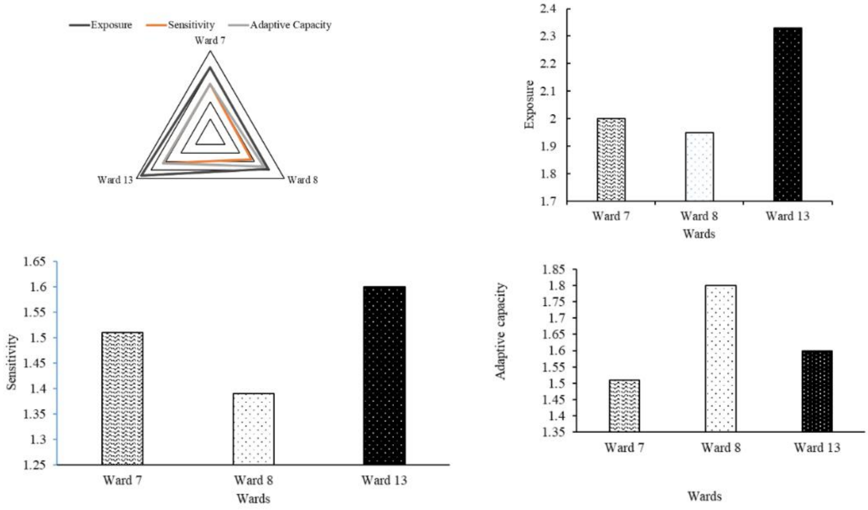
Climate Vulnerability Assessment and Upstream-Downstream Comparison

The community vulnerability index to climate change was calculated based on exposure, sensitivity, and adaptive capability, resulting in an estimated index of 2.3, which indicates a high level of vulnerability. This index reflects the combined effect of how much the community is exposed to climate risks, how sensitive it is, and its ability to adapt to these challenges. Temperature, rainfall, changes in flora and fauna behavior, natural disasters, livelihood shifts, and water resources were considered for exposure factors. According to community assessments, there has been a notable decrease in monsoon rainfall and an increase in drought, as well as unpredictable winter showers and early plant flowering, all of which point to seasonal changes. Major climate threats identified were landslides, floods, earthquakes, and droughts, resulting in a high overall exposure score of 2.13. Ward 13 showed the highest exposure (2.33), followed by Ward 7 (2.00), and Ward 8 (1.95) (Figure 12).

Communities downstream, especially those in the lowland parts of Ward 13, are more vulnerable to climatic risks, including droughts and floods, which have an effect on agriculture, food security, and public health (Pradhan et al., 2015). With an overall sensitivity score of 1.49, the sensitivity study took into account population, water, energy, agriculture, food security, forests, and health. Ward 13 again showed the highest sensitivity (1.6), followed by Ward 7 (1.51) and Ward 8 (1.39). Communities particularly noted drying water resources as a major concern. The community's overall adaptive capacity, which measures its ability to adapt to and deal with the effects of climate change, was modest (1.6). Because of its superior ecological, social, and economic resources, Ward 8 had the highest adaptation capability (1.8), while Wards 13 and 7 scored 1.6 and 1.51, respectively. These variations have an impact on how resilient each ward is.

Figure 12

Vulnerability Assessment Across Wards

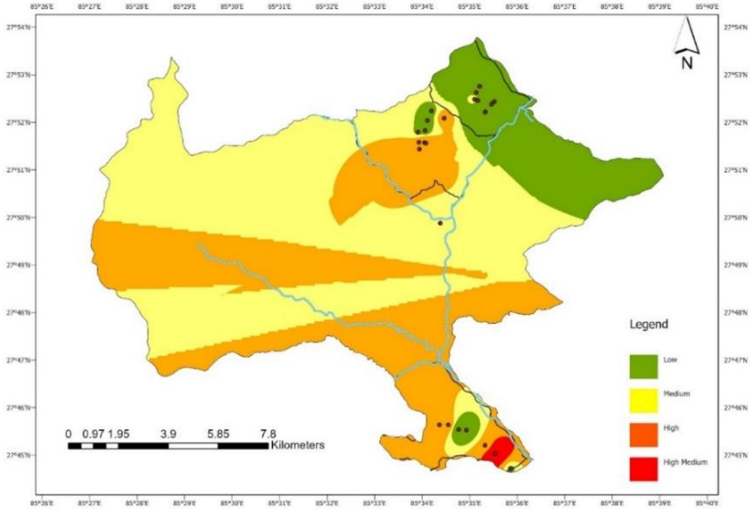


More exposure to floods, landslides, and socioeconomic inequalities, particularly among Dalit and Danuwar populations, made Ward 13 more vulnerable to climate change. Despite the advantages of seasonal river irrigation, there is not enough water available outside of the monsoon season. Upstream Ward 8 depends on rainfall and lacks irrigation infrastructure, even though it has more natural water sources. Access to water is also impacted by differences in wealth. Irrigation systems in both areas are being damaged by climate change, but upstream people have used NGO assistance to diversify their sources of income and manage their water resources.

