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Assessment of Warming in the Different Elevation of the Water Basin Area in Nepal

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Abstract

This study examines warming in the different elevations in the water Basin in Nepal. Using time series data sets of temperature variables from 1980 to 2020 collected from the Department of Hydrology and Metrology (DHM), Nepal, this study employs descriptive statistics, a time series-forecasting model, and Mann Kendal test and Sen's test to trace out temperature variable movement and potential results. As a result, we find rising temperature is +1.10c y-1 with +0.0270c y-1 and rising Tmin, and T max by +2.10c y-1 and +3.30c y-1 in all elevations from 205 m to 2744 m and decadal period in the last 40 years from 1980 to 2020. Except for the second time zone (1990-1999), Sen's Coefficients and Kendel's Tau of these remaining three time zones have a positive trend. It implies raising Tmean with more than +20c y-1 temperature difference between Tmin, and T max. It results in warming the water basin. We conclude that the basin's small cities and three ecological belts at present and in the future will be in threat of climate catastrophe. In mountain, the frequency of ice melting in Annapurna Mountain will be higher than the estimated value. The risk of flood in the summer season will be disastrous in the hills and the plain cities. Wildlife and crop cycle will be in the heat risk. Households may fall in extreme vulnerability and potential migrants. The result will be valuable inputs to scale up effective monitoring and tracking systems on climatic variables and climate change for further analysis and prediction. Further, the study will be helpful empirical insights to initiate resilient measures as appropriate to different elevations and households' resilient capacity, along with zero-cost indigenous knowledge and technology.

Keywords: *Temperature, Warming, Climate Change, Small Cities, The Water Basin, Nepal etc.*

Introduction

Temperature is a key climatic measure of either climate or climate change. The World Bank (2022) mentions climate as a long-term variation of temperature. UN (2022) explains its long-term shift to climate change. This is a scientific fact in the global climatic literature (Frimpong et al. 2022; Kajtar et al. 2021; Ragatoa et al. 2018). An interesting fact is that temperature is dynamic. Metrological evidence of the earth's temperature reveals temperature variation over time, elevations, and seasons. NASA (2022) sees increasing global temperatures with $+1^{0}cy^{-1}$ in the base year 1880. Its extreme variations, events, and frequencies are hidden factors behind climate change in the world and the theory of climate change. Therefore, temperature is an indicator of global warming.

Temperature is a composite index of three temperature indicators: annual mean temperature (T_{min}), annual maximum temperature (T_{max}), and annual mean temperature (T_{mean}) to measure variations, events, and frequencies of climate change. This temperature variable has been widely used in theoretical and empirical studies in recent years to capture the variation of temperature and its extreme events and implications. Studies (Yunling and Yiping, 2005; Modarres and Silva, 2007; ElNesr et al. 2010; Tabari and Talaee, 2011, Tabari and Hosseinzadeh Talaee, 2012, Karaburun et al. 2011; Tao et al. 2011; Xu et al. 2010; Ceppi et al. 2012; Agbo & Ekpo, 2021; Ajhaji, et al., 2022;) found similar positive trend of annual mean temperature (T_{mean}). In China, Yunling and Yiping (2005) found a similar result in the last 40-year-long temperature data sets from 1960 to 2000 collected from 19th metrological stations.

In India, Singh et al. (2008) examined the trend and variability of seasonal and annual rainfall and relative humidity on the basin scale for the northwest and central parts of India using the Mann-Kendall statistical test. The study found an increasing temperature trend in the relative humidity on both seasonal and annual

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scales. In Turkey, Karaburun et al. (2011) examined the trend of mean, minimum, and maximum temperatures in three-time formats (annual, seasonal, and monthly) in Istanbul in 31 years of data length from 1975 to 2006. The result of the Mann-Kendall test and Sen's method indicated a positive trend of these temperature variables. Similar evidence is available in Saudi Arabia, where ElNesr et al. (2010) investigated the variation of temperature covering the last 29 years' data from 1981 to 2010 collected from 29 meteorological stations. The evidence is warming trend was in the maximum, minimum, and average temperatures throughout the year except in the winter months of November to January. Similarly, in Iran, numerous studies examining the changes in meteorological variables (Modarres and Silva, 2007, Tabari and Hosseinzadeh Talaee, 2011) have found a significant change in meteorological variables at many stations.

Likewise, we can find other evidence in Switzerland, where Ceppi et al. (2012) studied the trend analysis of temperatures from 1959 to 2008. As evidence, the seasonal trends are all positive and mostly significant with an annual average warming rate of 0.35 °C y^{-10}. Agbo and Ekpo (2021) analyzed the temperature variations in Calabar, Southern Nigeria for 20 years (1998 – 2018) using the Mann-Kendall trend test and Sen"s slope estimator. The study found increasing annual trends of the maximum and average ambient temperature after showing positive Kendall Z-values (1.04 and 0.10 respectively) but decreasing minimum ambient temperature's trend. Alhaji et al. (2018) analyzed the temperature trend in Gombe State employing the Mann-Kendall trend test on an annual average of Maximum and Minimum Temperature data from the Nigerian Meteorological Agency (NIMET), Gombe State. In the study, a positive Kendall's Z value indicates an upward trend. The Test statistics for maximum and average temperatures are 4.38 and 4.43, respectively. So, there is a significant increase in the trend at a 5% level of significance since (p-values (0.0001) <0.05).

