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TREND ANALYSIS OF RAINFALL, TEMPERATURE AND RUNOFF DATA: A CASE STUDY OF RANGOON WATERSHED IN NEPAL

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Abstract----*The study has been carried out to investigate and assess the significance of the potential trend of three variables viz. rainfall, temperature and runoff over the Rangoon watershed in Dadeldhura district of Nepal. In this study, trend analysis has been carried out on monthly, seasonal and annual basis using the data period between 1979 to 2010 for rainfall and temperature and 1967 to 1996 for runoff. Mann-Kendall test and Sen's slope estimate test were applied to identify the existing trend direction and Sen's slope estimator test were used to detect the trend direction and magnitude of change over time. The most important findings are, i) There is warming trends over the Rangoon watershed as Mann-Kendall statistic (Z-value) for most of the maximum temperature values are positive, ii) Rainfall and runoff affected by fluctuations every year though the annual rainfall showing a rising trend whereas runoff showing a falling trend. The rainfall seasonal trend analysis indicates that monsoon and post-monsoon period showed a positive rainfall trend with z statistics of +1.93, and +1.12 respectively, whereas pre-monsoon and winter seasons showed a negative trend with z statistics of -1.02, and -0.54 respectively. However, the annual rainfall in the Rangoon watershed showed a positive trend with a z value of +1.70.*

Keywords----trend analysis, climate change, Rangoon watershed, Nepal.

I. INTRODUCTION

Water resource has the prime concern for any future planning and development including flood control, flood protection and sustainable watershed management. The rainfall available in the watershed is key factor for determining the availability of water to fulfil the different demand mainly for agriculture, hydropower water supply, industry, etc. The timely availability of water influences the agriculture sector, food security and energy sector. Global climate changes affect the long-term rainfall pattern causes availability of water and may danger of occurrence of serious drought and flood. The high instantaneous rainfall in monsoon(June-August) may have shortage of water availability in non-monsoon period. Due to uneven distribution of rainfall and mismatch between demand and water availability requires large storage structures to control the natural flow according to the requirement of the region (S Kundu, D Khare et al, 2015). Generally, the hydro-structures are designed assuming the stationary climate. Global warming affects the rainfall change which influence the stream flow rate, hydrologic cycle, water demand (specially in agriculture) requires review in planning, design and management of hydraulic structures (Deasy Nalley,2012) . Changes in run-off and its distribution will depend on likely future climate scenarios. The trend analysis of rainfall, temperature and other climatic variables on different spatial scales will help in the construction of future climate scenarios (Arijit Ganguly, Ranjana Ray Chaudhuri et al, 2015). Since average annual precipitation in the area is lesser than the overall country precipitation, so any rise or fall in trend will have significant impact on watershed management (Agnieszka Rutkowska, 2013). Any rise or fall in annual rainfall in the area leads to stress on annual average stream flow with consequent implications in planning and designing of water resources development projects (A. Serrano, V. L. Mateos et al,1998)

In view of the above, this study has been attempted to investigate the trend of climatic variables for the study area. There are three main variables which are critical in hydrologic studies: rainfall, runoff and temperature were summarized in this article. Changes in temperature will impact the various hydrological processes such as rainfall and their sequences (Basistha A, Arya D.S. et al 2008)

"There are various methods used to identify hydro-meteorological time series" (Duhan and Pandey, 2013). "Trend analysis of rainfall time series includes determination of increasing and decreasing trend and magnitude of trend and its statistical significance" (Jain and Kumar, 2012) by using parametric and non-parametric statistical methods. Trend analysis in various study shows that there are generally non-parametric methods were used, Mann-Kendall test (Mann, 1945 and Kendall, 1975) is one of the best methods amongst them, which is preferred by various researchers (D Khare, Douglas et al., 2000; Yue et al., 2003; Jain and Kumar, 2012). "Mann- Kendall test is used for analysis and ascertains statistical significance by hypothesis test of hydrological variables" (Yue et al, 2003).

"Mann-Kendall test does not require that datasets to follow normal distribution and show homogeneity in variance; transformations are not basically required if data already follows normal distribution, in skewed distribution greater power is achieved" (Duhan and Pandey, 2013). "Mann Kendall test also discusses about function of slope in the trend, coefficient of variation, and type of probability distribution" (Yue et al, 2002a). "Mann-Kendall test is used for trend analysis as it eliminates the effect of serial dependence on auto-correlated data which modifies the variance in datasets" (Hamed and Rao, 1998). Sen's slope estimation, non-parametric, (Sen,1968) method gives the magnitude of trend. "This method assumes the trend line is a linear function in the time series. In Sen's slope model, the slope value shows the rise and fall of the variable" (Jain and Kumar, 2012). "Another advantage of using Sen's slope is that it is not affected when outliers and single data errors are present in the dataset" (Salmi et al., 2002).

"Annual decrease in -6.75% of rainfall is observed from 1901-2011 in Madhya Pradesh, India" (S Kundu et.al.). "Change percentage for 111 years had shown rainfall variability throughout North India centre's with the highest increase in Delhi centre's (32.43%) and decrease in Patna centre's (-16.22%) annually" (PK Meena et.al.). "Change percentage for 141 years had shown rainfall variability throughout India with the highest increase in North-west India (5.14%) and decrease in core-monsoon India (-4.45%) annually" (S.Kundu et.al.).

The goal of this study is to analyse the variability of hydroclimatic factors in Rangoon watershed, Nepal where agricultural yield, which is the main source of income of the people, affected by mismatch of rainfall according to demand while the too much rainfall cause the landslides in higher slope area and flooding in lower zone including overlaying of river materials on productive land (Joshi M.K., Pandey A.C., 2011). The major objective of this study is to determine and analyse the trends of the precipitation, runoff and temperature on monthly, seasonal and annual basis.

II. STUDY AREA

The study area is situated in lower tropical to sub-tropical region in the western part of Nepal. The watershed (Rangoon) is part of the river Mahakali basin (Figure 1). The area is selected for investigation due to its variety in biodiversity including elevation differences from Sivalik range to higher elevation, and high soil erosion observed which is critical for the District Soil Conservation Office (Dadeldhura District, Nepal)

The study area is comprising a geographical area of about 481sq.km., occupying 32% of the Dadeldhura district and 0.33% of Nepal. The study area extends from 29º00'25" to 29º 15'45" North latitude and 80º25'10" to 80º35'25" East longitude. The climate varies from lower main valley to higher slopes, warm temperate at mid/lower-elevations to cold temperate in the higher elevations. In lower slope region, the annual average summer temperature is 31ºC with prevalent during the months from April to September. The average annual winter temperature is 20ºC (Jogbuda station). At higher elevations, average summer temperature is 23ºC and average winter temperature is 8ºC with extreme values of 3ºC in January (Dadeldhura station). Annual precipitation also varies according to elevation changes, from 598 mm in the low altitudes (Jogbuda, 350 m asl) to 1998 mm at higher altitudes (Hagulte, 2124 m asl), where average annual rainfall is less than the overall average of the country. Maximum rainfall occurs during the months of June to September. Agriculture is the major source of economy for the region.

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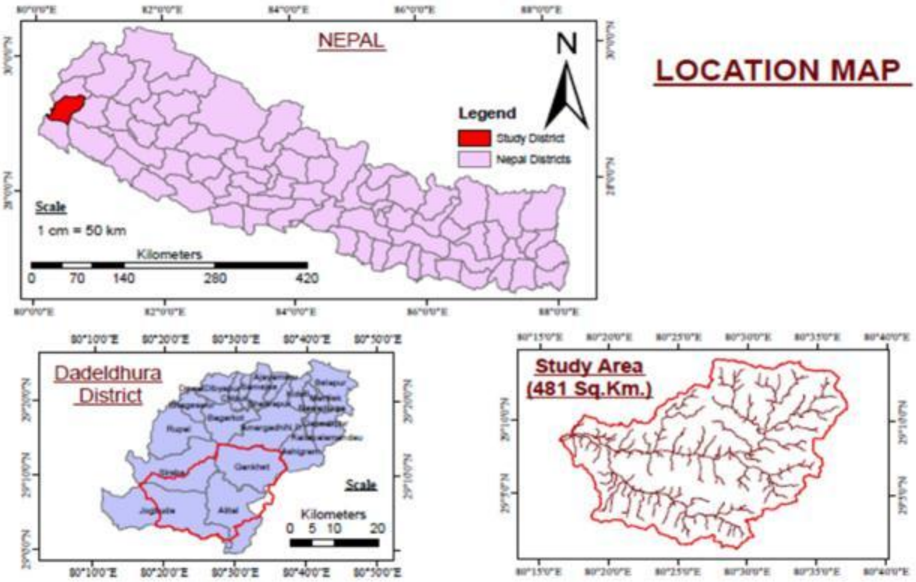

Fig. 1: Study area (Rangoon Watershed)

III. MATERIALS AND METHODS

Monthly precipitation and temperature data of 31 years (1979-2010), and monthly runoff data of 30 years (1967-1996) were collected from Department of Hydrology and Meteorology, Nepal. These data were investigated for trends using non-parametric Mann-Kendall test and Sen's slope estimator. Linear trends analysis was also carried out using linear regression procedure to detect the trend on monthly, seasonal and annual basis.

A. *Mann-Kendall (MK) Test*

The Mann-Kendall test used for trend analysis is a non-parametric method (Mann, 1945; Kendall, 1975). It is used for detection of statistically significant trend in variables like rainfall, temperature and stream flow. These are extremely important parameters for watershed modelling, studying catchment characteristics which are very important to determine water resources planning strategies in the long term for any region (Kothawale DR, Rupa Kumar K, 2005). The trend detection of the data is analyzed using the Mann-Kendall test (the significant trend of a data series). The Mann-Kendall Statistic S for trend is

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

here, x_i, xj are the sequential data values, n is the length of the data set and

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

The value of S indicates the direction of trend. A negative (positive) value indicates falling (rising) trend. Mann-Kendall has documented that when n≥8, the test statistic S is approximately normally distributed with mean and variance as follows:

$$E(S) = 0 \tag{3}$$

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

The standardized test statistics Z is computed as follows.

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

Where, m is the number of tied groups and t_i is the size of the i^{th} tie group

Also, Z_{MK} follows normal distribution, a positive Z_{MK} depicts an upward trend and negative Z_{MK} depicts downward trend for the period. At significance level α, $Z_{MK} \geq Z_{\alpha/2}$, then the trend of the data is considered to be significant. The Mann Kendall test checks the null hypothesis of no trend to the alternate hypothesis of existence of trend in data (Kumar, V and Jain SK, 2010). The above formula is valid when the number of observation n ≥ 10.

B. Sen's slope estimator

Sen's slope estimation (Sen, 1968) is another non-parametric method for trend analysis of hydroclimatic data set. It is used to detect the magnitude of the trend.'i'

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

Where X_j and X_k is the data values for j and k times of a period where j>k. the slope is estimated for each observation. Median is computed from N observations of the slope to estimate the Sen's Slope estimator is:

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

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

"When the N Slope observations are shown as Odd the Sen's Estimator is computed as Q_{med}= (N+1)/2 and for Even times of observations the Slope estimate as Q_{med}= [(N/2) + ((N+2)/2)]/2. The two-sided test is carried out at 100(1 – α) % of confidence interval to obtain the true slope for non-parametric test in the series" (Mondal et.al., 2012). The positive or negative slope Q_i is obtained as upward (increasing) or downward (decreasing) trend.

