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Historical Trend Analysis of A Terai Himalayan District Of Nepal : A Case Study

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ABSTRACT

This study work focused on key climatic variable rainfall together with temperature of the study area Morang District located in Eastern Development Region, Nepal. As rainfall is the ultimate natural source for the recharge of surface and groundwater resources, it became necessary to analyze the trend of rainfall. Rainfall and temperature data of 30 years (1982 to 2011) on daily basis was processed to find out the monthly, seasonal and annual rainfall and temperature variability by using nonparametric tests. The Mann-Kendall Test for monotonic analysis of trend together with non-parametric Sen's Slope Estimator was used to estimate the magnitude of trend. The trend of 30 years rainfall data has been drawn on monthly, seasonal and annual basis. The statistical analysis of whole reference time series data represents positive trend on annual basis. In summer, spring, pre-monsoon, monsoon, rabi and kharif seasons the rainfall trends are positive while in winter, autumn and post-monsoon seasons the precipitation trends are decreasing. Individually seven months (January, April, May, June, July, August and November) indicated rising trend while remaining five months (February, March, September, October and December) showed falling trend. Similarly, the trends of 30 years maximum and minimum temperature data have also been investigated on monthly, seasonal and annual basis. The trends showed that both maximum and minimum temperatures are rising irrespective of temporal scales. In case of maximum temperature, the month of January and cold winter season showed falling trend otherwise all other months and seasons showed rising trend while the minimum temperature trend analysis showed rising trend in all months and seasons.

Keywords : Rainfall trend, temperature trend, Mann-Kendall test, Sen's Slope Estimator

I. INTRODUCTION

In today's context, water resource is gaining much more attention from the planners and policy makers of the country all around the world. An in-depth knowledge of the water resources is vital to understand the micro level activities which are continuously happening within the natural system. For planning and developing projects such as hydropower projects, flood control projects and sustainability in agricultural profession and food production water resource holds the major position with respect to its existence, location, process of generation, natural yield and its behavior regarding to the changing environment. Rainfall and temperature are the key elements of water resource system. Rainfall is the only source on the earth for the availability of water and enhancing water resources. The fresh water which is needed for drinking, all other domestic purposes, agriculture and industrial needs comes from rainfall. Rainfall is the sole factor for the existence and regeneration of water resource. The time of occurrence and its amount are the major factors. The changes in rainfall trends are directly associated with climatic changes and according to IPCC 2007 reports – global surface temperature is increasing at the rate of 0.74±0.18^{o}C over the period of 1906-2005 and due to this change in climate the availability of fresh water will definitely reduce in future. It has also been demonstrated that in the middle of 21st century the available water and average annual runoff will reduced up to (10-30) % [10]. The change in rainfall trend based on time series is the temporal shift in rainfall in patterns which may be either increasing or decreasing depending upon the climatic variations. This rainfall trend change is the dominant component of the climatic variations. Human interventions are also the primary and leading factors of climate change with reference to changing land use from the impact of agriculture and irrigation practices [13]. So, the subject of climate change with changes in rainfall patterns directly affects water resources, disaster management sector, agriculture divisions and all other water related development projects. The global huge emission of greenhouse gases and the disability in controlling it, the temperature variation of country is increasing beyond its normal limits. Now even the cold place earlier are facing unexpected hotter days and nights during summer. The Copenhagen Accord, agreed in December 2009, has a stated aim of limiting global warming to 2^{o}C above preindustrial temperatures. This target may be technically possible to achieve but will probably require substantial cuts in global greenhouse gas emissions in the very near future [26]. However, current national emissions reduction pledges appear to be insufficient to keep global warming below 2^{o}C [33]. Under scenarios of emissions in the absence of international climate policy, climate model projections assessed in the Intergovernmental Panel on Climate Change (IPCC) Fourth Assessment report [25]; indicate a range of global mean warming between 1.1^{o}C and 6.4^{o}C for 2090-2099, relative to 1980-1999. Global temperatures rose by about 0.5^{o}C between the preindustrial period and 1980-1999. Hence, current climate projections encompass a range of 1.6^{o}C to 6.9^{o}C for the end of the twenty-first century, relative to the preindustrial period. Such changes would be expected to exert major impacts and stresses on physical and human systems worldwide [25,4].

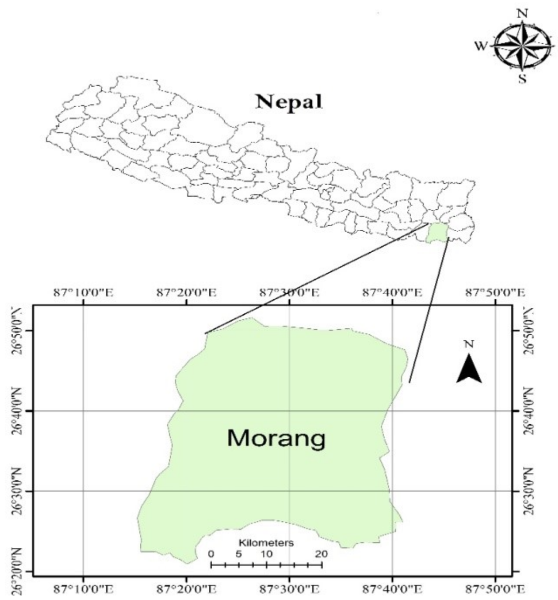
Nepal has experienced several disastrous floods in the past years. The 1978 Tinau flood, 1987 Bagmati flood, 2002 Makwanpur flood, 2008 Koshi flood, 2012 Seti flood, 2013 Mahakali flood, 2014 Babai flood and 2015 Sunkoshi flood are the most disastrous and life taking floods occurred in Nepal. The reasons behind these floods were heavy precipitation, avalanches in mountains. The changing precipitation pattern has also affected agricultural productivity, basically in the Terai; the food producer of the country. So, keeping in view these problems related to climate change and its effects in Nepal, this study was conducted for precipitation and temperature trends analysis of district Morang.

Trend analysis can be done using parametric and non-parametric approaches such as t-test is parametric test while non-parametric Mann-Kendall Test [24,15] give positive or negative trend for a given confidence level. Mann-Kendall test mostly used by different researchers to find out the trends of rainfall, temperature, runoff, and evapotranspiration on monthly, seasonally and annually. The objective of the study is to analyze rainfall and temperature trends from the long-term data series over the selected study area by using the Mann-Kendall (MK) Test to indicate the direction of the trend and Sen’s Slope Estimator to quantify the magnitude of the trend.

STUDY AREA

This study was conducted as a case study for precipitation and temperature trend analysis of the district Morang, Nepal, based on the station data installed by the Department of Hydrology and Meteorology. The station is located at a latitude of 26^{o} 37’N and longitude of 87^{o} 23’E at 152 m elevation. Morang District is located in Koshi Zone of the Eastern Development Region of Nepal. It borders with Bihar (India) to the South, Jhapa district to the East, Dhankuta and Panchthar districts to the North and Sunsari district to the west. The district has one sub metro politian city (Biratnagar), eight Municipalities and 65 VDCs. The total area of the district is 1,855 km^{2}. The current population of the district is 9,65,370 and the average population density is around 520 people per square kilometer till 2011. The lowest elevation point is 60 meters and the highest elevation point is 2410 meter above mean sea level. The district headquarter is connected by Koshi National High way to the East-West Mahendra National Highway at Itahari. The district is also connected to the Hilly parts of the eastern region of Nepal. This district is the core Industrial sector for the Eastern Development Region of Nepal and also has the potential for agriculture. The location map of the study area is shown in Figure 1.

According to the Census 2011, the total population of the district comprises of 51.6% female and 48.4% male residing in 2,13,997 households. The average household size is 4.51 persons. The district population growth rate is 1.35%. Immigration is rapidly increasing day to day from rural areas to this district in the search of better job and education. Life expectancy of the people is 69.6 years. The literacy rate is about 70.63% and 78.73% for male and female respectively. This district has multi ethnic composition; majorities are Brahmins, Chetri, Limbu, Rajput, Rajbanshi, Tamang, Kami, Damai. In terms of religion, Hindus are 80.1%, Kirat 7.3%, Muslim 4.4%, Buddhist 4.4%, Christian 0.8% and other 2.8%. The main languages are Nepali followed by Maithili, Rajbansi, Tharu, Rai, Limbu, Santhali, Bhojpuri and other.



II. METHODS AND MATERIAL

Daily rainfall and temperature data of thirty years (1982-2011) for district Morang was collected from the Department of Hydrology and Meteorology (DHM). This data included daily rainfall , maximum and minimum temperature during a month and peak rainfall event with intensity and duration. The time series analysis of rainfall and temperature data was carried out on monthly, seasonally and yearly basis. Monthly data were arranged in such a way that nine number of seasons were used and then these seasons were separated into three sub categories depending upon temperature variation, amount of rainfall and cropping system. Depending upon temperature variation of a whole year four seasons named as winter (October to March), summer (April to September), spring (March to May) and autumn (September to October) were used. According to amount of rainfall variability three seasons were used named as pre-monsoon (March to May), monsoon (June to September) and post-monsoon (October to December). Similarly, depending upon the cropping system two seasons Rabi (November to April) and Kharif (May to October) were used for seasonal trend analysis. The same categories were used for the temperature trend analysis. The trend analysis was done as discussed below.

Trend Analysis

A Statistical analysis defines trend as a significant change over time which is detectable by non-parametric and parametric tests. Trend analysis of a time series consists of the magnitude of trend and its statistical significance. In this study, statistical significance trend analysis was done by using Man-Kendall test while for the magnitude of trend was determined by non-parametric Sen's estimator method.

Mann-Kendall Test

Mann-Kendall test is the frequently used non-parametric test for identifying trends in hydrologic variables. It is a distribution free non-parametric test originally developed for non-correlated data. It is a statistical method which is mostly 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 test is fit for those data series where the trend may be assumed to be monotonic and no seasonal or other cycle is present.

MAKESENS [23] performs two types of statistics depending upon the number of data values i.e. S – statistics is used if number of data values are less than 10 and Z – statistics for data values greater than or equal to 10.

The statistic S is calculated as,

$$S = \sum_{i=1}^{n-1} \sum_{j=i+1}^{n} \operatorname{sgn}(x_j - x_i) \qquad (1)$$

Where, x_j and x_i are annual values in years 'i 'and 'j', j>i respectively, 'n' is the number of data points and sgn(x_j-x_i) is calculated using equation,

$$\operatorname{sgn}(t) = \begin{cases} 1, & for\, t > 0 \\ 0, & for\, t = 0 \\ -1, & for\, t < 0 \end{cases} \quad (2)$$

A positive or negative value of 'S' indicates an upward or downward trends respectively.

If number of data points are 10 or more, the S – statistics approximately behave as normally distributed and test is performed with normal distribution.

$$E(S) = 0 \quad (3)$$

$$Var(S) = \frac{n(n-1)(2n+5) - \sum_{i=1}^{m} t_i(t_i-1)(2t_i+5)}{18} \quad (4)$$

where, 'n' is the number of tied groups and t_i is the size of the i^{th} tie group. The standardized test statistics Z is computed as follows.

$$Z_{MK} = \begin{cases} \frac{S-1}{\sqrt{Var(S)}}, & for\, S > 0 \\ 0\quad, & for\, S = 0 \\ \frac{S+1}{\sqrt{Var(S)}}, & for\, S < 0 \end{cases} \quad (5)$$

The standardized Mann-Kendall statistics 'Z' follows the standard normal distribution with zero mean and unit variance. If $|Z| \geq Z_{1-(\alpha/2)}$, the null hypothesis about no trend is rejected at the significance level 'α'.

In MAKESENS the two-tailed test is used for four different significance levels α: 0.001, 0.01, 0.05 and 0.1. The significance level 0.001nmeans that there is a 0.1% probability that the values xi are from a random distribution and with that probability we make a mistake when rejecting Ho (null hypothesis) of no trend. Thus, the significance level 0.001 means that the existence of a monotonic trend is very probable. Respectively the significance level 0.1 means that there is a 10% probability that we make a mistake when rejecting Ho.