In Ghana, Larbi et al. (2018) examined this issue in the Vea Catchment area in the last 31 years period from 1985 to 2016 using the Mann–Kendall test and Sen's slope test. The study found a general warming trend. Gadedjisso-Tossou and Adjegan (2021) supplemented with similar evidence on its negative impact on the productivity of cereal crops using Mann-Kendall and Sen's Test in the last 35-year period from 1977 to 2012. Oduro et al. (2022) analyzing similar trends from 1960 to 2000 noted rising temperature with $+1^{0}c$ y^{-1}. Similar evidence was observed in the study of Klutse et al. (2020), although the time length was 1 year less than Oduro et al. (2022). Different evidence was observed in Subaar et al. (2018) in which the study analyzed the trend temperature in the last 29-year period from 1990 to 2009 in Wa, Upper West Region, Ghana. The study found a different rise in annual mean temperature with $+0.4\ ^{0}cy^{-1}$.

On this issue, the previous literature (Thakuri et al. 2019, Acharya & Bhatta, 2013, Dahal et al 2008, & Karn 2014) has well analysed at the national level but not at the local level. Thakuri et al. (2019) studied the temperature trend in Nepal over the last four decades (1976–2015) found maximum air temperature increased (+0.045 °C y-1, $p < .001$) more than the minimum temperature (+0.009 °C y-1, $p < .05$) and, consequently, DTR also increased significantly (+0.034 °C y-1, $p < .001$). Therefore, there is a scope to be studied in this catchment area. This study covers these issues in the study.

This paper examines climate change through dimensions, behaviors, and dynamics of temperature variables in the Marsyangdi Water Basin in Nepal. Its specific objectives are to analyse the temperature trend in the study area and to forward issues and recommendations for policy implication to the policymakers and further research.

This paper is organized into five sections: Section 1: Introduction, Section 2: Theoretical/ Conceptual Framework, Section 3: Method and Data, Section 4: Results, and Section 5: Discussion and Conclusion.

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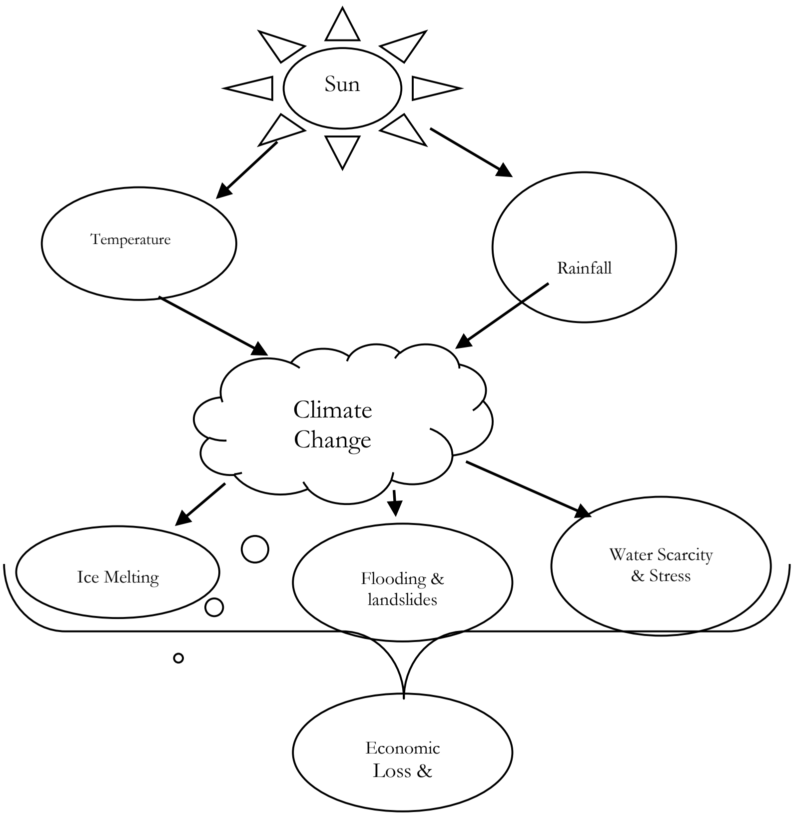
Theoretical / Conceptual Framework

Figure 1. Conceptual Framework



The relationship between climate change, ice melting, flooding and landslides, and water scarcity and stress are positive because climate change induces ice melting, flooding, landslides, and water scarcity. This is a scientific fact (IPCC, 2001; Gleick, 2000; Solomon, et al., 2007; Adams and Peck, 2008; and IPCC, 2018). This universally accepted fact is a concept idea of this study. If a 0.18^{0}c temperature rise per annum and 0.10 inches increasing global precipitation per decade induces ice melting, flooding and landslides, and drought-induced water scarcity and stress, households will respond immediately to these disasters with their Indigenous and socio-economic adaptive capacity to neutralize the impact of climate change and their economic losses as soon as possible (Figure 1). However, they expect the stability of climate change by employing mitigation of their causes to lead drivers for their life, livelihood, and survival in the future.

Methods and Data

Research Design

Designing the study explorative cum descriptive, the study is carried out to find objectives and test hypotheses to understand whether the variation of rainfall exists over a prolonged period and whether the dynamics of rainfall affect households in the study areas. This inquiry will produce new and interesting results.

