Examining Varying Rainfall in the different elevation of Nepal and Water Scarcity

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Abstract

This study assesses the variation of rainfall in the different elevations in the water basin in Nepal. Employing time series data sets of rainfall from 1980 to 2020 collected from Department of Hydrology and Metrology, Nepal, this study has used Mann Kendal test and Sen's test. In the different elevations, the variation of rainfall is heterogeneous. In the steep elevated landscapes, rainfall is extreme. In the last 47 years, trend of annual rainfall's mean (R_{mean}) and moving average (R_{meanma}) have been declining. During that period, there were extremes of higher and lower rainfall in the decadal time frame. Kendall's coefficient (τ) and Sen's coefficient (β) of R_{mean} are -3.65^{0}c and -0.13^{0}c respectively. It implies decreasing trend of R_{mean} from 1975 to 2020. Sen's coefficient (β) of R_{mean} validate decreasing trend of R_{mean}. However, it is insignificant ($P=0.2>0.05$). Differently, except Kendall's coefficient (τ) and Sen's coefficient (β) of R_{mean} in T_{zone2} (1990-1999), Kendall's coefficient (τ) and Sen's coefficient (β) of the remaining three time zones, T_{zone1} (1980-1989), T_{zone3} (2000-2009) and T_{zone4} (2010-2019) are negative. Therefore, rainfall has negative trend in the different elevations of the water basin. We conclude water scarcity & stress exist in the small cities. To minimize water vulnerability, water saving and preserving behaviour of household should be developed and the government agency should campaign tree plantation, protect water sources and initiate water management program.

Key words: *climate change, water stress, small cities, adaptation, mitigation*, etc.

1. INTRODUCTION

Erratic rainfall that is either an increase or decrease amount of precipitation is an emerging one of acute climatic issues in the world. It is a prominent variable to analyse climate change issue. Increasing irregular rainfall pattern in the different countries are considered as the result of raising temperature, distorting natural phenomenon and excessive anthropogenic economic activities of the people for livelihood & welfare. Bedeke (2023) found it in sub-Saharan African economies. Similarly, Indian Institute of Technology Bombay (IITB) and National Institute of Hydrology (NIH, 2023) mentioned it in Himachal Pradesh and the Ganga headwaters in Uttarakhand in India between 1980-91 and 1992-2003. In the Uttarakhand, erratic rain fall was 340 millimeters of rainfall – 375% more than the normal daily rainfall during the southwest monsoon that occurs between June and September on June 17 (NIH, 2023). It happened in Jackson, Mississippi, USA (CES, 2022). This has induced extreme rainfall events in either heavy rainfall or light rainfall. The heavy rainfall may result a heavy flooding, whereas the light rainfall may induce drought. Both extremes have made vulnerable with visible and invisible socio-economic cost to the community and obliged to improve preparedness and adaptation for minimizing their direct and indirect effects. In India, more than 6,000 people died in northern side and parts of Nepal, along with a damage of property worth billions was damaged (NIH, 2023). Similarly, extreme rainfall induced flooding killing three people and leaving more than 150000 without drinking water (CES, 2022). Therefore, growing climate change induces erratic rainfall more than before having unexpected and unprecedented loss of life and wealth as a big threat natural hazard.

In the world, this extreme rainfall imposes unpredictable climatic threats in the different spheres and economic activities in accordance with real time rainfall data monitoring station of the department of metrology. In human health, CES (2022) argues degrading water quality, harming human health, aquatic ecosystems and fishery operations as its adverse effects in USA. Sarkar, *et al.* (2022) and Baqir et al., (2012) have similar observations and worry about risk of the spread of diseases. IRC, (2022) notes an outbreak in waterborne disease such as diarrhoea and cholera, as well as skin and eye infections, and malaria across Sindh and Balochistan. In agriculture, Mairura et al. (2021) notes it making sensitive and exposing rain fed agriculture crops and small famers to some extent in the Sub-Saharan Africa (SSA). Similarly, in Kenya, it degrades soil and crop performance (Oduor et al., 2021). Further, Bedeke (2023) mentions a greater incidence of crop pests, loss of soil moisture content, rapid soil nutrient depletion and substantial decreases in crop productivity and yields in sub-Saharan African economies. It further threatens access to food, limit export earnings and markedly lower net crop revenue.

