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Analysis of Seasonal and Annual Rainfall variability and Trends for Selected Stations of Tripura, India

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Abstract

Agriculture is the primary livelihood for most of the people in Tripura state falling under northeast, India. The type and pattern of farming in the state are significantly influenced by rainfall distribution, which varies greatly over time and across different locations. Understanding long-term seasonal and annual rainfall variability and trend patterns are essential for effective water resource management, optimizing the use of rainwater for the drinking, domestic and agricultural use. This study used non-parametric tests, notably Mann-Kendall and Sen slope estimator to determine trends in seasonal and annual rainfall data in Tripura state. Monthly meteorological data from 2000 to 2019 was used from fifteen stations across the state. The seasonal and annual rainfall time series were used for analyzing rainfall variability and detection of trend pattern. The findings revealed that the coefficients of variation for the monsoon season ranged from 15.36% to 83.95%. Kamalpur recorded the largest coefficient of variation during the northeast season (78.31%), while Kanchanpur had the lowest (42.38%). No Significant trend was observed for in any of the stations during the monsoon season; however, there were indications of significance for other periods. Similarly, no Significant trend was observed in any of the stations throughout the winter and summer season, except for Sabroom in summer, which showed a considerable decrease in slope. Notably, Bishalgarh experienced a significant decrease in annual rainfall ($Z = -2.64$, $\beta = -84.1$), while other stations did not show any significant trends. Findings of the study highlighted the need for improved rainwater harvesting, climate-resilient agricultural practices, and enhanced water storage infrastructure to mitigate risks from rainfall variability.

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Introduction

The accessibility and quality of water significantly influence the socio-economic development of a region.[1] Water resource structures and agricultural planning significantly depend on rainfall, underscoring its importance within the water cycle.[2-3] A significant share of the income for the population in Northeast India is derived from crop harvesting.[4] The quantity, intensity, and distribution of rainfall, both spatially and temporally, significantly influence the characteristics and patterns of agriculture in the northeastern region.[5] Rainfall distribution in the north-eastern states exhibits significant variability over time and space. To optimize crop planning and effectively utilise rainwater for regional prosperity, accurate data on precipitation volume, frequency, and intensity is essential.[6] The significance and influence of these characteristics can vary, thereby affecting the cropping pattern in a specific location. Rainfall exhibits significant variability across the northeastern Indian states, despite its overall abundance. The northern terrain presents a significant challenge for the collection and storage of water for agricultural and other purposes. Effective management of a region's water resources for agricultural purposes necessitates an understanding of the long-term patterns and variability present in rainfall TS data. Rainfall fluctuations have a significant impact on the agricultural and socioeconomic conditions of Northeast India. In this region, rice is the primary crop, and research indicates that variations in rainfall patterns negatively affect rice production. Rainfall fluctuations greatly impact rice production in Northeast India. A study in Meghalaya analyzing weekly, monthly, and seasonal rainfall revealed August has the highest average rainfall but shows considerable yearly variation (49.69%), affecting cultivation.[7] Climate change has led to a rainfall decline in Northeast India over three decades, with notable drops in winter (-1.88 mm/year) and monsoon (-2.9 mm/year). This unpredictability harms rainfed farming, impacting crops and the region's socioeconomic structure.[8] A study on Assam's rainfall trends using the Mann-Kendall test (MNK) and Sen's slope estimator (SSE) revealed a decreasing annual rainfall, with notable declines during the monsoon season. This reduction threatens water availability and agricultural productivity, impacting farming-dependent communities.[9] Collectively, these studies underscore the intricate relationship between rainfall variability and the socio-economic and agricultural challenges in Northeast India, highlighting the need for adaptive strategies to ensure sustainable agriculture and livelihoods in the region

The northeastern region of India exhibits heightened vulnerability to climate change due to its distinct geographical characteristics.[1] Trend analysis is a mathematical technique used to forecast future events based on past performance, whereas TS analysis is a statistical method concentrated on time-series data. Long-term rainfall TS analysis is essential for identifying trends and variability across multiple locations.[1] Non-parametric approaches are commonly preferred for trend analysis globally. To analyze trends and variability in hydro-meteo-rological TS, several researchers have used non-parametric techniques such as the MNK test, Modified Mann-Kendall (MMNK) test, trend free pre-whitening (TFPW) MNK test, and innovative trend analysis (ITA) approaches.[10-11] The MNK test is among the more reliable options available. Several studies[12-13,3] utilized this tool. Sen's slope estimator (SSE), as proposed by Sen in 1968, is utilised for this purpose. The slope value in Sen's slope indicates an increase or decrease in a variable.[14]

The MNK test and SSE were utilized for long-term trend analysis of rainfall across multiple locations in India and other countries, aiming to identify annual, seasonal, and monthly trends within the rainfall time series.[15-20] The study's findings revealed trends of either increase (decrease) in rainfall within the context of climate change. Several studies indicate a decline in the frequency of rainfall events, the number of rainy days, and total annual rainfall across various regions of Asia.[21-23]

Tripura state is situated in the northeastern highland region of India. The population in the state predominantly relies on agriculture for subsistence. Tripura experiences an annual rainfall ranging from 1922 mm to 2855 mm. Precipitation exhibits a general increase from the Southwest to the Northeast. During summer, relative humidity varies between 50% and 74%, whereas it surpasses 85% in the monsoon season. Monsoons typically persist until September, concluding in the first week of June or the latter part of May. Station Dharmanagar records the highest levels of rainfall.[24] The variability and pattern of rainfall significantly influence crop production and the state's economy. This study aims to assess long-term trends in rainfall time series and the variability of seasonal and annual rainfall at 15 stations in Tripura over a 20-year period (2000-2019), considering the previously mentioned factors. The analysis primarily focused on the monsoon season, spanning from June to September, and was conducted over four seasons. Understanding the uncertainties related to rainfall patterns is essential for enhancing water resource management across the districts of Tripura state.