IV. RESULTS AND DISCUSSION

A. Trend analysis of Rainfall

The preliminary data analysis was carried out to find the statistical parameters (mean, standard deviation, skewness, kurtosis and coefficient of variation) of annual precipitation series for the period 1979-2010. Annual precipitation in the watershed varies between 598 mm (1987) to 1998 mm (1996) with a standard deviation of 425.50 mm. Skewness is the measure of asymmetry in frequency distribution about the mean predominantly positive skewness of average value 0.23 indicating annual precipitation in the region is asymmetric and it lies to the right of mean i.e. Right skewed. Kurtosis is the measure of peakedness or flatness of frequency distribution having value of -1.33 indicating Platykurtic shape. Coefficient of variation (CV) is the measure of spread data points in data series around the mean which is found 34.13%. All the statistical parameters for annual and seasonal basis are given in Table 1.

TABLE 1
STATISTICAL PARAMETERS OF ANNUAL AND SEASONAL RAINFALL PATTERN

Series	Mean	Minimum (Year)	Maximum (Year)	SD	CV	Skewness	Kurtosis
Annual	1246.59	598.26 (1987)	1998.30 (1996)	425.50	34.13	0.23	-1.33
Pre-monsoon	69.22	3.12 (1999)	244.93 (1982)	60.55	87.48	1.27	1.11
Monsoon	1038.89	425.20 (1987)	1726.09 (1996)	381.52	36.72	0.23	-1.29
Post-monsoon	34.29	0.01 (1993)	272.43 (2009)	55.62	162.21	2.91	10.34
Winter	104.20	3.28 (2006)	223.95 (2003)	58.76	56.39	0.14	-0.61

Note: SD=Standard Deviation and CV=Coefficient of variation

Before applying the MK test all the series are tested for serial correlation using Lag-1 autocorrelation at different significance level to make the series serially independent. The results of MK test and Sen's slope estimator are presented in Table 2. Figure 2 provide the graphical representation of MK statistics (Z value) and Sen's slope (Q value) of the trend analysis.

The results shown in Table 2 indicated a falling trend in month of January, March, and December with significant at 0.1 level of significance, whereas significant rising trends showed in the months of June and September at 0.05 level of significance. The annual precipitation in the Rangoon watershed showed an increasing trend (Z value +1.70). An increasing trend in the monsoon and post-monsoon season will augur well for the total water availability in the watershed, however, a rainfall during post-monsoon may trigger post-harvest crop losses. A decreasing winter precipitation will result in less water availability to winter crops. Figure 3 depicts the precipitation variability during the period 1979-2010. It also indicated the linear trend line overlaid on the time series for different months and seasons.

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TABLE2
RESULTS OF RAINFALL TREND ANALYSIS USING MK TEST AND SEN'S SLOPE ESTIMATOR

Time series	MK statistics (Z value)	Sen's slope (Q value)	Significance level
January	-0.96	-0.45	+
February	0.28	0.15	+
March	-1.86	-0.77	++
April	-0.02	0.00	+
May	0.41	0.09	+
June	2.22	3.24	+++
July	0.99	4.31	+
August	0.63	1.52	+
September	2.29	5.17	+++
October	1.67	0.51	++
November	0.77	0.00	+
December	-1.59	-0.37	+
Annual	1.70	13.9	++
Pre-Monsoon	-1.02	-0.64	+
Monsoon	1.93	12.9	++
Post-Monsoon	1.12	0.43	+
Winter	-0.54	-0.77	+

Note: +++ is for 0.05 level of significance, ++ is for 0.1 level of significance and + shows more than 0.1 level of significance.

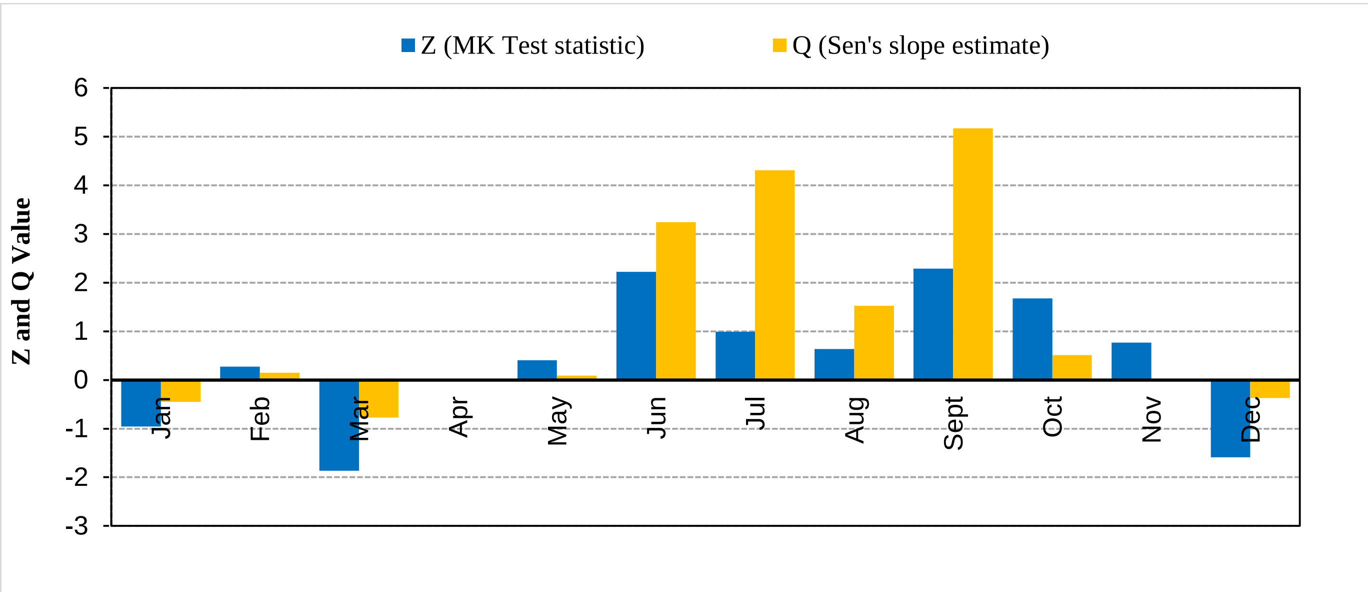

Fig. 2 MK statistics and Sen's slope for different months

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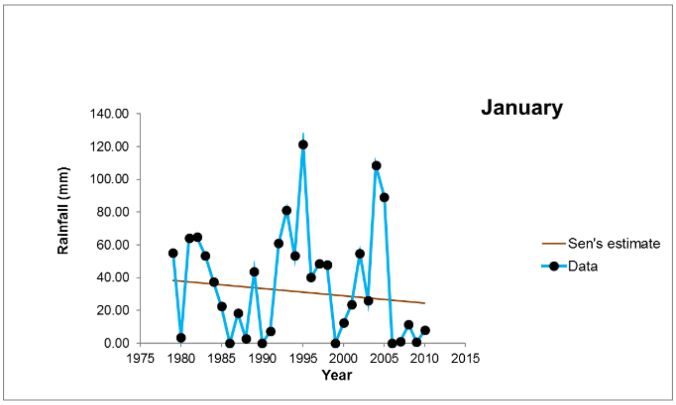

