Analysis of Rainfall Trends Over Assam, North East India

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Abstract

The spatio-temporal variations of long-term rainfall over Assam in the North Eastern part of India were analyzed using data from twenty-six locations during the period 1981-2017. The annual, monthly, and seasonal rainfall trends are assessed by using *Mann-Kendall* and *Sen slopetests* over different subregions. September, December, January and February months recorded decreasing trends, while May, June, and August exhibited statistically substantial increasing trends. Similarly, annual, pre monsoon season and monsoon seasons exhibited increasing trends, but post monsoon and winter seasons recorded statistically non-significant decreasing rainfall trends. The locations of Demaji, Dibrugarh, Karimganj, and North Lakhimpur were recorded with above 2000 mm annual rainfall. On seasonal time scales, premonsoon and monsoon rainfall over Assam witnessed increasing trends with statistically notable trends. The postmonsoon and winter rainfall recorded decreasing trends, but the trends were statistically non-significant. In the monsoon season, a declining trend was recorded during the first decade (2001-2010).The southern and northeastern portion of the state received the maximum average annual rainfall when compared to the central portion of the Brahmaputra valley of Assam state. The maximum variationsin rainfall have been recorded in the Karimganj (36.8%), Hailakandi (31.9%), Silchar (31.9%), and Dhuburi (26.5%) regions. Any slight variations in the rainfall trend could certainly be vulnerable as the state of Assam which comprises valley flood plains and sub-Himalayan boundaries, also supports a large chunk of human as well as ecosystem populations. In the present scenario, extreme and unprecedented rainfall events can affect agricultural activities, stream flow, the availability of food, etc., which may lead to disparities in the socio-economic conditions of the area. The results would be beneficial to policy makers in understanding the impact of changing climates and assessing the climatic vulnerability of natural and human resources.

Introduction

Agricultural activities mainly depend on the availability of water resources and soil productivity that support the livelihood and economy of the rural population of India. Changes in rainfall and temperature affect the socio-economic development of the natural environment by creating drought and flood-like conditions resulting in biodiversity loss as well as human lives. Climate studies require urgent and systematic attention, thus,this related research has gained importance around the world in order to understand the changing patterns of regional climates as they affect crop patterns and productivity, as well as the economy.[1-2] Climatic variables, particularly rainfall and temperature, can influence the water resources, which include the pattern of stream flow, groundwater reserves, and lakes/ponds/tanks of the concerned region.[3] Extreme rainfall events can create devastating floods, which are common in several parts of India. In recent years, many parts of the country received heavy to extreme rainfall (70 mm/day to about 120 mm/day) during the summer monsoon but maintained nearly the same average monsoon rainfall in total.[4-5]

Climatic studies at a regional scale are recognized as vital because changing climates influence the distribution of natural resources, including flora and fauna.The northeastern part of Indiais comprised of rich biodiversity, forest wealth, and good agricultural production. A large number of indigenous tribal people depend on various natural resources for their livelihood. Changing climates can impact the distribution and availability of resources, resulting in nutrition and food insecurity in these biologically diverse areas. IPCC[6] observed that climate change will disturb agriculture production, flood and drought, groundwater depletion and water scarcity, etc. Global warming and extreme weather events may influence the hydrological cycles and patterns of stream flows.

The studies were conducted to analyze rainfall trends and their variability, as well as extreme rainfall events, with longtime series data in India and the Assam region.[7-8] Several attempts have also been made to analyze the National Aeronautics and Space Administration (NASA) Precipitation Radar Tropical Rainfall Measuring Mission (PRTRMM) satellite data and India Meteorological Department (IMD) data for identifying anomalies at multiple time scales with the help of modeling techniques.[9] The study of patterns and trends in climatic variables like precipitation and temperature isnecessary for climate change predictions. The researchers used historical and longtime series to studythe spatiotemporal variation of rainfall and temperature in arid and semi-arid drought prone regions,[10-11] hilly and mountainous lands,[12-13] coastal and urban areas,[14-15] and river basins[16-18] around the globe. Mean annual rainfall variations and extreme rainfall events are recorded in the west and NE parts of India, mainly due to local orography. Deepak *et al.* (2012) recorded a notable change in long-time rainfall and in monsoon and postmonsoon seasons in Assam.[19]

Spatio-temporal analysis of rainfall trends on ayearly, monthly, and seasonal basis is important in planning and developing water resources, agricultural production, and climate change mitigation measures. But it needs well-distributed hydro-meteorological stations for collecting data. In the case of non-availability and missing rainfall data, the long-term satellite-based datasets can be used to estimate rainfall and get better results.[20] Namita and Soham, (2022)[21] observed a declining trend in monsoonal and annual rainfall since the 1950s over Sikkim, NE India. In Assam, it was expected to rise the temperature by +1.7 to 2.2°C and increase of extreme rainfall events nearly to 40% as per the observation of the climate action plan of Assam state.[22] Begum *et al.*(2022)[23] analyzed the spatiotemporal trends of rainfall over Assam and noted a non-significant decreasing trend during the monsoon season in various locations across the state.

