



Variability and Trend Analysis of Rainfall Data of Shillong and Agartala Stations of North East India

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Authors' contributions

This work was carried out in collaboration among all authors with equal contribution. All authors read and approved the final manuscript.

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ABSTRACT

This paper discusses the variability in rainfall and trend analysis of annual and seasonal rainfall time series of Shillong and Agartala stations located in the north-east region of India. Commonly used non-parametric statistical methods namely Mann-Kendall and Sen's slope estimator was used to analyse the seasonal and annual rainfall time series. Statistical analysis showed less variation in annual and south-west monsoon rainfall for both Shillong and Agartala stations. In the total annual rainfall, the share of south-west (SW) monsoon, north-east (NE) monsoon, winter season and summer season rainfall was observed 64.60%, 13.22%, 1.40% and 20.80%, respectively for Shillong station of Meghalaya state. However, the contribution of SW monsoon, NE monsoon, winter season and summer season rainfall in the total annual rainfall was 59.59%, 9.55%, 1.14% and 29.72%, respectively for Agartala station of Tripura state. Non-significant increasing trends of rainfall was observed by 4.54 mm/year, 2.80 mm/year and 2.54 mm/year for annual, SW monsoon, and summer season, whereas, non-significant decreasing trends in rainfall for NE monsoon and winter season was observed with a magnitude of 1.83 mm/year and 1.63 mm/year for Shillong, Meghalaya during 1992 to 2017. Results also revealed that rainfall increased by 1.07 mm/year and 0.18 mm/year in SW monsoon and winter season whereas, rainfall decreased by 7.64 mm/year, 2.58 mm/year and 1.29 mm/year during annual, NE monsoon and summer season non-significantly during 1995 to 2019 in case of Agartala. The findings of present study will be useful for water management and crop planning in hill agriculture of Meghalaya and Tripura state of India.

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1. INTRODUCTION

Rainfall is an important component of hydrologic cycle and plays an important role in the crop growth and crop yield [1]. Variability in rainfall during the crop season significantly affects the crop growth and decreases the crop yield if the ample quantity of water is not available at right time during the entire crop growth period. Agriculture is the main livelihood for the peoples of Meghalaya and Tripura states. Although, these states receive abundant quantity of rainfall but spatial and temporal variation is much more. Similarly, due to topographical constraints, water collection and storage facility for irrigation is limited in the entire region. Knowledge of variability and long term trends in rainfall is very important for accurate planning and management of water resource especially for the agriculture sector [2].

Trend analysis of rainfall time series comprises the identification of increasing and decreasing trends and magnitude of trend with its statistical significance by using parametric and non-parametric statistical methods [3,4]. Many studies carried out on the spatial and temporal variation in rainfall pattern and long term trends of rainfall over India has reported that there is no clear trend of increase or decrease in average rainfall over the country [5,6] whereas, few studies have reported significant increasing or decreasing trends in rainfall on a regional scale [6,7,8,9,10]. Generally, Mann-Kendall test for trend detection [11,12] and Sen's slope estimator [13] for knowing the increasing or decreasing magnitude of trend are used by various researchers. Jain et al. (2013) analysed rainfall and temperature trends in northeast India using non-parametric Mann-Kendall (MK) test and Sen's slope estimator. Trend analysis of rainfall data series for 1871–2008 did not show any clear trend for the region although there were seasonal trends for some seasons [10]. Patle and Libang (2014) [8] carried out trend analysis of annual and seasonal rainfall time series for the four districts of Arunachal Pradesh using MK test and Sen's slope estimator for identifying the rainfall variability and reported decreasing trends in annual mean rainfall in east Siang, upper Siang and lower Dibang valley and no trend in the west Siang district over the period of 1971-2007 [8].