Sen's Estimator method

Sen's non-parametric estimation method is used for predicting the magnitude or true slope of hydro-metrological time series data. It uses a linear model for the trend analysis. The slope (T_i) of all data pairs is calculated as

$$T_i = \frac{x_j - x_k}{j-k} \text{ for i= 1,2,3} \quad (6)$$

Where, x_j and x_k are data values at time j and k (j>k) separately.

The median of these 'n' values of T_i is represented by Sen's slope of estimation which is calculated using the following equation,

$$Q_i = T_{\frac{N+1}{2}} \text{ for n is odd}$$

$$= \frac{1}{2}\left(T_{\frac{N}{2}} + T_{\frac{N+1}{2}} \right) \text{ for n is even} \quad (7)$$

Sen's estimator is calculated using above equation and the use of the above equation depends upon value of 'n' is either odd or even. Then Q_{med} is computed using 100(1-α) % confidence interval using non-parametric test depending upon normal distribution.

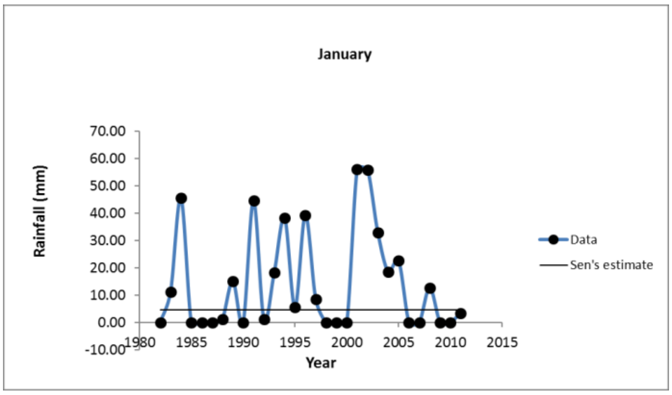
A positive value of Q_i indicates increasing trend and a negative value of Q_i represents downward trend.

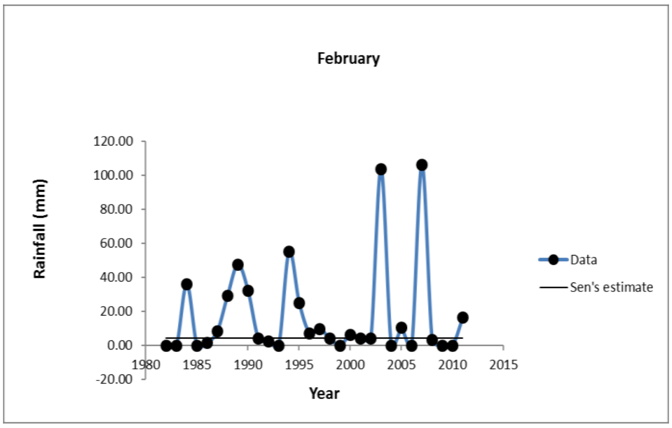
III. RESULTS AND DISCUSSION

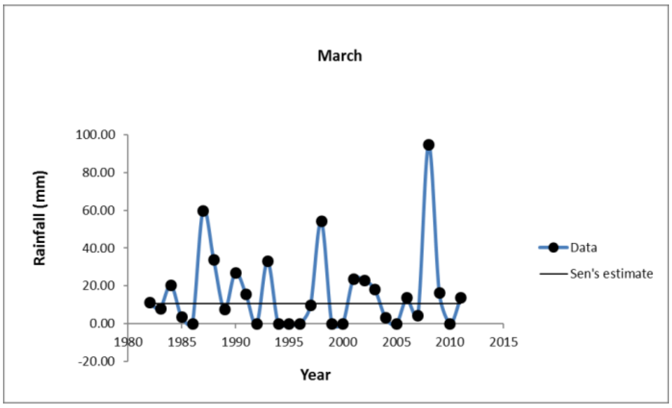
In the present study trend analysis of rainfall and temperature of district Morang, Nepal was done using MK test together with Sen's slope estimator for 30 years of time series data (1982-2011) on monthly, seasonally and yearly basis.

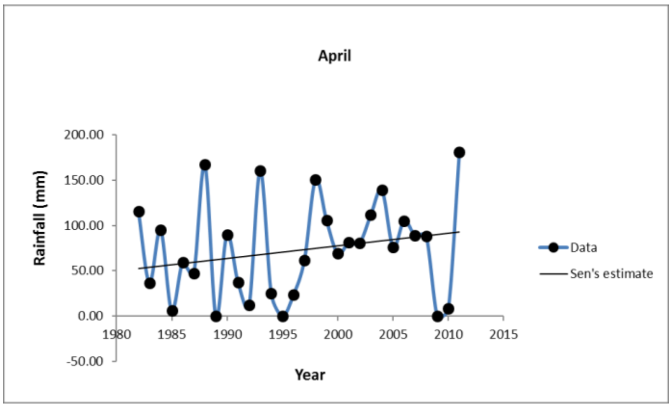
A. Monthly Rainfall Trend Analysis

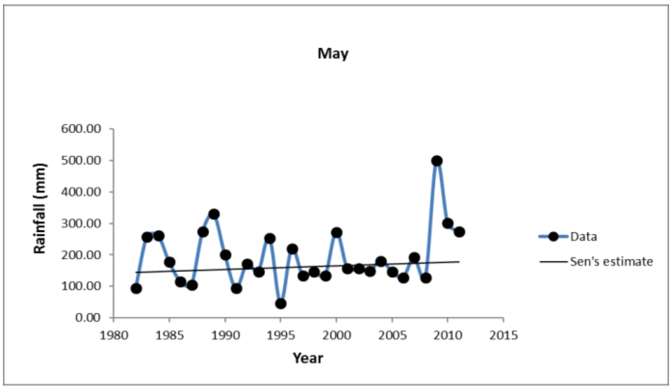
The variation in rainfall and temperature data on monthly basis is calculated individually for each month using Mann-Kendall statistical method and magnitude of slope is calculated with Sen's estimator as shown in Figure 2.

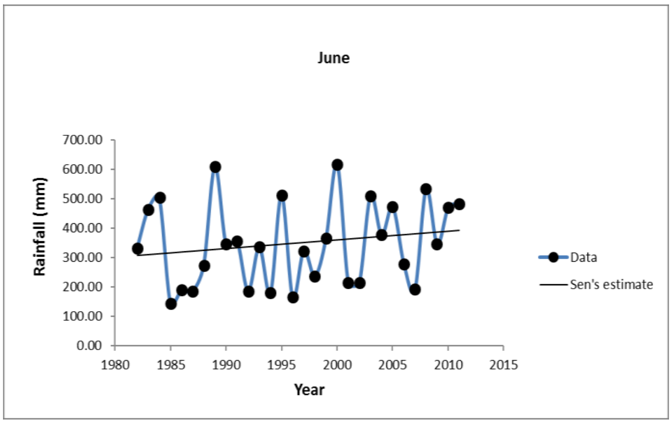

January
Rainfall (mm)
70.00
60.00
50.00
40.00
30.00
20.00
10.00
0.00
-10.00
1980 1985 1990 1995 2000 2005 2010 2015
Year
Data
Sen's estimate

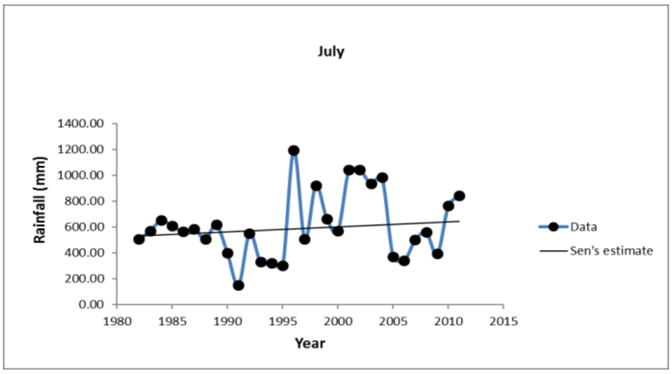

February
Rainfall (mm)
120.00
100.00
80.00
60.00
40.00
20.00
0.00
-20.00
1980 1985 1990 1995 2000 2005 2010 2015
Year
Data
Sen's estimate

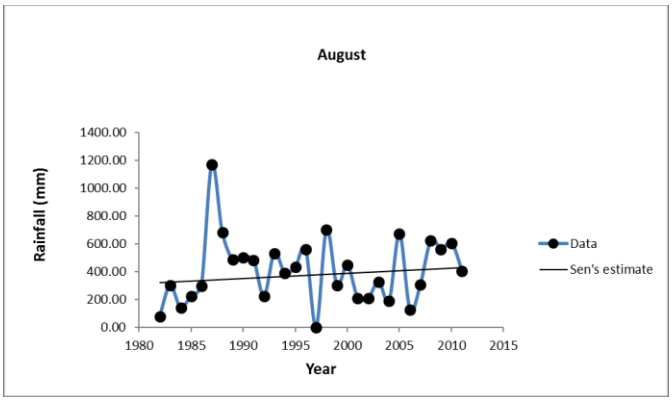

March
Rainfall (mm)
100.00
80.00
60.00
40.00
20.00
0.00
-20.00
1980 1985 1990 1995 2000 2005 2010 2015
Year
Data
Sen's estimate

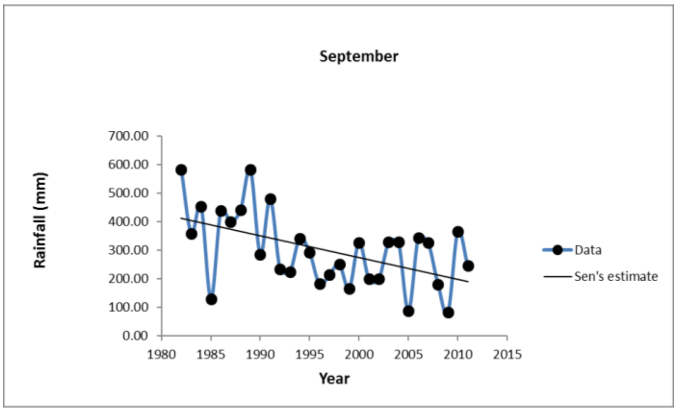

April
Rainfall (mm)
200.00
150.00
100.00
50.00
0.00
-50.00
1980 1985 1990 1995 2000 2005 2010 2015
Year
Data
Sen's estimate

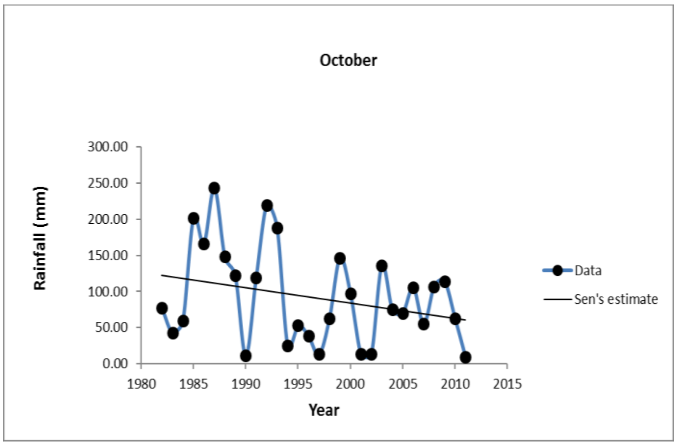

May
Rainfall (mm)
600.00
500.00
400.00
300.00
200.00
100.00
0.00
1980 1985 1990 1995 2000 2005 2010 2015
Year
Data
Sen's estimate