It is learned that the study of rainfall characteristics in a particular region is essential for assessing the consequences of changing climates. As suggested by IPCC,[6] the trends and variations of rainfall must be studied to prepare suitable strategies and adaptation plans to combat climate change. Although several studies on Indian summer monsoon rainfall were carried out, however, the present research work attempted to study rainfall variations during different seasons, monthly and annual over Assam of NE India by using the past dataset (1981-2017).

Methodology
Study Area

Assam is locatedin the south of the Eastern Himalayas in northeast India. It shares about 533 km

of international boundaries with Bangladesh in the south and Bhutan in the north. Assam covers an area of 78,438 sq. km and is located between 24° 08′ N -28° 02′ N latitude and 89° 42′ E - 96° 00′ E longitude. It is bounded in the north byArunachal Pradesh and Bhutan, Nagaland, Manipur and Arunachal Pradesh in the east, Meghalaya and Mizoram in the south, and West Bengal, Tripura, and Bangladesh in the west (Fig. 1). The rivers Brahmaputra and Barak,and their tributaries,receive high rainfall almost round the year, which creates large- scale flood plains in this region. The river Brahmaputra originates in Tibet and flows down through China, India, and Bangladesh. In India, it enters Arunachal Pradesh draining nearly 226 km to reach the Assam plains. The river flows its waters for 700 km in length and finally enters Bangladesh to confluence intothe Bay of Bengal. The channel length varies in the Assam valley and ranges between 1 and 18.5 km with an annual discharge of 19,820 cumecs.[20] The river Brahmaputra is known as the flooded river of Assam because of catastrophic events in 1954, 1962, 1966, 1972, 1973, 1977, 1978, 1983, 1984, 1987, 1988, 1991, 1993, 1995, 1996, 1998, 2016,

and 2017 that devastated nearly 50% of the total geographical region of Assam in 2014.[24] The climate is characterized by a tropical monsoon humid climate with temperatures varying from 6°C in December to 38°C in May, and the average annual rainfall is about 1140 cm, most of which receives from the southwest monsoon. The study area is home to rich biodiversity and true tropical rainforests. Intense rainfall and other factors that include deforestation may cause havoc in floods, resultingin loss of life, livelihood, and property. This region is also categorized as an earthquake-pronezone.

For a period of 37 years during 1981-2017, rainfall data was collected from 26 locations covering the entire Assam state of India (Fig. 1).Some of the stations are locatedin high elevation zones and others represent valley portions. The monthly data weredownloaded fromthe NASA website (https://power.larc.nasa.gov/) and the IMD stations. The geographical coordinates and altitude of locations are given in Table 1. The monthly, seasonal, and yearly analyses were carried out to ascertain trends in the rainfall data in the study area.
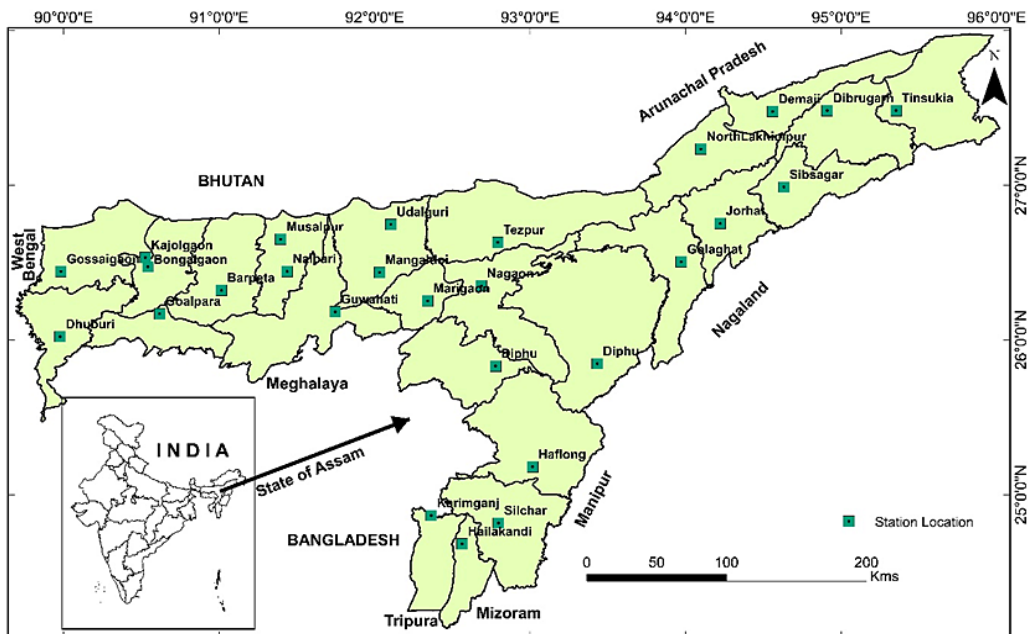