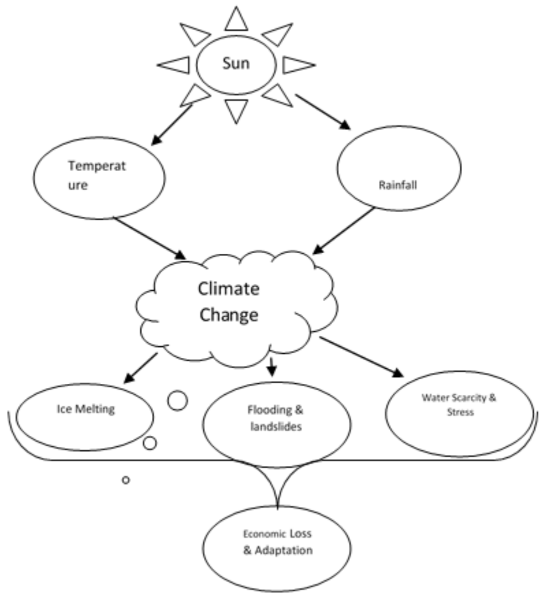
The similar scenario can be found in Asia, particularly Nepal. WB (2022) mentions Nepal in the 4th climatic vulnerable country. This global rank reflects extremity of climate instability. UNFCCC (2015) and IPCC (2018) mention variation of climatic variables as the third dimension are extreme in Nepal. Like a variation of temperature, DHM (2022) notes changing average rainfall over the last 50 years' periods. Bista (2019) argues erratic rainfall in Nepal with evidence of intense rainfall for four days and then intense flood in 2014 in Sot Khola Water Basin where NRs. 10 billion economic losses, as well as 37 people died and 3867 affected households. DHM (2021) records intense rainfall in Marshayangdi river basin. In 2021, its outcomes were disastrous with a huge infrastructure damages and losses (MOHA, 2022). In agriculture, varying rainfall is a key determinant in Nepal (Bista, 2021 and MoF, 2023). According to the Ministry of Agriculture and Livestock Development (MOALD), the unusual rainfall caused losses amounting to *Rs11.87 billion in 2022*. Therefore, erratic rainfall is a major threat in Nepal, especially the elevated landscapes including high and low hills.

In recent years, literatures are available to cover this issue at national level and at local level. However, most literatures (Bajracharya, *et al*. (2023); Bhandari, *et al*. (2023); Bom, Tiefenbacher, & Belbase, (2023); Chauhan, Thakuri, & Pradhan, (2023); Gautam, *et al*. (2023); Jamarkattel, *et al*. (2023); Kandel, *et al*. (2023); Karki, *et al*. (2023); KC, *et al*. (2023); Mohammed, *et al*. (2023); Pandey, *et al*. (2023); Parajuli, *et al*. (2021) Poudel, *et al*. (2023); Ranabhat, *et al*. (2023); Talchabhadel & Chhetri,(2023); Thapa, *et al*. (2023); Timilsina, *et al*. (2023); and Tiwari, *et al*. (2023) cover erratic rainfall and its adverse effects. However, they do not cover erratic rainfall related to the elevated landscapes. So, there is a research gap creating a scope to be studied further in Nepal. Therefore, this study is highly relevant to aim the study on these issues to fill up such research gaps. The broad objective of this paper is estimate the relationship between rainfall and elevations in the Marsyangdi Water Basin in Nepal. Its specific objectives are to analyse trend of rainfall in the study area, and to forward issues and recommendation for policy implication to the policy makers and further research. This paper is organized into the following sections: Section 1: Introduction, Section 2: Method and Data 3: Method and Data, Section 4: Results, and Section 5: Discussion and Conclusion.

2. METHODS AND DATA

2.1 Theoretical/Conceptual Framework

Rainfall is metrological and climatic variable. When mean temperature changes over more than 30 years, the pattern and trend of mean rainfall induces climate change. When mean rainfall increases, flooding will happen. In the reverse, drought induced water scarcity and stress happen. In the both cases, the society will get economic loss one side and another side explore adaptation methods in both cases to minimize economic loss and vulnerability (Figure 1). This is a scientific fact in the world (IPCC, 2001; Gleick, 2000; Solomon, et al., 2007; Adams and Peck, 2008; and IPCC, 2018). It is clear that the society expects the stability of climate change employing adaptation in short run period and mitigation in long run for better, safe, and beautiful life and security of livelihood in the future.