Gajbhiye et al. (2016) assessed precipitation trend analysis of Sindh River basin, India, from

102-year record (1901–2002) for seasonal and annual trends. The Mann–Kendall test and Sen's slope model were used and reported significantly increasing precipitation trend in both seasonal and annual rainfall in the span of 102 years [14]. Asfaw et al. (2018) carried out variability and time series trend analysis of rainfall and temperature in north central Ethiopia using non-parametric Mann Kendall test [15]. Bisai (2019) carried out an analysis of temporal trends of rainfall time series (1901-2002) of Purulia Weather Observatory by Sequential Mann-Kendall Test, West Bengal, India and reported decrease in monsoonal rainfall trend after 1945 [16]. Brema (2018) carried out rainfall trend analysis by Mann Kendall test for Vamanapuram river basin, Kerala for monthly rainfall time series data using Mann-Kendall test and Sen's slope estimation methods [17]. They reported increasing trends for the month of March, April, June, July, September, October, November and December, whereas, decreasing trends for January, February, May and August months. The magnitude of the variability of rainfall varies according to locations. The purpose of the present study is to examine the time series trend analysis and variability of rainfall on annual and seasonal basis for better understanding of the hydrological environment humid region and water management and crop planning for sustainable hill agriculture.

2. MATERIALS AND METHODS

2.1 Study Area

Rainfall variability and trend analysis was carried out for the two meteorological stations namely Shillong in Meghalaya and Agartala in Tripura states of north east India. Total Geographical area of Meghalaya is 22,429 sq.km and lies between 20.1°N and 26.5°N latitude and 85.49°E and 92.52°E longitude. Climate of the study area varies from tropical to temperate. Nearly 10% of the total geographical area of Meghalaya is under cultivation. Meghalaya has three types of soils namely red- loam or hills soils, lateritic soils and alluviums. pH varies from 4.5 to 6.0. Soil depth is varying from 20-200 cm. Tripura state is situated between 22°7' and 24°2' North latitudes and 91°0' and 92°0' East longitudes (Fig. 1.). Tripura state has three distinct physiographic zones namely hill ranges, undulating plateau land and low-lying alluvial land. Tripura state is characterized by a warm and humid tropical

climate. Broadly the soils in Tripura state are of reddish yellow sandy soil, lateritic, sandy loam and alluvial soil.

2.2 Data Collection and Pre Processing

Monthly rainfall data were collected from the meteorological observatory located in the campus of *Indian Council of Agricultural Research (ICAR)*, Research Complex for North Eastern Hill Region, Shillong, Meghalaya for the period of 1992-2017 and India Meteorological Department (IMD), Agartala, Tripura for the period of 1992 to 2019. Rainfall data was checked for the missing data values, if any and the outliers for both stations. Then it was converted into the annual and seasonal time series for the rainfall variability and trend analysis. Four seasons were considered in this study namely, South west monsoon (starting from the month June to September), North east monsoon (starting from the month October to December), winter (starting from January to February) and summer (starting from the month of March to May).

2.3 Methodology for the Analysis of Rainfall Data

Descriptive analysis was performed for the annual and seasonal time series of rainfall data of Shillong and Agartala stations. A minimum, maximum, mean value, standard deviation and coefficient of variation of rainfall was estimated for both the stations.

2.3.1 Mann-Kendall test

The Mann-Kendall (MK) is a statistical test widely used for trend analysis in climatological and hydrological time series. According to this test, the null hypothesis H_0 assumes that there is no trend. This is tested against the alternative hypothesis H_1 , which assumes that there is a trend. Procedure adopted by Patle et al. (2013) [18] was used in this study. The Mann-Kendall statistic is computed as follows:

$$S = \sum_{k=1}^{n-1} \sum_{j=k+1}^n \text{Sgn}(x_j - x_k) \quad (1)$$

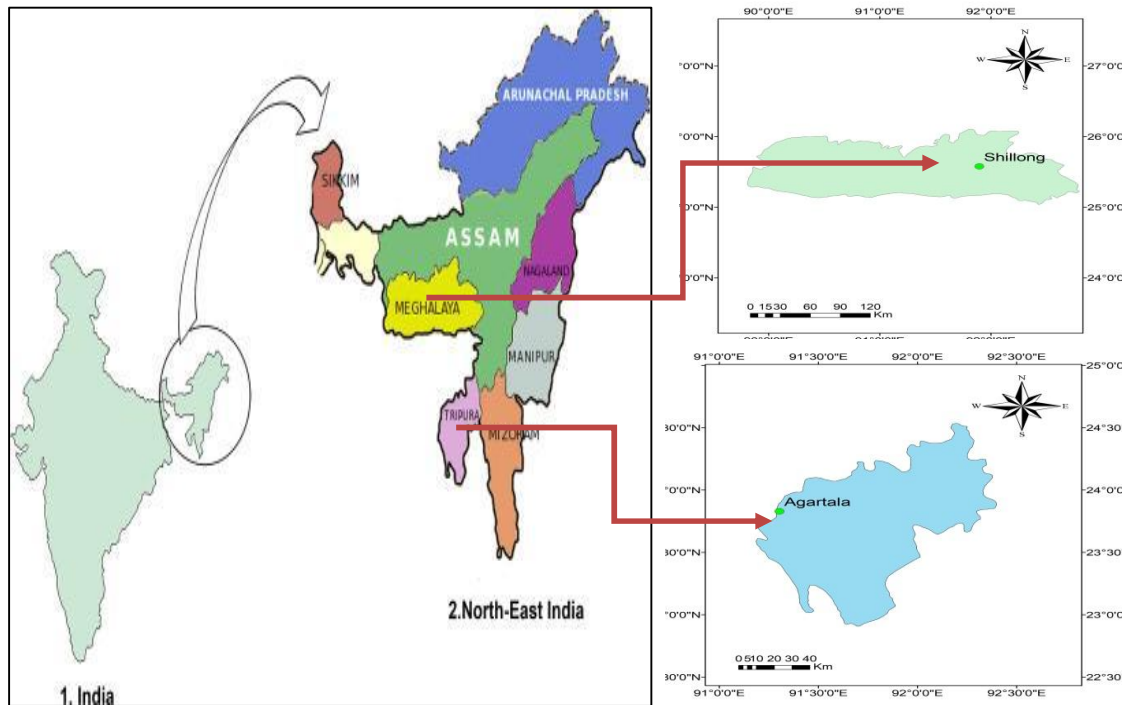


Fig. 1. Study area

The trend test is applied to a time series x_k , which is ranked from $k = 1, 2, 3, \dots, n-1$, which is ranked from $j = i+1, i+2, i+3, \dots, n$. Each of the data points x_j is taken as reference point, which is compared with the rest of the data point x_k so that,

$$\begin{aligned} \text{Sgn}(x_j - x_k) &= 1 && \text{if } x_j - x_k > 0 \\ &= 0 && \text{if } x_j - x_k = 0 \\ &= -1 && \text{if } x_j - x_k < 0 \end{aligned} \quad (2)$$

Here x_j and x_k are the sequential data values, and n is the length of the data set. For samples greater than 10, the test is conducted using a normal distribution with the mean and variance as follows:

The variance for the S statistic is defined by: $E[S] = 0$

$$\text{Var}(S) = \frac{1}{18} [n(n-1)(2n+5) - \sum_{p=1}^q t_p(t_p-1)(2t_p+5)] \quad (3)$$

Here t_p is the number of data points in the p^{th} tied group, and q is the number of tied groups in the data set.

The standardized test statistic Z_c is calculated by:

$$Z_c = \begin{cases} \frac{S-1}{\sqrt{\text{var}(S)}} & \text{if } S > 0 \\ \frac{S-1}{\sqrt{\text{var}(S)}} & \text{if } S < 0 \\ 0 & \text{if } S = 0 \end{cases} \quad (4)$$

Where the value of Z_c is the Mann-Kendall test statistics that follow the standard normal distribution with a mean of zero and a variance of one. Thus, in a two-sided trend test, the null hypothesis H_0 is accepted if $-Z_{1-\alpha/2} \leq Z_c \leq Z_{1-\alpha/2}$, where α is the level of significance that indicates the trend's strength [18].

Coefficient of Variation (CV): Coefficient of Variation was calculated using equation 5.

$$CV = \sigma / \mu \times 100 \quad (5)$$

Where, CV is the coefficient of variation; σ is standard deviation and μ is the mean rainfall. Coefficient of variation (CV) is used to classify the degree of variability of rainfall events as less ($CV < 20$), moderate ($20 < CV < 30$), and high ($CV > 30$).

2.3.2 Sen's slope estimator test

The magnitude of a trend in a time series can be determined using a non-parametric method known as Sen's estimator [13]. Sen's method can be used in cases where the trend can be assumed to be linear such as:

$$f(t) = Qt + B \quad (6)$$

Here Q is the slope, and B is a constant.

To get the slope estimate Q in Eq. 5, the slopes of all the data value pairs are calculated as:

$$Q_i = \frac{x_j - x_k}{j - k} \quad (7)$$

Here, x_j and x_k are the data values in years j and k , $j > k$. If there are n values of x_j in the time series, one gets as many as $N = n(n-1)/2$ slope estimates Q_i .

