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Temperature Changes in Kaski District of Nepal: A Study of Trends (1970-2018)

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ABSTRACT

Climate change is one of the most complex and crucial issues in the world. It has impacted environmental, social, and economic sectors of our planet. Unsurprisingly, Nepal is not immune to climate change. In fact, it is one of the most susceptible countries to climate change. One of the most impacted variables in Nepal due to climate change is the maximum temperature. The rate of change of temperature per year, in Nepal is ever-increasing. This paper examines the temperature trend and how it has affected environmental, social, and economic sustainability of Kaski District in Nepal. The paper utilizes the maximum temperature trend of Kaski District during 1970-2018. The monthly minimum and maximum temperatures are obtained from the Department of Hydrology and Meteorology (DHM). The study is done based on the data obtained from Pokhara Airport and Lumle stations. The paper uses three statistical tools alongside descriptive statistics to analyze the data. First, the Man-Kendall test is used to figure out the trend of temperature. Second, Sen's slope is used to find the magnitude of a trend. Third, the Time series model has been used for forecasting temperature trends. Finally, SPSS and R software were used to calculate the results. The trend of maximum temperature has been significantly increased in Kaski District. The maximum temperature in Kaski during 1970-2018, recorded, was 24.99°C in 2005 and was closely followed by 24.66°C temperature in 2010. The average maximum temperature during the 1970-2018 period was 23.49°C. The maximum variation of maximum temperature during 1970-2018 was in 1992 with a standard deviation of 5.94°C. The minimum temperature during 1970-2018 was 21.12°C in 1978 and was closely followed by 22.19°C in 1997. There is an increasing trend of maximum temperature in Kaski District. In addition, the trend of maximum temperature is higher and faster after 1998 in Kaski District of Western Nepal during 1970-2018.

KEYWORDS: Climate change, environment, sustainability, temperature, temperature trends

INTRODUCTION

Climate itself is not directly observable since it refers to the average weather over a certain period of time and thus climate change is "only really knowable through mathematical models" and scientific measurement (Lee et al., 2005).

Climate change is one of the great challenges for the sustainable development of human society, resulting in a great environmental risk. It has affected the physical change in the world like rising sea levels, melting of glaciers, and extreme weather events. The Kyoto Protocol Treaty (1997), the first step to globally reduce human influence on the climate system, is in force due to climate change. As a result, climate change has recently been the subject of increased international and scholarly attention. It can be universally experienced by the change in temperature. Temperature is one of the most important variables in weather and climate forecasting. Hence, temperature behavior is important for the knowledge of climate variability which can vary spatially and temporally at different local, regional, and global scales (IPCC, 2013).

The International Panel on Climate Change (IPCC) mentions temperature trends on the global scale that shows a warming of 0.85°C over the period 1880-2012. Furthermore, IPCC points out each of the last three decades that has been successively warmer than its preceding decades. There is also a trend of increasing global mean temperature; Global surface temperature is projected to be increased by 1.5-2.0°C relative to 1850-1900 by the end of this century (IPCC, 2013). Climate scientists have confirmed that the process of global warming is accelerating (Wenban & Smith, 2015), making the mitigation and adaptation to climate change as an urgent task for our generation (IPCC, 2014).

The contribution of Nepal in the emission of greenhouse gases (GHGs) is negligible. However, Nepal will be hit hardest by climate change for three main reasons. First, Nepal is a mountainous country; More than 75% of its area is covered by young and fragile mountains. Due to the melting of snow and fast changes in climatic patterns, the risk of depletion of water is very high. Second, Nepal is highly dependent on agriculture and tourism. Agriculture employs around 65% of the population and contributes about 38% of the total GDP. Tourism is also one of the main income sources for many Nepali people. It is affected by natural hazards, change in rainfall patterns, shifting of treeline, and rise of temperature due to climate change (Eugenio-Martin & Campos-Soria, 2010; Ghimire, 2015). Third, Nepal lacks resources to adapt to changing climate as it is among the least developed countries in the world, with more than 40% of the population below the poverty line (Lama & Devkota, 2009; Stern, 2006). The impact of climate change is worsened by geographical location, rugged topography, social condition, political influence, lack of skilled manpower, illiteracy, and economic prosperity, nature dependent likelihood, and poverty (Bhandari & Gurung, 2009). As a result, Nepal has been ranked as the fourth most vulnerable country to climate change (Maplecroft, 2011)