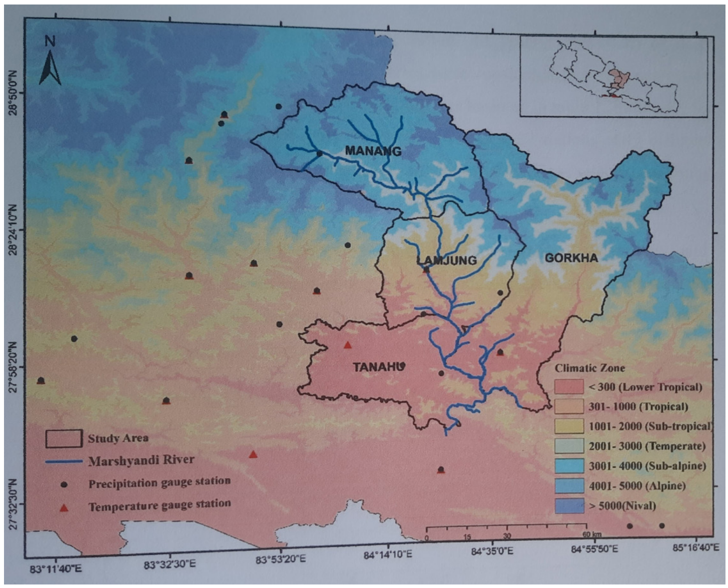
Research Design

Using explorative cum descriptive research design, the study is undertaken to explore the existing and potential relationship between rainfall, landscapes and elevations across the three ecological belts of the water basin and to test the mentioned hypotheses in the study areas. The study searches whether the variation of rainfall exists over a long period, and whether the relationship between dynamics of rainfall and elevations is positive in the study areas. It is expected that this inquiry carry new and interesting results.

Study Areas

Located in Gandaki Province, Nepal, the study covers Marshyangdi river basin. This basin of 4787 sq.km. spreads 150 km long situating 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 (Figure 1). This basin starts from Annapurna trans Himalayan range and ends at the low land of Chitwan. In the basin, water is rain fed. Its level is steady in both monsoon (rainy) and winter (dry) seasons. Ecologically, it ranges from the cold high-alpine type to the hot and humid tropical type. Its mean slope is about 29.42°degrees. The basin is highly exposed to climatic variables, particularly rainfall. The cluster of dense small cities is highly vulnerable from flooding, landslides, and droughts. Therefore, rainfall varies across the different landscapes (Figure 1).

Figure 1: The Study Area- Marshyangdi River Basin



Source: Koirala, 2022

Figure 1 shows the study area. The study area is highly relevant because of two major reasons: a) DHM (2022) reports that the basin has erratic rainfall and adverse effects at the catchment areas; b) the study area has different elevation from 200 meter to 7800 meter. In the elevation, the study area 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.

Data

Like temperature, rainfall is a crucial variable in the climatology study to understand climate instability in the study area. This variable is a metrological real time data. It is in the scope of the department of hydrology and metrology (DHM), the government of Nepal. Employing annual data sets of rainfall such as R_{max}, R_{min}, and $R_{mean,}$ the study covers 3o years long from 1980 to 2020. The rainfall data are collected from the 11 metrological stations in the water basin area.

We proceed carefully and technically the rainfall data in excel sheet one by one from three key aspects: *missing data*, *manipulated extreme values*, and *data coverage to the water basin* for their reliability and validity. Since we consider less than 3 percent missing data in scientific work, we observe the data by descriptive statistics. Similarly, the study identifies the manipulated extreme values. Fortunately, such data are not found. Additionally, the coverage of all stations are checked with respect to heterogeneous elevations from the plain land to trans Himalayan ranges for understanding rainfall variable's movement, pattern, and impacts. After assuring all these measures, the data sets are processed further.

The supplementary data sets of rainfall are collected from desk review from June 1 to June 20, 2021. The desk review includes a) The 15th Five Years Plan Development (2018|19-2022|23; b) Sustainable Development Goal: Roadmap (2016-2030); c) Statistics Pocket book, 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

We find that time series forecasting model (TSFM) is relevant to this study for testing above hypothesis. This model is widely used. In Nepal, Bista (2018) applied it to capture dynamics and variation of temperature and rainfall in the time series data set in the Sotkhola Water Basin. Therefore, we use it to cover the movement of rainfalls over time for exploring and explaining their pattern and trend. As stated in the conceptual framework, rainfall is climate variable. Let's consider "y" as a dependent variable to time variable "t" as independent variable. 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.

$y_t = \alpha_0 + \beta t^n$……………………………………(1)

Where,

y_t = rainfall in "t" time,

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

"α_0" and "β" are unknown parameters.