Women, the poor, marginalized groups, and indigenous people are particularly impacted by climate change vulnerability. Vulnerability is determined not only by exposure to risks but also by existing infrastructure, resources' accessibility, and distance (Government of Nepal, 2021). Vulnerability was perceived at a higher level in our study as about 54% of people in communities completely depend upon agriculture for their livelihood, and the frequent floods, droughts, and landslides negatively influence this sector.

Figure 13

Vulnerability Level of Communities



Vulnerability is determined not only by exposure to risks socioeconomic changes are predicted to increase exposure and susceptibility in the future, increasing the risks for vulnerable populations, especially women and girls (MoFE, 2021b). The Sindhupalchowk district has only a low capacity for adaptation and a high level of susceptibility to climate threats (MoFE, 2021a). Frequent natural disasters threaten agricultural livelihoods, prompting young people to migrate for jobs in the service industry and international labor market (Sunam & McCarthy, 2016).

Community Coping and Adaptation Strategies

Coping and adaptation are key strategies for lowering the severity and costs of climate change. FGD and KII in Melamchi municipality discussed that the communities primarily depend on autonomous adaptations; water management, community resilience, agricultural adaptation, and infrastructure development. Common strategies include migration to urban areas for off-farm jobs and remittances, alongside adopting new technologies and infrastructure improvements. Locally developed strategies include rainwater harvesting, shifting crop calendars, digging ponds, and constructing canals. Initiatives like deep boring for water sources and inter-municipality water transfer projects aim to alleviate water scarcity, benefiting a significant portion of households. Furthermore, communities employ diverse tactics like greenhouse farming, drip irrigation, and livestock trading to enhance resilience against climate variability. These diverse responses highlight the community's proactive role in adapting to climate variability.

Institutional structure and group dynamics have a crucial role in the evaluation of options and opportunities for community resilience building. Melamchi Municipality is responsible for the management and reduction of risk and hazards within the municipality. There was also relief management program in each ward for reduction and relief of climatic hazards. They have established a hazard management fund. Their main function is relief, recovery and reconstruction.

Conclusion

This study showed the interconnection of local perceptions and scientific data regarding climate change in the Melamchi municipality. Community perception, backed by meteorological trends, highlights noticeable changes in temperature and rainfall patterns, impacting agriculture, water resources, biodiversity and livelihood activities. While there is discrepancies exist between local's experience and official climate stations' records, due to limited local weather stations. Despite this, both sources agree that summers are getting longer and winters shorter, and climate variability is intensifying.

Water sources, availability, and agricultural productivity are increasingly affected by climate-induced challenges, including pest outbreaks, lower crop yields, altered cropping patterns, and damaged infrastructure. The study underscores the urgent need for integrated adaptation efforts that combine scientific knowledge with community-based insights.

Marginalized groups, including women, indigenous people, and the poor remain disproportionately vulnerable due to limited awareness and fewer resources to cope.

Addressing this requires targeted education, capacity-building, and investment in resilient infrastructure. Notably, communities have demonstrated adaptive resilience through initiatives like well construction, water-lifting systems, rainwater harvesting, and household water management. Both locally and nationally, there is insufficient understanding among professionals in governmental and non-governmental organizations. This gap underscores the need for enhanced education and empowerment at the community level to strengthen long-term adaptation efforts.

Despite these challenges, local communities have displayed resilience through proactive measures such as well construction, distant water lifting, and household-level water management. Given the declining water availability over the past two decades, enhancing water storage systems and irrigation infrastructure is critical. Community engagement, climate literacy, and tailored local strategies must be prioritized to build long-term climate resilience and protect sustainable livelihoods.

Based on the findings, this study proposed several recommendations to address the challenges faced by in the Melamchi municipality so to promote sustainable development. Firstly, the impact of inefficient irrigation systems on the availability of water must be addressed through investments in modern and efficient infrastructure. Not only is this measure dedicated to optimizing water use but also to enhance agricultural productivity within the region. There is a good reason why local community-led water schemes should be promoted. It not only provides a sense of belongingness to the community but also enhances their technical knowledge and managerial skills, hence promoting sustainable methods of water management. There should be specially focused education and awareness campaigns conducted at the grassroots level. It is crucial in facilitating residents with the information needed to understand, adapt to, and mitigate the impacts of climate change on livelihood and local ecosystems. Furthermore, indigenous knowledge and practices must be integrated into adaptation strategies as a priority. Collaborative efforts that utilize local knowledge can adequately complement scientific approaches and enhance communities' resilience to climate variability. Lastly, having robust systems of monitoring and evaluating the effect of undertaken action is paramount. These systems ensure that interventions are constantly adaptive and able to address the evolving challenges climate change presents.

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