Sen's estimator of the slope is the median of these N values of Q_i . The N values of Q_i are ranked from the smallest to the largest, and Sen's estimator is

$$Q = \begin{cases} Q_{[\frac{N+1}{2}]} & \text{If } N \text{ is odd} \\ \frac{1}{2}(Q_{[\frac{N}{2}]} + Q_{[\frac{N+1}{2}]}) & \text{If } N \text{ is even} \end{cases} \quad (8)$$

A positive value of Q_i indicates an upward or increasing trend, and a negative value gives a downward or decreasing trend in the time series [18].

3. RESULTS AND DISCUSSION

3.1 Variability Analysis of Annual and Seasonal Rainfall

Variability of annual and seasonal rainfall was carried out and is presented in Table 1 and Fig. 2 for the Shillong station of Meghalaya. Annual rainfall varies from 1808.20 mm to 3096.90 mm with an annual mean rainfall value of 2369.84 mm. South West (SW) monsoon rainfall varies from 1074.10 mm to 1958.20 mm with a mean rainfall value of 1531.70 mm. North East (NE) monsoon rainfall varies from 142.10 mm to 648.50 mm with a mean rainfall value of 313.33 mm. In the winter season, rainfall varies from 0.00 mm to 117.90 mm with a mean rainfall value of 32.82 mm. In summer season, total rainfall varies from 242.20 mm to 748.90 mm with a

mean rainfall value of 491.99 mm. The coefficient variation (CV) for annual, SW monsoon, NE monsoon, winter and summer season rainfall was 13.82, 16.50, 33.05, 96.88 and 23.74 per cent respectively. Less variation was found for the annual and south west monsoon rainfall. The share of SW monsoon rainfall, NE monsoon rainfall, winter season rainfall and summer season rainfall in the total annual rainfall is about 64.60%, 13.22%, 1.40% and 20.80%, respectively.

Variability of annual and seasonal rainfall for Agartala of Tripura state is presented in Table 2 and Fig. 3. Results show that annual rainfall varies from 1353.70 mm to 2985.10 mm with an annual mean rainfall value of 2097.00 mm. South west monsoon rainfall varies from 772.10 mm to 1963.50 mm with a mean rainfall value of 1249.70 mm. NE monsoon rainfall varies from 64.10 mm to 369.60 mm with a mean rainfall value of 200.24 mm. In the winter season rainfall varies from 0.00 mm to 84.20 mm with a mean rainfall value of 23.84 mm. In summer season, total rainfall varies from 162.10 mm to 979.70 mm with a mean rainfall value of 623.21 mm. The Coefficient variation for annual, south west monsoon, NE monsoon, winter and summer season was 17.62, 26.65, 46.22, 102.92 and 34.23 per cent, respectively.

Less variation was found for the annual and south west monsoon rainfall. The share of SW monsoon rainfall, NE monsoon rainfall, winter season rainfall and summer season rainfall in the total annual rainfall is about 59.59%, 9.55%, 1.14% and 29.72%, respectively.

3.2 Trend Analysis and Sen's Slope Estimation for Annual and Seasonal Rainfall Time Series

Mann-Kendall statistics and Sen's slope magnitude was derived at 95% confidence level. In the Mann-Kendall test, the Z_c statistics were considered to identify the increasing or decreasing trend in the annual and seasonal time series of rainfall. Results of trend analysis of annual and seasonal rainfall and Sen's slope for Shillong, Meghalaya are presented in Table 3 and are summarised as below.

The value of Z_c statistic for the annual, south west (SW) monsoon, north east (NE) monsoon, winter and summer rainfall is 0.53, 0.44, -0.97, -1.87, and 0.79. The positive value of Z_c statistic indicates the increasing rainfall trends for annual, SW Monsoon and summer season, whereas, the negative value of Z_c statistics, in case of north-east and winter rainfall shows decreasing trends of rainfall. Since, $Z_c < Z_{1-\alpha/2}$, time series of annual and seasonal rainfall did not reveal the statistically significant trend for annual and seasonal time series.