Materials and Methods

Tripura is one of the seven states in northeastern India which known for its diverse ethnic communities, lush green landscapes, and rich cultural heritage. Covering an area of 10,491.69 km², it is traversed by the Tropic of Cancer. The state is located between latitudes 22°56'N and 24°32'N, and longitudes 91°09'E and 92°20'E. Tripura is bordered to the east by Assam and Mizoram, while Bangladesh lies to its north, west, and south. As the third-smallest state in India, Tripura offers a unique blend of history, cultural diversity, and natural beauty. The state comprises three different physiographic zones: low-lying alluvial soil, undulating plateau area, and mountainous ranges. Spring, summer, monsoon, autumn, and winter are the five different seasons that make up the state's pleasant and humid tropical climate. Spring begins from late mid-February to mid-March. Winter is likely to return following a fresh rainfall in mid-February. Pre-monsoon rainfall is regularly observed in the hills following Jhum harvesting in March-April, with the summer season beginning in mid-March and peaking in April-May. The monsoon generally ends in late May or early June and persists until September. Humidity is generally high throughout the year. Rainfall varies across different locations, years, and seasons. Precipitation ranges from 1922 mm to 2855 mm each year.

The months of April, June, and July through September receive the greatest amount of rainfall. In the State, the Kharif season is the main time for agriculture. Lateritic soil (4.86%), older alluvial soil (9.71%), later alluvial soil (9.34%), red and sandy loam (44.07%), and reddish yellow-brown sandy soil (30.06%) are the five primary soil types in Tripura. 91% of the state's agricultural land is used for rice cultivation, making it the main crop. Fruits such as jackfruit, pineapples, oranges, and mangoes, along with cotton, tea, and sugarcane, are classified as cash commodities. Potatoes and coconuts are also significant.

The monthly total rainfall data of 20 years (2000 – 2019) used in this study was provided by the Agriculture Department of Agartala, Tripura. This includes 15 stations (Dharmanagar, Kailasahar, Kamalpur, Khowai, Sadar, Amarpur, Sonamura, Udaipur, Belonia, Sabroom, Kanchanpur, Chawmanu, Teliamura, Bogafa, and Bishalgarh) across eight district from Tripura. Using historical rainfall data in time series trend analysis offers numerous benefits across various fields. It helps in the identification of seasonal fluctuations and long-term trends, allowing researchers to comprehend how rainfall has changed over time and spot anomalies like droughts or severe rainfall occurrences which is essential for agricultural planning because it helps farmers choose the ideal planting and harvesting seasons. Furthermore, it facilitates the management of water resources by guaranteeing the effective utilization of irrigation systems and reservoirs in catastrophe risk reduction. Monitoring rainfall trends is essential for understanding climate change for the state of Tripura as being prone to natural disaster, since rainfall trends offers insights into changing weather patterns and informs environmental sustainability policy.

Descriptive Statistics of Rainfall Data

The descriptive statistics are brief coefficients that summaries a specific data set. The rainfall time series from several stations in Tripura state, both annually and seasonally, were subjected to descriptive analysis. We determined the average, standard deviation, lowest and highest precipitation data values for every station.

Trend Analysis - General Methodology

The statistical significance and magnitude of the observed trend determine how trends in TS are analyzed. The analysis of trends in a time series relies on the statistical significance and magnitude of the observed trends. Two primary techniques used to evaluate these trends are SSE method, which is a non-parametric technique, and regression analysis, which is a parametric test.[25-27] Both methods assume a linear trend in the TS data.

Non-Parametric Tests

A non-parametric test, or distribution-free test, makes no assumptions about the underlying data's distribution. Non-parametric tests encompass a range of methods and models.[28-29] The most popular non-parametric tests and their parametric equivalents. Mood's Median Test, Sen's Slope Test, Friedman Test, MNK Test, Kruskal-Wallis Test, Mann-Whitney U Test, and MMNK Test are a few examples.[30]

Mann-Kendall Test

In hydrological and climatological TS, trend analysis is frequently conducted using the MNK test.[31-32] This examination offers two benefits. First, it is non-parametric test; it does not require the data to be normally distributed. Second, it is robust against non-homogeneous time series, making it insensitive to sudden gaps in the data. When dealing with "non-detects" data, a common strategy is to assign a value that is lower than the smallest measurable value in the dataset. The test's null hypothesis (H0) asserts that there is no trend among the data since they are independent and ordered randomly. In contrast, the alternative hypothesis (H1) assumes that a trend does exist. The MNK test statistic (S) may be calculated to evaluate these hypotheses are given below.

$$S = \sum_{a=1}^{n-1}\sum_{b=a+1}^{n} sgn(x_a - x_b) \qquad ...(1)$$

A time series can be ranked from a= 1, 2, 3,…….,n-1, and b=a+1, a+2, a+3……a + n, is subjected to the trend test. Every data point x_b is used as allusion point, and the remaining data points x_a are compared with each other so that.

$$sgn(x_k - x_j) = \begin{cases} 1, \; if(x_a - x_b) > 0 \\ 0, \; if(x_a - x_b) = 0 \\ -1, \; if(x_a - x_b) < 0 \end{cases} \qquad ...(2)$$

In this case, n indicate number of observations, x_a and x_b are sequential data values. For samples bigger than 10, the test is conducted using a normal distribution, with the mean and variance as follows.