Fig.1: Station locations of Assam, India.

Method for Trend Analysis

In the present research work, the Mann–Kendall (*MK*) test was applied to evaluatethe statistical significance of the rainfall trend in time series.[25-26] The test is more favored than any other test and has been applied in several hydro-meteorological studies across the world, including Ahmed *et al.* (2022),[27] Priyanka and Naresh, (2022)[28] in Assam and NE India, Praveen *et al.*(2020)[29] in other parts of India, Mallick *et al.* (2021)[30] in South West Asia, Muthoni *et al.* (2019)[31] in Africa, and Gocić (2021)[32] in Europe, Bartels *et al.* (2020)[33] in Americas, and Yildirim and Rahman (2022)[34] in Australia. It is based on the sample of data (Xi, i=1, 2, 3,....n) is independent and equally spread when satisfying H0 (null hypothesis). On the other hand, if a monotonic trend exists in X, then the alternative hypothesis (H1) is considered. The significance level is α=0.05 for *Kendall's* p-value.

The S of *Kendall's tau* is shown as Eq.1:

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

here, x_i and $x_j (y=x_j-x_i)$ =sequential time series observations, *n*=span of the time series.

$$sgn(y) = \begin{cases} 1 .... if (y > 0) \\ 0 .... if (y = 0) \\ -1 .... if (y < 0) \end{cases}$$

For the sample size more than 10, a normal distribution with a meanzero is usedand the discrepancy of statistics S has been calculated using Eq. 2:

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

where,m is the number of tied groups and t_i is the extent of the ith tied group. The Z is considered by using Eq.3:

$$Z_{MK} = \begin{cases} \dfrac{S-1}{\sqrt{Var(S)}} \, whenS > 0 \\ 0 .... whenS = 0 \\ \dfrac{S+1}{\sqrt{Var(S)}} \, whenS < 0 \end{cases} \qquad ...(3)$$

If IZI>$Z_{1-\alpha/2}$, the hypothesis of no trend is rejected where Z is taken from the standard normal distribution table and α is the level of significance.[35] The significance level i.e., 0.05 in hypothesis testing is used for rejecting the H$_0$ in the present study.

The Magnitude of Trend

Sen's Slope (SS) test, which works efficiently on monotonic data, was determined for analyzing the magnitude of trend in a time series.[36] Each individual slope (Q) was estimated using the Eq. 4.

$$Q = \frac{x_j - x'_j}{j' - j} \qquad ...(4)$$

where, Q = slope between data pointsx'_j and x_j; x'_j = data measurement at time i'; x_j = data measurement at time 'i' and i' = time after time i.

The Sen's slope is the median of these N values of Q. The Sen's slope (Q') was computed based on the Eq. 5.

$$Q' = Q\left[\frac{N+1}{2}\right], if \, N \, is \, odd \qquad ...(5)$$

$$= \frac{Q\frac{N}{2} + Q\frac{N+2}{2}}{2}, if \, N \, is \, even \qquad ...(6)$$

where, N= number of calculated slopes.

Frequency Analysis of Rainfall

Recurrence interval or return period and exceedance probability (reciprocal of return period) were calculated in the study area by using 37 years of annual precipitation data with the help of Weibul's equation[37] as follows:

Return period (T$_r$) = n+1 /m　　　　...(7)

Exceedance Probability=P(x$_m$)=1/Tr　　...(8)

where, n = total number of observations, m = rank of the observation.

Excel spreadsheet 2007 and Xl stat software were utilized for analytical calculations. The spatial distribution of rainfall maps was prepared with help of the Inverse Distance Weight (IDW), which is an interpolation algorithm that works between measurements, method in the Arc GIS environment.