Temperature has been increasing in Nepal for the past few decades. The maximum temperature increased at a rate of 0.06 °C/year between 1978 and 1994. The maximum temperature trend each year is significantly positive (0.056 ^{0}C /yr). The annual minimum temperature trend is also positive (0.02 ^{0}C/yr) but it is insignificant (DHM, 2017). Moreover, the results from the Coupled Model Intercomparison Project, Phase 5 (CMIP5) suggest that the mean annual temperatures are projected to increase between 1.3°C–3.8°C by the 2060s (WorldBank, 2019).

There is a chance of an increase in the frequency and intensity of extreme events caused by climate change (Aryal, et al., 2014). The observed impacts of climate change in Nepal include the temperature increase, erratic rainfall, unpredictable monsoon seasons, increased occurrence of storms, landslides, and drought (Gentle & Maraseni, 2012; Lama & Devkota, 2009; Khanal et al., 2019).

Nepal is one of the most geographically and biologically diverse places on earth due to its complex topography ranges from subtropical in the south to arctic in the north. It is important to know which area/seasons could be more affected by these changes due to local variability (Shrestha & Aryal, 2011).

In terms of seasons, the winters are being affected more than summer (Shrestha, et al., 1999). In terms of region, the temperature levels in western and central Nepal are expected to increase at higher rates compared to eastern Nepal (Timsina, 2011). In terms of topography, Himalayas will be the hardest hit by climate change. Hindu Kush Himalayan region including Nepal experience severe effects of climate change due to the high altitudinal variation fragile geographic structure. Furthermore, there is an increasing concern about the Himalayan glacier melt and it has resulted in glacial lake outburst floods (GLOF) (Mool et al., 2001; Bajracharya et al., 2007; Shrestha & Aryal, 2011).

There have been a lot of researches about climate change in Nepal but a few researches carried out for the Kaski district of Western Nepal. Kaski District is in the western part of Nepal, as mentioned above; it is expected to be hit harder than other parts. Also, it is home to Annapurna range which includes Machhapuchhre Himal. Hence, it can synthesize that Kaski District is likely to experience an increase in temperature, an increase in frequency and intensity of extreme events, and difficulty in the agricultural and tourism industry in foreseeable future. Thus, the main objective of this study is to explore the trend of maximum, minimum, and average temperature during 1970–2018, including its magnitude temperature variability.

DATA AND METHODS

Study Area

To measure the trends of maximum temperature, the Kaski district has been chosen. Kaski District is one of the famous destinations for tourists in Nepal. The people of this district rely on agriculture. The district also consists of diverse topography including mountains, hills, and valleys. Another reason for the selection of the district was the lack of research on the field of climate change in this area. Altogether, 18 stations are established in different locations to report on the climate data in Kaski District. Out of them, 13 stations provide data about precipitation only because of which it is not useful in the study. In addition, there are four stations that has data for less than five years or have missing data. So only two stations, Pokhara Airport and Lumle stations, have been selected for this study. The data are extracted from the Department of Hydrology and Meteorology. It was started to record the data since 1966. As a result, the temperature data from 1970-2018 were used for this study.

Data Collection

The monthly data of maximum, minimum, and mean temperatures were obtained from the Department of Hydrology and Meteorology of Nepal during the period of 1970–2018. For analysis, the monthly data were grouped into four seasons namely Pre-monsoon (march-may), Monsoon (June-September), Post-monsoon (October-November), and Winter (December-February). Data has a monthly temporal resolution and spans of a 49-years period from 1970 to 2018. The seasonal mean temperature for four prominent seasons (pre-monsoon, monsoon, post-monsoon, and winter) were calculated.