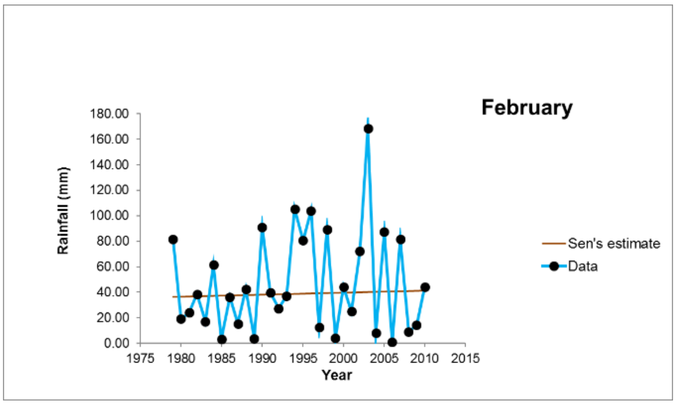

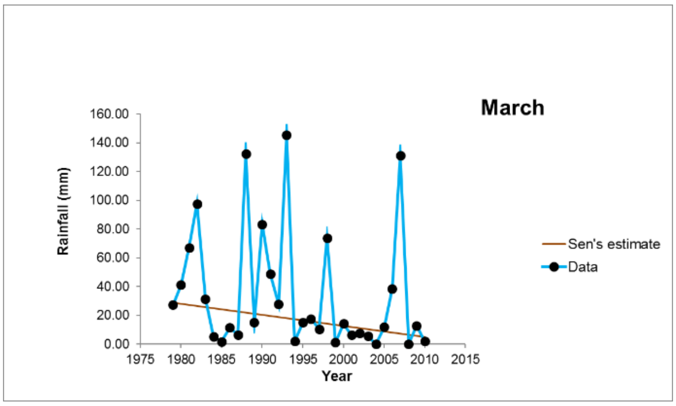

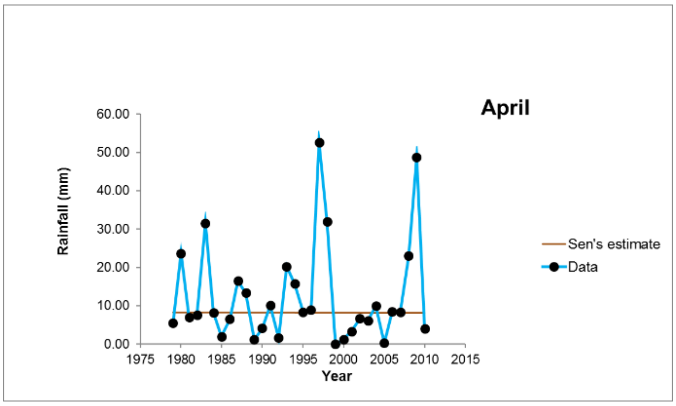

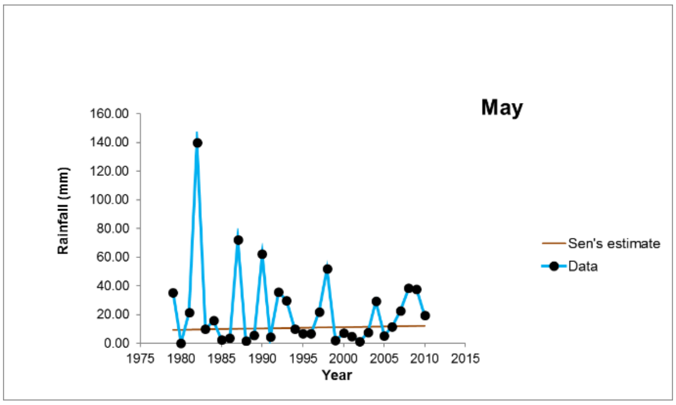

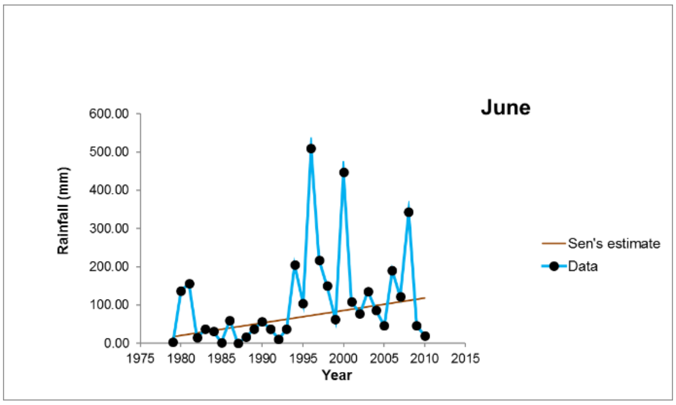

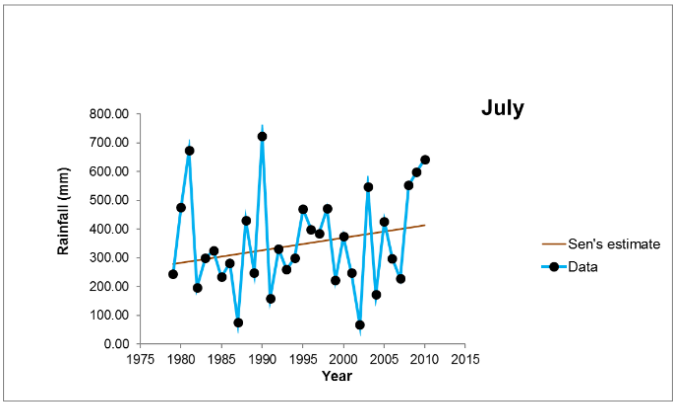

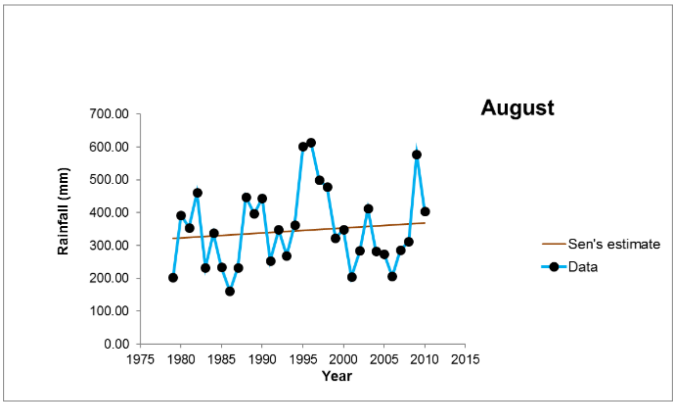

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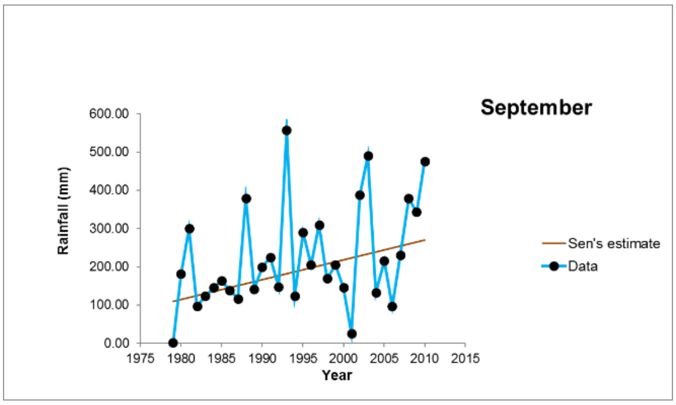

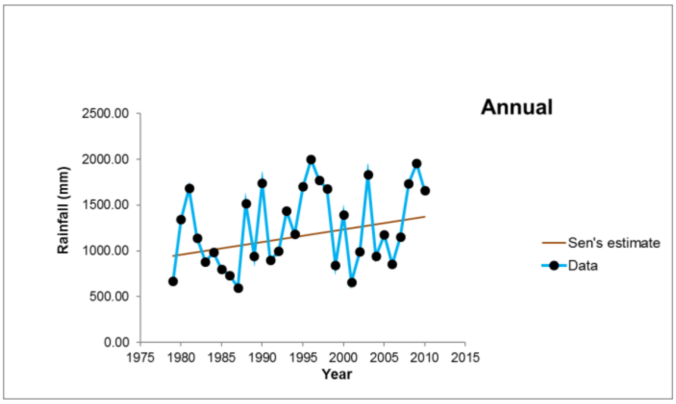

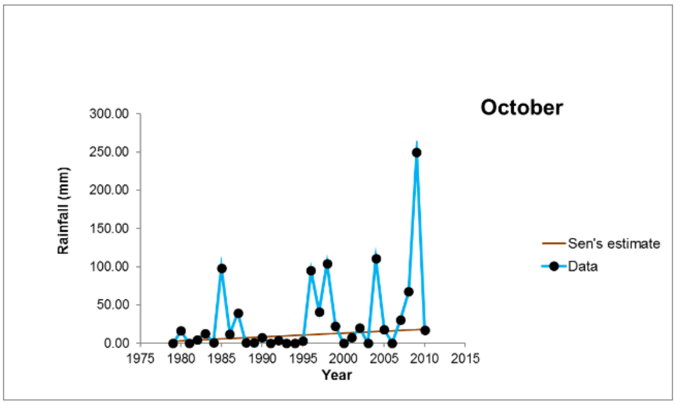

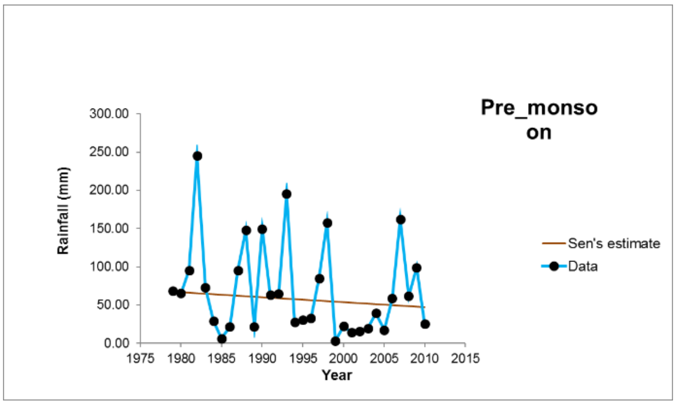

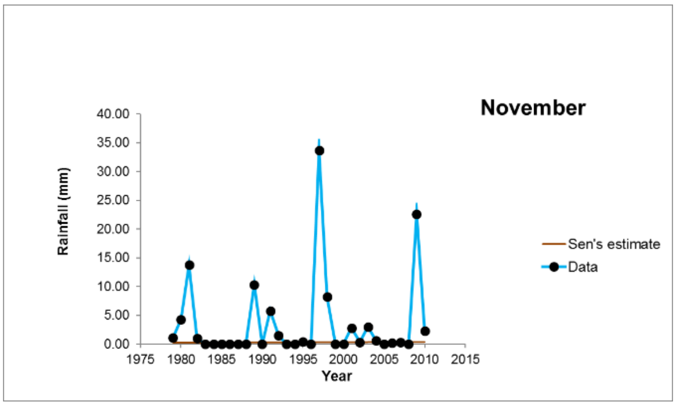

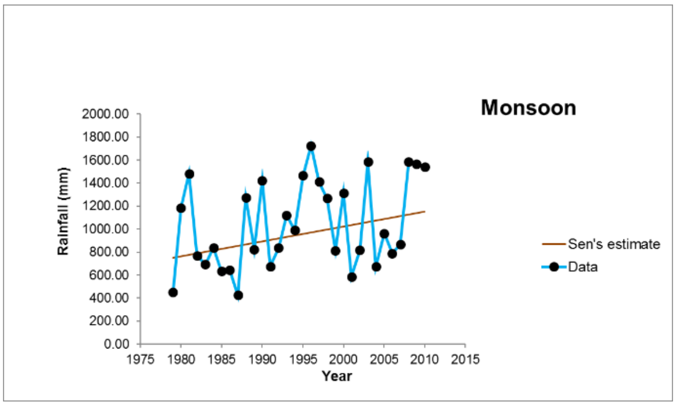

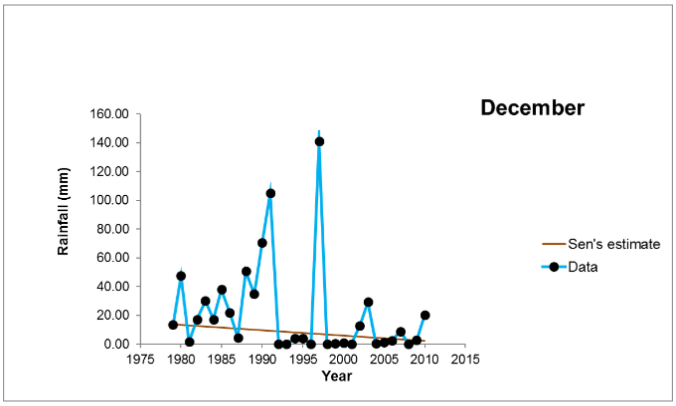

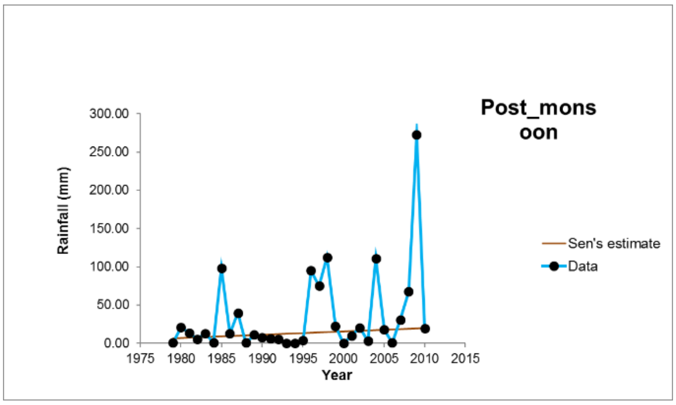

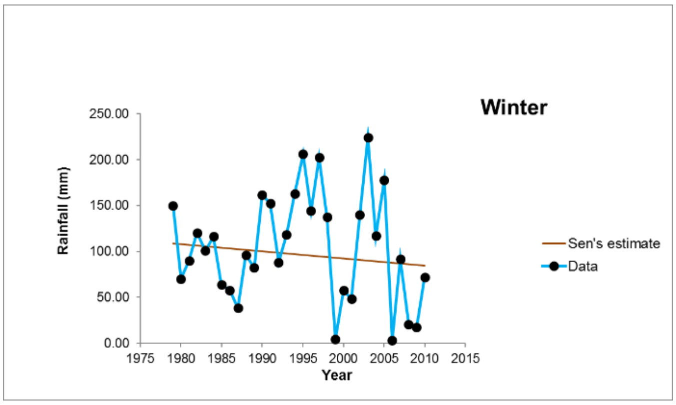

Fig. 3 Linear rainfall trends for the period 1979-2010 on monthly, seasonal and annual basis

B. Trend analysis of Temperature

Maximum Temperature

The preliminary data analysis was carried out to find the statistical parameters (mean, standard deviation, skewness, kurtosis and coefficient of variation) of annual maximum temperature series for the period 1979-2010. Maximum temperature in the watershed varies between 16.40^{0}C(January-1981) to 38.2^{0}C (June-1987) where mean annual maximum temperature is 27.57 ^{0}C with standard deviation 0.85^{0}C. The skewness of average value -0.41 indicating annual maximum temperature in the region is asymmetric and it lies to the left of mean i.e. left skewed. Kurtosis value of 0.16 represents the platykurtic shape of annual data distribution. All the statistical parameters for annual and seasonal basis are shown in Table 3.