The variance S statistic Var (S) and mean E(S) is defined by:

$$E(S)=0 \qquad ...(3)$$

$$Var(S) = \frac{n(n-1(2n+5)}{18} \qquad ...(4)$$

The above equation (4) is rewritten against the presence of tied group in the time series is given as:

$$Var(S) = \frac{n(n-1(2n+5) - \sum_{p-1}^{q} t_p - 1)(2t_p+5)}{18} \qquad (5)$$

The data set and number of data points in the p^th tied group are denoted by q and t_p, respectively. Formula for calculating the standardized test statistic Z_{mk} is:

$$Z_{mk} = \begin{cases} \frac{S-1}{\sqrt{var(S)}} & \text{if } S > 0 \\ \frac{S-1}{\sqrt{var(S)}} & \text{if } S < 0 \\ 0 & \text{if } S = 0 \end{cases} \qquad (6)$$

The Mann-Kendall test statistics, which have mean of 0 and variance of 1, are represented by the value of Z_{mk}. The null hypothesis, H_O is thus accepted in a two-sided trend test, if $-Z_{1-\alpha/2} \leq Z_{mk}\; Z_{1-\alpha/2}$, where α is the threshold of significance that reflects the strength of the trend.

Sen's Slope Estimator Test

SSE is a non-parametric method for determining the true slope in trend analysis, like an annual variation, and for predicting the size of a trend in a TS.[33] Sen's approach may be applied in situations where a linear trend can be assumed, such as:

$$\beta = Median\left[\frac{x_a - x_b}{a-b}\right] \quad for\; b < a \qquad ...(7)$$

Data values in years j and k are represented by x_a and x_b are in this case, so that b > a. The number of slopes (N) is determined as follows if the TS contains n values of x_b:

$$N = \frac{n(n-1)}{2} \qquad ...(8)$$

Sen's estimator of the slope is the median of these N values used to find β. If the N values of β are ranked from the smallest to the largest, and Sen's estimator is

When determining β, the median of these N values serves as number of SSE of the slope. In the event when SSE is used and the N values of β are arranged from lowest to highest,

$$\beta = \left(\frac{N+1}{2}\right) \quad if\ N\ is\ odd \qquad ...(9)$$

$$\beta = \left(\frac{N}{2} + \frac{N+1}{2}\right)\ if\ N\ is\ even \qquad ...(10)$$

Regarding the slope estimation, the non-parametric approach based on the normal distribution gives a 100(1 – α)% two-sided confidence interval. The method works for n as low as 10 unless there are many ties. A rising or falling trend in the TS is shown by a positive or negative value.

Results

Variability Analysis of Annual and Seasonal Rainfall

Tables 1 to 5 illustrate the variability of seasonal and annual rainfall. Table 1 displays the mean rainfall, maximum rainfall, and minimum rainfall for the 15 stations during the monsoon season, along with the estimated coefficient of variation and standard deviation. In addition to the maximum and minimum rainfall reported at 15 locations during the monsoon season, Table 1 displays the mean, coefficient of variation, and standard deviation. The highest mean rainfall during the monsoon season was recorded in Sabroom (1696.055 mm), followed by Udaipur (1565.76 mm), Bogafa (1512.76 mm), and Kanchanpur (1500.07 mm). Conversely, the lowest mean rainfall was observed in Teliamura (1206.07 mm), Sadar (1260.72 mm), Chawmanu (1275.79 mm), and Sonamura (1295.99 mm). The monsoon season in Teliamura experiences rainfall ranging from a maximum of 1637.4 mm to a minimum of 845.6 mm. In contrast, Sabroom records a maxi-mum rainfall of 2380.3 mm and a minimum of 1056.9 mm. The highest coefficient of variation, at 83.95%, was recorded at Udaipur station, followed by Bishalgarh (48.10%), Kamalpur (36.74%), and Sadar (30.09%). The lowest values were noted in Kailasahar (15.36%), Dharmanagar (16.03%), Chawmanu (17.72%), and Teliamura (20.75%) during the monsoon season.

Table 1: Variability of monsoon season rainfall of 15 rain gauged stations of Tripura

Stations	Rainfall Maximum (mm)	Rainfall Minimum (mm)	Mean Rainfall (mm)	Standard Deviation (mm)	CV (%)
Dharmanagar	1890.9	1139.9	1459.53	234.02	16.03
Kamalpur	2687.8	605.9	1378.9	506.5	36.7
Khowai	2136.1	879.6	1336.1	317.6	23.7
Sadar	2028.7	763.1	1260.7	379.3	30.0
Amarpur	2187.4	1016.4	1364.3	302.6	22.1
Sonamura	1921.8	806.2	1295.9	305.1	23.5
Udaipur	6610.9	499.3	1565.7	1314.4	83.9
Belonia	2576.3	1058.6	1476.1	359.3	24.3
Sabroom	2380.3	1056.9	1696.1	414.5	24.4
Kailasahar	1756.6	932.3	1357.6	208.9	15.3
Kanchanpur	2101.8	1088.9	1500.1	293.6	19.5
Chawmanu	1853.6	846.8	1275.8	226.0	17.7
Teliamura	1637.4	845.6	1206.1	250.3	20.7
Bishalgarh	3476	649.7	1334.47	641.9	48.1
Bogafa	2384.1	977.4	1512.76	352.35	23.29