Study Areas

The study area was the Marshyangdi river basin of Gandaki Province, Nepal. This river basin is 150 km (about 93.21 mi)

Figure 1: The study area- the Marshyangdi River Basin

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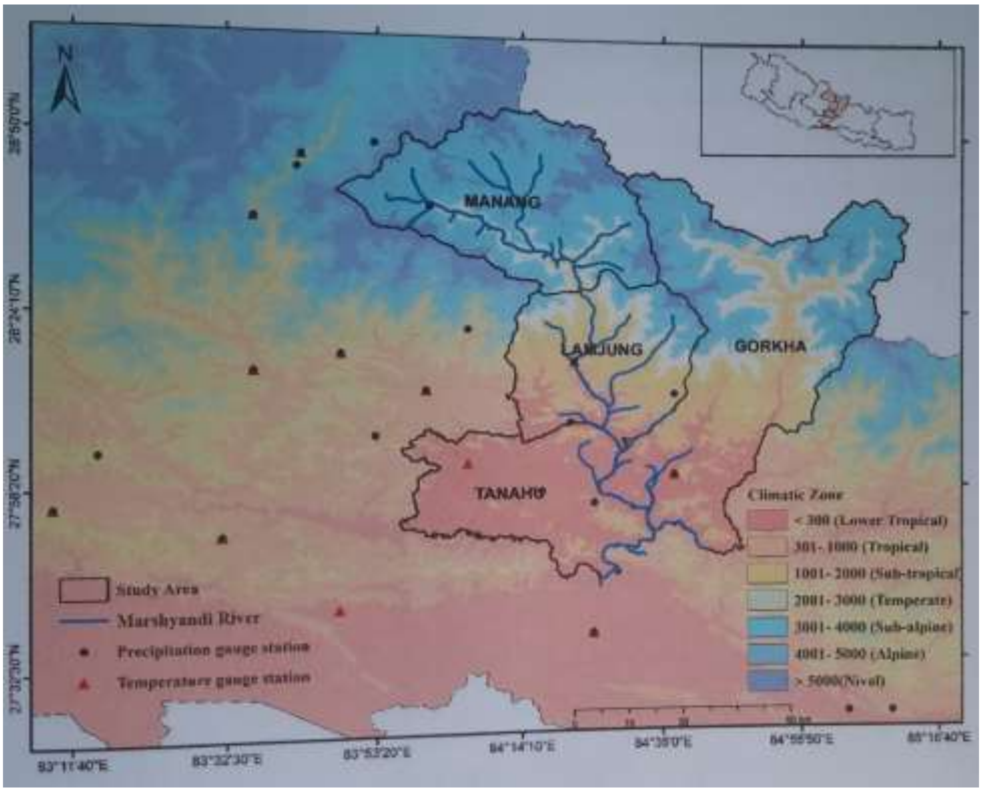
long situated between 27^{0}50’42”N to 28^{0}54’11” latitudes and 83^{0}47’24”E to 84^{0}48’04”E longitudes. The basin lies in a total area of 4787 sq. km. Its elevation varies from 200 meters (about 656.17 ft) to 7800 meters (about 4.85 mi). Geographically, the basin covers four districts of three ecological zones as follows: Manang from the Himal (high altitude), Lamjung and Tanuhu from the Hills (middle altitude), and Chitwan from the Terai (low altitude). In these districts, there are 12 emerging small cities as municipalities (Figure 2).



Source: Koirala, 2022

In the basin, there is a beautiful confluence of climatic variables and hydro variables. Starting from the range of the Annapurna Himalayan to the Chitwan lowland, this snow-fed river is consistent in both monsoon (rainy) and winter (dry) seasons. Interestingly, the glacier area is about 508 km^2 (Parajuli et al. 2015). It ranges from the cold high-alpine to the hot and humid tropical type. Its mean slope is about 29.42°degrees. The basin is highly exposed to climate variables. The clusters of small cities are highly vulnerable to flooding, landslides, and droughts. Therefore, climatic variables may vary in such varied landscapes.

Data and Method

Temperature is a key variable of the study. The annual temperature is the metrological data set recorded, processed, and managed by the Department of Metrology and Hydrology, the government of Nepal from the metrological stations. Annual T_{max}, T_{min}, T_{mean}, and annual rainfall data sets collected from the 11 metrological stations of the periphery of the water basin area covering 3o-years data from 1980 to 2020 were collected for this study. For the reliability and validity of these data sets, the collected data sets in an Excel sheet were manually checked one by one from three key aspects: *missing data*, *manipulated extreme values*, and *data coverage to the water basin*. However less than 3 percent of missing data in scientific work was considered, and the data was thoroughly observed using descriptive statistics. The study was started to find the manipulated extreme values. Fortunately, such data was not found. Additionally, the coverage of all stations was checked concerning heterogeneous elevations from the plain land to the Himalayan ranges to

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understand the temperature variable's movement, pattern, and impacts. After assuring all these measures, the data sets were prepared for further processing.