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

Mann- Kendall Test

We use another method of Mann-Kendall Test (Kenadall, 1975; Mann, 1945) to measure whether movement of annual rainfall (R_{min}, R_{max} and R_{mean}) are increasing or decreasing over time and whether the trend of rainfall is statistically significant or not.

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

In the result, Z_s is positive value, it indicates increasing trends. When Z_s is negative, it reveals decreasing trends.

Sen's Slope Estimator

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

$Q_i=X_j+X_k/_{j-k}$ 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 Q_{med} 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 Q_{med} 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.

3. RESULT AND DISCUSSION

Trend Analysis of R_{mean}: Time series forecasting Method

Descriptive Statistics of Mean Rainfall in different seasons

Descriptive statistics of annual mean rainfalls (Rmean and Rmoving average) is used to describe statistically rainfall variables of R_{mean}, and R_{meanma} to capture static situation of rainfall over 40 years on average. Table 1 shows mean, standard deviation, minimum, maximum, range and other descriptive statistics in column 1 followed by annual mean rainfall average (R_{mean}) (1980-2020) in column 2, and annual mean rainfall in moving average (R_{meanma}) (1980-2020) in column 3. Its details is in table 1 .

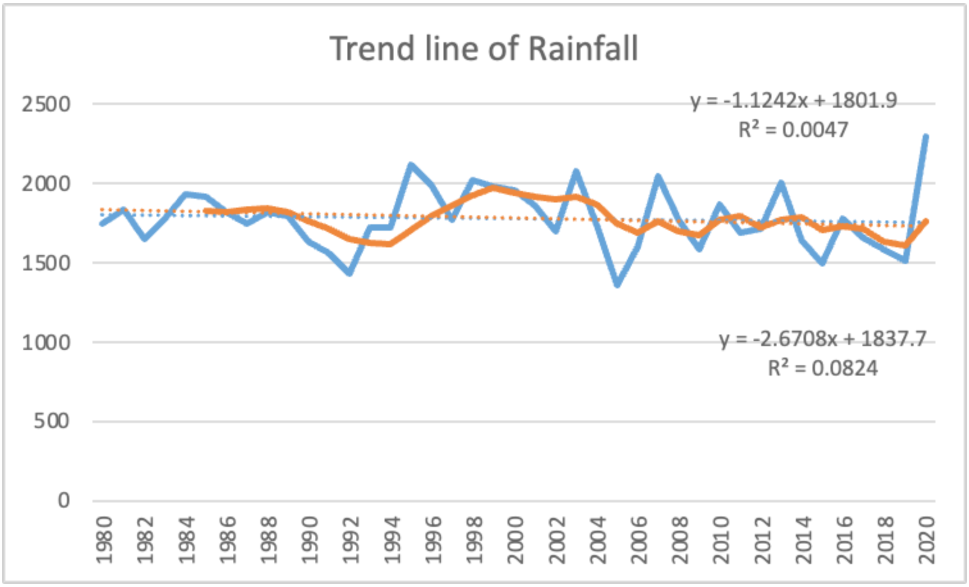
Table 1: Descriptive Statistics of Mean Rainfall Rmean

Description	Rmean	Rmoving mean
Mean	1779.16	1773.58
Standard Deviation	198.95	99.07
Minimum	1354.88	1606.46
Maximum	2297.84	1974.42
Range	942.96	367.97
Sample Variance	39582.06	9814.44
Median	1768.84	1766.40
Kurtosis	0.13	-0.72
Skewness	0.26	0.22
Standard Error	31.46	16.75
Count	40	35

Source: DHM Data (1980-2020)