In Table 2, highest mean rainfall was recorded in Kamalpur (239.04 mm), followed by Bogafa (236.18 mm), Khowai (226.38 mm), and Sabroom (217.4 mm). In contrast, the lowest mean rainfall was noted in Chawmanu (162.71 mm), followed by Bishalgarh (173.54 mm), Kailasahar (186.86 mm), and Kanchanpur (197.41 mm). The seasonal rainfall in Kamalpur ranges from 719.8 mm to 18.2 mm, while in Chawmanu, it ranges from 363.22 mm to 17.1 mm. The highest coefficient of variation was observed in Kamalpur (78.31%), followed by Bishalgarh (73.94%), Sonamura (71.67%), and Udaipur (68.40%). Conversely, the lowest coefficient was recorded in Kanchanpur (42.38%), followed by Sadar (52.20%), Kailasahar (53.82%), and Khowai (54.64%).

Table 2: Variability of rainfall for North-east monsoon season at 15 rain gauged stations of Tripura

Stations	Rainfall Maximum (mm)	Rainfall Minimum (mm)	Mean Rainfall (mm)	Standard Deviation (mm)	CV (%)
Dharmanagar	435.9	18.2	188.7	124.6	66.0
Kamalpur	719.8	21.8	239.0	187.1	78.3
Khowai	399.7	44.0	226.3	114.6	54.6
Sadar	401.7	0.0	200.2	104.5	52.2
Amarpur	454.6	54.2	190.6	123.3	64.7
Sonamura	485.8	19.0	188.9	135.4	71.6
Udaipur	439.6	26.0	202.5	138.5	68.4
Belonia	540.8	50.6	202.5	129.1	63.7
Sabroom	624.5	11.3	217.	132.2	60.8
Kailasahar	411.9	22.5	186.8	100.5	53.8
Kanchanpur	404.8	63.7	197.4	83.6	42.3
Chawmanu	363.2	17.1	162.7	99.7	61.3
Teliamura	459.4	22.1	201.6	116.9	57.9
Bishalgarh	475.8	0.0	173.5	128.3	73.9
Bogafa	509.4	15.4	236.2	142.2	60.2

In Table 3 the highest recorded summer rainfall occurred in Dharmanagar at 877.15 mm, followed by Kamalpur at 876.25 mm, Kailasahar at 755.89 mm, and Kanchanpur at 747.09 mm. In contrast, the lowest rainfall was observed in Belonia at 506.89 mm, followed by Sabroom and Sonamura, both at 522.6 mm, and Sadar at 531.05 mm. The seasonal rainfall in Dharmanagar ranges from 1213.1 mm to 309.2 mm, while in Belonia, it ranges from 958.9 mm to 254 mm. The highest coefficient of variation was observed in Bishalgarh (60.4%), followed by Kamalpur (38.19%), Belonia (36.91%), and Sadar (34.85%). In contrast, the lowest coefficient was recorded in Bogafa (24.19%), followed by Kanchanpur (24.48%), Dharmanagar (26.33%), and Kailasahar (27.06%).

Table 3: Variability of rainfall for summer season at 15 rain gauged stations of Tripura

Stations	Rainfall Maximum (mm)	Rainfall Minimum (mm)	Mean Rainfall (mm)	Standard Deviation (mm)	CV (%)
Dharmanagar	1213.1	309.2	877.1	230.9	26.3
Kamalpur	1581	322.3	876.2	334.6	38.1
Khowai	1071.6	242.2	724.4	197.2	27.2
Sadar	854.6	201.2	531.0	185.1	34.8
Amarpur	893.4	253.6	543.9	185.9	34.1
Sonamura	938.5	210.6	522.6	165.8	31.7
Udaipur	956.8	278.4	566.1	180.9	31.9

Belonia	958.9	254	506.8	187.0	36.9
Sabroom	1031.8	225.1	521.3	181.3	34.7
Kailasahar	1091.4	325	755.8	204.5	27.0
Kanchanpur	1015.3	377.6	747.0	182.9	24.4
Chawmanu	1102.2	315.3	670.6	202.1	30.1
Teliamura	869.8	248.4	594.3	161.3	27.1
Bishalgarh	1479.4	132.1	610.4	368.7	60.4
Bogafa	847.8	249.6	571.3	138.2	24.2

Table 4 also includes the highest and minimum rainfall. Following Kamalpur (34.46%), Khowai (34.71%), and Kailasahar (32.05%) in terms of mean rainfall, Dharmanagar (52.22 mm) is the location that receives the largest amount of rainfall. In terms of average rainfall, the places with the least amount of precipitation are Amarpur (13.23 mm), Chawmanu (15.88 mm), Udaipur (17.62 mm), and Sabroom (17.69 mm). In Dharmanagr, the seasonal rainfall ranges from 537.8 millimetres to 0 millimetres, but in Amarpur, it ranges from 50.2 millimetres to 0 millimetres. The highest coefficient of variation was found in Dharmanagar, which was 228.09%. Bogafa, Sabroom, and Sonamura came in second, third, and fourth, respectively, with 153.88%, 150.23%, and 148.70% respectively. While Khowai had the lowest coefficient of variation (83.30 percent), Teliamura had the highest (111.99%), Udaipur had the highest (119.39 percent), and Kailasahar had the highest (122.19%).