The supplementary data sets of temperature and rainfall were collected from desk review from June 1 to June 20, 2021. The supplementary data, elevation, ecological zones, and location of the metrological station were collected from documents of Government and non-government. Its lists are as follows: a) The 15th Five Years Plan Development (2018|19-2022|23; b) Sustainable Development Goal: Roadmap (2016-2030); c) Statistics Pocketbook, Central Bureau of Statistics (CBS), d) Nepal Living Standard Survey III, Central Bureau of Statistics (CBS), and e) Economic Survey, Ministry of Finance (MoF).

Model

Time Series Forecasting Model

A time series forecasting model (TSFM) was employed. In Nepal, Bista (2018) applied it in the Sotkhola Water Basin to understand the dynamics and variation of temperature and rainfall in the time series data set. TSFM is a simple forecasting regression model to capture the movement of rainfalls and temperature over time variables for understanding their pattern and trend. As mentioned in the conceptual framework, Y (dependent variable) is a climatic variable (temperature or rainfall) and X (independent variable) is time (t). The study employed the least square curve fitting technique. Let us fit a regression model to find a linear trend between the time series data(Y) and time (t) as given in the equation below.

$$Y_t = a_0 + a_n t^n \quad \text{……………………………………(1)}$$

Where,

y_t = temperature/rainfall over time,

t^n = n^{th} time (year),

"a_0" and "a_n" are unknown parameters.

If "a_n" is greater than "0", then "y" increases at a constant rate (=dy/dt). The trend line of "y" will be positive. If "a_n" is lower than "0", then "y" decreases at a constant rate. The trend line of y will be negative.

Mann- Kendall Test

Mann-Kendall Test (Kendall, 1975; Mann, 1945) is a popular method to assess whether the movement of annual temperature (T_{min}, T_{max}, and T_{mean}) and rainfall are increasing or decreasing over time and whether the trend of temperatures and rainfall are statistically significant or not.

$$Z = \begin{cases} \dfrac{S-1}{[VAR(S)]^{1/2}}, & \text{if } S > 0 \\ 0, & \text{if } S = 0 \\ \dfrac{S+1}{[VAR(S)]^{1/2}}, & \text{if } S < 0 \end{cases} \quad \textbf{……………………………….(2)}$$

Positive values of Z_s indicate increasing trends, while negative Z_s values show decreasing trends.

Sen's Slope Estimator

Sen (1968) built the non-parametric method for the estimation of the slope of a trend in the sample N pairs of data:

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$Qi=x_j+x_k/_{j-k}$ for i=1, ……,N…………………………(3)

Where, x_j and x_k = the data values at times j and k(j>k), respectively. If there is only one datum in each period, then N=n(n-1)/2, where n= number of periods

If there are multiple observations in one or more time periods, then N<n(n-1)/2. Where n=total number of observations.

The N values of Qi are ranked from the least to the highest and the median slope or Sen's slope estimator was calculated as

$Q_{med}=Q(_N+1)/2$ if N is odd…………………………………..(4)

Q(n/2)+Q(N+2/2), if N is even……………………(5)

The Qmed sign reflects the data trend, while its value indicates the steepness of the trend. To determine whether the median slope is statistically different from zero, the computation of the confidence interval of Qmed at a specific probability is done.

The confidence interval about the time slope is calculated as

$C_\alpha = Z_{1-\alpha/2}\ \sqrt{Var(S)}$, …………………………………….…(6)

Where Var(S) is defined and $Z_{1-\alpha/2}$ is obtained from the standard normal distribution table. The significance level of α= 0.05.

Then, $M1=N-C_{\alpha/2}$ is computed.

Result and Discussion

Study Area

The Marshyangdi River Basin of 4104.59 km² is the study area (Figure 2). This south-north river basin is located between 27°50'42" N to 28°54'11" N latitudes and 83°47'24" E to 84°48'04" E longitudes physically and hydrologically in central Nepal in the latitude of 27.4696° N and longitude of 85.2722° E (Figure 2). Spreading 150 km in the elevation from 318 meters to 8124 meters, the catchment areas of this snow-fed mountain river basin are six districts of three ecological zones and five elevations: Manang and Gorkha from the Himal (Mountain), Lamjung and Tanuhu from the Hill, Nawalparashi, and Chitwan from the Terai in Figure 2 (Khadka & Pathak 2016). Temperature and rainfall may vary in these heterogeneous elevations from plain to the steepest Mountain. In the variation, the snow-fed water in either river basin as the confluence of two mountain rivers, Khangsar Khola and Jharsang Khola, in the northwest of the Annapurna at an altitude of 3600 meters near Manang village may have a considerable influence on stabilize mean temperature or provocative to rainfall and the flow of water (Figure 2). Thus, the elevation and the flow of water may influence the variation in the trend of temperature and rainfall and their adversaries in the basin's emerging small cities (Figure 3).