The estimated Sen's slope for time series of annual, south west monsoon, north east monsoon, winter and summer rainfall found to be 4.54, 2.80, -1.83, -1.63 and 2.54 per year, respectively. The negative sign represents the decreasing slope and the positive sign represents the increasing slope. Results revealed that rainfall increased by 4.54 mm/year, 2.80 mm/year and 2.54 mm/year in annual,

Table 1. Variability of annual and seasonal rainfall for Shillong, Meghalaya

Rainfall time series	Minimum (mm)	Maximum (mm)	Mean (mm)	SD	CV (%)	Rainfall share (%)
Annual Rainfall	1808.20	3096.90	2369.84	327.52	13.82	(100.0)
SW Monsoon	1074.10	1958.20	1531.70	252.73	16.50	64.60
NE Monsoon	142.10	648.50	313.33	103.55	33.05	13.22
Winter	0.00	117.90	32.82	31.80	96.88	1.40
Summer	242.20	748.90	491.99	116.81	23.74	20.80

Table 2. Variability of annual and seasonal rainfall for Agartala, Tripura

Rainfall time series	Minimum (mm)	Maximum (mm)	Mean (mm)	SD	CV (%)	Rainfall share (%)
Annual Rainfall	1353.70	2985.10	2097.00	369.53	17.62	(100.0)
SW Monsoon	772.10	1963.50	1249.70	333.05	26.65	59.59
NE Monsoon	64.10	369.60	200.24	92.56	46.22	9.55
Winter	0.00	84.20	23.84	24.54	102.92	1.14
Summer	162.10	979.70	623.21	213.34	34.23	29.72