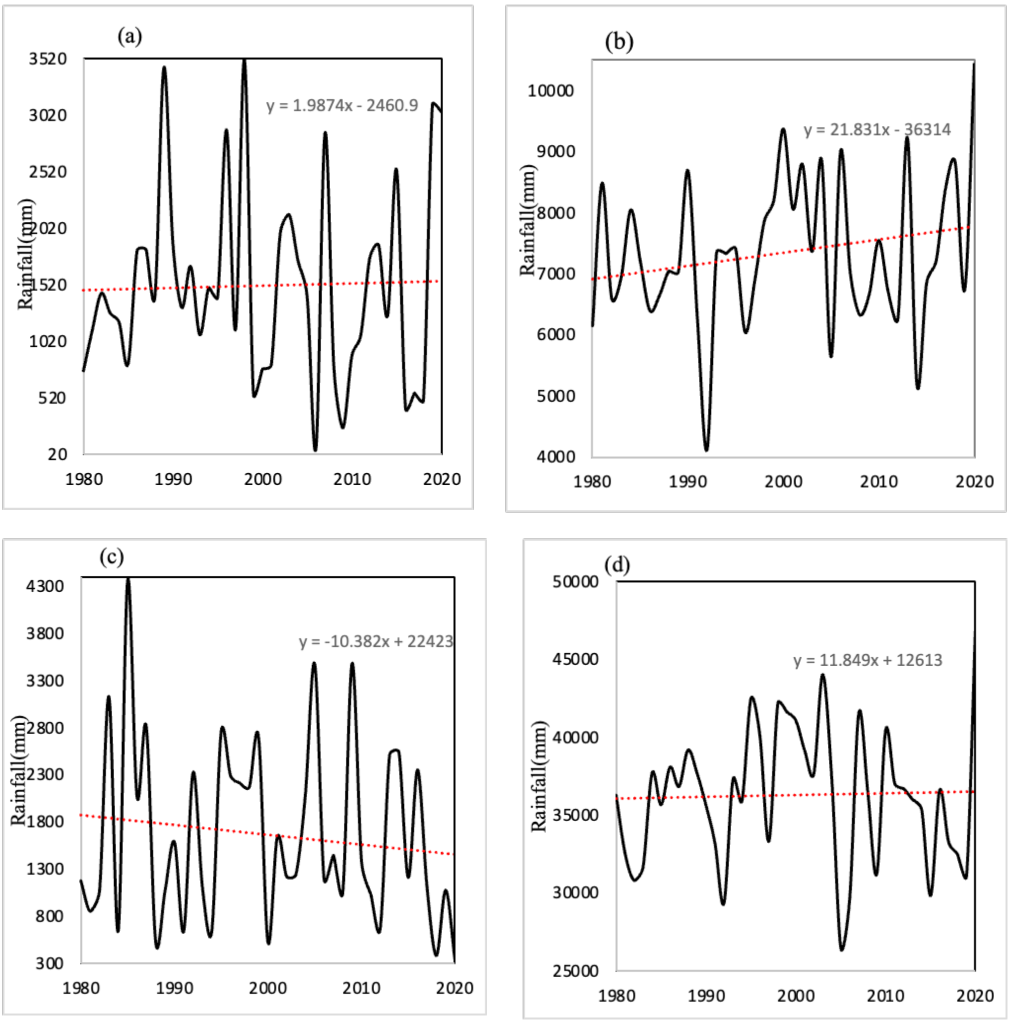
Trend analysis (1980-2020) examines the pattern of annual rainfall (1980-2020) from two variables and two dimensions: annual mean rainfall (R_{mean}), and annual mean temperature on moving average (R_{meanma}) whether trend of these two variables are decreasing or increasing. If the trend is decreasing, drought will increase in the historical data and then climate stress will be in the future. Trend of these two rainfall variables (R_{mean}, and R_{meanma}) are in the figure 2 with time series forecasting linear equations below.

Figure 2: Trend line of Mean Rainfall



Similarly, seasonal breaks are important aspects to understand the pattern of annual mean rainfall in four seasonal breaks: (a) winter, (b) pre-monsoon, (c) post-monsoon, and (d) monsoon seasons whether annual mean rainfall is increasing or decreasing. Trend lines of annual mean rainfall in the seasons are in the figure 3 below.

Figure 3: Trend of Annual Average Rainfall (1980-2020)



Note: Average annual rainfall in (a) winter, (b) pre-monsoon, (c) post-monsoon, and (d) monsoon seasons.

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

Trend Analysis, Overall Time and Time Zones

The trend analysis of R_{min}, R_{max}, & R_{mean} is a powerful statistical tool to measure a direction of rainfall trend over time from 1975 to 2020 and to understand the indicator of climate change. For this objective, there are two time clusters: a) overall time from

1975 to 2020 and b) decadal time zones. Firstly, in this trend analysis, Mann Kendall's test (1975) as non-parametric test is popular to test whether R_{min}, R_{max} and R_{mean} trends are decreasing or increasing. For this, hypothesis is as follows: 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, secondly, Mann Kendall's Test examines whether trend of R_{min}, R_{max} and R_{mean} is decreasing or increasing. Further, it tests hypothesis in the four-decadal time zones: a) Tzone 1 (1980-1989), b) Tzone 2 (1990-1999), Tzone 3 (1999-2009), and Tzone 4 (2009-2020). The results of Kendall's coefficient (τ) and Sen's coefficient (β) are in column 3 and 4, along with variables in column 1 and time in column 2. The value of S is in column 5 and p-value is in column 10. Besides, there are var(s) in column 6, R_{mean} in column 7, R_{min} in column 8, and R_{max} in column 9 are in table 2.