Each value of the amount of rainfall at a location estimated in IDW interpolation is a weighted average of the neighboring sample points. As it provides good results in estimating interpolation maps, the method can be used to prepare spatial distribution maps for point data.[38]

Results and Discussion
Rainfall Pattern
The rainfall received in 26 locations of different districts of Assam during the period of 1981-2017 is presented in Table 1. The 37-year time series data represents the typical spatial distribution

Table 1: Geographic details and rainfall (in mm) statistics (1981-2017) of different locations of Assam in NE India.

Location	Lat	Long	Elev (m)	Min	Max	Mean	Median	SD	Variance	CV (%)	Kur	Ske
Barpeta	26.32101	91.01471	117.55	1280.8	2354.1	1873.8	1904.0	271.4	73638.6	14.5	-0.7	-0.1
Bongaigaon	26.47331	90.54161	116.51	1318.5	2466.9	1858.6	1889.2	294.9	86953.1	15.9	-0.6	-0.1
Demaji	27.47701	94.56061	300.40	1380.4	2911.7	2102.8	2084.9	376.9	142067.3	17.9	-0.4	0.3
Dhuburi	26.02171	89.97681	119.16	896.9	2611.1	1641.9	1649.4	434.3	188628.2	26.5	-0.6	0.2
Dibrugarh	27.48251	94.91081	300.40	1380.4	2911.7	2102.8	2084.9	376.9	142067.3	17.9	-0.4	0.3
Diphu	25.84691	93.43201	447.60	947.6	1980.6	1325.1	1301.7	235.6	55530.3	17.8	0.6	0.7
Goalpara	26.16951	90.61741	116.51	1318.5	2466.9	1858.6	1889.2	294.9	86953.1	15.9	-0.6	-0.1
Golaghat	26.50531	93.97241	369.77	1278.2	2483.0	1835.9	1803.8	300.0	90026.2	16.3	-0.4	0.2
Gossaigaon	26.44241	89.98231	119.16	896.9	2611.1	1641.9	1649.4	434.3	188628.2	26.5	-0.6	0.2
Guwahati	26.18231	91.74681	239.30	1225.5	2289.6	1804.0	1819.1	265.0	70220.9	14.7	-0.7	-0.1
Haflong	25.17981	93.01631	592.42	954.9	2430.5	1388.5	1343.0	315.4	99497.2	22.7	2.4	1.3
Hailakandi	24.68171	92.56291	295.13	1100.2	4146.3	1852.6	1756.6	590.8	349091.0	31.9	5.7	2.0
Jorhat	26.75361	94.22241	343.72	1234.4	2493.9	1813.8	1721.0	318.0	101130.0	17.5	-0.4	0.4
Kajalgaon	26.53231	90.52541	697.69	1308.4	2197.3	1753.8	1789.2	234.0	54751.1	13.3	-0.7	-0.3
Karimganj	24.86521	92.36381	137.22	1233.5	5673.1	2251.4	2081.7	829.5	688037.4	36.8	7.4	2.2
Mangaldoi	26.43681	92.03211	269.07	1152.7	2068.9	1641.3	1623.2	236.2	55798.5	14.4	-0.8	0.0
Marigaon	26.25251	92.34091	269.07	1152.7	2068.9	1641.3	1623.2	236.2	55798.5	14.4	-0.8	0.0
Mushalpur	26.65121	91.39631	618.90	1263.9	2249.0	1803.4	1815.5	238.4	56838.1	13.2	-0.5	-0.2
Nagaon	26.34961	92.68621	258.95	1113.0	1950.6	1512.4	1499.7	221.4	49007.4	14.6	-0.8	0.0
Nalbari	26.44381	91.43781	117.55	1280.8	2354.1	1873.8	1904.0	271.4	73638.6	14.5	-0.7	-0.1
North Lakhimpur	27.23421	94.09881	451.81	1418.6	2869.4	2149.0	2079.1	351.1	123263.6	16.3	-0.3	0.2
Sibsagar	26.98851	94.63201	557.95	1021.4	2560.9	1744.3	1674.7	379.9	144326.6	21.8	-0.6	0.4
Silchar	24.81671	92.79641	295.13	1100.2	4146.3	1852.6	1756.6	590.8	349091.0	31.9	5.7	2.0
Tezpur	26.63101	92.79201	496.61	1207.0	2125.0	1668.7	1667.6	245.4	60241.8	14.7	-0.7	-0.1
Tinsukia	27.48281	95.35371	373.96	1158.0	2890.5	1994.0	1967.0	426.6	182024.5	21.4	-0.5	0.3
Udalguri	26.74721	92.10461	631.32	1168.9	2063.8	1645.9	1638.1	231.2	53435.8	14.0	-0.6	-0.1