Table 4: Variability of rainfall for winter season at 15 rain gauge stations of Tripura

Stations	Rainfall Maximum (mm)	Rainfall Minimum (mm)	Mean Rainfall (mm)	Standard Deviation (mm)	CV (%)
Dharmanagar	537.8	0	52.2	119.1	228.0
Kamalpur	171.1	0	34.4	46.5	135.2
Khowai	93.5	0	34.7	28.9	83.3
Sadar	80	0	19.3	24.6	126.8
Amarpur	50.2	0	13.2	17.6	133.5
Sonamura	141.8	0	22.6	33.6	148.7
Udaipur	66.6	0	17.6	21.0	119.3
Belonia	88.4	0	19.8	28.0	141.2
Sabroom	105.6	0	17.6	26.5	150.2
Kailasahar	129.1	0	32.0	39.1	122.1
Kanchanpur	89.4	0	21.5	27.4	127.8
Chawmanu	70	0	15.8	21.0	132.4
Teliamura	73.8	0	19.5	21.8	111.9
Bishalgarh	128.44	0	20.1	25.7	128.4
Bogafa	124.2	0	20.2	31.0	153.8

Table 5 shows the annual rainfall for the given parameters. Dharmanagar had the highest annual mean rainfall of 2662.16 mm, followed by Kamalpur (2528.56 mm), Kanchanpur (2463.7 mm), and Sabroom (2456.6 mm). Bishalgarh had the lowest annual average rainfall (1868.63 mm), followed by Teliamura (2022.04 mm), Sonamura (2030.14 mm), and Sadar (2036.18 mm). The seasonal rainfall in Dharmanagr ranges from 4773.8 mm to 1853 mm, whilst in Bishalgarh it ranges from 2939.2 mm to 854.5 mm. Udaipur had the largest coefficient of variation, at 35.13%, followed by Bishalgarh

(33.2%), Kamalpur (32.82%), and Dharmanagar (23.57%). The lowest coefficient of variation was found at Kailasahar (14.06%), followed by Kanchanpur (14.72%), Chawmanu (16.90%), and Teliamura (18.66%).

Table 5: Variability of rainfall for annual rainfall at 15 rain gauge stations of Tripura

Stations	Rainfall Maximum (mm)	Rainfall Minimum (mm)	Mean Rainfall (mm)	Standard Deviation (mm)	CV (%)
Dharmanagar	4773.8	1853.0	2662.1	627.4	23.5
Kamalpur	4417.4	1446.8	2528.6	830.0	32.8
Khowai	3405.2	1834.2	2309.1	426.2	18.4
Sadar	3075.3	1381	2036.1	461.9	22.6
Amarpur	3336.1	1556.8	2109.3	452.8	21.4
Sonamura	2931.4	1204.1	2030.1	414.4	20.4
Udaipur	4185	1216.4	2081.0	731.0	35.1
Belonia	3335.5	1609.7	2205.5	417.3	18.9
Sabroom	3448.5	1844.9	2456.6	509.3	20.7
Kailasahar	2869.7	1801.7	2332.8	328.0	14.0
Kanchanpur	3273.1	2038.5	2463.7	362.6	14.7
Chawmanu	2722.8	1411.2	2121.9	358.7	16.9
Teliamura	2906.6	1520.8	2022.0	377.3	18.6
Bishalgarh	2939.2	854.5	1868.6	620.3	33.2
Bogafa	3439.4	1774.2	2348.4	459.2	19.6