Result of trend analysis: Mann Kendall's test with Kendall's coefficient (τ) and Sen's coefficient (β) of R_{mean} from 1980 to 2020 and four time zones.

Table 2: Result of Mann Kendall's Test on Rmean

Variable	Time	Sen's coefficients	Kendall's tau	S	Var(s)	R_{mean}	R_{Min}	R_{Max}	P-value	Std. deviation
		0c	0c							
Rmean	1980-2020	-3.65	-0.13	-102	7366.7	1779.2	1354.9	2297.8	0.2	199.0
Rmean										
Tzone 1	1980-1989	-3.07	-0.06	-2	92	1810.5	1651.4	1934.3	0.9	85.8
Tzone2	1990-1999	63.15	0.50	18	92	1811.7	1427.4	2115.0	0.1	230.1
Tzone3	2000-2009	-19.75	-0.22	-8	92	1747.4	1354.9	2079.9	0.5	228.3
Tzone4	2010-2019	-13.21	-0.11	-5	125	1737.9	1498.1	2297.8	0.7	244.5

Source: DHM data (1980-2020)

Table 2 shows the result of Kendall's coefficient (τ) and Sen's coefficient (β) of $R_{mean,}$ where R_{mean} from 1975 to 2020 is 1779.2 millimetres, along with 1354.9 millimetres (mmy^{-1}) of R_{min} and 2297.8 mmy^{-1} of R_{max}. This descriptive statistics of rainfall from 1975 to 2020 illustrates the water basin having neither minimum rainfall nor maximum rainfall in the different elevations. In the water basin, R_{mean} rainfall is slightly higher than national rainfall mean (1600 mmy^{-1}) (DHM, 2022), although R_{max} is higher than R_{mean} and R_{min} is lower than national rainfall mean. It implies the moderate rainfall of the basin supplies reliable water sources for recharging water system and maintaining water particles in the ecosystem. Similarly, Kendall's coefficient (τ) and Sen's coefficient (β) of R_{mean} are -3.65^{0}c and -0.13^{0}c respectively. It implies decreasing trend of R_{mean} from

1975 to 2020. Sen's coefficient (β) of R_{mean} validate decreasing trend of R_{mean}. However, it is insignificant (P=0.2>0.05).

In the decadal time zones, there are four time zones: T_{zone1} (1980-1989), T_{zone2} (1990-1999), T_{zone3} (2000-2009) and T_{zone4} (2010-2019) out of which except Kendall's coefficient (τ) and Sen's coefficient (β) of R_{mean} in T_{zone2} (1990-1999), Kendall's coefficient (τ) and Sen's coefficient (β) of the remaining three time zones, T_{zone1} (1980-1989), T_{zone3} (2000-2009) and T_{zone4} (2010-2019) are negative. The result of Kendall's coefficient (τ) and Sen's coefficient (β) of R_{mean} are evidence of decreasing rainfall in these three decadal time zones but of increasing rainfall in the second decadal time zones. However, all are statistically insignificant. Therefore, trend of decadal time zones and overall rainfall scenarios are decreasing in the different elevations in the water basin.

Trend Analysis, Location and Elevations

The trend analysis of R_{min}, R_{max}, & R_{mean} measures a direction of rainfall trend across locations and elevations from 1975 to 2020 and to understand the impact of location and elevation on climate change. For this objective, there are locations in the different elevations. Firstly, in this trend analysis, Mann Kendall's test (1975) test whether R_{min}, R_{max} and R_{mean} trends across locations are decreasing or increasing. For this, hypothesis is as follows: null hypothesis (H0) is no monotonous trend in the locations in the different elevations from 1980 to 2020 or alternative hypothesis (H1) is monotonous trend in in the locations in the different elevations from 1980 to 2020.

The results of Kendall's coefficient (τ) and Sen's coefficient (β) are in column 7 and 8, along with station in column 1, location in column 2, latitude in column 3, longitude in column 4, elevation in column 5 and ecology in column 6. The value of S is in column 9 and p-value is in column 10. Besides, there are R_{mean} in column 11, and Std. in column 12 are in table 3.