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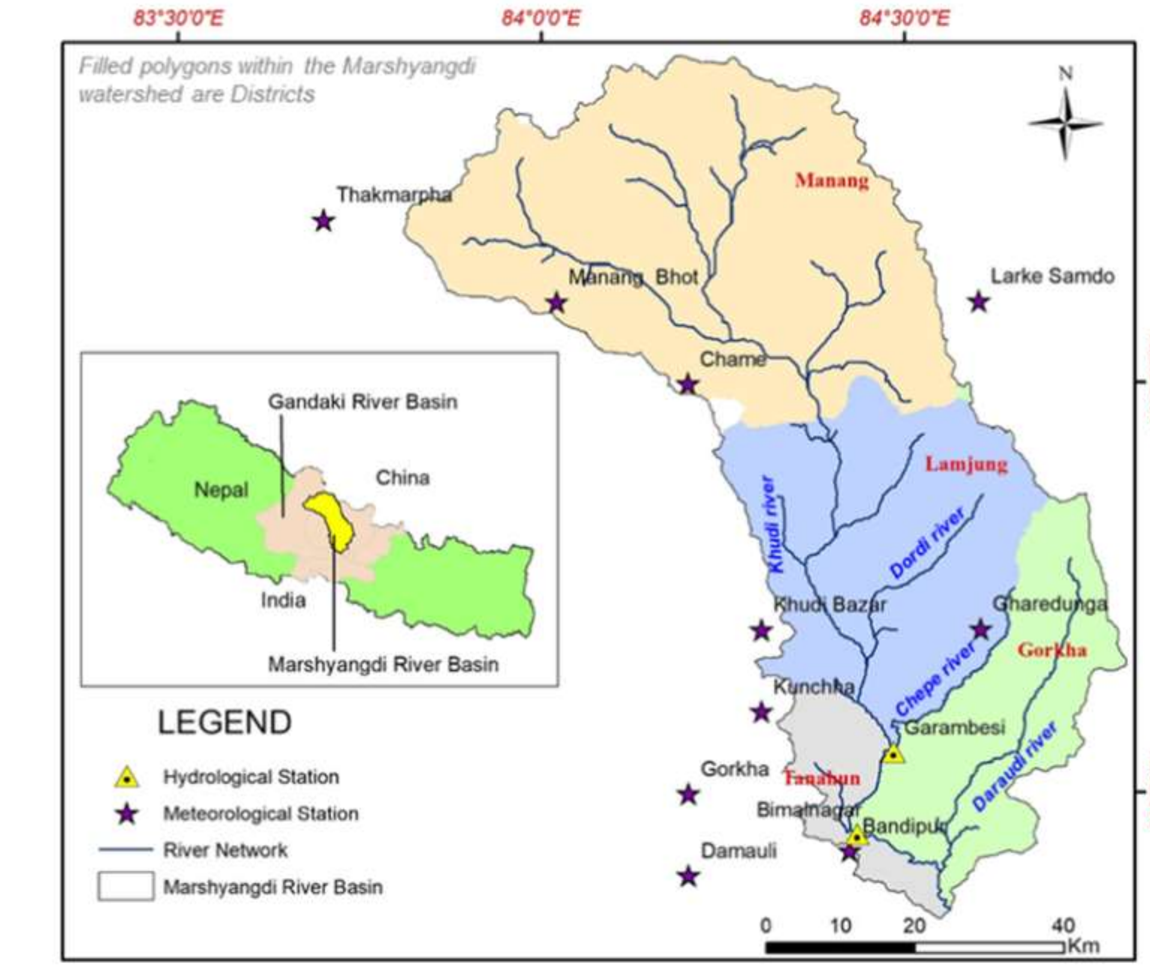
Figure 2. The Marshyangdi River Basin



Source: Singh, Pandey, & Kayastha, 2021

Trend Analysis of T_{min}, T_{max}, T_{mean}, and Rainfall: Time series forecasting Method

The time series forecasting method is quite popular for analyzing the trend of time series data sets of climate variables: T_{min}, T_{max}, T_{mean}, and Rainfall. This method is dynamic to capture whether climatic variables are increasing or decreasing in the water basin areas and to understand whether the study area is warming over time. This is important to decide the status of climate stress in the heterogeneous elevation of the study area.

Descriptive statistics is a powerful tool to describe statistical temperature variables of T_{min}, T_{max}, and T_{mean} to understand the preliminary static position of temperature over 40 years on average.

Table 1. Descriptive Statistics of Tmin, Tmax and Tmean

Description	1980-2020		
	Tmax	Tmin	Tmean
Mean	21.42	19.12	20.27
Standard Deviation	0.54	0.71	0.58
Minimum	20.29	17.30	18.80
Maximum	22.37	20.57	21.20

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Median	21.51	19.13	20.37
Range	2.08	3.27	2.40
Sample Variance	0.29	0.50	0.33
Kurtosis	-0.35	0.30	-0.09
Skewness	-0.54	-0.33	-0.53
Standard Error	0.08	0.11	0.09
Count	40.00	40.00	40.00

Table 1 shows mean, standard deviation, minimum, maximum, range, and other descriptive statistics in column 1 followed by the annual temperature maximum average (T_{max}) (1980-2020) in column 2, annual temperature minimum average (T_{min}) (1980-2020) in column 3 and annual temperature mean (T_{mean}) (1980-2020) in the column. Its details are in Table 1.

Trend Analysis of T_{min}, T_{max}, and T_{mean}: Time Series Forecasting Method

Trend analysis (1980-2020) insights the pattern of annual temperature (1980-2020) from three variables and three dimensions: annual temperature maximum average (T_{max}), annual temperature minimum average (T_{min}), and annual temperature mean (T_{mean}) whether the trend of these variables is decreasing or increasing. If the temperature trend is positive, warming will increase in the historical data, and climate stress will follow in the future. The trends of these three temperature variables (T_{min}, T_{max}, and T_{mean}) are in the three figures with time series forecasting linear equations in Figure 4 below.