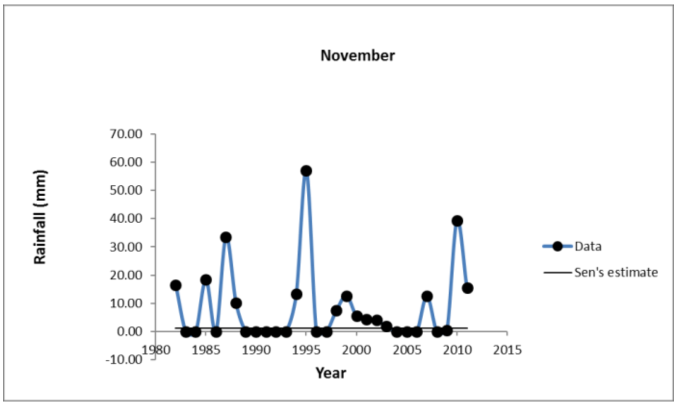

June
Rainfall (mm)
700.00
600.00
500.00
400.00
300.00
200.00
100.00
0.00
1980 1985 1990 1995 2000 2005 2010 2015
Year
Data
Sen's estimate

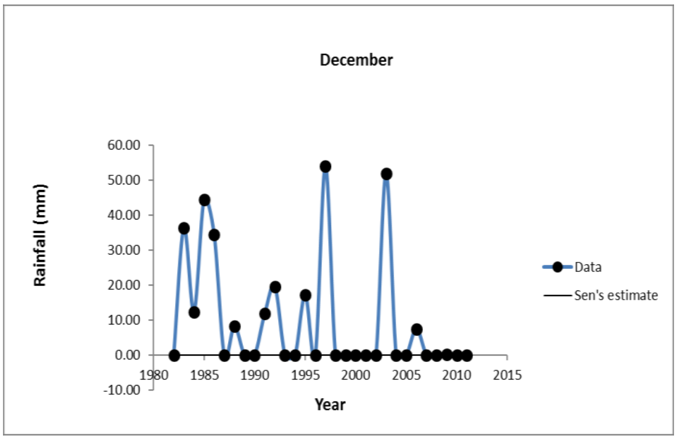

July
Rainfall (mm)
1400.00
1200.00
1000.00
800.00
600.00
400.00
200.00
0.00
1980 1985 1990 1995 2000 2005 2010 2015
Year
Data
Sen's estimate


August
Rainfall (mm)
1400.00
1200.00
1000.00
800.00
600.00
400.00
200.00
0.00
1980 1985 1990 1995 2000 2005 2010 2015
Year
Data
Sen's estimate









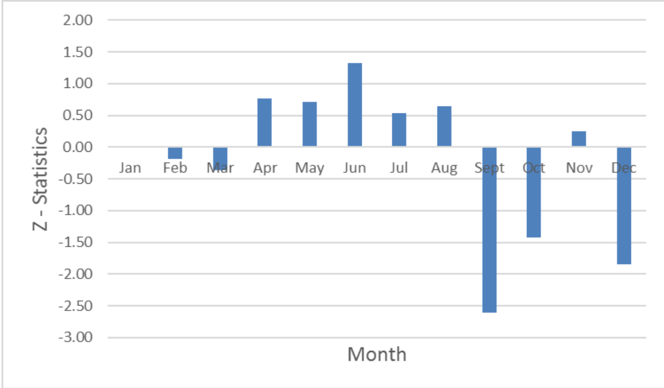


Figure 3: The Mann-Kendall Z – Statistics for Trend Analysis

The magnitude of slope is also calculated by Sen's Slope (Q) estimator for each month separately. The months Jan, Feb, March, Nov and Dec showed no change in Sen's Slope magnitude. The months April, May, Jun, July and Aug give increasing slope magnitude. The months Sep and Oct showed significant decreasing trend as shown in Figure 4.

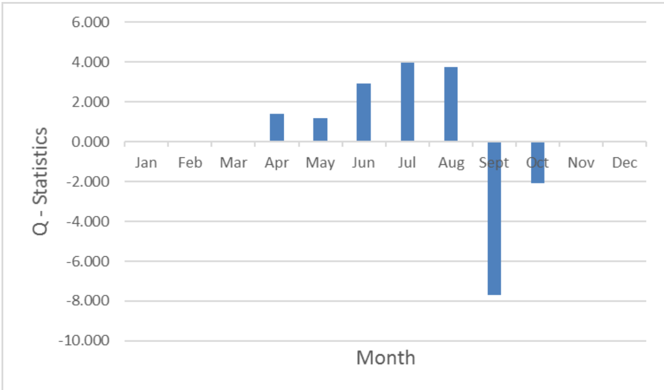


Figure 4: The Median Qi Representing Magnitude of Slope

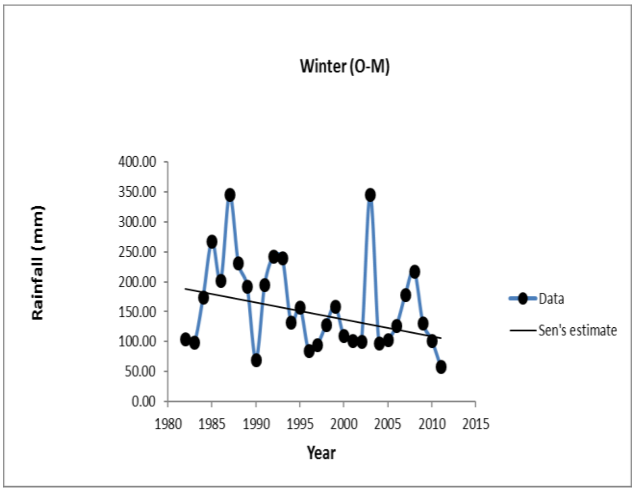
Seasonally Rainfall Trend Analysis

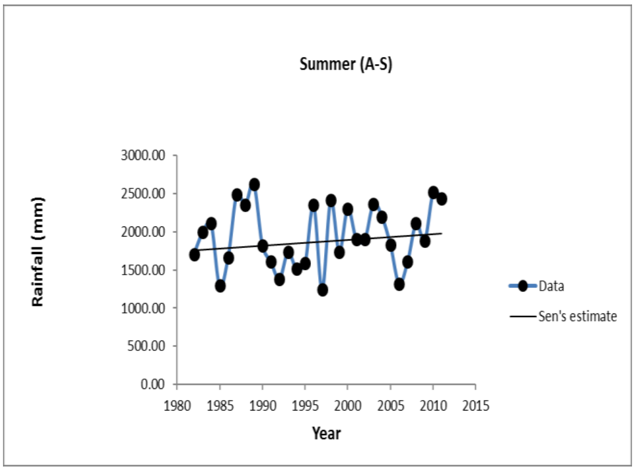
Rainfall trend was analyzed on different sub-categories of seasons as discussed below.

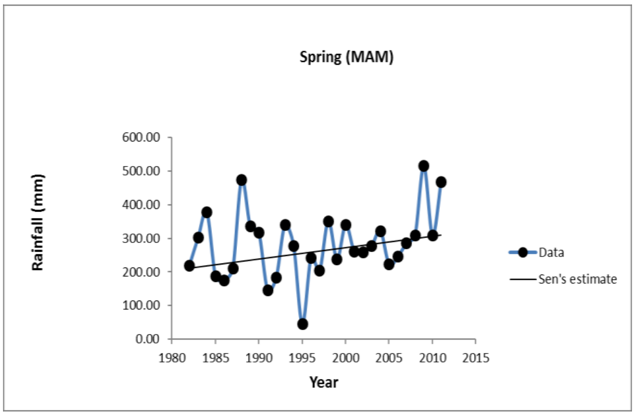
Seasonal variation of rainfall trend

Four seasons were used depending upon temperature i.e. winter, summer, spring and autumn.

The value of Z and Q statistics for two seasons summer and spring are positive which showed significant increasing trend while the other two seasons winter and autumn indicated significantly decreasing trend as shown in Figure 5.







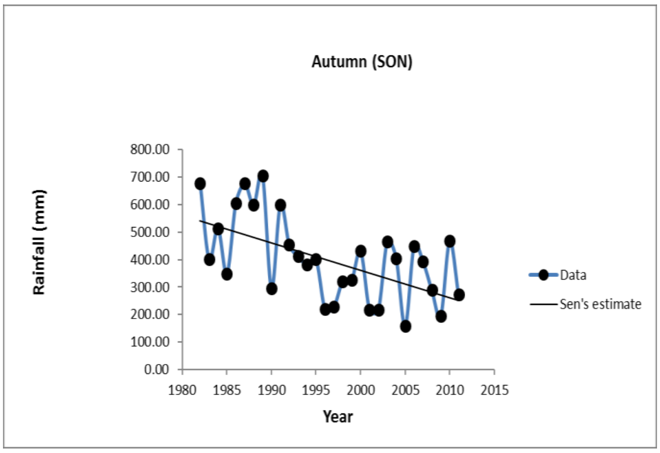
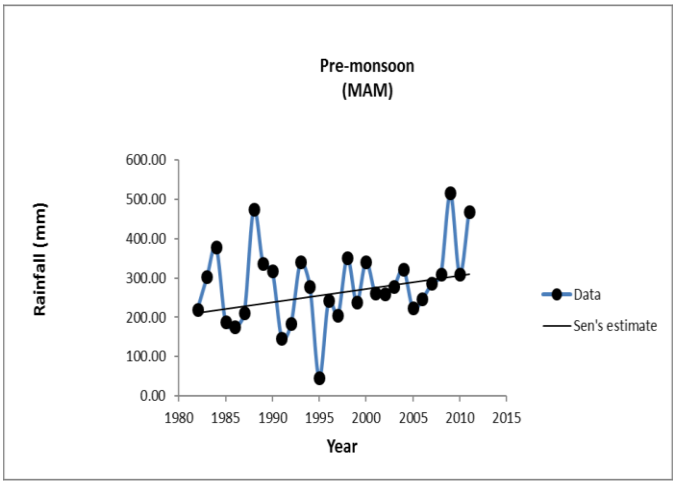
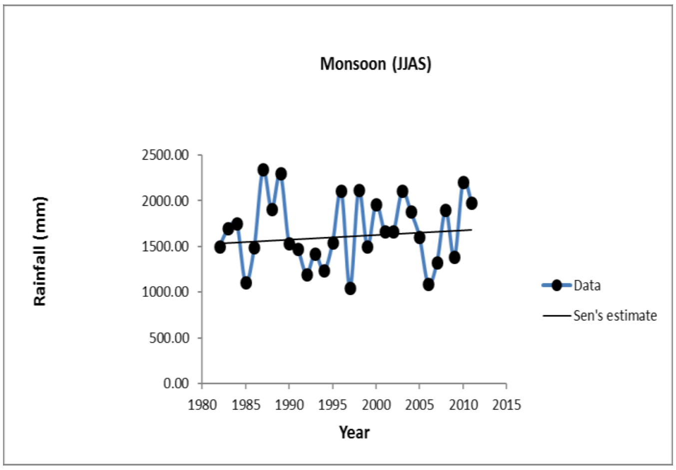


Figure 5: Seasonal Variation of Rainfall Trend Depending upon Temperature

Seasonal variation of rainfall trend depending upon amount of rainfall variation

The frequency and amount of rainfall varies throughout the year. Depending upon the occurrence and amount of rainfall, three type of seasons were used i.e. pre-monsoon (March to May), monsoon (June to September) and post-monsoon (October to December). The pre-monsoon and monsoon seasons showed increasing or upward trend having positive values of both Z and Q statistics while post-monsoon season showed significant downward or decreasing trend due to negative values of Z and Q statistics as shown in Figure 6.