(Lat- Latitude; Long- Longitude; Ele- Elevation; Min- Minimum; Max- Maximum; SD- Standard Deviation; CV- Coefficient of Variation; Kur- Kurtosis; Ske- Skewness)

of rainfall over Karimganj, Hailakandi, Silchar, Dhuburi, and Gossaigaon and others received a good rainfall throughout the monsoon months. The mean maximum and minimum were recorded as 2251.4 mm (Karimganj) and 1325.1 mm (Diphu). The dataset is skewed between -0.3 (Kajalgaon) and 2.2 (Karimganj). Most of the stations are positively skewed. The Kurtosis of the rainfall datasets ranged from -0.8 (Mangaldoi and Nagaon) to 5.7 (Hailakandi and Silchar) indicating *platykurtic* and *leptokurtic* distribution. The coefficient of variance (*CV*) was found to be 19.2%.

The long-term series of yearly rainfall explained that the average annual rainfall received was 1793.5 mm with a SDof ±346.2 mm. The average annual rainfall varies from 1325.1 to 2251.4 mm with CV from 13.2 to 36.8%. The highest variation was observed at Karimganj station (southern part) with 2251.4 mm (±829.5 mm) with CV 36.8% and the lowest was 1325.1 mm (±221.4 mm) at Diphu. The central and western portions of the study area received low rainfall when compared to north-eastern and southern parts (Fig. 2a). The coefficient of variation was noted to be contrary to the mean, which was

high in the western and southern parts and low in the central region (Fig. 2b). The monsoon season (MS) contributes 71.8% of the total annual rainfall, the premonsoon season (PRMS) 24.8%, and the winter season (WS) 2% of total rainfall, whereas rainfall inthe postmonsoon season (POMS) is the least (1.4%). The highest monthly rainfall is noted in July (348 mm) followed byJune (309.3 mm), and Aug. (290.1 mm), while Jan. (10.3 mm), Dec. (10.5 mm), and Nov. (15.3 mm) months recorded low rainfall. The uneven distribution of rainfall events isa possible cause of floods in different portions ofthe state.

Rainfall Trends
The *MK* and SS testare generally applied for quantifying the trends in hydro-meteorological time series.[39-40] The analysis of rainfall data (1981-2017) was carried out in winter season (WS):January-February, premonsoon season (PRMS): March-May, monsoon season (MS): June-October, and postmonsoon season (POMS): November-December. Monthly, seasonal, and annual rainfall trends of the study were analyzed by using *MK* and SS tests.

Table 2: *MK* test and *Sen's* slope (Q) results for the period 1981-2017 in Assam, India.

	K tau	S	p-value	Q	Min	Max	Mean	SD
Jan	-0.069	-46	0.556	-0.052	0.5	45.6	10.3	9.3
Feb	-0.084	-56	0.472	-0.230	0.7	71.9	25.8	17.6
Mar	0.129	86	0.266	0.537	6.8	126.3	54.0	33.8
Apr	0.165	110	0.154	1.909	37.5	349.8	163.7	82.3
May	0.408	272	0.000	4.246	59.9	416.7	226.5	79.4
Jun	0.360	240	0.002	4.418	148.9	504.8	309.3	83.6
Jul	0.072	48	0.539	0.816	204.8	508.7	348.0	79.3
Aug	0.291	194	0.012	3.550	160.8	528.9	290.1	91.2
Sep	-0.012	-8	0.927	-0.141	123.1	388.8	233.2	63.6
Oct	0.189	126	0.102	1.698	12.8	239.5	106.9	56.8
Nov	0.078	52	0.505	0.116	0.4	50.9	15.3	14.1
Dec	-0.057	-38	0.628	-0.058	0.0	57.0	10.5	11.3
Annual	0.429	286	0.000	16.504	1357.7	2593.8	1793.5	279.0
WS	-0.048	-32	0.685	-0.180	2.1	108.5	36.1	21.6
PRMS	0.366	244	0.001	6.700	182.5	774.4	444.1	137.6
MS	0.393	262	0.001	9.270	922.6	1767.3	1274.2	180.7
POMS	-0.087	-58	0.456	-0.193	2.8	67.7	25.8	18.2

(*K tau-Kendall's tau*;Min- Minimum; Max- Maximum. SD- Standard Deviation; WS-Winter;
PRMS- Pre Monsoon; MS- Monsoon; POMS- Post Monsoon)

Annual Rainfall Trend

The statistical results are presented in Table 2. 'S' value shows an increasing trend (+veS value) and a decreasing trend (-veS value). The annual rainfall shows an increasing trend with *Sen's* slope magnitude of 16.504, while the winter and postmonsoon seasons are recorded with decreasing trends. The magnitudes of the slope for winter and POMS are -0.180 and -0.193, respectively.During the study period 1901-2002, Goyal (2014)[41] recorded insignificant changes in annual rainfall, but the monsoon season hadastrong correlation with yearly rainfall, trailed by precipitation rainfall in summer and winter over Assam. The present study results also show the changes in rainfall patterns for the last two decades.