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

Table 3: Result of Mann Kendall's test in the different elevations

Station	location	Latitude	Longitude	Elevation	Ecology	Kendall(τ)	Sen's slope (β)	S	P value	R_{mean}	Std
601	Jomsom	28.78	83.72	2744	High mountain	0.20	2.15	158	0.067	281.11	78.90
715	Arghakhachi	27.56	83.09	1760	Mountain	-0.27	-11.96	-212	0.01	1755.90	348.81
814	Lumle	28.29	83.81	1740	Mountain	-0.01	-0.37	-10	0.92	5450.08	549.83
725	Gulmi	28.04	83.15	1530	Mountain	-0.17	-7.48	-132	0.13	1856.31	351.86

802	Khudi Bazar	28.28	84.267	1280	hill	-0.10	-7.61	-78	0.37	3235.64	740.09
809	Gorkha	28	84.37	1097	hill	-0.10	-4.39	-78	0.37	1668.91	333.78
702	Palpa	27.52	83.32	1067	hill	0.00	-0.21	-2	0.99	1443.51	471.32
605	Baglung	28.16	83.36	984	hill	-0.08	-5.30	-64	0.47	1909.66	490.62
804	Phokara Airport	28.2	83.97	827	hill	-0.06	-0.47	-50	0.57	320.15	49.58
814	Tanahun	28.02	84.06	500	Plain land	-0.01	-0.37	-10	0.92	5450.08	549.83
902	Rampur	27.69	83.46	205	Plain land	-0.02	-0.80	-16	0.86	2004.55	414.25

Source: DHM data (1980-2020)

Table 3 shows the result of Kendall's coefficient (τ) and Sen's coefficient (β) of $R_{mean,}$ where R_{mean} of Jomsom at 2744 highest elevation is lower rainfall of 281.11 millimetres (mmy^{-1}) but R_{mean} of Rampur at 205 lowest elevations is higher rainfall of 2004.55 millimetres (mmy^{-1}). There are exceptional R_{mean} in Lumle of 1740 elevation and Pokhara Airport of 827 elevation having 5450.08 millimetres (mmy^{-1}) and 320.15 millimetres (mmy^{-1}) respectively. This descriptive statistic exemplifies the water basin having heterogeneous mean rainfall in locations of the different elevations. Except few locations and elevations, rainfall and elevations have inverse relationship in which higher elevation means lower rainfall and lower elevation means higher rainfall. In hill and plain ecological belts of moderate elevations, rainfall is major charger to the water basin and its river system, ground water, water related ecosystem and production activities.

<u>Result of Kendall's coefficient (τ) and Sen's coefficient (β)</u>

In Kendall's test, there are hypothesis: Null hypothesis is τ=0 (no correlation between rainfall and elevation). Alternative is τ≠0 (correlation between rainfall and elevation). The result of table shows Kendall coefficients of high mountain, mountain, hill and plain are not zero, except of Palpa. It implies rainfall has a correlation with all locations and elevation, except of Palpa. In the correlation, rainfall have negative correlation with elevation at decreasing rate, except of Jomsom. Therefore, null hypothesis is rejected. Except Arghakhachi, the correlations are insignificant because of P value (= > 0.05). The result of Kendall's coefficient is validated by the result of Sen's coefficient (β). The median values show downward slopes of rainfall and elevations.

Discussion

The study observes varying rainfall in the different elevations in the water basin of Nepal using Kendall and Sen's test. We test varying rainfall over time and across the different elevations. In the first test, there are two different results. Firstly, over the last 46 years' time period, the result of Kendall's coefficient (τ) and Sen's coefficient (β) of $R_{mean,}$ where R_{mean} from 1975 to 2020 illustrates the water basin having neither minimum rainfall nor maximum rainfall in the different elevations. In the water basin, R_{mean} rainfall is slightly higher than national rainfall mean (1600 mmy^{-1}) (DHM, 2022), although R_{max} is higher than R_{mean} and R_{min} is lower than national rainfall mean. Similarly, Kendall's coefficient (τ) and Sen's coefficient (β) of R_{mean} are -3.65^{0}c and -0.13^{0}c respectively. Trend of R_{mean} from 1975 to 2020 is decreasing. Sen's coefficient (β) of R_{mean} validate it. However, it is insignificant (P=0.2>0.05).