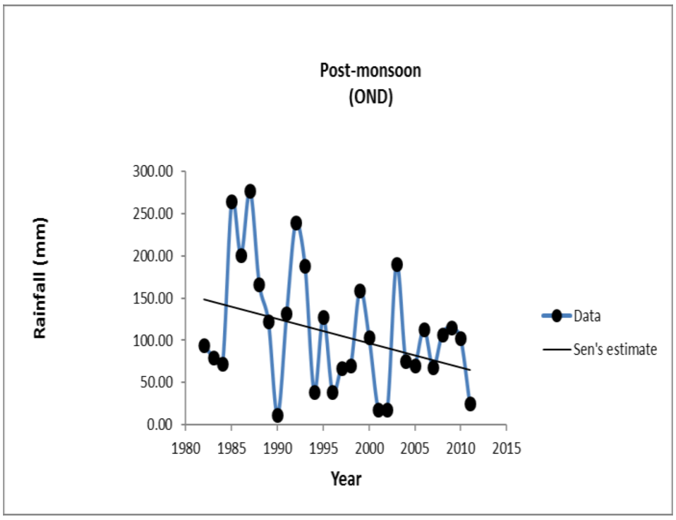
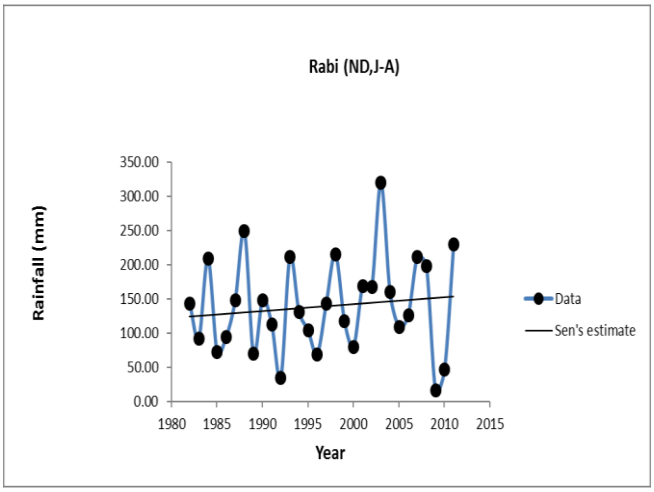


Figure 6: Seasonal Variation of Rainfall Trends Depending upon Amount of Rainfall



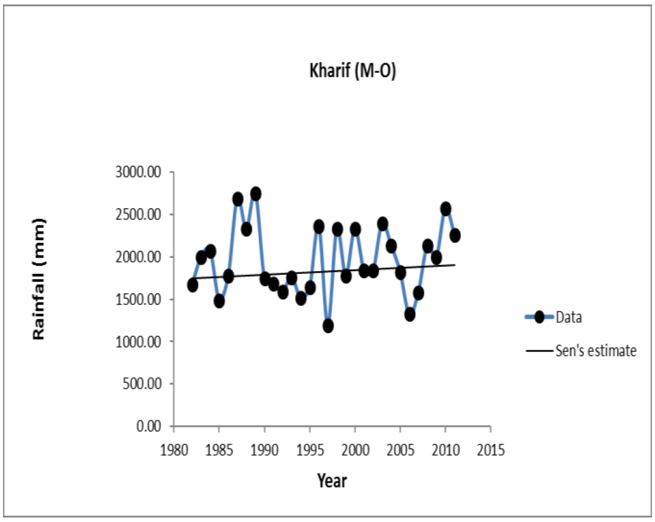


Figure 7: Seasonal Variation of Rainfall Trends Depending upon Cropping System

Seasonal variation of rainfall trend depending upon cropping system

As per cropping practices and type of crops two type of seasons Rabi and Kharif are generally followed. Rabi season consist of Nov to April months and this season showed upward trend due to positive values of Z and Q statistics. The months from May to Oct represent Kharif season and this season also showed upward trend as shown in Figure 7.

Annual Rainfall Trend Analysis

The trend of total annual rainfall of 30 years' period is analyzed which showed a mean annual rainfall as 2093.50 mm. The maximum annual rainfall has occurred in the year 1987 which is 2837.50 mm and minimum in the year 1997 which is 1335.40 mm. The positive value of Z and Q statistics showed that there is a rising trend with an upward slope of rainfall on annual basis. The trend is as shown in Figure 8.

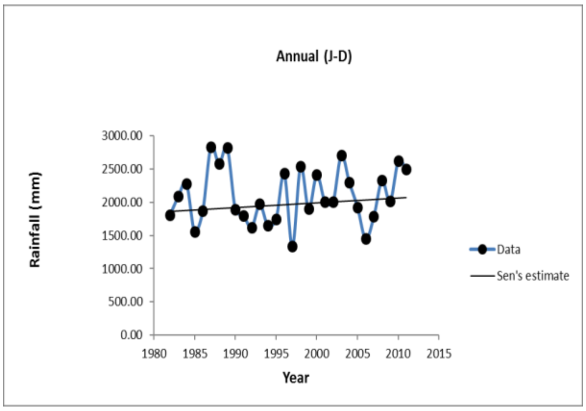


Figure 8: Annual Rainfall Trend Analysis

The statistical analysis of rainfall data was done using central tendency parameters i.e. mean and median and the dispersion of data from mean was done using standard deviation and coefficient of variance as shown in Table I.

Table I. Statistical Analysis of Rainfall Data Along With Mann-Kendall Trend And Sen's Slope

Time Series	Mean (mm)	Median (mm)	Maxi (mm)	Mini (mm)	St. Dev	Coeff. Var	Mann-Kendall Trend	Signific (α)	Sen's Slope
Jan	14.38	4.5	56.2	0	18.65	129.67	0.02		0.00
Feb	17.30	4.2	106.4	0	28.18	162.91	-0.18		0.00
Mar	16.54	10.55	94.9	0	21.52	130.09	-0.36		0.00
Apr	74.16	78.65	181.2	0	53.17	71.69	0.77		1.40
May	191.36	164.35	499.2	45.8	90.90	47.50	0.71		1.19
Jun	347.62	340.85	617.8	145.3	141.44	40.69	1.32		2.92
Jul	610.71	568.2	1195	151.8	255.17	41.78	0.54		3.96
Aug	406.97	397.95	1169.8	0	239.06	58.74	0.64		3.76
Sept	302.70	309.15	582.6	82.1	129.94	42.93	-2.60	**	-7.69
Oct	93.40	76.4	243.1	9.8	65.45	70.08	-1.43		-2.10
Nov	8.43	1.15	57.1	0	13.62	161.67	0.25		0.00
Dec	9.93	0	54.1	0	16.85	169.58	-1.84	+	0.00
Annual (J-D)	2093.5	2006	2837.5	1335.4	413.14	19.73	0.75		7.21
Winter (O-M)	159.98	131.75	345.10	59.10	75.30	47.07	-1.64		-2.84
Summer (A-S)	1933.52	1892.9	2627.1	1240	403.66	20.88	0.89		7.75
Cold Winter (DJF)	41.61	34.55	188.7	0	40.856	98.19	-1.12		-0.82
Spring (MAM)	282.063	278.8	515.5	45.8	98.807	35.03	1.50		3.39
Hot Summer (JJA)	1365.3	1336.35	1941.5	745.7	355.54	26.04	1.46		15.06
Autumn (SON)	404.523	402.4	703.9	158	152.82	37.78	-2.89	**	-9.99
Pre-monsoon (MAM)	282.063	278.8	515.5	45.8	98.807	35.03	1.50		3.39
Monsoon (JJAS)	1668	1633.5	2341.3	1044	368.27	22.08	0.46		5.13
Post-monsoon (OND)	111.76	102.8	276.7	11.1	71.924	64.36	-1.71	+	-2.91
Rabi (ND,J-A)	140.74	137.8	320.6	17	69.443	49.34	0.75		1.03
Kharif (M-O)	1952.76	1837.2	2749.1	1191.2	399.01	20.43	0.71		5.32

From Table I, the minimum mean monthly rainfall occurred in the month of November (8.43 mm) while maximum mean monthly rainfall occurred in the month of July (610.71 mm). It is also depicted from the table that total maximum rainfall was occurred in month of July as 1195 mm in the year 1996. The calculated mean annual rainfall for the period 1982 to 2011 is 2093.50 mm and maximum total annual rainfall as 2837.50 mm occurred in 1987.

Monthly Maximum and Minimum Temperature Trend Analysis

The variation in maximum and minimum temperature data on monthly basis is calculated individually for each month using Mann-Kendall statistical method and magnitude of slope is calculated with Sen's estimator as shown in Figures 9 to 12.

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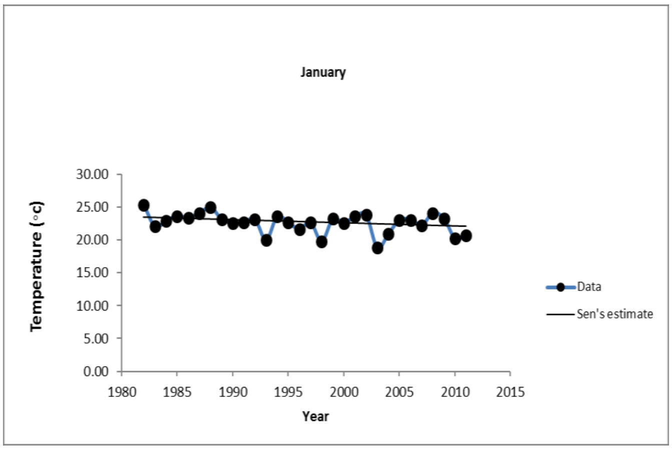
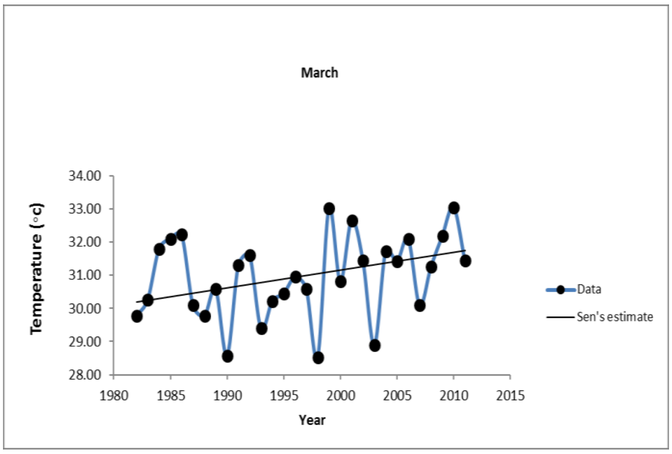
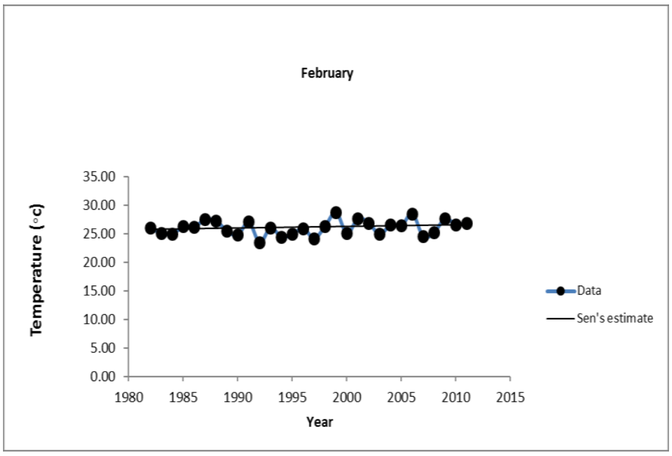