Mann–Kendall Test

It is a statistical method used to check the null hypothesis of no trend versus the alternative hypothesis of the existence of monotonic increasing or decreasing trend of hydro-climatic time series data. The non-parametric Mann Kendall test is fit for those data series where the trend is assumed to be monotonic (i.e. mathematically the trend is consistently increasing and never decreasing or consistently decreasing and never increasing) and no seasonal or other cycle is present. MAKESENS performs two types of statistics depending upon the number of data values. S – statistics is used if the number of data is less than 10 while Z – statistics (normal approximation/distribution) is used for data values greater than or equal to 10. The statistic S is calculated as,

$$S = \sum_{i=1}^{n-1} \cdot \sum_{j=1}^{n+1} \text{sign}(x_j - x_i) \qquad \text{Equation 1}$$

Where x_j and x_i are annual values in years j and i respectively and n is the number of data points. In the above equation $j > i$, the value of $sign(x_j - x_i)$ is calculated in the equation below:

$$\text{sign}(x_j - x_i) = \begin{cases} 1 \;\; if \; x_j - x_i > 0 \\ 0 \;\; if \; x_j - x_i = 0 \\ -1 \; if \; x_j - x_i < 0 \end{cases} \qquad \text{Equation 2}$$

A positive value S indicates an upward (increasing) trend while a negative value of S indicates a downward (decreasing) trend.

If a number of data values is 10 or more, the S – statistics approximately behave as a normal distribution. The test then is performed with normal distribution with the mean and variation that are given below:

$$E(S) = 0 \qquad \text{Equation 3}$$

$$Var\ (S) = \frac{[\,n(n-1)(2n+5) - \sum_{i=1}^{n} t_i(t_{i-1} - 1)(2t_{i-2} + 5)]}{18} \qquad \text{Equation 4}$$

Where n is the number of tied (zero difference between compared values) groups and t_i is the number of data points in the i^{th} tied group, the standard normal distribution (Z – statistics) is computed using the equation below.

$$Z = \begin{cases} \frac{S-1}{\sqrt{var(s)}} \;, & if\, S > 0 \\ 0, & if\, S = 0 \\ \frac{S+1}{\sqrt{var(s)}}, & if\, S < 0 \end{cases} \qquad \text{Equation 5}$$

Statistically, the significance of the trend is assessed using Z- value. A positive value of Z shows upwards (increasing) trend while the negative value indicates a downward (decreasing) trend.

In MAKESENS, the two-tailed test is used for four different significance levels (where α: 0.1, 0.05, 0.01, and 0.001). The significance level 0.001 means that there is a 0.1% probability that the values x_i are from a random distribution when rejecting H_o (null hypothesis) of no trend. Thus, the significance level 0.001 means that the existence of a monotonic trend is very probable.

Similarly, the significance level 0.1 means that there is a 10% probability that we make a mistake when rejecting H_o.

Sen's Estimator Method

Sen's non-parametric estimator method has been used for predicting the magnitude (true slope) of hydro-metrological time series data. The Sen's slope estimator method uses a linear model for the trend analysis. The slope (T_i) of all data pairs is calculated using the equation below:

$$T_i = \frac{x_j - x_k}{j - k} \qquad \text{Equation 6}$$

Where x_j and x_k are data values at time j and k respectively. In the equation above $j > k$, the median of these n values, of T_i is represented by Sen's slope of estimation (true slope) in equation 6.

$$Qi = T_{n+\frac{1}{2}} \;, \qquad for\ n\ is\ odd,$$

$$Qi = [T_{\frac{n}{2}} + T_{\frac{n+1}{2}}]/2, \qquad for\ n\ is\ even$$

Sen's estimator Q_{med} is calculated using the above equation depending upon the value of n, whether n is odd or even. Then, Q_{med} is computed using a 100 (1 – α) % confidence interval using a non-parametric test depending upon normal distribution. A positive value of Q_i indicates an increasing (upward) trend while the negative value of Q_i represents a downward or decreasing trend of time series data.