Secondly, in the decadal time zones, except Kendall's coefficient (τ) and Sen's coefficient (β) of R_{mean} in T_{zone2} (1990-1999), Kendall's coefficient (τ) and Sen's coefficient (β) of the remaining three time zones, T_{zone1} (1980-1989), T_{zone3} (2000-2009) and T_{zone4} (2010-2019) are negative. The result of Kendall's coefficient (τ) and Sen's coefficient (β) of R_{mean} are evidence of decreasing rainfall in these three decadal time zones but of increasing rainfall in the second decadal time zones. However, all are statistically insignificant. Therefore, trend of decadal time zones and overall rainfall scenarios are decreasing in the different elevations in the water basin.

Similarly, in the second test, the result of Kendall's coefficient (τ) and Sen's coefficient (β) of $R_{mean,}$ exemplifies the water basin having heterogeneous mean rainfall in locations of the different elevations. Except few locations and elevations, rainfall and elevations have inverse relationship in which higher elevation means lower rainfall and lower elevation means higher rainfall. In hill and plain ecological belts of moderate elevations, rainfall is major charger to the water basin and its river system, ground water, water related ecosystem and production activities.

In Kendall's test, Kendall coefficients of high mountain, mountain, hill and plain are not zero, except of Palpa. It implies rainfall has a correlation with all locations and elevation, except of Palpa. In the correlation, rainfall have negative correlation with elevation at decreasing rate, except of Jomsom. Therefore, null hypothesis is rejected. Except Arghakhachi, the correlations are insignificant because of P value (= > 0.05). The result of Kendall's coefficient is validated by the result of Sen's coefficient (β). The median values show downward slopes of rainfall and elevations. Thus, rainfall trend is decreasing in the water basin.

This result is generic and similar with the result of IPCC (2008), Khadka, and Pathak (2016), Bista (2020) and DHM (2022). This result reflects national scenario of declining national rainfall in Nepal. Specifically, elevations have not role in this regard. However, Thakuri, *et al*. (2019) argues temperature raising in the elevations where rainfall declines. Therefore, the result is an evidence of climate change. However, the result reveals different scenario in high mountain elevation and declining rainfall proportions because these literatures have different issues and methods.

4. CONCLUSION

This study examines dimensions, behaviors and dynamics of climatic variables (R_{min}, R_{max} and R_{mean}) in Marsyangdi Water Basin in Nepal using time series data sets of R_{min}, R_{max} and R_{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:

- R_{min}, R_{max} and R_{mean} are annually decreasing with a narrow gap between R_{min} and R_{max} from 1980 to 2020. In the basin, R_{mean} (1779 mm y^{-1}) is moderate rainfall i.e. neither higher rainfall not lower rainfall, despite Himalayan ranges and higher hill.

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

- In the last 40 years, R_{mean} is 1737.2 mm y^{-1} in 2020 as an decreasing of base R_{mean} in 1980 was 1810mm y^{-1} but rising temperature is +1.1^{0}c y^{-1} with +0.027^{0}c y^{-1}. Both R_{min}, and R_{max} are decreasing by - 153.3mm y^{-1} and + 363.5 mm y^{-1} respectively.

- Except second time zone (1990-1999), Sen's Coefficients and Kendel's Tau of these remaining three time zones have negative trend. It implies raising R_{mean} with more than +697mm y^{-1} rainfall difference between R_{min}, and R_{max} in the time zone.

- Except high mountain, Sen's Coefficients and Kendel's Tau of these remaining elevations and locations have negative trend.

- Except mountain, Sen's Coefficients and Kendel's Tau of these remaining elevations and locations have insignificant result.

We can reach a conclusion that rainfalls (R_{min}, R_{max} and R_{mean}) decline in all elevations, except high mountain elevation and all seasons in all time zones, except second time zone in the water basin. The intensity of decreasing rainfall is in mountain and hill elevations more than plain and high mountain. Drought induced water deficit and stress are major consequences of such decreasing rainfall in the steep elevations including mountain and rainfall more than plain and high mountain. Further, there is negative implication of a changing agricultural crop cycle and pattern led food deficit and further enforcing migration to explore alternative livelihood sources. Therefore, climate change is being a major threat to the community of small cities in all elevations of the basin. We can predict that this challenge will be further complicated economic loss in the future. To stabilize declining rainfall and drought induced economic losses, stopping deforestation and changing landscapes in the different elevations should be minimized with forest conservation, forestation and reforestation. Further, low cost innovative water saving technology, rain water harvesting technology and reuse of the used water technology should be given top priority for reducing water deficit and stress for drinking water and for increasing irrigation for maintaining crop production and productivity. Furthermore, the government should make an instrumental to drip irrigation technology and less water required seeds in agriculture for food security and welfare.

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