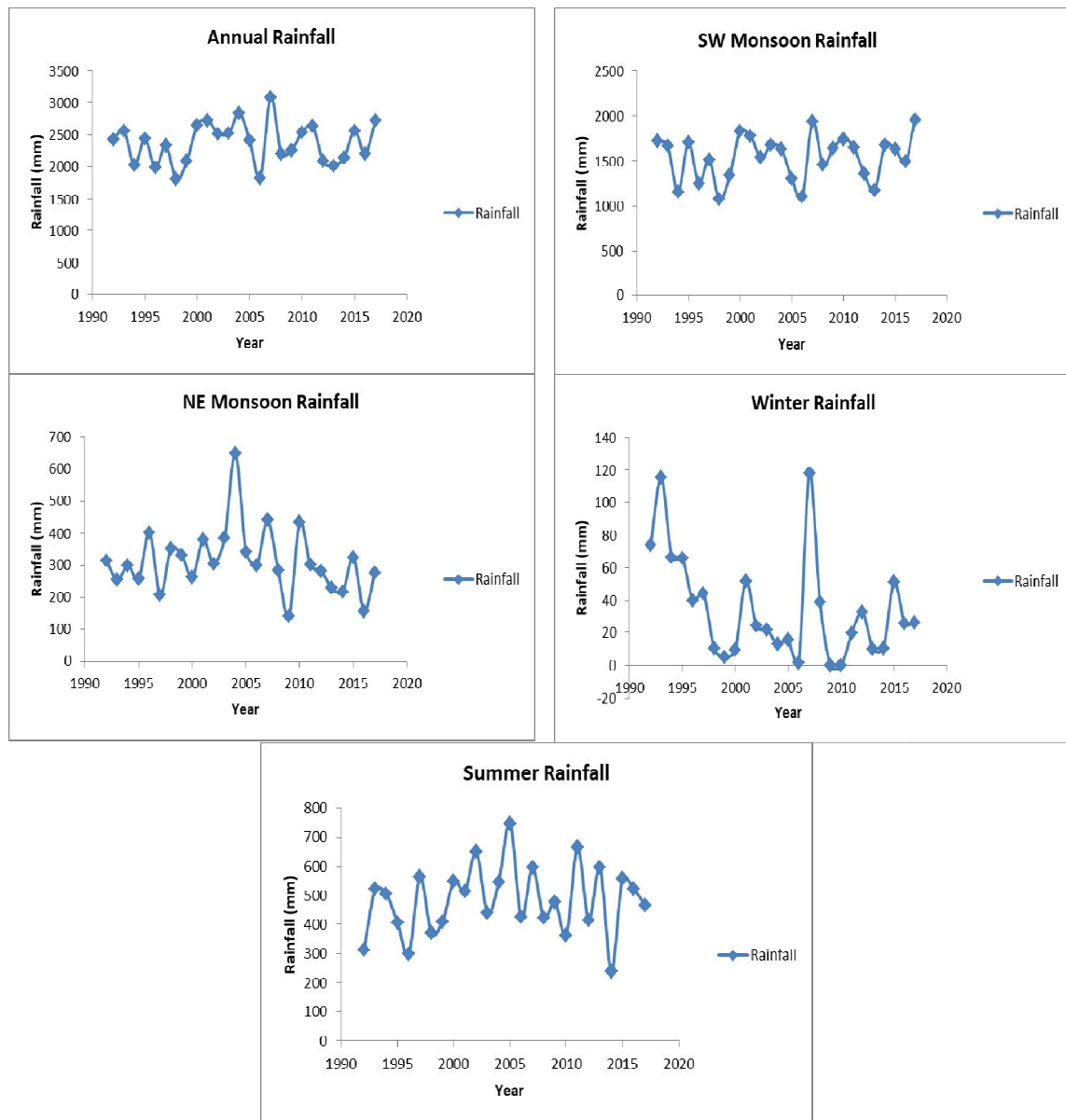


Fig. 2. Annual and seasonal variation in rainfall for Shillong, Meghalaya

Table 3. Mann-Kendall's Statistic and Sen's slope for Shillong and Agartala station

Rainfall time series	Shillong station			Agartala station		
	Z_c statistic	Sen's slope	Tests results	Z_c statistic	Sen's slope	Tests results
Annual	0.53	4.54	Increasing	-0.56	-7.64	Decreasing
SW Monsoon	0.44	2.80	Increasing	0.09	1.07	Increasing
NE Monsoon	-0.97	-1.83	Decreasing	-0.98	-2.58	Decreasing
Winter	-1.87	-1.63	Decreasing	0.26	0.18	Increasing
Summer	0.79	2.54	Increasing	-0.14	-1.29	Decreasing

(All increasing and decreasing trend of rainfall are statistically non-significant at 95 % confidence level)