The analysis was formulated using the R and SPSS software by using the methods mentioned above. The raw data were entered into the software and process with the statistical tool. Then, SPSS software was used to create all the graphs as well as the table mentioned in the analysis of the data.

RESULTS AND DISCUSSION

The average minimum temperature, maximum temperature, and average temperature for each month over a period of 49 years from 1970 to 2018 are shown in Table 1. The average annual maximum and minimum temperatures are 23.36°C and 13.73°C respectively. The mean annual temperature for the same period is 18.54°C. The maximum variation in maximum temperature in the period of 1970-2018 is in 1992 with a standard deviation equal to 5.94°C. It means that there was an extreme effect of climate change in that year.

The average temperature for each year was also calculated and analyzed. The highest mean of the maximum temperature of 24.99°C was recorded in 2009. Similarly, the lowest mean of the maximum temperature of 24.66°C was recorded in 2010.

Table 1

Monthly Temperature and Rainfall Data from 1970-2018

Month	Minimum Temperature	Maximum Temperature	Average Temperature
January	5.945	16.500	11.222
February	7.791	18.677	13.234
March	11.179	23.032	17.105
April	14.205	26.207	20.206
May	16.361	26.566	21.464
June	18.751	27.081	22.925
July	19.722	26.633	23.178

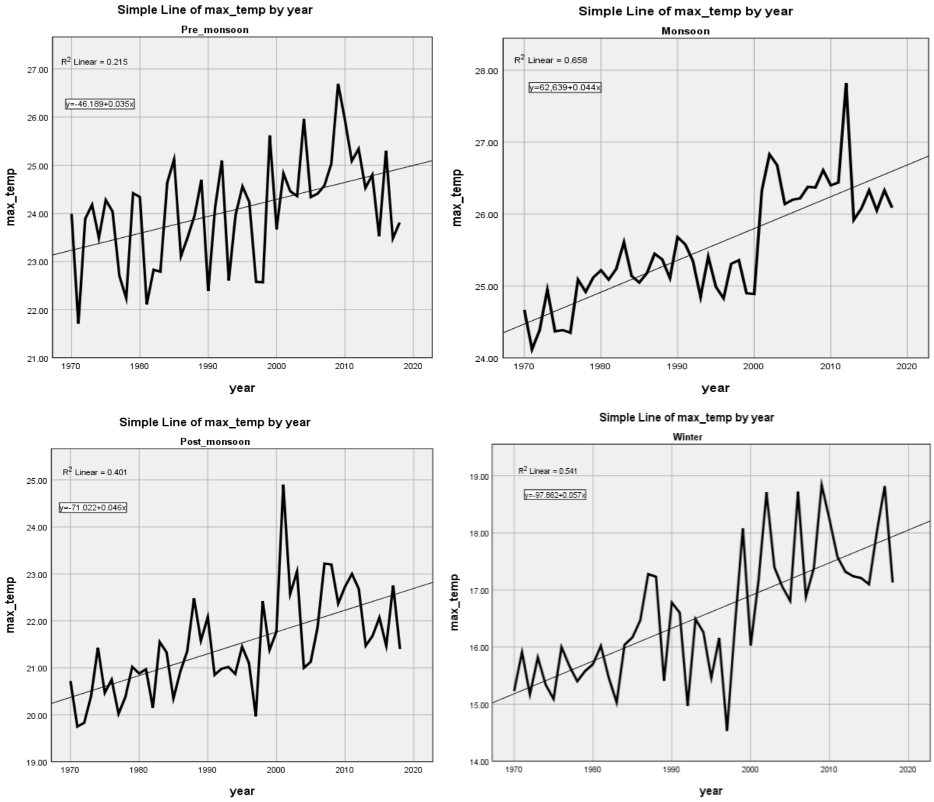
August	19.646	26.821	23.234
September	18.516	26.034	22.275
October	14.888	24.205	19.552
November	10.638	20.898	15.768
December	7.062	17.653	12.358
Total	13.725	23.355	18.539