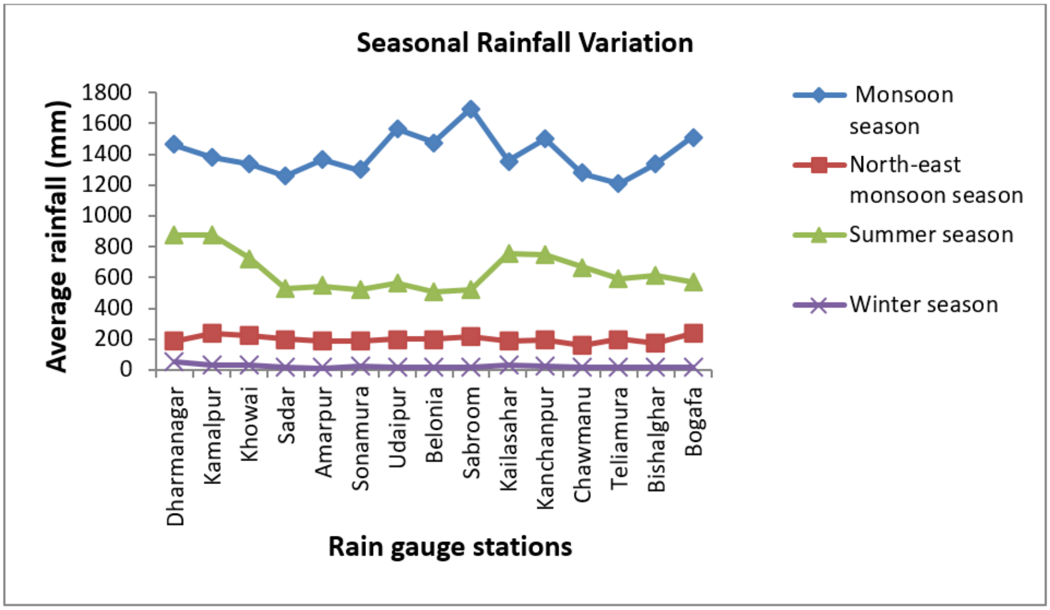

Fig. 1: Seasonal variation of rainfall over 15 rain gauge stations of Tripura

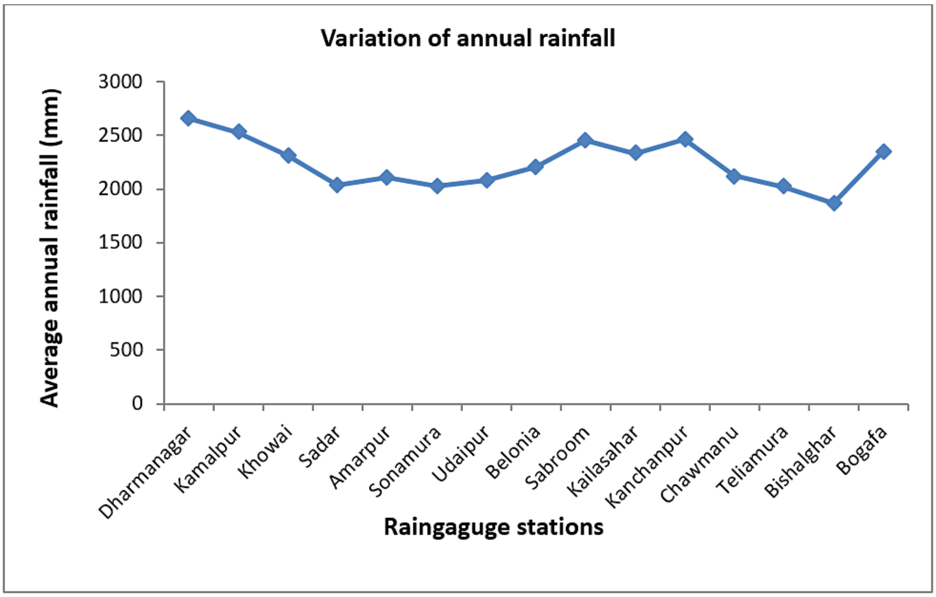

Fig. 2: Annual variation of rainfall over 15 rain gauge station of Tripura

Both Figure 1 and Figure 2 provide graphical representations of the seasonal and yearly fluctuation of rainfall.

Trend Analysis for Seasonal and Annual Rainfall at 15 Selected Stations in Tripura

Table 6 shows the findings of an analysis of the Sen's slope trend for the yearly and seasonal rainfall of 15 stations in Tripura. During the monsoon season, there is no discernible pattern that can be seen in any of the stations (Fig 3). It is worth noting that Bishalgarh (Z = -1.51, β = -30.80) and Kanchan-pur (Z = -1.59, β =-19.43) demonstrate a significant drop in slope (Figure 4 & 5), but Kamalpur (Z = 1.4, β = 38.65) displays a significant increase in slope (Fig. 6). In contrast, just a few of the other sites indicated an increase in slope, while the majority of the other stations showed a little decrease in slope. Sample figures (3-6) shows non-significant falling trends in monsoon rainfall, the significant falling trends and significant increasing trends in monsoon rainfall during the period 2000 to 2019 for trend visualization in Tripura state.

It has been found that there is no trend at any of the sites during the summer season. However, it is worth noting that Sabroom displays a significant drop in slope (Z = -1.65, β = -12.15), although Kamalpur station also displays a significant increase in slope (Z = 0.61, β = 9.16). The other stations had varying degrees of incline, displaying both an increase and a reduction across the board. Additionally, throughout the winter season, there is no discernable trend at any of the stations. In terms of slope, Amarpur has the most significant decrease (Z= -0.53, β= -6.8), whilst Teliamura displays a slight rise in slope (Z= 1.2, β= 1.78). There were also other stations that displayed a slight rise or reduction in slope, and some of them even displayed a slope that never changed. There is no discernible pattern that can be seen in any of the stations throughout the North-East Monsoon season. Nevertheless, it is worth noting that Amarpur (Z = -0.53, β = -6.8), Khowai (Z = -0.68, β = -4.49), Chawmanu (Z = -0.91, β = -4.071), and Sonamura (Z = -0.81, β = -4.83) all demonstrate a notable drop in slope. In terms of slope, Kamalpur (Z = 0.94, β = 8.74) and Dharmanagar (Z = 0.84, β = 4.82) both demonstrate a noteworthy rise in slope.

In contrast, just a few of the other sites indicated an increase in slope, while the majority of the other stations showed a little decrease in slope. At some of the other sites, there were also some slight slopes that were increasing and decreasing overall. Bishalgarh is the only location that displays a substantial downward slope and a downward trend in yearly rainfall (Z = -2.64, β = -84.1). It was determined that there was no discernible pattern for the other stations. In the case of Khowai (Z = -1.65, β = -25.11), Kailasahar (Z = -1.46, β = -26.98), and Chawmanu (Z = -1.21, β = -25.09), the slope was significantly dropping. On the other hand, Kamalpur (Z = 1.46, β = 56.47) and Udaipur (Z = 0.62, β = 17.37) displayed a significant growing slope. Additionally, several stations displayed a combination of slopes that were both growing and decreasing.