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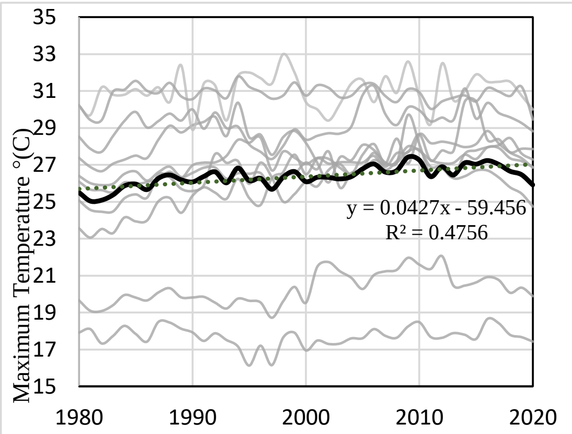
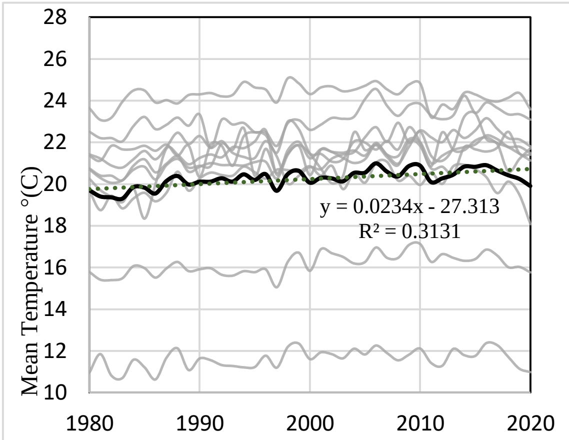
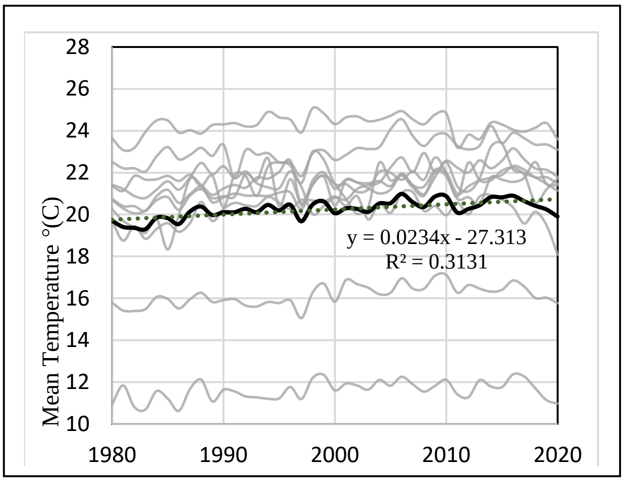
Figure 4. Trend of Tmin, Tmax and Tmean







Trend Analysis of T_{min}, T_{max}, T_{mean},: Mann-Kendell Test

Mann Kendall's test (1975) is a non-parametric test applied to test whether T_{min}, T_{max}, and T_{mean} trends are decreasing or increasing and to test hypothesis: null hypothesis (H0) is no monotonous trend in the time series data from 1980 to 2020 or alternative hypothesis (H1) is monotonous trend in the time series data from 1980 to 2020. Besides, the test is applied to test whether T_{min}, T_{max}, and T_{mean} trends are decreasing or increasing, and the hypothesis in the four-decade time zones: a) Tzone 1 (1980-1989), b) Tzone 2 (1990-1999), Tzone 3 (1999-2009), and Tzone 4 (2009-2020). In these tests, the results of Kendall's coefficient (τ **)** and Sen's coefficient (β) are in columns 3 and 4. The value of S is in column 5 and the p-value is in column 10. Besides, there are var(s) in column 6, T_{mean} in column 7, T_{min} in column 8, and T_{max} in column 9 in the table.

Result of trend analysis: Mann Kendall's test with Kendall's coefficient (τ **)** and Sen's coefficient (β) from 1980 to 2020.

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Descriptive Information of Tmin, Tmax, and Tmean across the elevation, stations, and ecological zone in the water basin and the Sen's slope coefficients for the period (1980-2020) is in Table 2 below.

Table 2. Descriptive Information of Tmin, Tmax and Tmean

Station	location	Latitude	Longitude	Elevation	Ecology	Tmax $^0Cy^{-1}$	Tmin^0C y^{-1}	Tmean^0 Cy^{-1}
601	Jomsom	28.78	83.72	2744	High mountain	0.024**	0.006*	0.015**
715	Arghakhachi	27.56	83.09	1760	Mountain	0.017**	0.064***	0.041**
814	Lumle	28.29	83.81	1740	Mountain	0.041**	0.005*	0.026**
725	Gulmi	28.04	83.15	1530	Mountain	0.050**	-0.002*	0.021**
802	Khudi Bazar	28.28	84.267	1280	hill	0.061***	0.044**	0.047**
809	Gorkha	28	84.37	1097	hill	0.087***	0.055***	0.031**
702	Palpa	27.52	83.32	1067	hill	0.025**	0.096***	-0.044**
605	Baglung	28.16	83.36	984	Hill	0.003*	-0.013**	0.011**
804	Phokara Airport	28.2	83.97	827	Hill	0.036**	0.036**	0.037**
815	Tanahun	28.02	84.06	500	Plain land	0.045**	0.033**	0.037**
902	Rampur	27.69	83.46	205	Plain land	-0.006*	0.019**	0.001*