Maximum Temperature by Season

The average change in maximum temperature (from 1970- 2018) is increasing by 0.057°C/year in the winter season according to the temperature pattern. In the post-monsoon season, it is increased by 0.046°C/year. In the monsoon season the average change in maximum temperature increases by 0.044°C/year. Finally, the average change in maximum temperature in the pre-monsoon season is 0.035°C /year. This information can be synthesized from the trend and graph shown in Figure1. It indicates the winter season is the most affected season and the pre-monsoon season is least affected by climate change.

Figure 1

Pattern of maximum temperature in different seasons



Significance and Trend of Maximum Temperature

The following table shows the Mann-Kendall test and Sen's slope of maximum temperature from 1970 to 2018 that indicates significance and trend of maximum temperature.

Table 2

Mann-Kendall test and Sen's slope of Maximum temperature from 1970 to 2018

Temperature	Tau-value	p-value	Sen's slope	p-value	trend	significance
Pre-monsoon	0.321	<0.001	0.032	<0.001	Positive	significant
Monsoon	0.041	<0.001	0.044	<0.001	Positive	significant
Post-monsoon	0.506	<0.001	0.046	<0.025	Positive	significant
Winter	0.544	<0.001	0.053	<0.001	Positive	significant

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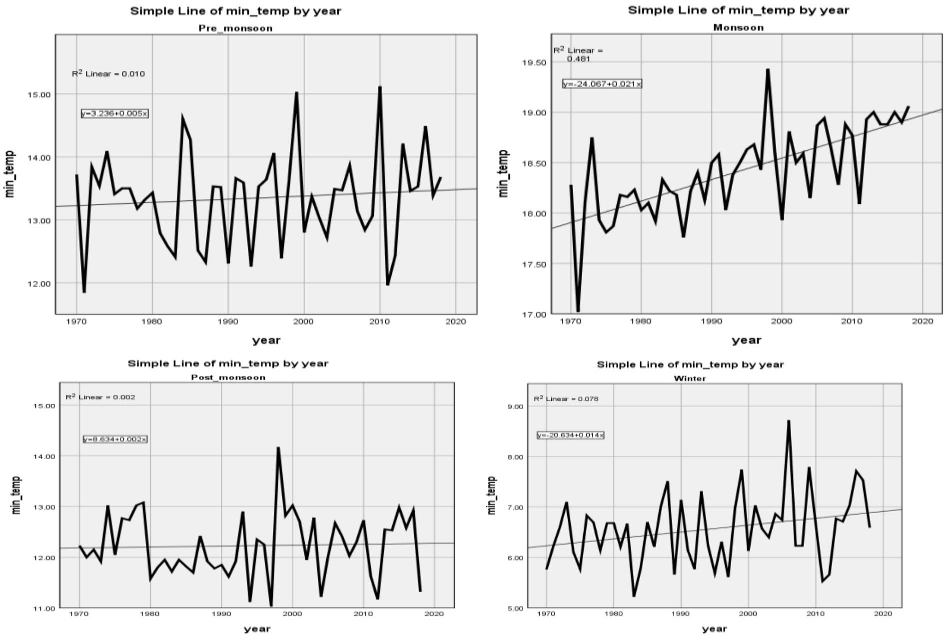
The Mann-Kendall test and Sen's slope indicate that maximum temperature trends are positive and are significant in all-season. This means that the glacier is shrinking and the snow is melting at a faster rate than the previous year. As a result of faster increasing temperature, the possibility of glacier lake outburst flood may increase.

Minimum Temperature

The average change in minimum temperature (from 1970-2018) is increasing by 0.014°C/year in the winter season as depicted in Figure 2. In the post-monsoon season, it is increased by 0.002°C /year. In the monsoon season, the average change in minimum temperature increases by 0.021°C/year. The average change in minimum temperature in the pre-monsoon season is 0.005°C/year. As depicted in Figure 2, the winter season is the most affected season and monsoon season is least affected by climate change in terms of minimum temperature.