Monthly Rainfall Trend

Monthly rainfall trends inferred that the rainfall in the monsoon months (June and August) recorded an increasing trend of 4.4 and 3.5 mm/year, respectively. July and October were recorded with a slightly increasing trend, while the month of September decreased to -0.141 mm/y rainfall (Table 2). In particular, the month of May showed an increasing trend with 4.2 mm/y, and rainfall in June leads to flooding of fields in the region. However, the increasing trends of PRMS rainfall may help to perform the agricultural activities of field preparation and planting of crops at the beginning of the season. It is observed that December, January, and February show a decreasing trend in rainfall,which may lead to difficulties for farmers in preparing crops. The decreasing trend of rainfall in September may lead to water stress conditions for crops during the flowering stage and reduced production.

Seasonal Rainfall Trend

The winter season (January to February) rainfall has a general decreasing trend over the study period. With a decreasing value of 0.2346 mm/year, it was extremely variable compared to the normals (Fig. 3a). There is a significant increasing trend from the 2000s as the moving average shows positive trend in the PRMS (Fig. 3b). The MS rainfall (June-October) has an increasing trend over the study period (9.6753 mm/year) (Fig. 3c). The POMS rainfall has shown an overall declining trend. The data is highly flexible compared to the normals (Fig. 3d). It has decreased by almost 5% over the long-term normal in the past 10 years period.The substantial decrease in rainfall (1901-2010) during MS and POMS over Assam was recorded.[42] A non-significant negative trend for the MS and a positive trend in rainfall for PRMS and POMS over Northeast India was noted by Lairenjam *et al.* (2017).[43] Kumar *et al.* (2010)[44] found no significant trend for monthly, seasonal and yearly rainfall during 1871-2005 in India. Haryana, Punjab, and Coastal Karnataka divisions of India data were found to be statistically significant. However, the rainfall was recorded in a decreasing trend over the north eastern parts, east Madhya Pradesh, and parts of Gujarat and Kerala.[45-46] Therefore, the spatial and temporal rainfall trends may vary from station to station or region to region data.

Long Term Average (*LTA*) Rainfall

The analysis shows that the study area exhibits heterogeneous rainfall patterns over space and time during 1981-2017. Out of 37 years, it was recorded that a total of 19 years received rainfall less than the long-term average (*LTA*), while 18 years were noted with more rainfall than *LTA* (Fig.4). The *LTA* is recorded with 1793.5 mm rainfall. The minimum average annual rainfall (*AAR*) was recorded as 1357.7 mm in 1986, whereas the maximum *AAR* was noted as 2593.8 mm in 2017. The maximum downpour of more than 1900 mm was recorded with *AAR* of 1928.5 (1990), 1929.4 (2013), 1978.1 (1981), 1987.8 (2007), and above 2000 mm *AAR* noted were of 2010.5 (1988), 2060.7 (2004), 2112.5 (2012), 2178.6 (2015), 2200 (2016), 2375.7 (2010), 2593.8 (2017). During 2007-2017, the area received excess rainfall than *LTA*, except in 2014 (1758.6). Overall, the trend of rainfall in Assam during 1982-2017 indicates an increasing rainfall with an average value of 16.092 mm/yr. There was a significant excess of rainfall with departures varying between 0-200 mm for 12 years, and 6 years received 200-800 mm more rainfall than *LTA*. On the other hand, 8 years received less rainfall with departures varying between 0-200 mm less rainfall from *LTA*, and 10 years recorded more than 200 mm up to 435.8 mm. During 1981-2000 the area received nearly 49% of total rainfall whereas 51% of it was contributed in the last 17 years. Particularly, in the last decade during the study period, it was recorded that there was 15% excess rainfall of *LTA*. The highest percentage of excess rainfall than *LTA* observed

was in 2017 (44.5%) preceded by 2010 (32.5%), 2016 (22.7%), and 2015 (21.5%) while the least rainfall was recorded in 1986 (24.3%), 1983 (23.2%, 1996 (19.7), and 1992 (18.7%).