TABLE 3
STATISTICAL PARAMETERS OF ANNUAL AND SEASONAL MAXIMUM TEMPERATURE PATTERN

Series	Mean	Minimum (Year)	Maximum (Year)	SD	CV	Skewness	Kurtosis
Annual	27.57	25.584 (1981)	29.082 (2002)	0.85	3.08	-0.41	0.16
Pre-monsoon	31.40	27.251 (1981)	33.896 (2010)	1.65	5.27	-1.09	1.07
Monsoon	30.94	27.622 (2008)	33.944 (1987)	1.33	4.29	0.08	0.92
Post-monsoon	25.76	23.175 (1983)	28.071 (1979)	1.27	4.92	-0.21	-0.83
Winter	20.45	18.601 (1981)	23.438 (2006)	1.09	5.33	0.36	0.40

Note: SD=Standard Deviation and CV=Coefficient of variation

Before applying the MK test all the series are tested for serial correlation using Lag-1 autocorrelation. The results of MK test and Sen's slope estimator are presented in Table 4.

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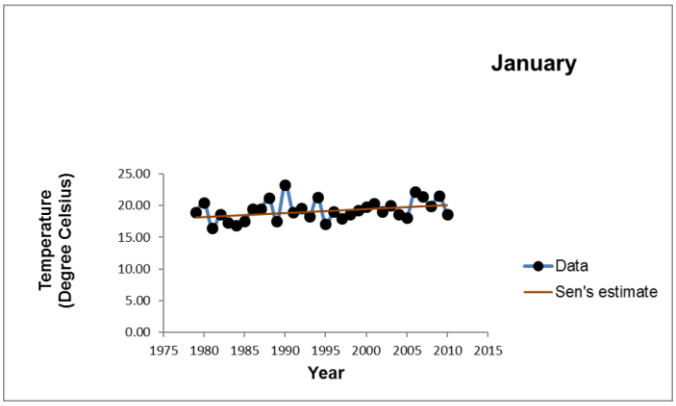
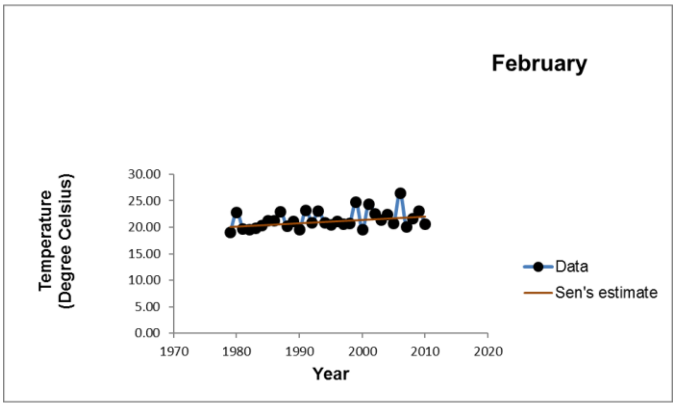
TABLE 4
RESULTS OF MAXIMUM TEMPERATURE TREND ANALYSIS USING MK TEST AND SEN'S SLOPE ESTIMATOR

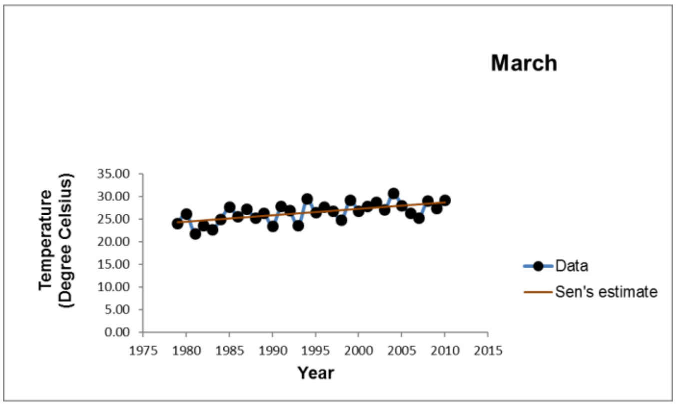
Time series	MK statistics (Z value)	Sen's slope (Q value)	Significance level
January	1.99	0.06	+++
February	1.96	0.06	+++
March	3.49	0.14	+++++
April	4.46	0.17	+++++
May	0.05	0.00	+
June	-1.02	-0.04	+
July	-1.83	-0.07	++
August	-1.96	-0.06	+++
September	-1.70	-0.04	++
October	-0.44	-0.01	+
November	1.02	0.03	+
December	1.99	0.05	+++
Annual	1.12	0.02	+
Pre-Monsoon	3.84	0.10	+++++
Monsoon	-2.29	-0.06	+++
Post-Monsoon	0.34	0.01	+
Winter	2.42	0.06	+++

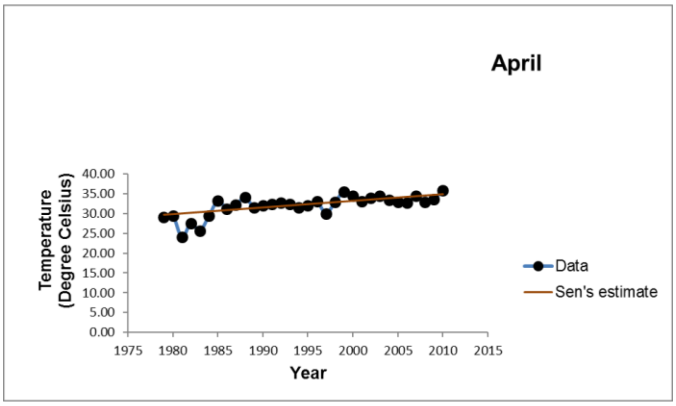
Note : +++++ is for 0.001 level of significance, ++++ is for 0.01 level of significance, +++ is for 0.05 level of significance, ++ is for 0.1 level of significance and + shows more than 0.1 level of significance.

The results shown in Table 4 indicated a falling trend in month of July, August and September with significant at 0.1 level of significance, whereas significant rising trends showed in the months of March and April at 0.001 level of significance and significant rising trend in the month of December to February at 0.05 level of significance. The annual average maximum temperature in the Rangoon watershed showed an increasing trend (Z value +1.12). An increasing trend in the winter and pre-monsoon season will lead to increase in annual mean temperature and consequently decrease the crop period, however, a maximum temperature during monsoon may auger the soil moisture content. A decreasing monsoon maximum temperature will result in less evaporation loss causing to rise in the ground water table. Figure 4 depicts the maximum temperature variability during the period 1979-2010.









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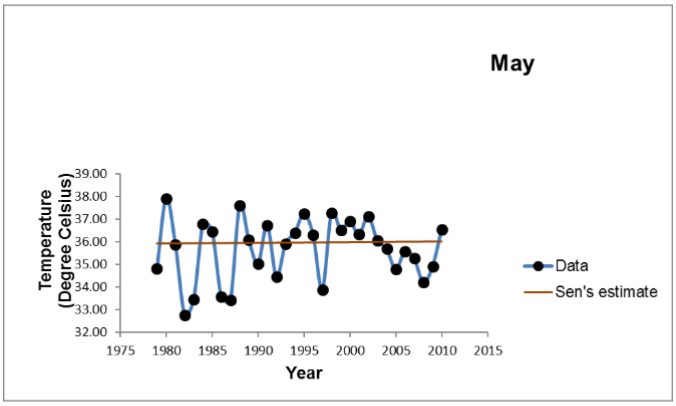