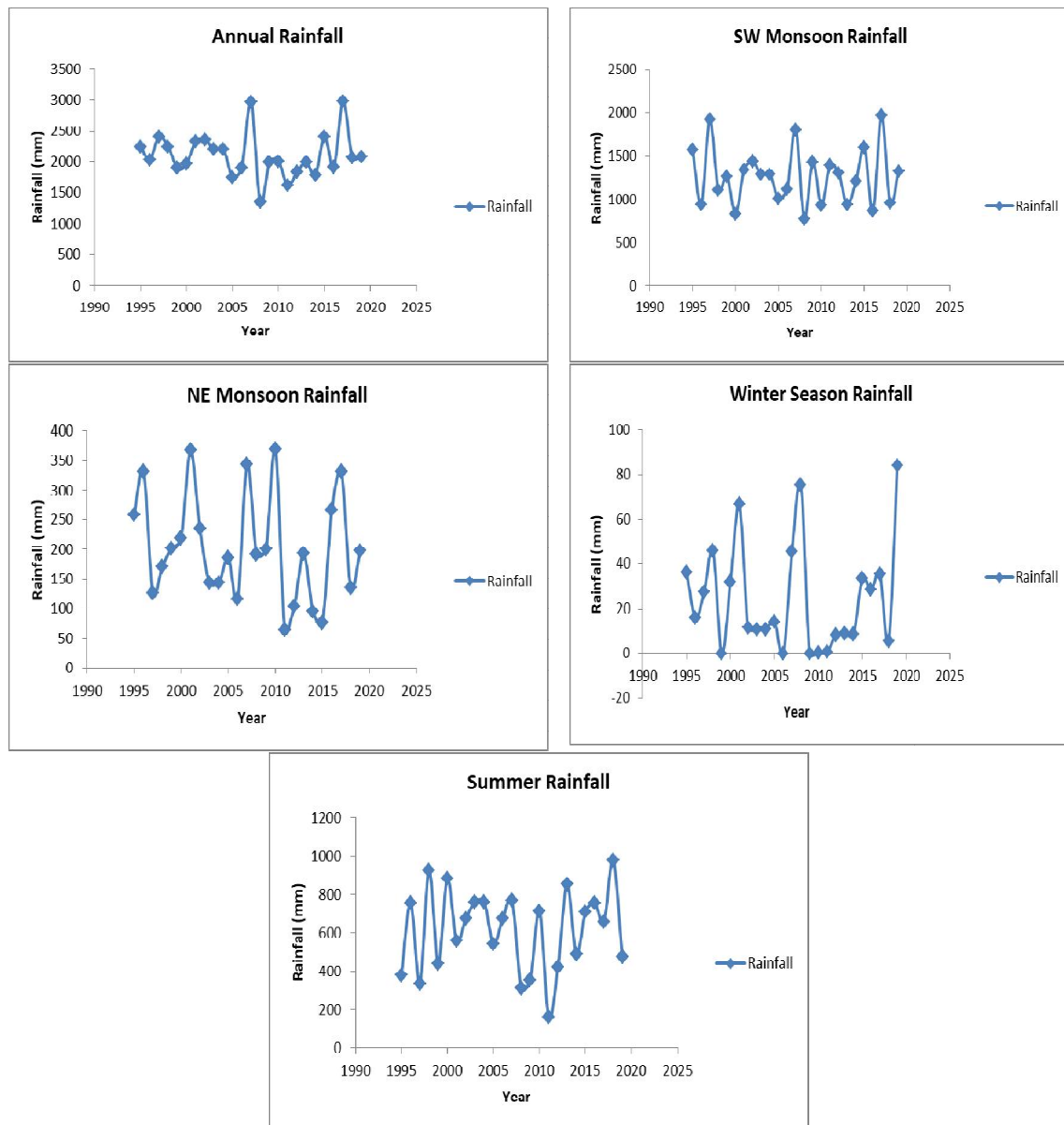


Fig. 3. Annual and seasonal variation in rainfall for Agartala, Tripura

SW monsoon, and summer, whereas rainfall decreased by 1.83 mm/year and 1.63 mm/year during the NE monsoon and winter season for Shillong station in Meghalaya during 1992 to 2017.

Results of trend analysis of annual and seasonal rainfall and Sen's slope for Agartala station of Tripura state are also presented in Table 3. The value of Z_c statistic for the annual, south west (SW) monsoon, north east (NE) monsoon, winter and summer rainfall is -0.56, 0.09, -0.98, 0.26

and -0.14, respectively. Decreasing trends of rainfall was observed for annual, north east monsoon and summer rainfall (negative value of Z_c statistics) whereas; positive Z_c statistics shows increasing trends of rainfall for SW monsoon and winter season rainfall. In case of Agartala station also $Z_c < Z_{1-\alpha/2}$. Therefore, all increasing or decreasing trends are non-significant and revealed no trend either in seasonal or annual time series of rainfall at 95% confidence level for Agartala station of Tripura state.

The estimated Sen's slope for time series of annual, SW monsoon, NE monsoon, winter and summer rainfall were -7.64, 1.07, -2.58, 0.18 and -1.29 mm per year, respectively. The negative sign represents the decreasing slope and the positive sign represents the increasing slope. Results revealed that rainfall increased by 1.07 mm/year and 0.18 mm/year in SW monsoon and winter season, whereas, rainfall decreased by 7.64 mm/year, 2.58 mm/year and 1.29 mm/year during annual, NE monsoon and summer season for Agartala in Tripura during 1995 to 2019.

Similar results were also reported for the seasonal and annual events of rainfall for other locations of the north east states by Patle and Libang [8] and Jain et al. [10]. From the trend analysis, it was concluded that rainfall is almost consistent for both the study area as observed trends in the annual and seasonal rainfall found to be statistically non-significant at 95% confidence level.

4. CONCLUSION

Rainfall variability and trend analysis of time series of annual and seasonal rainfall data of Shillong and Agartala Stations of North East India was carried out using non-parametric methods namely Mann-Kendall and Sen's slope estimator test. Value of estimated coefficient of variation exhibited the less variation in annual and SW monsoon rainfall for both Shillong and Agartala stations. Variation of rainfall was more for the NE monsoon and winter season for both the stations. Although, the Sen's slope estimator shown the increasing or decreasing magnitude of rainfall for annual and seasonal rainfall time series of both the Shillong and Agartala stations, but the statistically no trend was observed. Both the stations are the part of the north eastern hill region, but large inter annual variation was depicted within the stations. Therefore, considering the importance of rainfall in crop and water management planning, it is suggested for variability and trend analysis of rainfall at micro level for the better water and crop planning for the hilly states of Meghalaya and Tripura of India.

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COMPETING INTERESTS

Authors have declared that no competing interests exist.

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