Rainfall Frequency Analysis

The average annual rainfall and respective exceedance probabilities are presented in the form of graphs (Fig. 5). It shows that the maximum exceedance probability with the high value for the return period and the low rainfall has the minimum exceedance probability with a minimum value of recurrence interval or return period. The study area has a 51% of exceedance probability of receiving rainfall above *LTA*. It implies that in 19 years out of every 37 years over Assam state rainfall of 1793 mm or more can be expected. The amount of rainfall around 2000 mm corresponding to 0.75 of exceedance probability and 1800 mm (p=0.5) can be expected respectively in 28 years and 19 years over the study area.
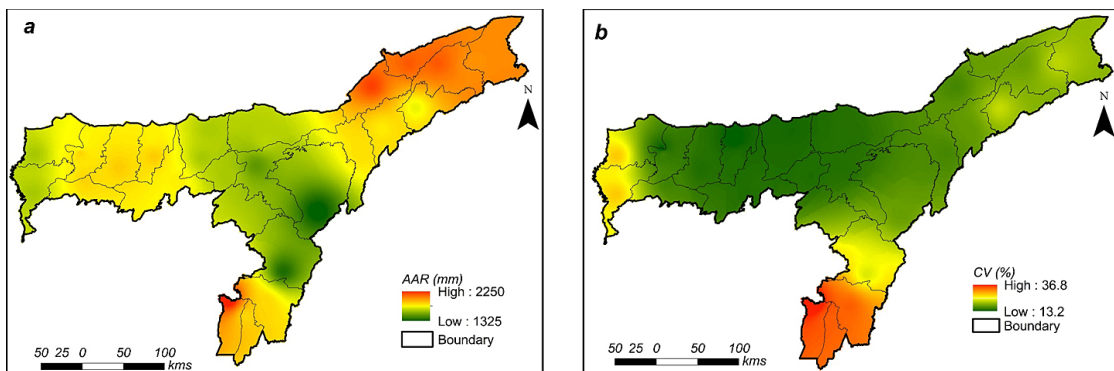

Fig. 2: Spatial distribution of rainfall pattern in Assam, NE India during 1981-2017 a) average annual rainfall (*AAR*) and b) coefficient of variation (*CV*).
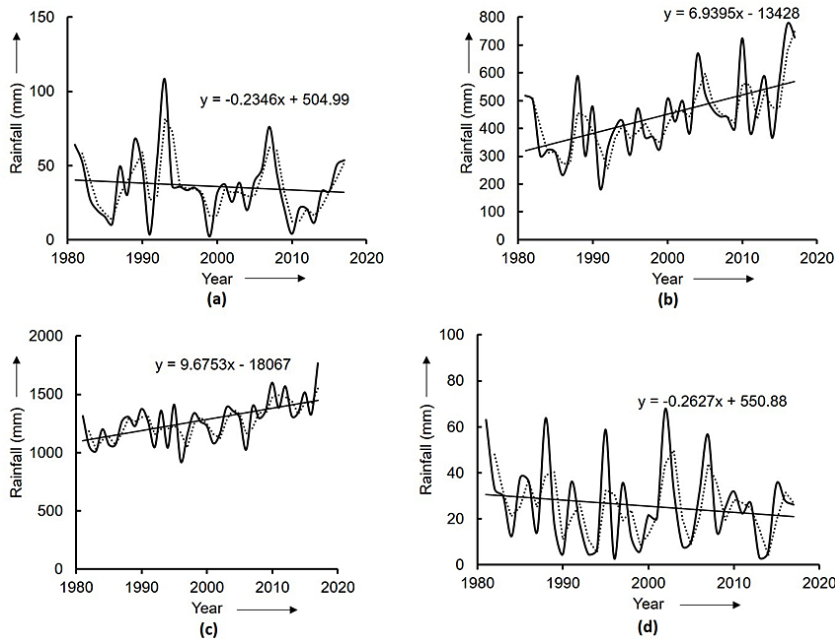