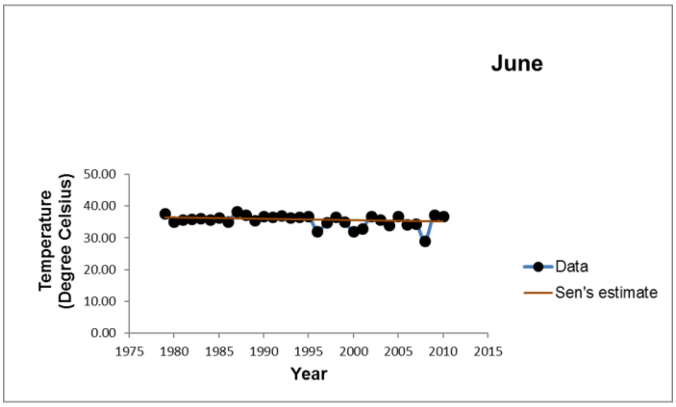

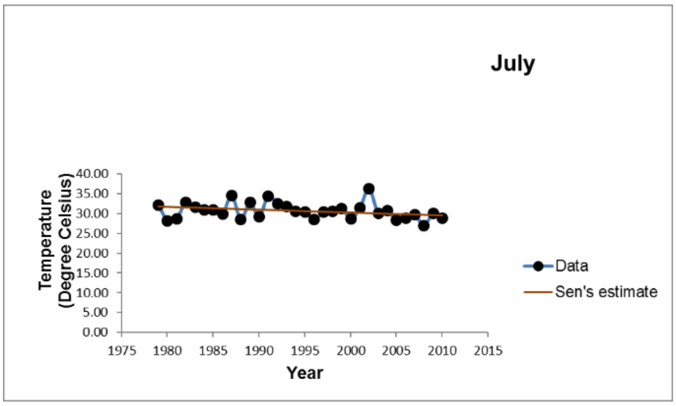

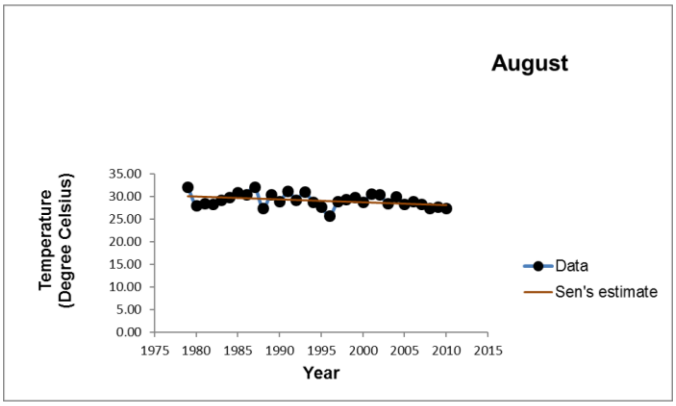

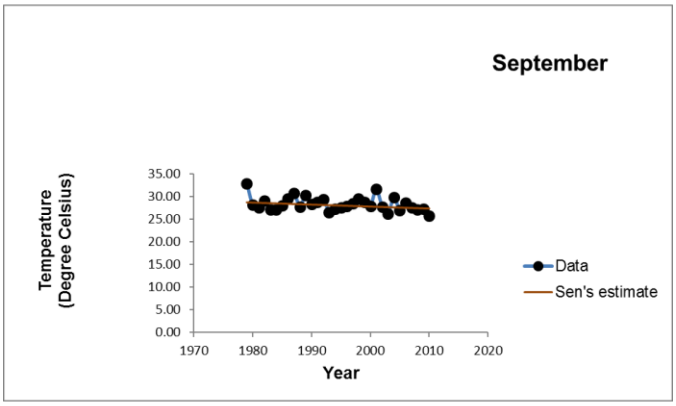

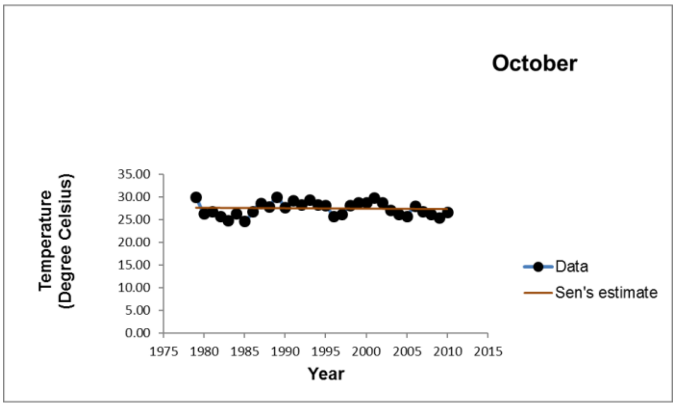

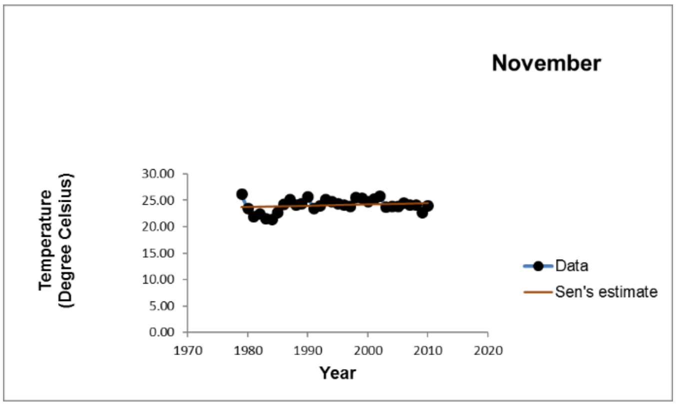

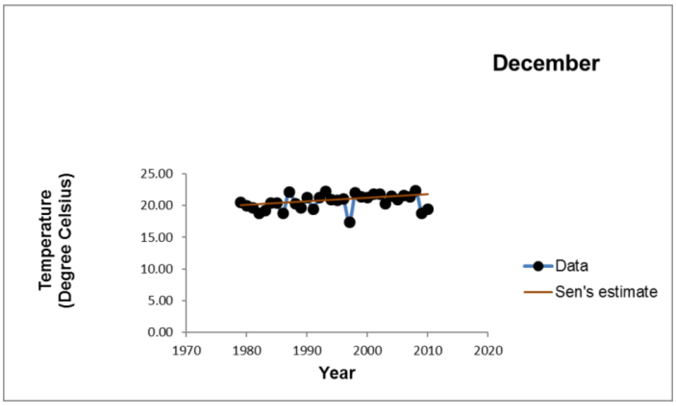

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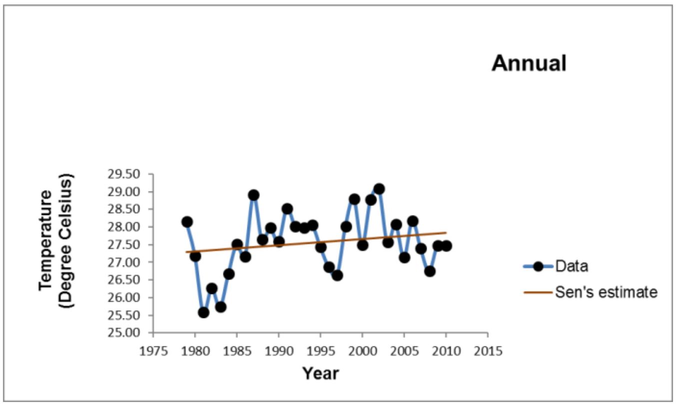

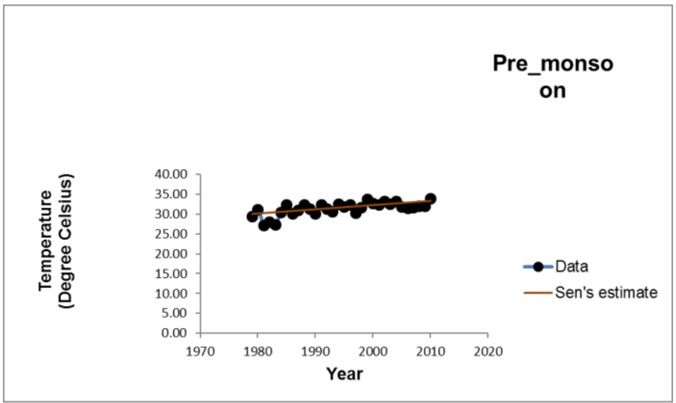

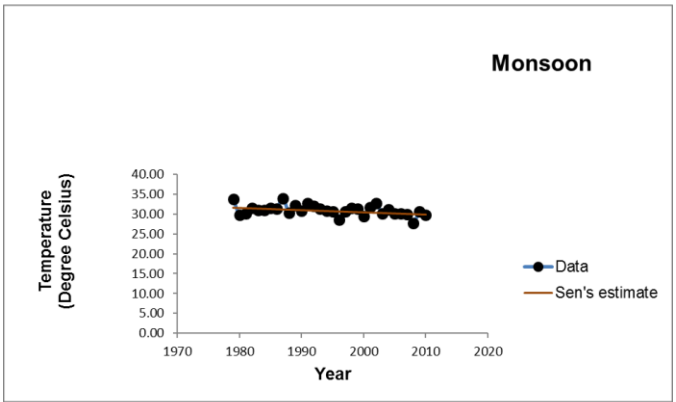

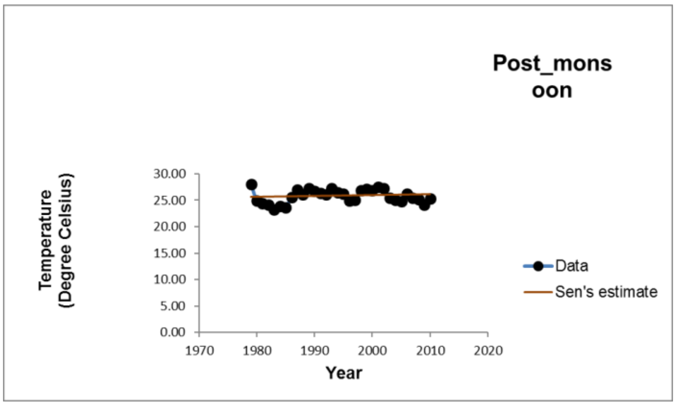

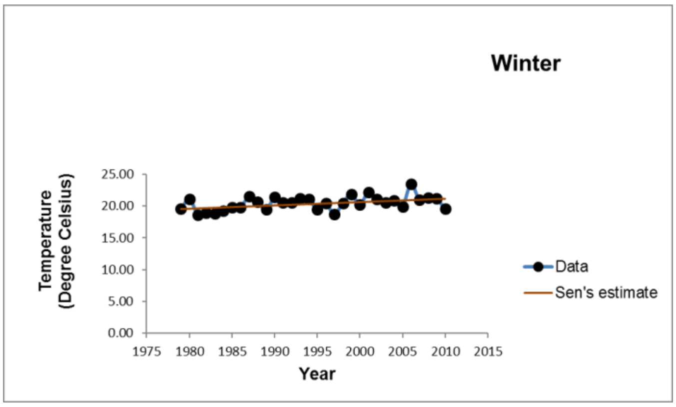

Fig. 4 Linear maximum temperature trends for the period 1979-2010 on monthly, seasonal and annual basis

Minimum Temperature

The preliminary data analysis was carried out to find the statistical parameters (mean, standard deviation, skewness, kurtosis and coefficient of variation) of annual minimum temperature series for the period 1979-2010. Minimum temperature in the watershed varies between 3.26 ^{0}C (January-1984) to 23.08 ^{0}C (June-2005) where mean annual minimum temperature is 13.77 ^{0}C with standard deviation 0.875 ^{0}C. The predominantly negative skewness of average value -1.042 indicating annual minimum temperature in the region is asymmetric and it lies to the left of mean. Kurtosis of annual frequency distribution 0.385 indicating Platykurtic shape. All other statistical parameter for annual and seasonal basis are depicted in Table 5.

TABLE 5
STATISTICAL PARAMETERS OF ANNUAL AND SEASONAL MINIMUM TEMPERATURE PATTERN

Series	Mean	Minimum (Year)	Maximum (Year)	SD	CV	Skewness	Kurtosis
Annual	13.769	11.585 (1981)	15.136 (2002)	0.875	6.354	-1.042	0.385
Pre-monsoon	15.739	10.476 (2081)	17.965 (2004)	2.068	13.139	-1.500	1.171
Monsoon	19.637	16.099 (1996)	20.628 (2005)	0.842	4.289	-2.527	9.378
Post-monsoon	10.780	7.075 (1984)	13.176 (1998)	1.368	12.694	-0.829	1.030

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Winter	5.966	4.220 (1981)	7.888 (2006)	0.761	12.751	0.088	0.286

Note: SD=Standard Deviation and CV=Coefficient of variation

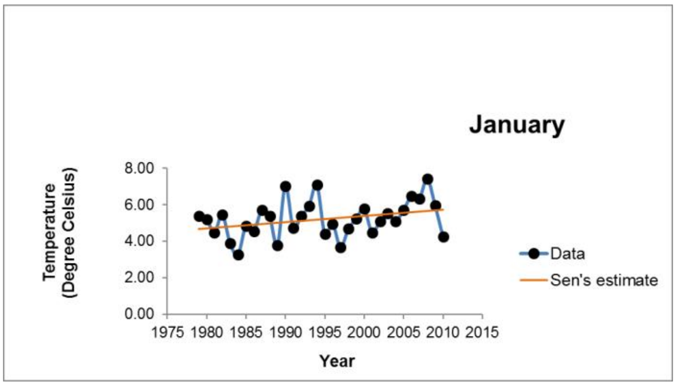
Before applying the MK test all the series are tested for serial correlation using Lag-1 autocorrelation. The results of MK test and Sen's slope estimator are presented in Table 6.