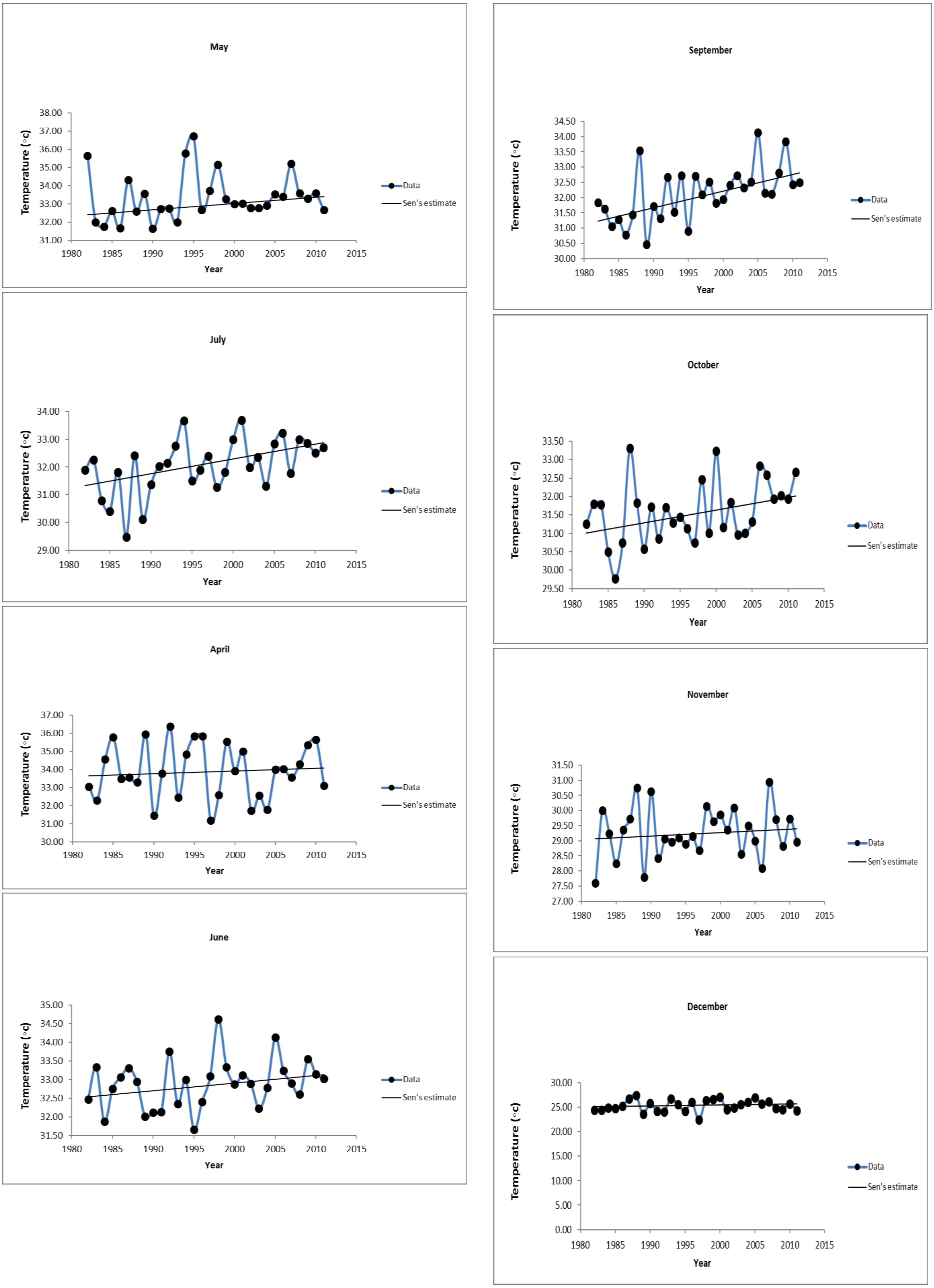


Figure 9: Monthly Maximum Temperature Trend Analysis

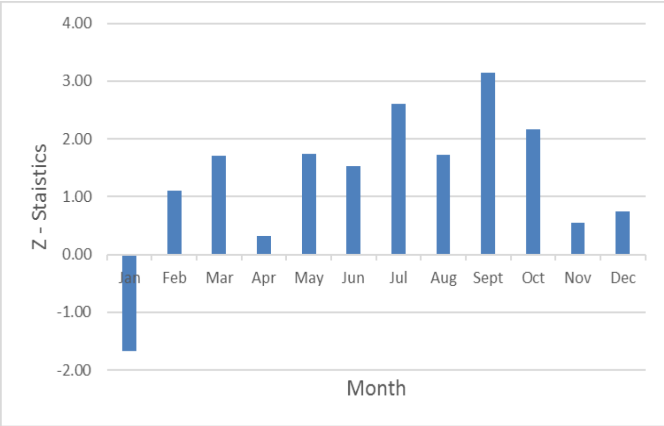


Figure 10: The Mann-Kendall Z – Statistics of T_{max} for Trend Analysis

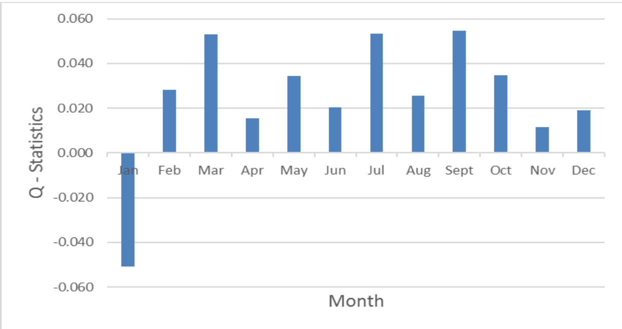
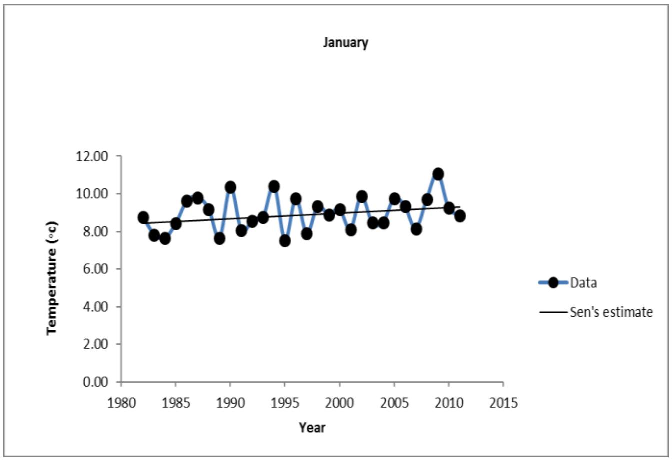
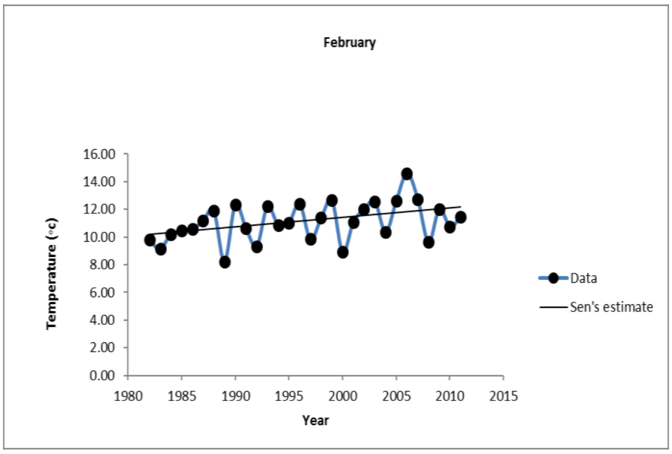
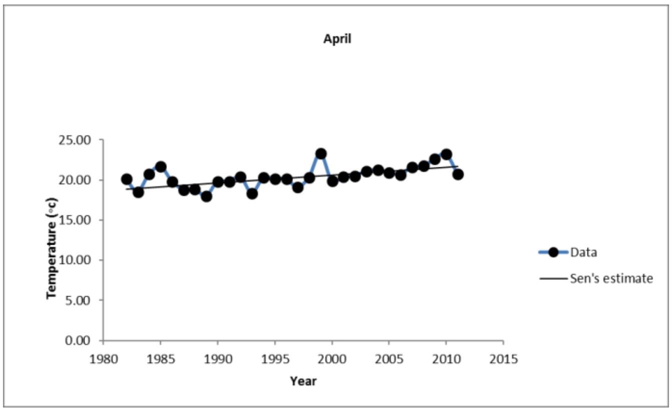


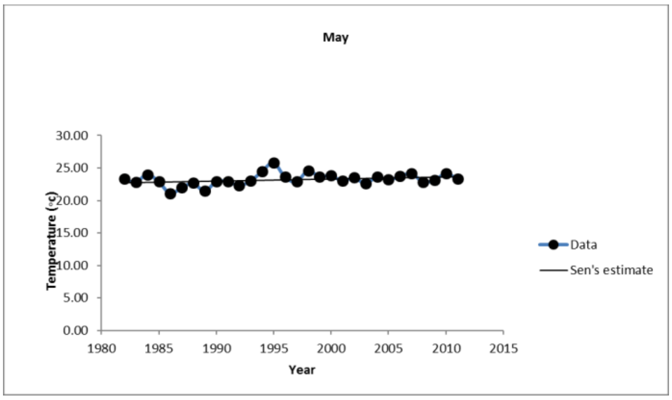
Figure 11: Median Q_i of T_{max} Representing Magnitude of Slope

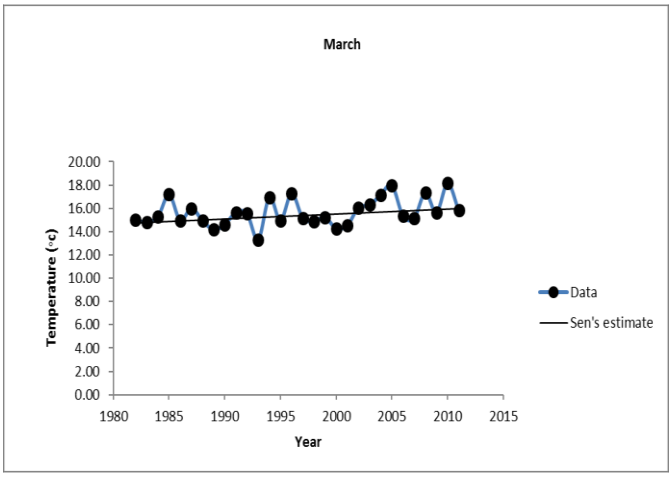
Here as shown in Fig.8, the data analyzed over the 30 years of time series showed significant increasing trend of T_{max} in the months of February, March, May, June, July, August, September and October. Both Z and Q statistics indicated a positive sign as shown in Figures 9 and 10. The months of April, November and December are insignificantly increasing whereas January month showed a significantly decreasing trend.