Table 6: Mann kendal's trend and Sen's slope for seasonal and annual rainfall

Site name	Monsoon		Summer		Winter		NE monsoon		Annual	
	Z	β	Z	β	Z	B	Z	β	Z	β
Dharmanagar	-0.45	-5.03	0.77	3.70	-0.36	-0.13	0.84	4.82	-0.77	-10.52
Kamalpur	1.40	38.65	0.61	9.16	-0.09	0	0.94	8.74	1.46	56.47
Khowai	-1.40	-10.43	-0.16	-2.54	-0.38	-0.56	-0.68	-4.49	-1.65	-25.11
Sadar	-0.61	-7.98	0.55	4.23	-0.33	-0.06	-0.36	-1.54	-0.16	-4.79
Amarpur	0.53	-6.80	-0.53	-6.80	-0.53	-6.80	-0.53	-6.80	-0.53	-6.80
Sonamura	0	0.25	0.09	0.65	-0.20	0	-0.81	-4.83	-0.22	-6.76
Udaipur	0.55	5.01	-0.81	-4.53	-0.55	-0.51	0.22	0.49	0.62	17.37
Belonia	-0.16	-0.82	-0.03	-0.86	-0.07	0	-0.55	-1.53	-0.49	-9.54
Sabroom	0.61	11.41	-1.65	-12.15	0.03	0	0.29	2.04	0	0.14
Kailasahar	-1.92	-17.14	-0.29	-1.17	-0.79	-0.21	0.03	0.36	-1.46	-26.98
Kanchanpur	-1.59	-19.43	0.92	0.35	0.92	0.35	0.76	0.04	-0.833	-13.13
Chawmanu	-0.45	-3.22	1.61	0.90	1.61	0.9	-0.91	-4.071	-1.21	-25.09
Teliamura	0.757	-2.53	1.78	1.20	1.78	1.20	0.303	0.87	0.83	16.9
Bishalghar	-1.51	-30.80	0.76	0.40	0.76	0.40	-0.76	-3.40	-2.65	-84.10
Bogafa	-0.53	-10.31	0.34	0.20	0.34	0.20	-0.303	-1.98	-0.53	-8.88

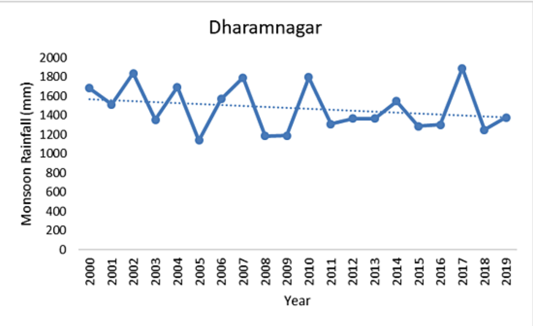

Fig: 3

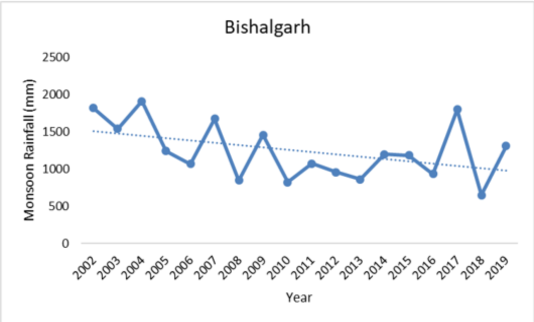

Fig: 4

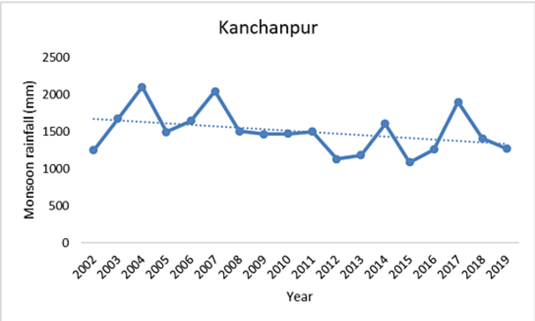

Fig: 5

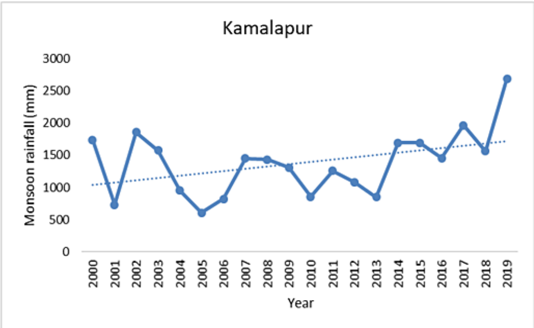

Fig: 6

Figure (3-6). Trends detection in monsoon rainfall for selected stations (2000-2019)

Discussions

The MNK test and SSE are two non-parametric statistical tests used in this work to examine the trends and temporal changes in seasonal and annual rainfall across 15 stations in Tripura, India. The findings offer a thorough grasp of rainfall variability, which is essential for managing water resources, agriculture, and climate adaption measures in the area.