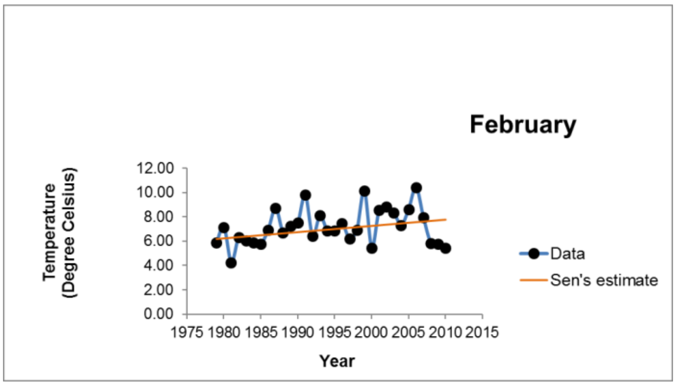
TABLE 6
RESULTS OF MINIMUM TEMPERATURE TREND ANALYSIS USING MK TEST AND SEN'S SLOPE ESTIMATO

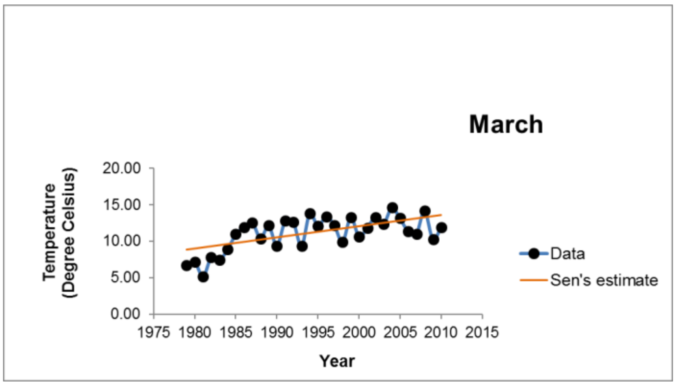
Time series	***MK statistics (Z value)***	***Sen's slope (Q value)***	***Significance level***
January	*1.86*	*0.03*	++
February	*1.48*	*0.05*	+
March	*3.19*	*0.15*	++++
April	*4.10*	*0.16*	+++++
May	*0.66*	*0.01*	+
June	*0.00*	*0.00*	+
July	*1.57*	*0.02*	+
August	*1.93*	*0.02*	++
September	*2.97*	*0.04*	++++
October	*4.04*	*0.09*	+++++
November	*3.16*	*0.07*	++++
December	*0.86*	*0.02*	+
Annual	*4.52*	*0.06*	+++++
Pre-monsooon	*4.17*	*0.11*	+++++
Monsoon	*2.19*	*0.02*	+++
Post-monsoon	*3.94*	*0.09*	+++++
Winter	*2.32*	*0.05*	+++

Note: +++++ is for 0.001 level of significance, ++++ is for 0.01 level of significance, +++ is for 0.05 level of significance, ++ is for 0.1 level of significance and + shows more than 0.1 level of significance.

The results shown in Table 6 indicated a rising trend in all months with significant at 0.001 level of significance in April and October, whereas in the months of March, September and November at 0.01 level of significance and 0.1 level of significance for the month January and August. The annual mean minimum temperature in the Rangoon watershed showed an increasing trend (Z value +4.52). An increasing trend with highly significant minimum temperature in the pre-monsoon and post-monsoon season will increase the duration of the summer season and enhance the global warming (Prathasarathy, B, Dhar,1974), however, a lesser significant rising minimum temperature during monsoon and winter may decrease the length of crop period without reaching to its maturity hence reduce the yield. An increasing minimum temperature will support the global warming causing climate change (Kharmeshu N. 2012). This suggests that temperature trend shows rising and due to this rising temperature, other climatic variables may experience affected in the hydrologic processes and surrounding environment of the watershed (Rao, P.G.,1993). The minimum temperature variability during the period 1979-2010 is presented in Figure 5. It also indicated the linear trend line overlaid on the time series for different months and seasons.







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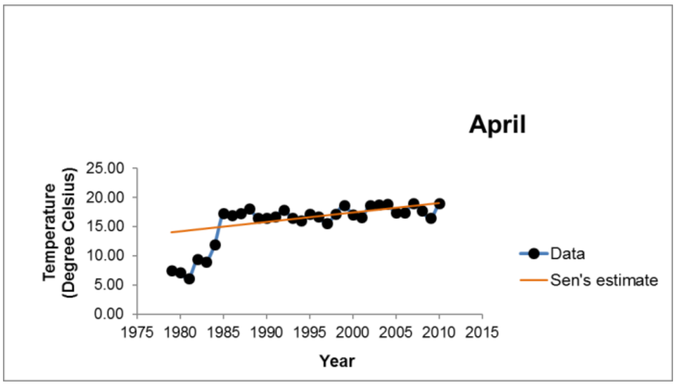