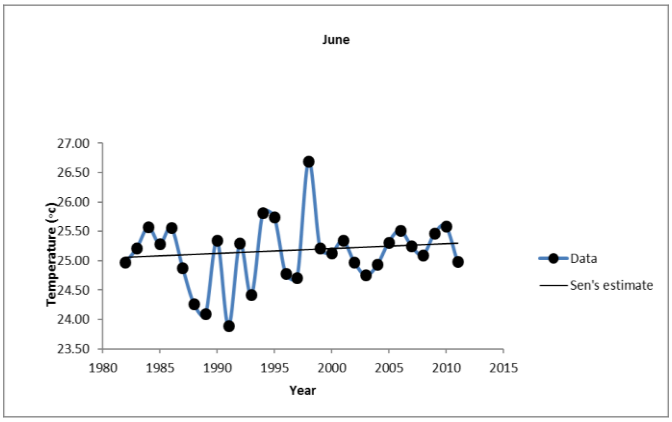


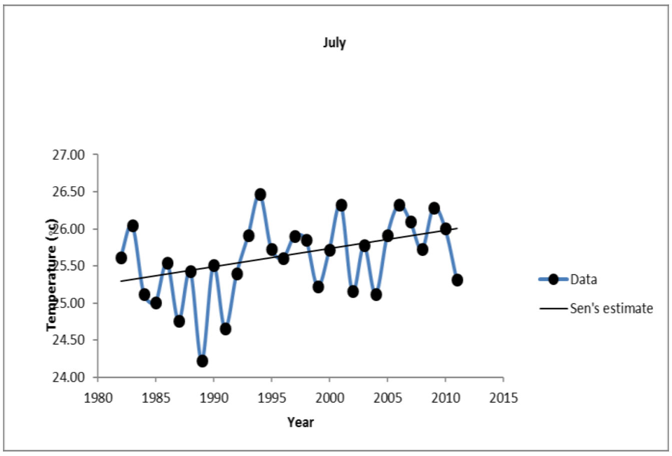


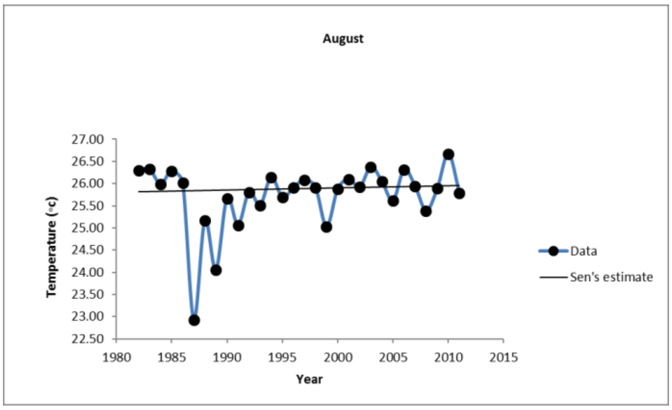


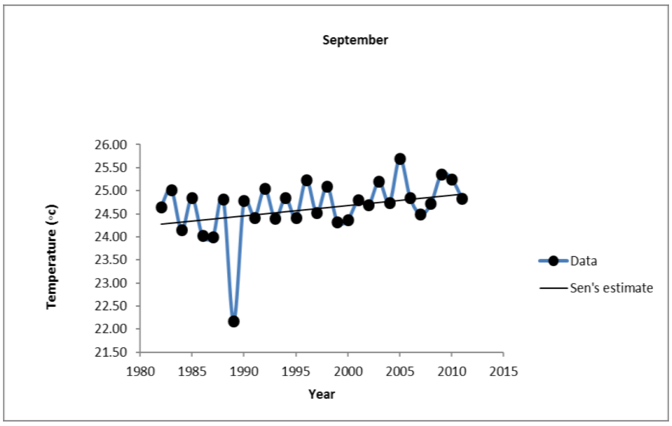












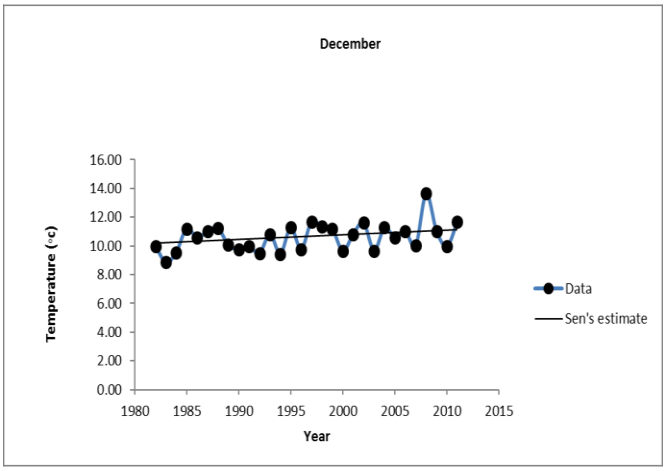
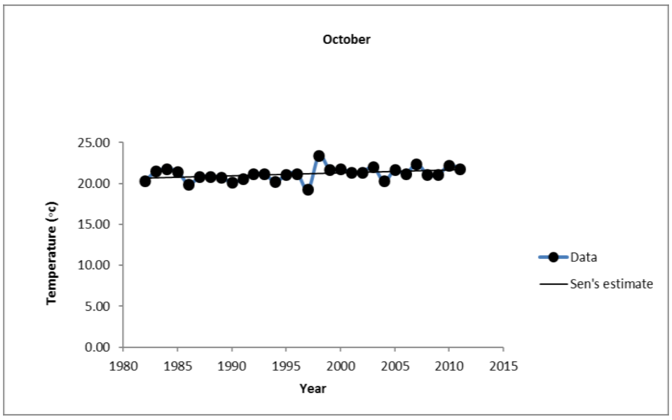
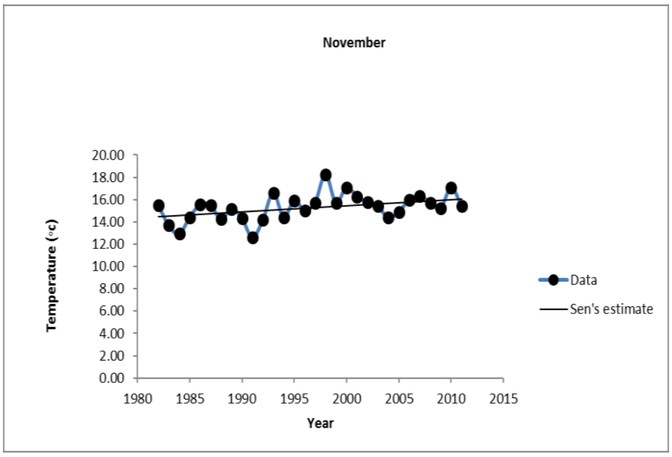


Figure 12. Monthly Minimum Temperature Trend Analysis





The trend in Figure 12 showed insignificant increase of T_{min} data series in two months Jun and August whereas rest of the months showed significant increase. All the months showed the positive values of Z and Q statistics as shown in Figures 13 and 14.

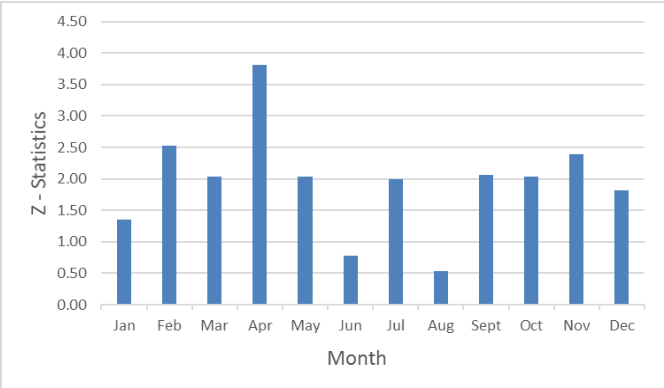


Figure 13: The Mann-Kendall Z – Statistics of T_{max} for Trend Analysis

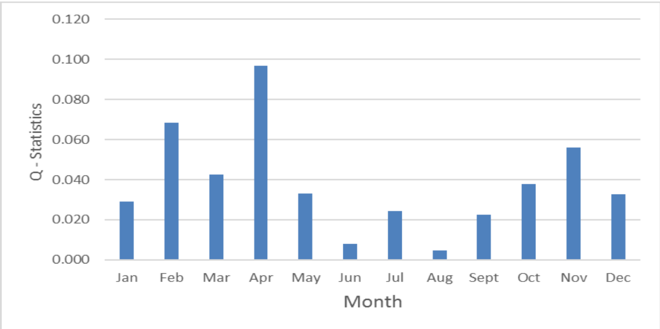


Figure 14: Median Qi of Tmin Representing Magnitude of Slope

Seasonal Temperature Trend Analysis

Trend analysis for maximum and minimum temperature of different seasons in the year is analyzed as discussed below.

Seasonal variation of temperature trend

Four seasons winter, summer, spring and autumn were analyzed. The values of Z and Q statistics for T_{max} of all the four seasons are positive which showed significant increasing trend as shown in Figure 15. The value of Z and Q statistics for T_{min} of all four seasons are also positive which showed significant increasing trend as shown in Figure 16.

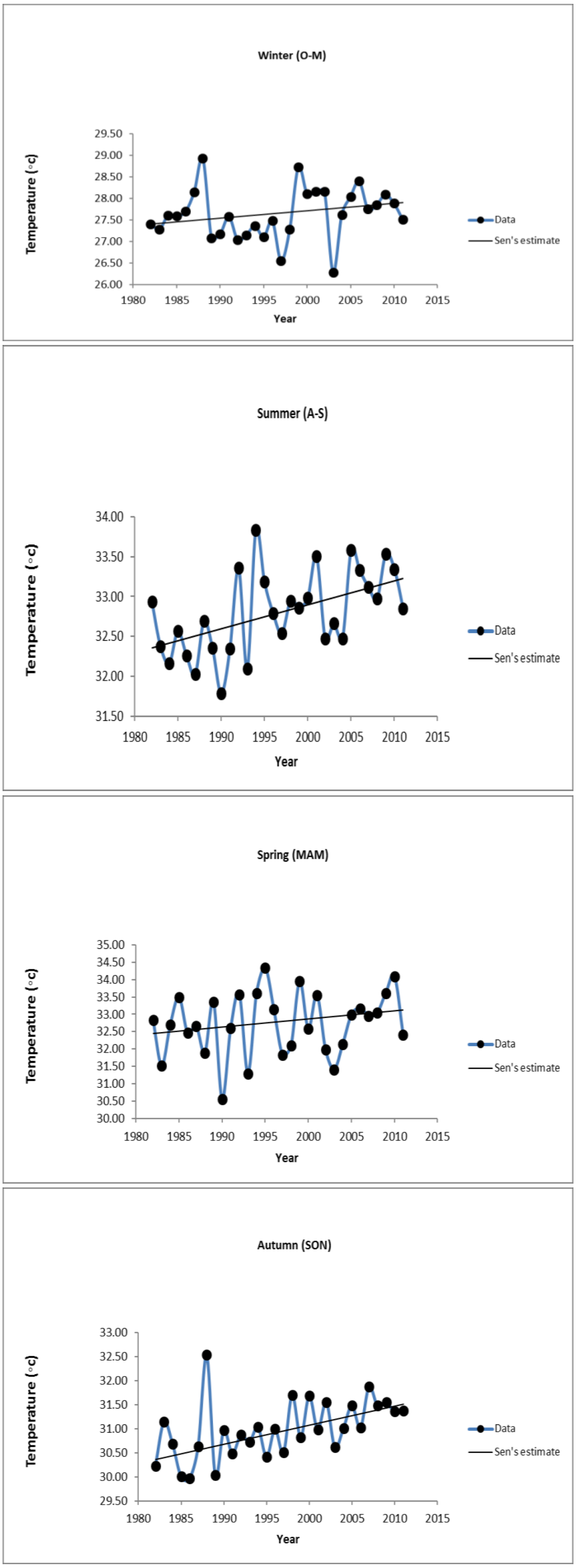


Figure 15: Seasonal Variation of Maximum Temperature Trend

Seasonal variation of maximum and minimum temperature trend with respect to pre-monsoon, monsoon and post-monsoon seasons.

Pre-monsoon, monsoon and post-monsoon seasons have the positive values of Z and Q statistics for both the Tmax and Tmin data series which showed the significant increasing trend as shown in Figures 17 and 18.