Figure 2

Pattern of minimum temperature in different seasons



Significance and Trend of Minimum Temperature

The following table shows the Mann-Kendall test and Sen's slope of minimum temperature from 1970 to 2018, indicating the significance and trend of minimum temperature.

Table 3

Mann-Kendall test and Sen's slope of Minimum temperature from 1970 to 2018

Temperature	Tau-value	p-value	Sen's slope	p-value	trend	Significance
Pre-monsoon	0.204	0.843	0.001	0.843	Positive	Insignificant
Monsoon	0.553	<0.001	0.022	<0.001	Positive	Significant
Post-monsoon	0.035	<0.750	0.003	0.750	Positive	Insignificant
Winter	0.182	0.068	0.012	0.068	Positive	Insignificant

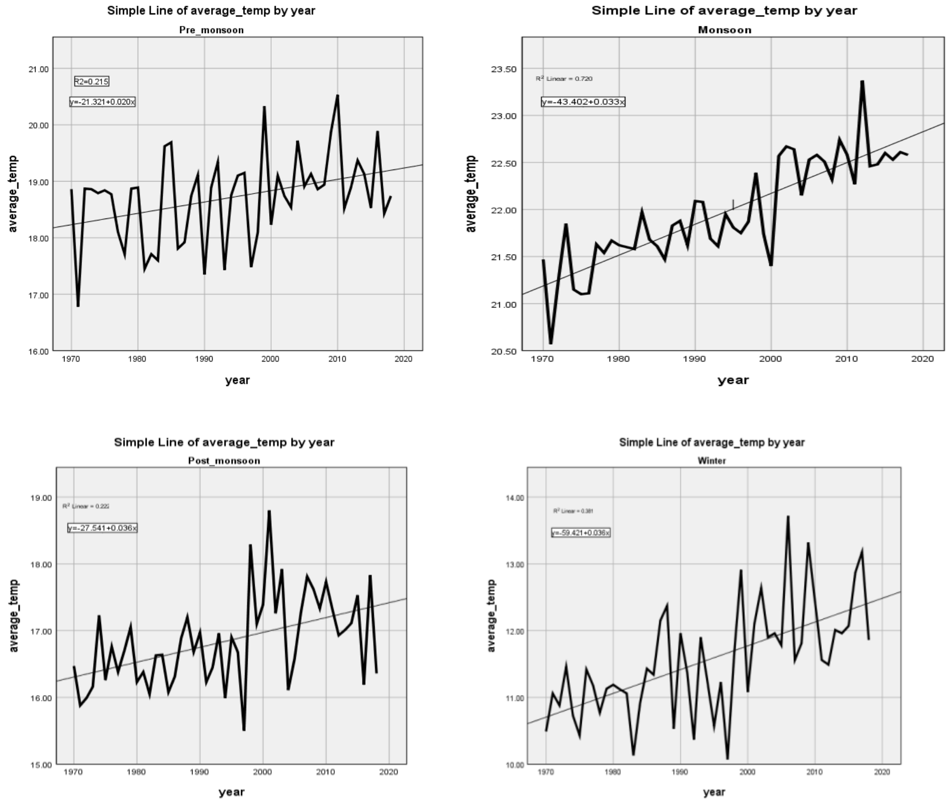
The Maan-Kendall test and Sen's slope indicate that minimum temperature trends are positive in all seasons. They are significant only in monsoon. This result indicates that the minimum temperature is not increasing significantly as compared to the maximum temperature.

Average Temperature

The average change in average temperature (from 1970- 2018) is increasing by 0.036°C/year in the winter season according to the temperature pattern. In the post-monsoon season, it is increased by 0.022°C/year. In the monsoon season, the average change in minimum temperature increases by 0.033°C/year. The average change in minimum temperature in the pre-monsoon season is 0.02°C/year. Figure 3 shows that the winter season is the most affected season and monsoon season is least affected by climate change in terms of average temperature from 1970-2018.