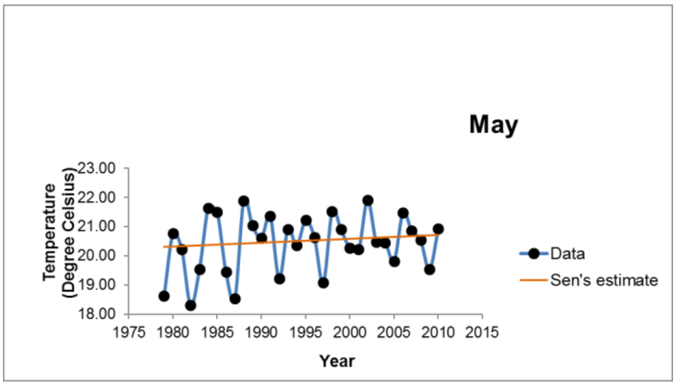

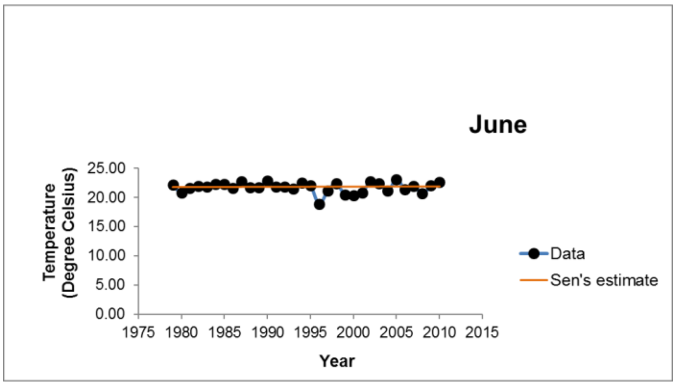

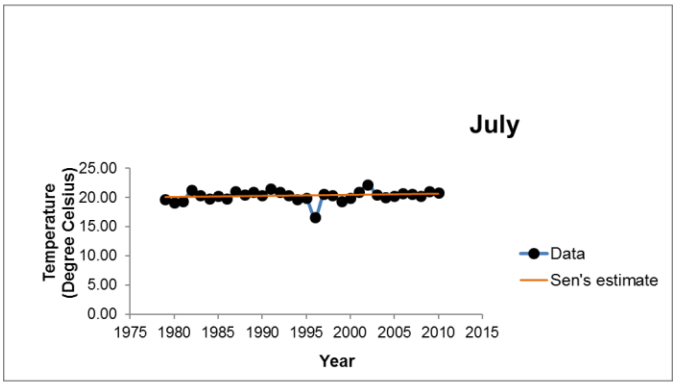

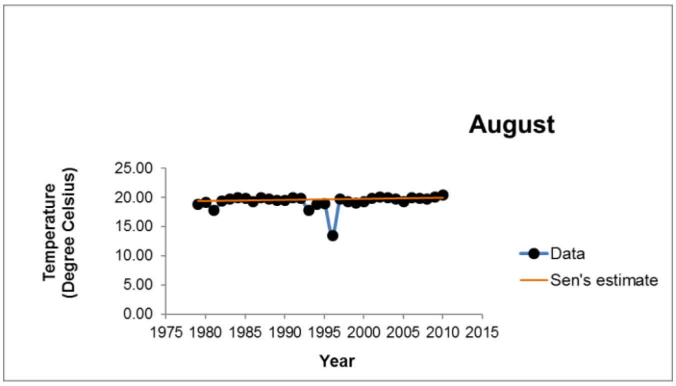

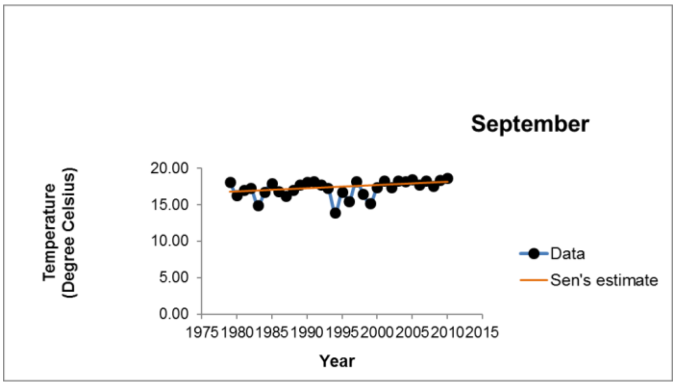

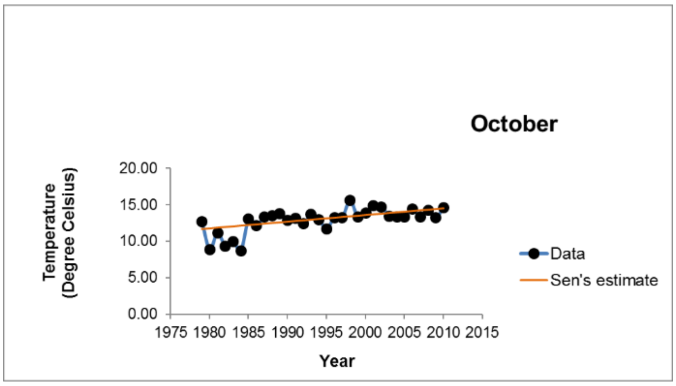

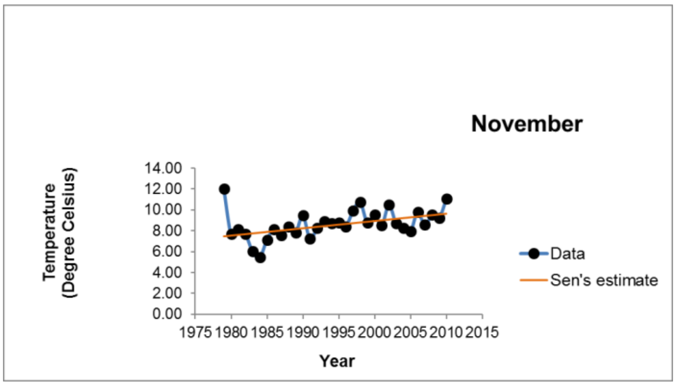

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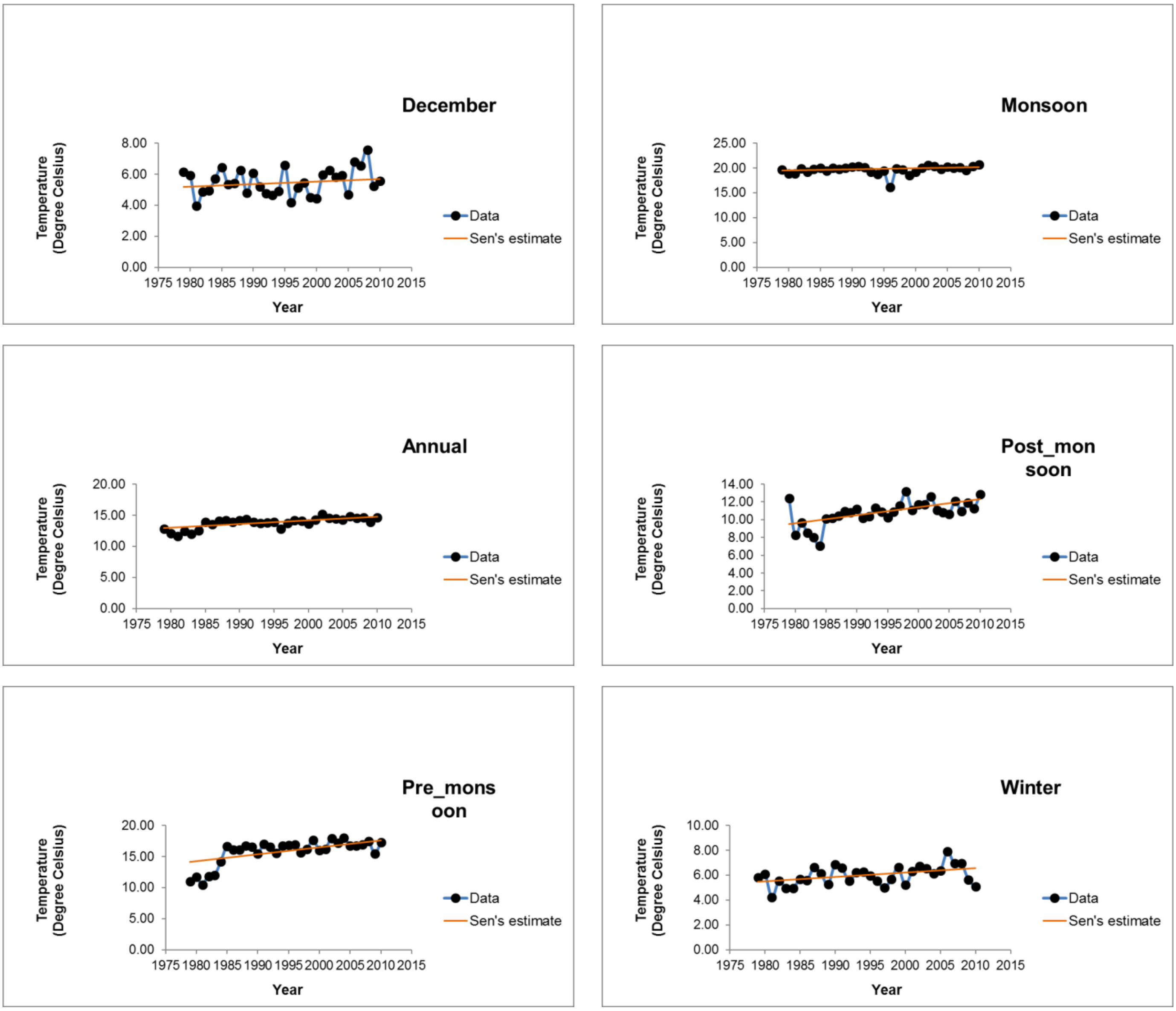

Fig. 5 Linear minimum temperature trends for the period 1979-2010 on monthly, seasonal and annual basis

C. Trend analysis of Runoff

The preliminary data analysis was carried out to find the statistical parameters (mean, standard deviation, skewness, kurtosis and coefficient of variation) of annual runoff series for the period 1967-1996. Annual runoff in the watershed predominantly positive skewness of annual frequency distribution having value of 1.09 indicating annual runoff in the region is asymmetric and it lies to the right of mean. varies between 7.87m^3/sec (1987) to 36.60m^3/sec (1970) where mean annual runoff is 16.86 m^3/sec with standard deviation 6.75. The Kurtosis value of 1.45 indicates the annual frequency distribution have the Platykurtic shape. All other statistical parameters are shown in the Table 7.

TABLE 7
STATISTICAL PARAMETERS OF ANNUAL AND SEASONAL MAXIMUM TEMPERATURE PATTERN

Series	Mean	Minimum (Year)	Maximum (Year)	SD	CV	Skewness	Kurtosis
Annual	16.86	7.87 (1987)	36.60 (1970)	6.75	40.01	1.09	1.45

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Pre-monsoon	3.21	1.29 (1989)	9.96 (1971)	1.88	58.56	2.35	6.36
Monsoon	39.31	15.106 (1987)	97.795 (1970)	19.56	49.77	1.29	1.79
Post-monsoon	11.30	3.505 (1979)	36.5 (1985)	7.31	64.72	2.61	7.17
Winter	4.29	2.367 (1980)	6.027 (1985)	1.12	25.98	-0.10	-1.18

Note: SD=Standard Deviation and CV=Coefficient of variation

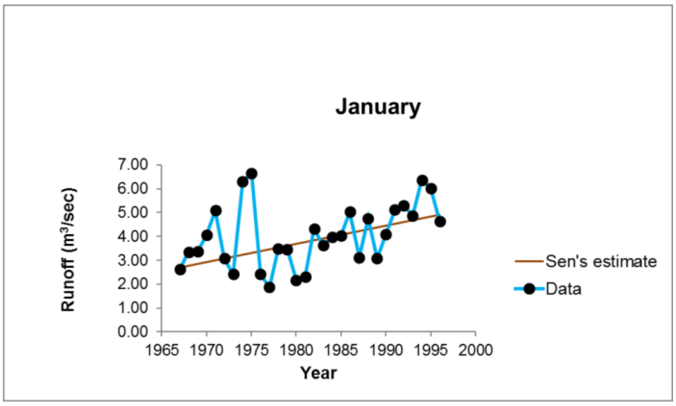
Before applying the MK test all the series are tested for serial correlation using Lag-1 autocorrelation (Longobardi A, Villani P., 2010). The results of MK test and Sen's slope estimator are presented in Table 8.

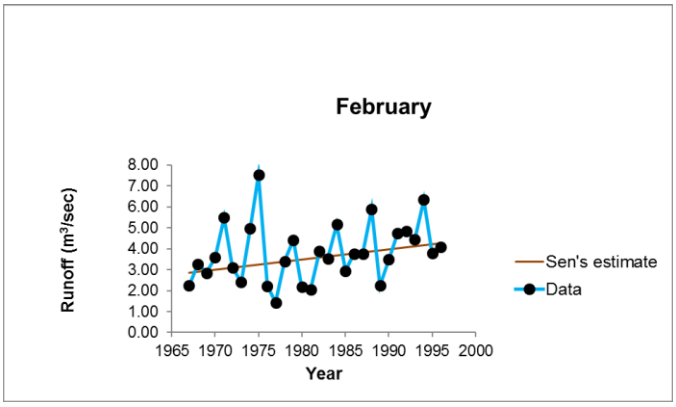
TABLE 8
RESULTS OF RUNOFF TREND ANALYSIS USING MK TEST AND SEN'S SLOPE ESTIMATOR

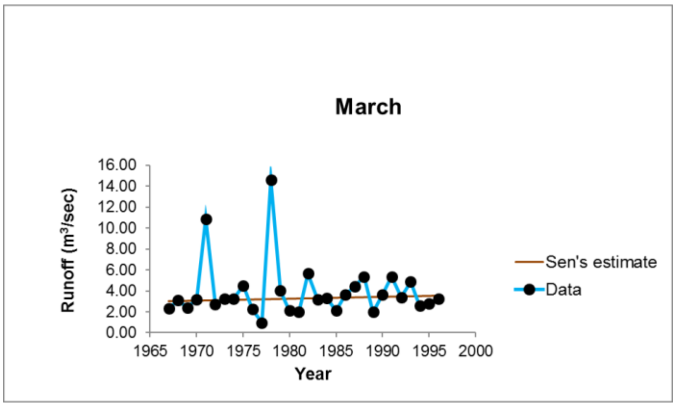
Time series	MK statistics (Z value)	Sen's slope (Q value)	Significance level
January	2.57	0.08	+++
February	1.87	0.05	++
March	0.80	0.02	+
April	-0.09	0.00	+
May	-0.61	-0.02	+
June	-0.18	-0.03	+
July	-0.93	-0.42	+
August	-2.94	-1.71	++++
September	-1.59	-0.44	+
October	0.68	0.07	+
November	1.62	0.07	+
December	2.46	0.08	+++
Annual	-2.23	-0.28	+++
Pre-Monsoon	0.18	0.00	+
Monsoon	-2.39	-0.92	+++
Post-Monsoon	1.03	0.08	+
Winter	2.71	0.08	++++

Note: ++++ is for 0.01 level of significance, +++ is for 0.05 level of significance, ++ is for 0.1 level of significance and + shows more than 0.1 level of significance.

The results (Table 8) indicates a falling trend in month of August with significant at 0.01 level of significance, whereas significant rising trends showed in the months of December and January at 0.05 level of significance. The annual runoff in the Rangoon watershed showed a decreasing trend (Z value -2.23). A decreasing trend in the monsoon season will increase the water table level of certain part of the watershed, however, a runoff during winter may trigger the erosion of loose crop land with increase in runoff. A decreasing monsoon runoff may be due to diversion of water to number of newly constructed canals/ponds mainly for the irrigation and small hydropower. Figure 6 depicts the runoff variability during the period 1967-1996. It also indicated the linear trend line overlaid on the time series for different months and seasons







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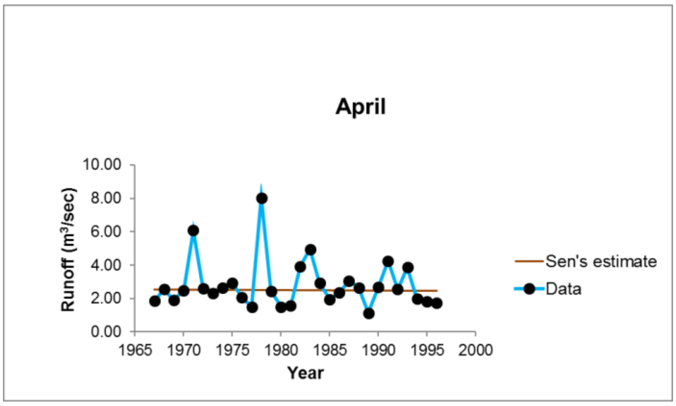