Fig. 3: Rainfall linear trend shows with moving average over Assam of India during 1981-2017 a) WS, b) PRMS, c) MS,and d) POMS.
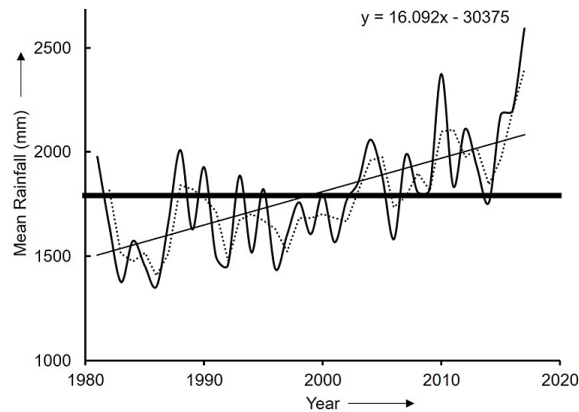
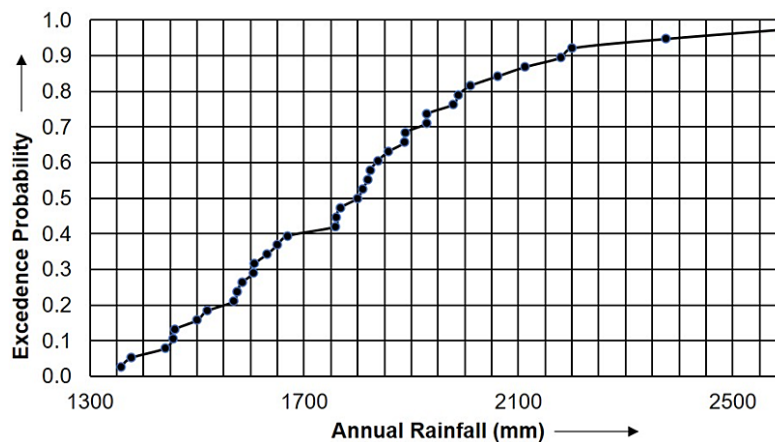**Fig. 4: Long term average rainfall trend over Assam of India during 1981-2017.**

Fig. 5: Average annual rainfall and respective exceedance probabilities over Assam state in North-Eastern India.

Conclusions

The long-term rainfall during 1981–2017 over Assam state, NE India was analyzed to examine yearly, monthly, and seasonal trends. Trends in total rainfall are assessed using the *MK* and *Sen's* slope test. Monthly rainfall trends witnessed a decreasing trend in September, December, January, and February. The months of May, June, and August recorded an increasing trend found to be statistically significant. Similarly, annual, PRMS, and MS increasing trends in rainfall witnessed with significant level, while POMS and WS trends were statistically non-significant. In the case of the location-wise rainfall in Assam, the four stations, i.e., Demaji, Dibrugarh, Karimganj, and North Lakhimpur, recorded with above 2000 mm average yearly rainfall, while Diphu and Hulflong noted less than 1500 mm. Karimganj, Hailakand,

Silchar, Gossiagaon, and Dhuburi stations witnessed more than 25% of the CV rainfall. On seasonal scales, premonsoon and monsoon rainfall over Assam witnessed increasing trends with statistically high significance levels. Whereas postmonsoon and winter rainfall recorded decreasing trends, but the trend was statistically non-significant. Therefore, the stations for collecting data may need to be increased for analyzing trends in rainfall to arrive at reasonable conclusions in the present study.

Climate change can impact people's livelihoods, particularly those who are dependent on natural resources. Assam is considered a global biodiversity hotspot since it supports varied ethnic and folk groups with a rich cultural heritage and traditional knowledge of the environment. The increased

carbon foot print in Assam could be attributed to changing land use pattern, urbanization, growth of population, the use of fossil fuels, shifting cultivation along with deforestation, and other factors. The available evidence shows that the decline of forest cover and significant growth of population from about 8 million (1951) to 32 million (2011) also put pressure on the natural resources of the area. To make appropriate adaptation and mitigation plans by considering future climates, the concerned authorities must take necessary steps for establishing eco-restoration, education and awareness programs, and development of mechanisms at the regional and national levels coordination in protecting and conserving the natural resources of Assam. The decrease of rainfall in the POMS and the WS, and sudden rainfall events are a cause of great concern because they may have implications for the ecosystem as well as human health. It has been reported that flash floods in several parts of the state are occurring due to unprecedented and sudden heavy rainfall. The Nor'westers, locally called Bordoisila, comprise violent thunderstorms accompanied by strong winds. They raise alarm about changing of climates, which needs to be combated with suitable adaptation plans to avoid economic burden in the future. In view of the accelerated growth of extreme weather events, for example, floods and heatwaves in NE India in general and Assam in particular, the future studies need to be conducted by using daily rainfall and rainy days data for long-term historical time series. Due to the non-availability of data and data discontinuities, the present study only focused on monthly, seasonal, and yearly rainfall analysis for the period 1981-2017 to assess the rainfall trends. The distribution of established meteorological stations in the study area is relatively scarce and it is also impossible to establish them everywhere because of unsupported topography. Hence, considering the limitations of meteorological stations in the area, further research is possible by using long-term satellite-based rainfall estimates, which have become important sources across the globe for getting precipitation data for sparse regions.

Conflict of Interest
The authors declare no conflict of interest.

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