Mann Kendall's test (1975) is a non-parametric test applied to test whether T_{min}, $T_{max,}$ and T_{mean} trends are decreasing or increasing and to test hypothesis: null hypothesis (H0) is no monotonous trend in the time series data from 1980 to 2020 or alternative hypothesis (H1) is monotonous trend in the time series data from 1980 to 2020. Besides, the test is applied to test whether T_{min}, $T_{max,}$ and T_{mean} trends are decreasing or increasing and hypothesis in the four-decade time zones: a) Tzone 1 (1980-1989), b) Tzone 2 (1990-1999), Tzone 3 (1999-2009), and Tzone 4 (2009-2020). In these tests, the results of Kendall's coefficient (τ) and Sen's coefficient (β) are in columns 3 and 4. The value of S is in column 5 and the p-value is in column 10. Besides, there are var(s) in column 6, T_{mean} in column 7, Tmin in column 8, and T_{max} in column 9 in the table.

Result of trend analysis: Mann-Kendall's test with Kendall's coefficient (τ) and Sen's coefficient (β) from 1980 to 2020 is presented in Table 3 below.

Table 3: Result of Sen and Kendall Test

Variables	Period	Sen's coefficients ($^0cy^{-1}$)	Kendall's tau τ ($^0cy^{-1}$)	S	Var(s)	Tmean^0C y^{-1}	Tmin^0C y^{-1}	Tmax $^0Cy^{-1}$	P-value
Tmean^0C y^{-1}	1980-2020	0.0	0.5	386.0	7366.7	20.2	19.1	21.4	0.0
Tmin$^0Cy^{-1}$	1980-2020	0.04	0.6	452.0	9135.4	19.1	17.3	20.6	0.0
Tmax $^0Cy^{-1}$	1980-2020	0.02	0.4	306.0	5596.8	21.4	20.3	22.4	0.0
Tmean^0C y^{-1}									
Tzone 1	1980-1989	0.14	0.61	22	92	19.72	19.19	20.37	0.04
Tzone2	1990-1999	-0.01	0.00	0	92	20.02	18.79	20.67	0.92

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Tzone3	2000-2009	0.12	0.66	22	92	20.57	19.78	21.05	0.013
Tzone4	2010-2019	0.04	0.24	11	125	20.65	20.21	21.20	0.38
Tmin $^0Cy^{-1}$									
Tzone 1	1980-1989	0.14	0.6	20.0	92.0	18.4	17.8	19.2	0.048
Tzone2	1990-1999	-0.01	-0.1	-2.0	92.0	18.9	17.3	19.6	0.92
Tzone3	2000-2009	0.09	0.6	20.0	92.0	19.4	18.9	20.0	0.04
Tzone4	2010-2019	0.1	0.4	19.0	125.0	19.7	19.0	20.6	0.1
Tmax $^0Cy^{-1}$									
Tzone 1	1980-1989	0.1	0.5	18	92	21.05	20.36	21.59	0.08
Tzone2	1990-1999	-0.01	0.00	0.00	92.00	21.15	20.29	21.73	0.91
Tzone3	2000-2009	0.1	0.56	20.00	92.00	21.76	20.49	22.37	0.04
Tzone4	2010-2019	-0.02	-0.1	-3.0	125.0	21.6	21.0	22.1	0.9

Discussion

The result of the descriptive statistics of three temperature variables such as minimum temperature (T_{min}), maximum temperature (T_{max}), and mean temperature (T_{mean}) from 1980 to 2020 collected from 11 stations of the water basin is presented in Table 1. The mean values of T_{min} and T_{max} are 19.12^{0}c y^{-1} and 21.42^{0}c y^{-1}. These values reveal moderate warm temperatures. The gap between T_{min} and T_{max} is -2.3^{0}c y^{-1}. These values are a strong description of warming in terms of the one-directional rise of T_{min} and T_{max} and the narrow gap between T_{min} and T_{max} from 1980 to 2020, although T_{mean} (20.27 ^{0}c y^{-1}) is moderate temperature i.e. neither extreme warm nor extreme cold. In the nominal standard deviation and standard error, median values of T_{min}, $T_{max,}$ and T_{mean} are comfortable over the last 40 years. Despite Himalayan ranges, these stations show moderately warming water basin areas.

Similarly, the result of the time series forecasting method is shown in Table 2. The result provides convincing evidence of a positive trend of three temperatures such as T_{min}, $T_{max,}$ and T_{mean} over 40 years from 1980 to 2020 with marginal changes of +0.015 ^{o}c y^{-1}, +0.042^{0}c y^{-1} and +0.023^{0}c y^{-1} respectively. The results are statistically significant, although R^2 values are below 50 percent. The positive trends of temperatures (T_{min}, $T_{max,}$ and T_{mean}) have been in the last 40 years from 1980 to 2020. In these trends, the marginal change of upper temperature (T_{max}) per annum is greater than the rate of marginal change of lower temperature (T_{min}) per annum. The water basin has been warming in the last 40 years, if we consider 1980 as the baseline of T_{min}, $T_{max,}$ and T_{mean}. This implies climate change in the real sense in the water basin. In the business-as-usual scenario, it will be consistent and complicated in the future. However, if the three tiers of governments awake on this issue to act preparedness through policy instruments, it will be simple. This result is like the national evidence of climate change.