Rainfall patterns across Tripura exhibit significant spatial and seasonal variability. The monsoon season contributes the highest amount of precipitation, while winter experiences the lowest. The rainfall coefficient of variation during the monsoon season shows significant differences between various stations. For these the highest coefficient of variation was recorded at Kamalpur, whereas Kanchanpur exhibited the lowest. These variations suggest that while some areas receive relatively stable rainfall, others are prone to fluctuations that could impact agricultural productivity. Such variations suggest that while certain areas receive relatively consistent rainfall, others experience erratic precipitation, which can significantly impact agriculture and water resource management. These findings align with previous studies that have reported high inter annual rainfall variability in north-eastern India.[34]

The trend analysis revealed no significant trend in monsoon rainfall at any station, though some locations exhibited a slight increase or decrease in slope values. Similarly, there were no clear trends in the summer and winter seasons, except for a noticeable decline in rainfall at Sabroom during summer. In the monsoon season, a few stations—Amarpur, Khowai, Chawmanu, and Sonamura—exhibited a downward trend in rainfall, suggesting a possible reduction in precipitation during this period. The annual rainfall trend analysis revealed that Bishalgarh experienced a significant decreasing trend, which may indicate a drying trend at this station. However, no other stations showed strong annual trends. The general lack of significant trends across multiple locations suggests that, while rainfall variability exists, long-term rainfall patterns in Tripura have remained relatively stable over the past two decades. The variability in rainfall patterns has profound implications for agriculture in Tripura, where farming is predominantly rainfed. While stable monsoon rainfall supports agricultural production, the lack of a significant increasing trend in annual rainfall, combined with seasonal fluctuations, poses challenges for water availability.[35] The lack of a significant increasing trend in rainfall means that agricultural productivity remains vulnerable to rainfall variability. Farmers relying on rainfed agriculture may experience inconsistent water availability, affecting sowing periods and crop growth cycles.[36] The decline in rainfall at some stations, such as Bishalgarh, suggests potential risks for groundwater depletion and irrigation shortages. Droughts and heavy rainfall are examples of extreme weather events that can still occur even in the absence of a significant upward trend in monsoon rainfall. Sudden heavy downpours, coupled with poor drainage infrastructure, could result in floods, while prolonged dry spells could lead to drought-like conditions.[37]

Although the study did not explicitly analyze the impact of climate change, the observed trends align with broader findings on changing rainfall patterns in north-eastern India. Previous studies have highlighted an increase in extreme weather events, such as short-duration heavy rainfall and prolonged dry spells, which could disrupt traditional farming practices.[38] The findings of this study underscore the need for climate-resilient agricultural planning, improved water storage infrastructure, and early warning systems to mitigate the risks associated with rainfall variability.[39]

While the study provides important insights, it is limited to 20 years of data, extending the analysis beyond 2000–2019 to include a longer historical dataset (e.g., 50–100 years) can provide a clearer picture of long-term trends and variability. Future research could extend the analysis using longer datasets and incorporate climate models to assess future rainfall projections.[38] Additionally, using climate models to project future rainfall trends under different climate change scenarios will help in risk assessment and preparedness by establishing early warning systems for extreme rainfall events to help communities prepare for floods or dry spells. Strengthening flood control measures, particularly in areas prone to heavy monsoon rains.

Conclusion

Knowledge of rainfall and its spatio-temporal variability play an important role for the planning and managing of water resources for sustainable development of agriculture. In order to analyse seasonal and annual rainfall variability and to detect the long term trends, total 20 years of rainfall data collected from the 15 stations was utilized. From the findings of the study, it was observed that during the monsoon season, the coefficient of variation varied between 83.95% and 15.36%. While Kanchanpur's coefficient of variation was 42.38 percent and for Kamalpur station found to be 78.13% during the northeastern season. No pattern emerged at any of the stations during the monsoon season. Similarly, throughout the summer, no discernible trend was observed at any of the sites. In addition, there were no noticeable trends at any location during the winter season. There was no discernible pattern across all sites during the North-East Monsoon. Bishalgarh station reported the noticeably decreasing trends for yearly rainfall and no significant trend was seen for the remaining stations. In Northeast India, rainfall has both benefits and difficulties. The region's agrarian economy depends heavily on pre-monsoon crop production, which is especially benefited by the plentiful rainfall, which supplies enough water for a variety of farming, forests and a wide range of flora. Additionally, while rainfall is essential for agriculture, unpredictable patterns often result in waterlogging or drought-like conditions, leading to disruptions in crop production and negatively impacting farmer’s livelihoods. Climate change have exacerbated these issues by altering rainfall patterns and increasing the vulnerability of rainfed agriculture. Therefore, study findings would be helpful for the planning and management of water resources and strategic interventions to mitigate its adverse impacts on agriculture in Tripura state of India.

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Ethics Statement

This research did not involve human participants, animal subjects, or any material that requires ethical approval.

Informed Consent Statement

This study did not involve human participants, and therefore, informed consent was not required.

Author Contributions

- **Tanusri Baidya:** Conducted data collection and formal analysis and Result Writing
- **Ghanshyam T. Patle:** Conceptualization, Visualization, Methodology, Supervision, Writing- Original Draft.
- **Mukesh Kumar:** Writing- Original Draft, Review & Editing.
- **Neetu Kataria:** Critical Review in Analysis, Methodology
- **Bivek Chakma:** Reviewed, Revised, and Finalized the Manuscript- Writing & Editing

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