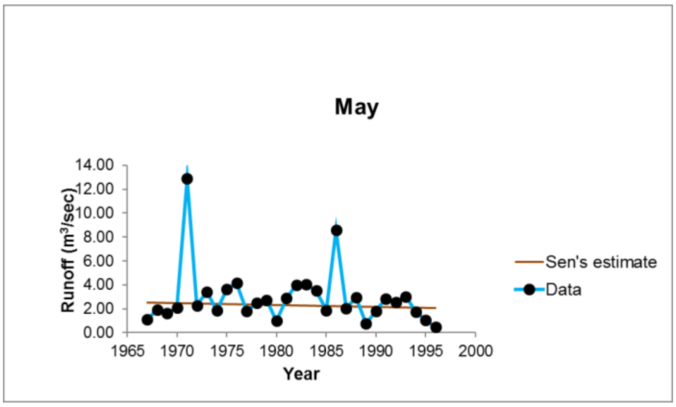

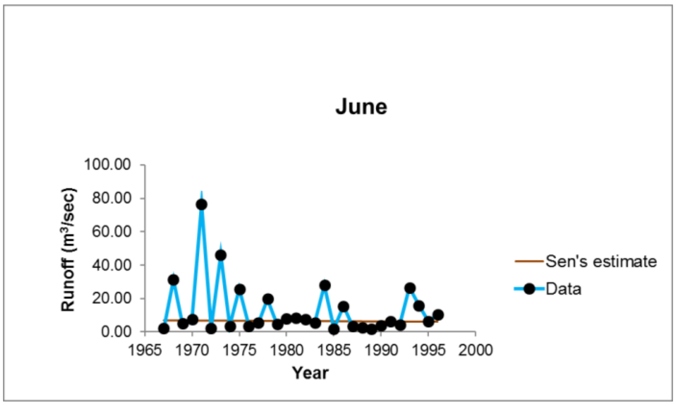

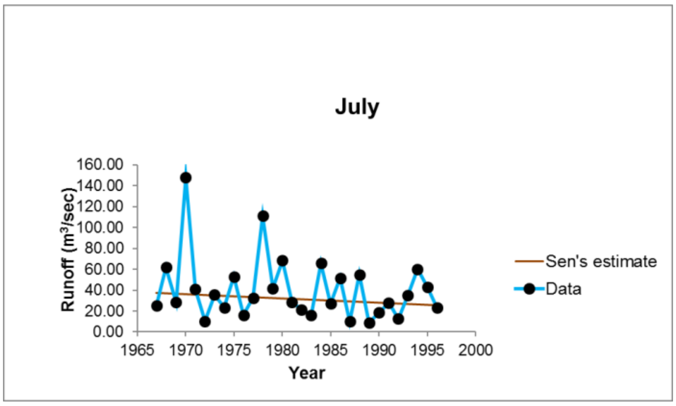

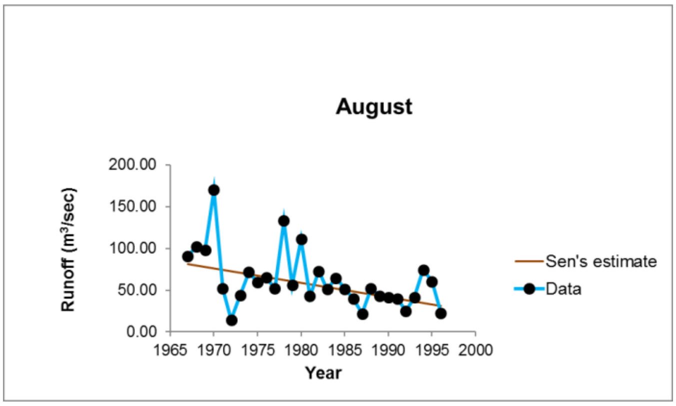

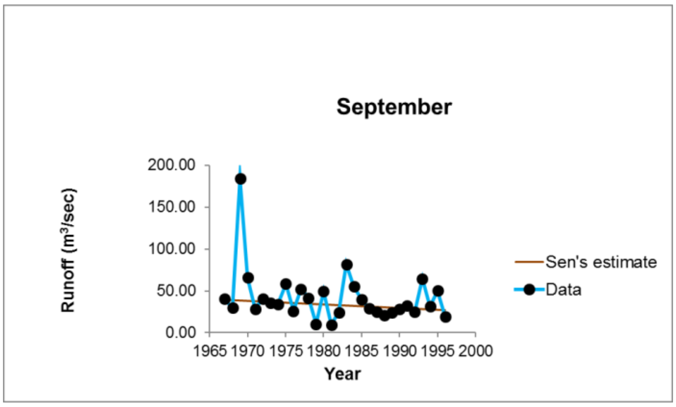

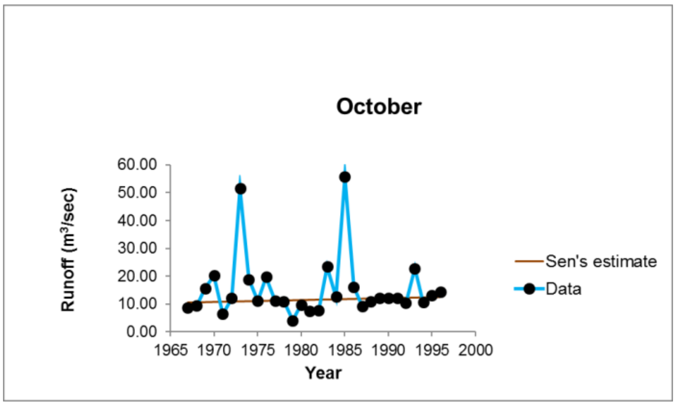

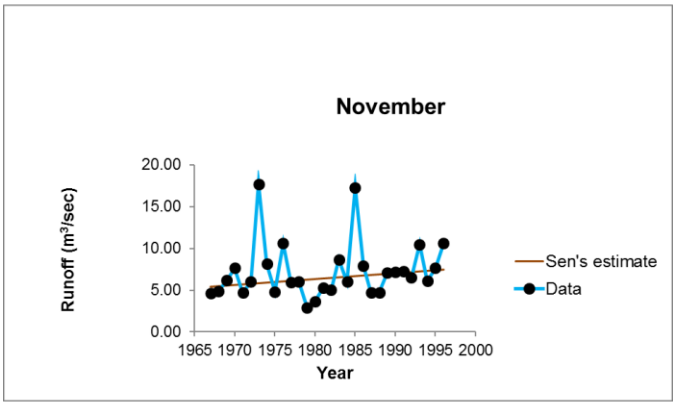

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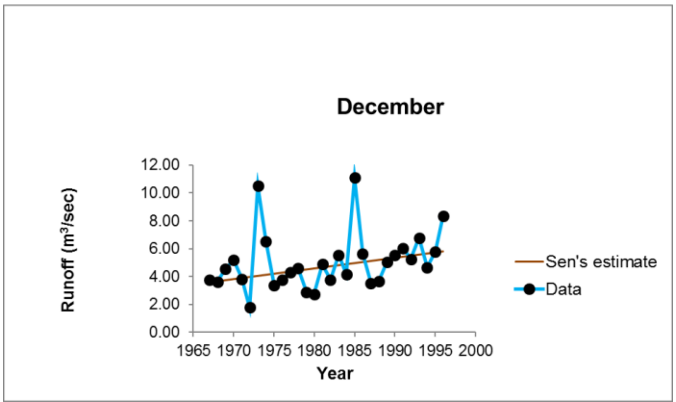

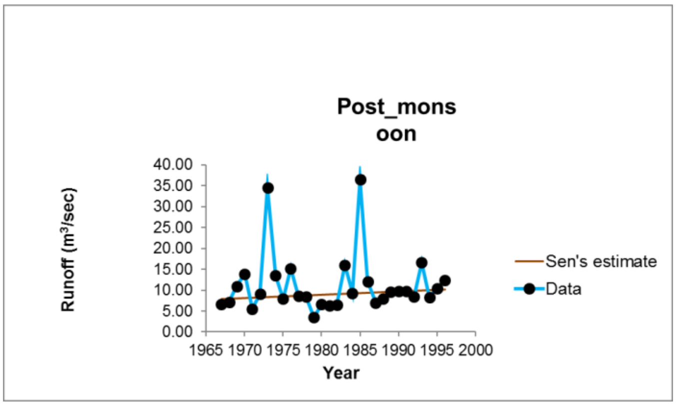

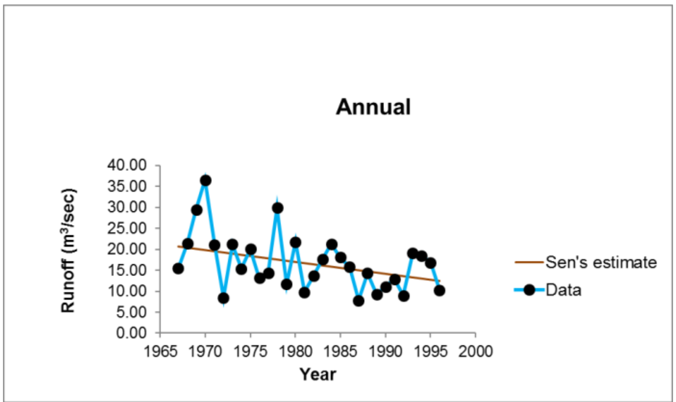

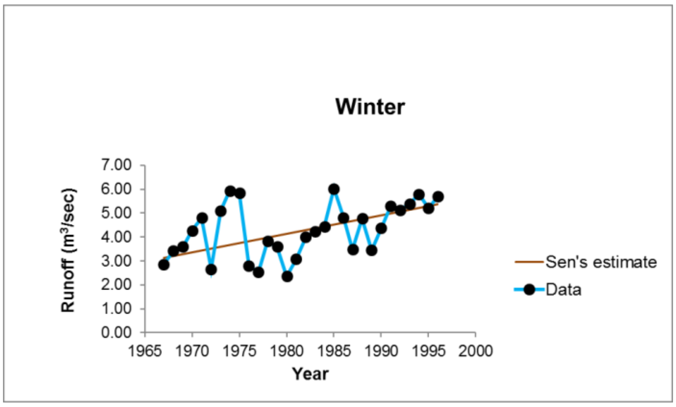

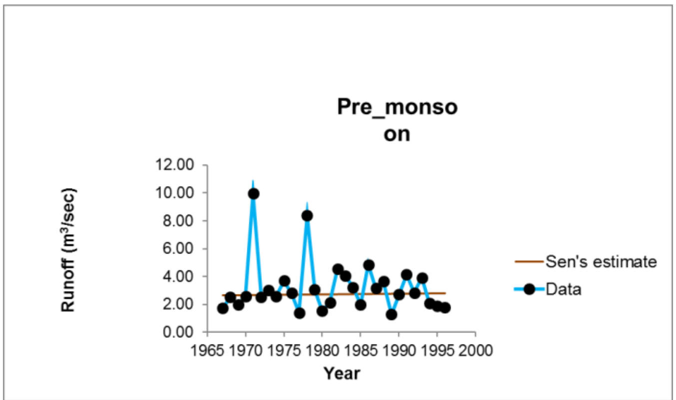

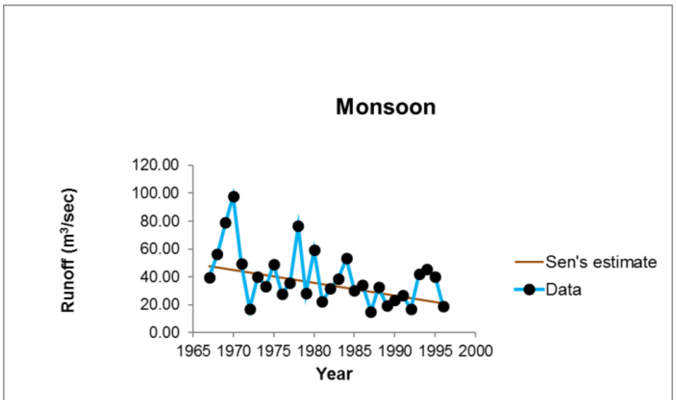

Fig. 6 Linear runoff trends for the period 1967-1996 on monthly, seasonal and annual basis

V. CONCLUSIONS

The study area is unique including higher elevation (2124m) steep slope to low Sivalik range (350 m, amsl) for which the climatic data taken from 1979 to 2010 for rainfall and temperature and 1967 to 1996 for runoff trend analysis. There is variation in the data in each month of each year. The mean annual rainfall and average annual temperature data series shows rising trend with significant increase of rainfall and nonsignificant increase in temperature where mean annual runoff data series shows falling trend. Some part of the study area has rich cultivable land, some has going to urbanization and seen land use changes, fragile ecosystem, unstable and fragile hill slopes so further study may take up to assess the present agriculture practice, land use patterns, sedimentation, erosion rate and their impacts on the watershed such as rainfall, runoff etc. The analysis of these data gives identification of any serious events; hence assessment of trend of data set would be helpful to water resources managers to minimize the effects of vulnerable disasters. The flora, fauna, ecosystem and human being in this area are always vulnerable to these types of disasters.

Various distinguished trends in all above mentioned hydroclimatic factors need to further study. The Rangoon watershed along with its many tributaries reaching to

Mahakali River from where number of hydropower, irrigation schemes are implemented including flood control structures and river training works.

VI. ACKNOWLEDGEMENTS

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