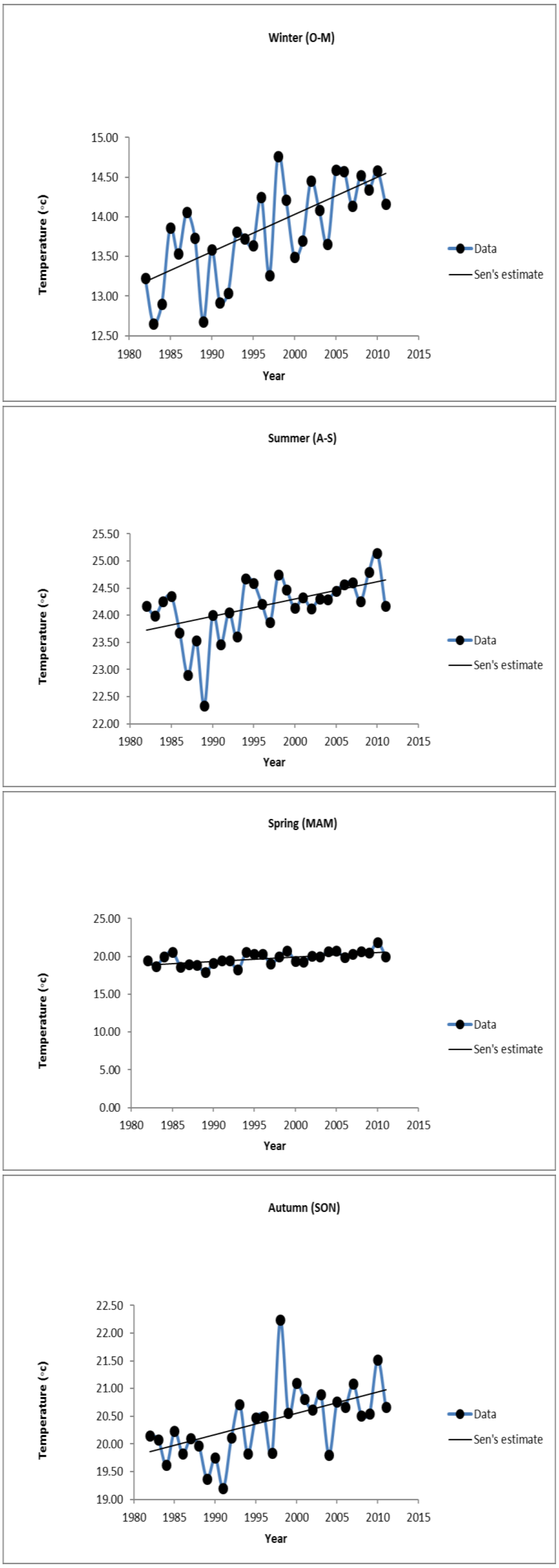


Figure 16: Seasonal Variation of Minimum Temperature Trend

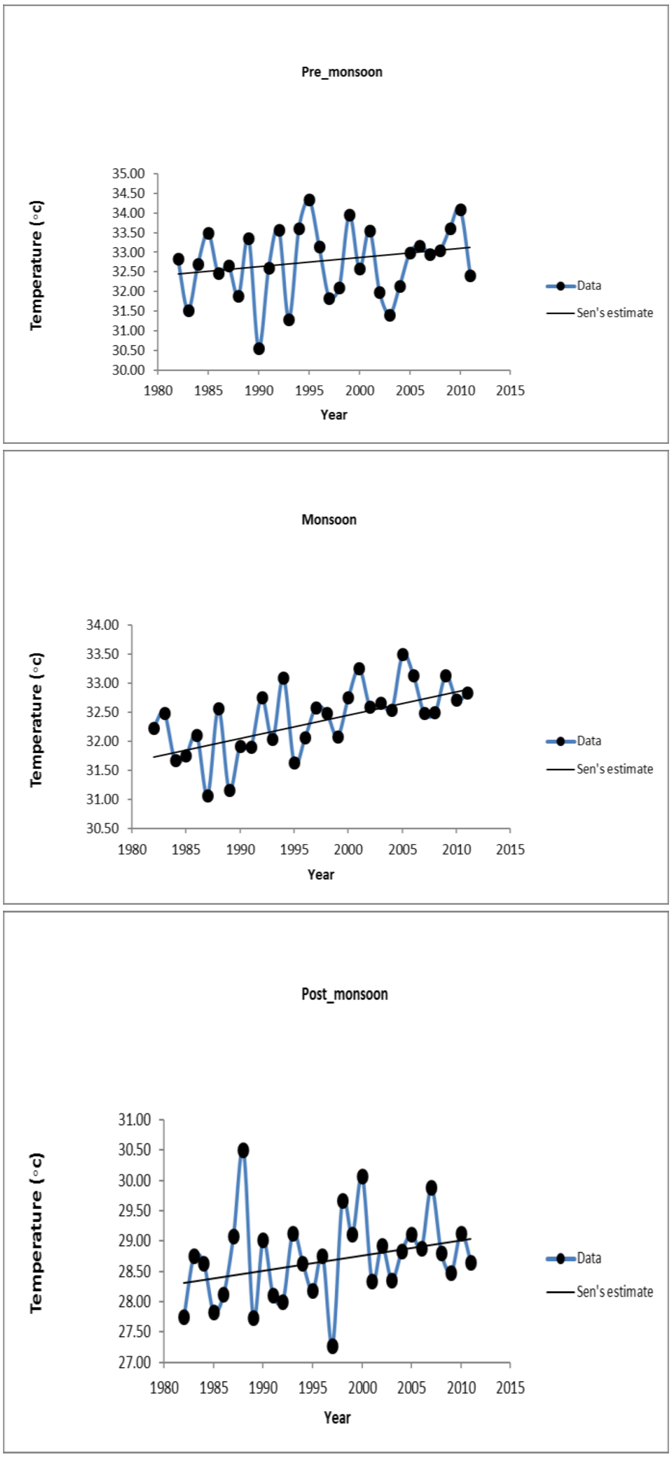


Figure 17: Seasonal Variation of Maximum Temperature Trend

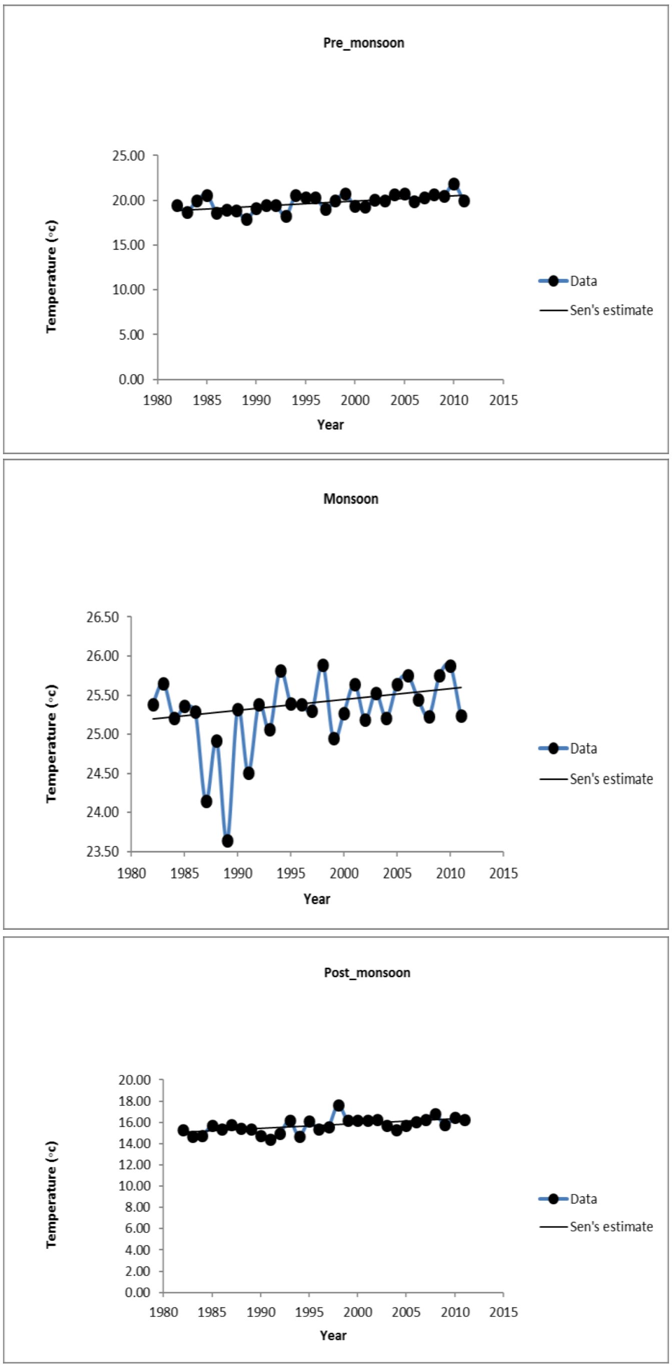


Figure 18: Seasonal Variation of Minimum Temperature Trend

Seasonal variation of temperature trend depending upon cropping system

The Z and Q statistics for T_{max} data series showed positive values both in Rabi and Kharif seasons. In Rabi season, there is an insignificant increasing trend while in Kharif the trend is significantly increasing as shown in Fig.19. The Z and Q statistics for T_{min} data series showed positive values with a significantly increasing trend as shown in Figure 20.

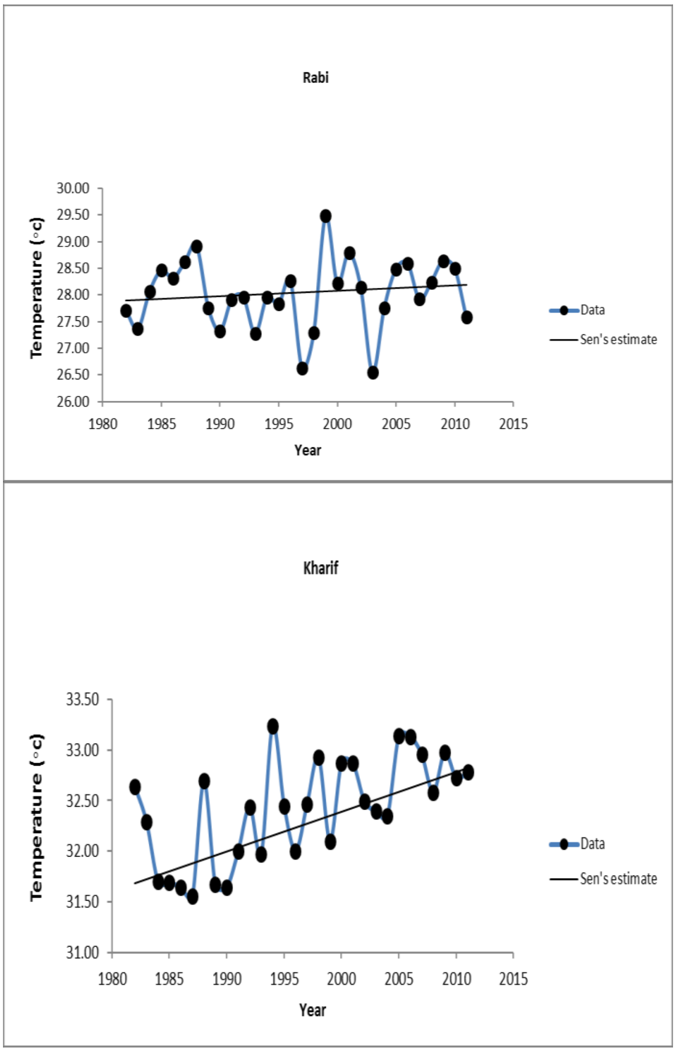
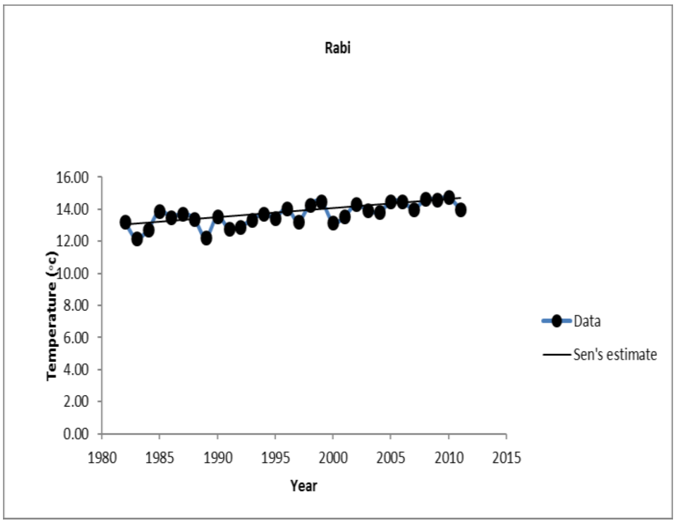


Figure 19: Seasonal Variation of Tmax Trend Depending upon Cropping System



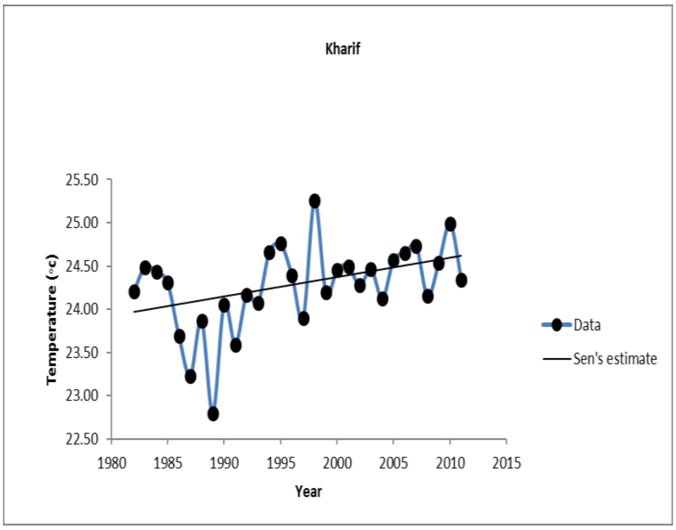


Figure 20: Seasonal Variation of Tmin Trend Depending upon Cropping System

Annual Maximum and Minimum Temperature Trend Analysis

The trends of average annual maximum and minimum temperature of 30 years' data series are represented in Fig. 21 & 22. The figure depicted that the average annual maximum temperature is 30.22^{o}C. The positive values of Z and Q statistics showed a significant increasing trend for maximum temperature. The average annual minimum temperature is 18.97^{o}C and the positive values of Z and Q statistics showed a significant increasing trend in minimum temperature data series.