Figure 3

Pattern of average temperature in different seasons



Significance and Trend of Average Temperature

The following table shows the Mann-Kendall test and Sen's slope of average temperature from 1970 to 2018 that indicates significance and trend of average temperature.

Table 4

Mann-Kendall test and Sen's slope of Average temperature from 1970 to 2018

Temperature	Tau-value	p-value	Sen's slope	p-value	trend	Significant
Pre-monsoon	0.220	0.027	0.015	0.027	Positive	Significant
Monsoon	0.639	<0.001	0.032	<0.001	Positive	Significant
Post-monsoon	0.351	<0.001	0.024	<0.001	Positive	Significant
Winter	0.421	<0.001	0.037	<0.001	Positive	Significant

The Mann-Kendall test and Sen's slope indicate that average temperature trends are positive and significant in all seasons. This means that the average temperature of Kaski is increasing and significant.

Discussion

The paper does not necessarily resonate, for the two studied stations with a general finding of maximum temperature, minimum temperature, and average temperature with the absolute value of studies of Nepal and abroad. It is because it was done in peripheral of the Kaski district, which is by no means covers all the diverse topography and climate of Nepal. However, it does contribute to the IPCC reports of an argument of the need for more details about the regional pattern of climate change. To discuss the findings, due to limited studies about Kaski district, the paper compares its results with the trend of Nepal and in some cases with the world.

A study done by CBS reveals that the variation in maximum temperature trends is stronger compared to those of average and minimum temperatures. Warming in winter has been especially pronounced. The maximum temperature trends in the winter season in this study area are greater than the national level, which is 0.056°C/year (CBS, 2017). According to our results, the winter has been far more affected by climate change in terms of an increase of maximum temperature, average temperature, and minimum temperature.

Even though the results do not necessarily coincide in terms of the absolute value of maximum temperature with that of Nepal, the significance and trend of maximum temperature do resonate with Nepal. The previous studies show that there is an increasing concern about the Himalayan glacier melt and it has resulted in glacial lake outburst floods (GLOF) (Mool et al., 2001; Bajracharya et al., 2007; Shrestha & Aryal, 2011). As our results mentioned, the significance of maximum temperature does lead to the melting of a glacier in the Kaski District.

Like the maximum temperature, the significance and trend of minimum temperature do resonate with the study. According to the previous research, the annual minimum temperature trend is also positive (0.02 ^{0}C/yr.) but it is insignificant (DHM, 2017). According to this research too, the trend of annual minimum temperature is positive. However, it is significant merely only in monsoon season.

The significance and trend of average temperature in Kaski District do resonate with Nepal's and global trends. There is a positive and significant trend in average temperature, which means that the temperature of the Kaski district is increasing and significant. Past studies have shown the trend of increasing global mean temperature (IPCC, 2013). According to the previous research, the temperature has been increasing in Nepal for the past few decades (DHM, 2017). Both of these reports resonate with the findings that the average temperature of the Kaski district is increasing.

CONCLUSIONS

The trend of maximum temperature is positive and significant in all seasons. The minimum temperature is insignificant in all seasons except monsoon. However, the trend of minimum temperature is still positive. The average temperature is significant and positive in all seasons. It means that the temperature of Kaski is increasing. The maximum temperature is most significant in all seasons compared to average temperature and minimum temperature. Winter season is the most affected season in terms of maximum temperature and average temperature. This means that the rate of change of temperature every year in Winter is greater than those of the other seasons. Monsoon season is the most affected season in terms of trend and significance of the minimum temperature. This means that the minimum temperature of monsoon is increasing. The highest mean of the maximum temperature of 24.99°C was recorded in 2009 while the lowest mean of the maximum temperature of 24.66°C was recorded in 2010. The maximum variation in maximum temperature in the period of 1970-2018 is in 1992 with a standard deviation equal to 5.94°C. It means that there was an extreme effect of climate change in that year.

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