Likewise, the relationship between temperature and elevation is an important dimension. In general, the relationship between temperature and elevation is inverse. It means higher elevation and low temperature and vice versa. We observe it using Mann-Kendall's test. The result of Mann-Kendall's test (1975) across the heterogeneous elevations from plain elevation to steepest elevation is presented in Table 3. This result rejects a general assumption that higher elevation and low temperature and vice versa is convincing evidence

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of rising annual mean temperature in the heterogeneous elevation from plain elevation to steepest elevation with rising of T_{min}, and T_{max}, except for few events, locations, and elevations. The coefficients of annual mean temperature from plain land (205 elevation) to high Mountains (2744 elevation) are positive and statistically significant, except negative and statistically significant in hills (1067 elevation). It implies warming in all elevations out of which its intensity in hills is higher than plain, mountain, and high Mountains. In this warming, rising T_{min}, and T_{max} are key drivers, except elevations (205, 984, and 1530). Therefore, the water basins in all elevations are warmer than it was in the year the 1980s. Its examples are warming mountains and hills of the water basins.

As supplementary, the relationship between temperature and time is a curiosity because temperature is dynamic. We observe the trends of T_{min}, T_{max}, and T_{mean} over the last 40 years using Mann-Kendall's and Sen's tests. The result of Mann-Kendall's test and Sen's Test is presented in Table 4. The result validates the warming of the basin with robust evidence of annual temperature rising from 1980 to 2020. It meets the 30-year threshold of climate change (IPCC, 2001). It can be said climate change. As a result, in the last 40 years, T_{mean} is 20.2^0c y^{-1} in 2020 as an incremental of base T_{mean} in 1980 was 19.1 0c y^{-1}. Raising temperature is $+1.1^0$c y^{-1}. Raising T_{mean} is $+0.027^0$c y^{-1}. It is less than the national annual temperature rising in Nepal. T_{min} and T_{max} are raised by $+2.1^0$c y^{-1} and $+3.3^0$c y^{-1} respectively.

Let us check T_{mean} over 40 years (1980-2020) into four decadal time zones: first time zone (1980-1989), second time zone (1990-1999), third time zone (2000-2009) and fourth time zone (2010-2019). Except for the second time zone (1990-1999), Sen's Coefficients and Kendel's Tau of these remaining three time zones have a positive trend. It implies raising T_{mean} with more than $+2^0$c y^{-1} temperature difference between T_{min}, and T_{max}. Such reflection can be found in time zones of T_{min}, and T_{max}. However, in T_{max}, the second and fourth time zones have negative Sen's Coefficients and Kendall's tau.

Conclusion

This study examines dimensions, behaviors, and dynamics of climatic variables (T_{min}, T_{max}, and T_{mean}) in Marsyangdi Water Basin in Nepal using time series data sets of T_{min}, T_{max}, and T_{mean} from 1980 to 2020 by a time series-forecasting model and Mann Kendall's test and Sen's test. The study finds key findings as follows:

- T_{min}, T_{max}, and T_{mean} are annually rising with a narrow gap between T_{min} and T_{max} from 1980 to 2020. In the basin, T_{mean} (20.27 ^{0}c y^{-1}) is moderate temperature i.e. neither extreme warm nor extreme cold, despite Himalayan ranges and higher hills.

- In the different elevations, T_{min}, T_{max}, and T_{mean} in the last 40 years are consistently rising. Interestingly, its intensity in hills is higher than in plain, mountain, and high Mountain. The water basins in all elevations are warmer than it was in the year the 1980s. Its examples are warming mountains and hills of the water basins.

- In the last 40 years, T_{mean} is 20.2^0c y^{-1} in 2020 as an incremental of base T_{mean} in 1980 was 19.1 ^{0}c y^{-1}. Rising temperature is $+1.1^0$c y^{-1} with $+0.027^0$c y^{-1}. Both T_{min} and T_{max} are raised by $+2.1^0$c y^{-1} and $+3.3^0$c y^{-1} respectively.

- Except for the second time zone (1990-1999), Sen's Coefficients and Kendel's Tau of these remaining three time zones have a positive trend. It implies raising T_{mean} with more than $+2^0$c y^{-1} temperature difference between T_{min}, and T_{max}.

The study can conclude that the water basin has been suffering from climate change with a positive increasing trend of T_{min}, T_{max}, and T_{mean} across the elevation and time. Climate change is the main reason behind the hydrological change of the Marshangadi River, increasing drought-induced water deficit and stress, ice melting at mountains and unpredicted flooding, extinction of species at high altitudes, biodiversity, changing crop cycle and patterns, and migrating residents. Therefore, emerging climate change is a sensitive

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and decent issue to be quickly responded to for improving adaptive and mitigated capacity, instruments, funds, and programs at all elevations of the basin so that the cost and vulnerability of climate change-induced stress and disaster could be substantially reduced, livelihood resources could be maintained for economic development and welfare of the locals.

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