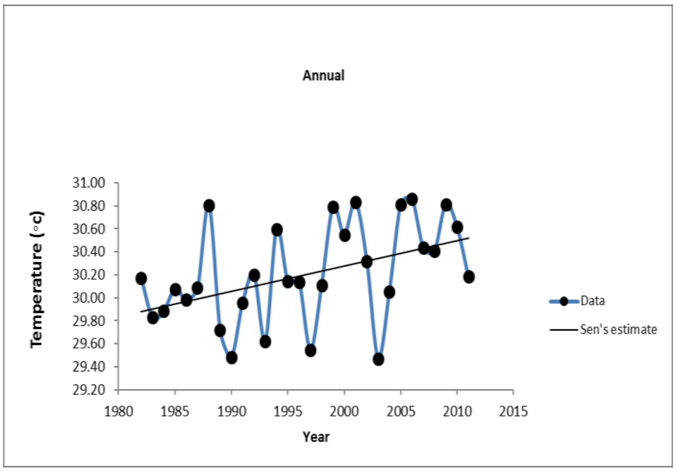


Figure 21: Annual Maximum Temperature Trend Analysis

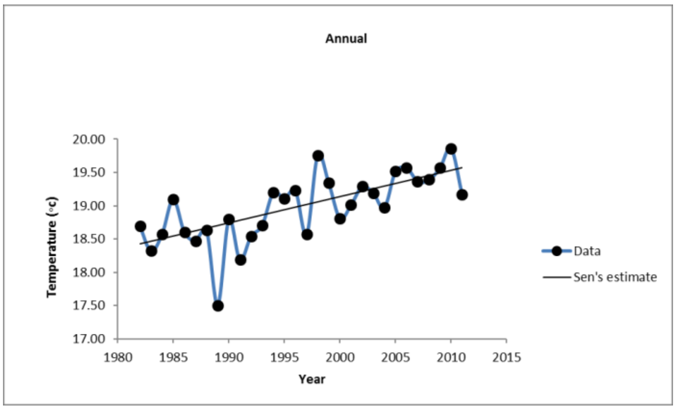


Figure 22: Annual Minimum Temperature Trend Analysis

The statistical analysis of temperature (maximum and minimum) data was done using central tendency parameters i.e. mean and median and the dispersion of data from mean was done using standard deviation and coefficient of variance as shown in Table 2 and Table 3.

Table 2 shows the annual mean of maximum temperature is 30.22^{o}C and the maximum mean monthly temperature is 33.89^{o}C in the month of April. And the Table 3 shows the annual mean of minimum temperature is 18.97^{o}C. The maximum mean monthly temperature is 25.73^{o}C in the month of August and minimum mean monthly temperature is 8.96^{o}C in the month of January.

TABLE 2. STATISTICAL ANALYSIS OF TMAX DATA ALONG WITH MANN-KENDALL AND SEN'S SLOPE

Time Series	Mean (mm)	Median (mm)	Maxi (mm)	Mini (mm)	St. Dev	Coeff. Var	Mann-Kendall Trend	Signific (α)	Sen's Slope
Jan	22.61	22.99	25.40	18.8	1.52	6.72	-1.68	+	-0.051
Feb	26.08	26.16	28.77	23.48	1.29	4.95	1.11		0.028
Mar	30.95	31.10	33.06	28.52	1.23	3.97	1.71	+	0.053
Apr	33.89	33.84	36.37	31.17	1.49	4.40	0.32		0.016
May	33.34	33.01	36.73	31.62	1.26	3.78	1.75	+	0.034
Jun	32.89	32.93	34.63	31.65	0.65	1.98	1.53		0.020

Jul	32.04	32.09	33.69	29.48	0.98	3.06	2.60	**	0.053
Aug	32.50	32.72	33.95	30.02	0.87	2.68	1.73	+	0.026
Sept	32.13	32.13	34.13	30.47	0.86	2.68	3.14	**	0.055
Oct	31.58	31.57	33.31	29.76	0.83	2.63	2.16	*	0.035
Nov	29.27	29.19	30.93	27.6	0.82	2.80	0.55		0.012
Dec	25.33	25.38	27.45	22.4	1.18	4.66	0.75		0.019
Annual (J-D)	30.22	30.16	30.86	29.47	0.43	1.42	2.46	*	0.022
Winter (O-M)	27.63	27.60	28.92	26.28	0.58	2.10	1.25		0.017
Summer (A-S)	32.80	32.82	33.83	31.79	0.52	1.57	2.78	**	0.030
Cold Winter (DJF)	24.67	24.54	26.57	23.10	0.84	3.42	-0.07		-0.002
Spring (MAM)	32.73	32.76	34.34	30.55	0.90	2.76	1.11		0.023
Hot Summer (JJA)	32.48	32.55	33.54	30.94	0.59	1.82	2.96	**	0.037
Autumn (SON)	30.99	30.98	32.53	29.96	0.60	1.93	3.14	**	0.040
Pre-monsoon (MAM)	32.73	32.76	34.34	30.55	0.90	2.76	1.11		0.023
Monsoon (JJAS)	32.39	32.49	33.49	31.06	0.59	1.82	3.43	***	0.040
Post-monsoon (OND)	28.73	28.76	30.50	27.28	0.72	2.49	1.78	+	0.025
Rabi (ND,J-A)	28.02	28.01	29.48	26.55	0.65	2.31	0.68		0.010
Kharif (M-O)	32.41	32.46	33.24	31.55	0.51	1.58	3.35	***	0.039

TABLE 3. STATISTICAL ANALYSIS OF TMIN DATA ALONG WITH MANN-KENDALL TREND AND SEN'S SLOPE

Time Series	Mean (mm)	Median (mm)	Maxi (mm)	Mini (mm)	St. Dev	Coeff. Var	Mann-Kendall Trend	Signific (α)	Sen's Slope
Jan	8.96	8.86	11.08	7.53	0.9	10.05	1.36	#	0.029
Feb	11.11	11.07	14.62	8.21	1.4	12.60	2.53	*	0.068
Mar	15.66	15.31	18.16	13.28	1.18	7.54	2.03	*	0.043
Apr	20.43	20.36	23.31	17.99	1.31	6.41	3.82	***	0.097
May	23.27	23.18	25.86	21.11	0.93	4.00	2.03	*	0.033
Jun	25.14	25.22	26.70	23.88	0.55	2.19	0.79		0.008
Jul	25.59	25.66	26.46	24.22	0.52	2.03	2.00	*	0.024
Aug	25.73	25.91	26.67	22.93	0.73	2.84	0.54		0.005
Sept	24.66	24.76	25.70	22.17	0.61	2.47	2.07	*	0.022
Oct	21.18	21.18	23.39	19.26	0.82	3.87	2.03	*	0.038
Nov	15.32	15.48	18.24	12.63	1.2	7.84	2.39	*	0.056
Dec	10.61	10.71	13.65	8.85	0.97	9.14	1.82	+	0.033
Annual (J-D)	18.97	19.06	19.87	17.51	0.51	2.71	4.32	***	0.040
Winter (O-M)	13.81	13.77	14.77	12.65	0.60	4.35	3.78	***	0.047
Summer (A-S)	24.14	24.23	25.15	22.33	0.57	2.35	3.03	**	0.032
Cold Winter (DJF)	10.22	10.26	11.66	8.62	0.77	7.55	2.78	**	0.048
Spring (MAM)	19.79	19.97	21.85	17.88	0.88	4.45	3.03	**	0.060
Hot Summer (JJA)	25.48	25.56	26.15	24.12	0.50	1.96	1.32		0.009
Autumn (SON)	20.39	20.49	22.24	19.20	0.64	3.14	3.28	**	0.039
Pre-monsoon (MAM)	19.79	19.97	21.85	17.88	0.88	4.45	3.03	**	0.060
Monsoon (JJAS)	25.28	25.34	25.89	23.64	0.49	1.93	1.71	+	0.014
Post-monsoon (OND)	15.70	15.72	17.66	14.39	0.71	4.55	3.50	***	0.043
Rabi (ND,J-A)	13.68	13.73	14.74	12.15	0.69	5.05	4.32	***	0.056
Kharif (M-O)	24.26	24.32	25.26	22.80	0.50	2.04	2.53	*	0.022

Note: The Mann-Kendall trend, its statistical significance along with magnitude of Sen's Slope for 1982 to 2011-year rainfall and temperature data are shown in respective tables. The month of September showed a monotonic decreasing trend with significance level 0.01, that there is a 1% probability that we make a mistake when rejecting Ho (null hypothesis) of no trend.

The maximum temperature has a monotonic increasing trend in the months July and September with significance level 0.01. The minimum temperature has a monotonic increasing trend in month of April with a significance level 0.001. Tables with a column significance (α) having (***) denotes 0.001 significance level, (**) denotes 0.01 significance level, (*) denotes 0.05 significance level, (+) denotes 0.1 significance level. The cells which are blank, the significance level is greater than 0.1.

Generally, those time series data give quite significant trends whose both Mann-Kendall trend (Z statistics) and Sen's Slope magnitude (Q statistics) having either positive or negative values.

IV. CONCLUSIONS

The results of study depicted erratic rainfall patterns of monthly and seasonal data. Some months and seasons have increasing trend while some other have decreasing trends. Individually seven months (Jan, Apr, May, Jun, July, Aug and Nov) represent increasing trend while other five months (Feb, Mar, Sep, Oct and Dec) represent decreasing trend. Annually rainfall is in rising trend and in most of the seasons also rainfall is positive. The winter, cold winter, autumn and post-monsoon seasons showed decreasing trend while other showed increasing trend. In the seasons with increasing trend the increase is significant and seasons with decreasing trend the decrease is also significant. The monthly analysis indicated that the months of April, May, June, July and August give significant increasing trend due to positive values of both Z and Q statistics while the months January and November showed non-significant increasing trend. The month of February, March and December give non- significant decreasing trend while in the month of September and October the trend is significantly decreasing. The trend of whole data on annual basis showed positive increasing trend.

The statistical analysis of whole data series indicated that the average annual rainfall of study area raingauge is 2093.50 mm. The value of standard deviation of rainfall data depicted that there is a great fluctuation in rainfall, about 80% amount of rainfall occurs in the months of monsoon season. The month of July gives the maximum amount of rainfall while the months of November and December give minimum amount of rainfall.

The analysis of T_{max} data series from 1982 to 2011 depicted that month-wise month of January gives the significant decreasing trend while all other months give the increasing trend. The monthly analysis indicated that the months of February, March, April, May, June, July, August, September, October, November and December give significant increasing trend due to positive value of both Z and Q statistics. The trend looks predominantly increasing both at the annual and seasonal scale. Only in the cold winter season the temperature is insignificantly decreasing.

From the analysis of T_{min} data series it is observed that the minimum temperature is also significantly increasing. The month wise analysis of data showed a significant increasing trend from January to December. The trend is also significant in annual and seasonal analysis.

Rainfall is the most important agro-climatic variable that determines the cropping system and overall agricultural productivity in rainfed areas of Nepal. The study showed an increasing trend of rainfall on annual and seasonal basis. However, the temperature is also increasing and days are becoming hotter in future days. But the positive thing is that even with the increase in temperature the rainfall is also increasing which can create favorable environment for the cropping and increasing agricultural productivity. This increasing trend of rainfall on annual and seasonal basis can be used for better planning of water resources development and management schemes as well as conservation of soil moisture in study area of Morang region Nepal.

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