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Research article

Assessment of climate change induced rainfall trend and variability with non-parametric and linear approach for Sirajganj district, Bangladesh

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ABSTRACT

The monthly and annual trends and variance of rainfall have been studied for five stations in an economically important Bangladeshi district named Sirajganj since 1965 to 2021. Natural disasters have prevalent in Sirajganj which is indispensable to assess. But, several researchers have been normally focused on river bank management and flood risk assessment. However, no extensive research has been conducted on Sirajganj based on non-normally distributed time series meteorological data such as rainfall time series so the current study is very important. In this study, the non-parametric Mann-Kendall and Sen's methods have been used to determine the statistical significance of a positive or negative trend in rainfall data. Also, cumulative sum charts and bootstrapping, one-way ANOVA, Tukey's range tests, and linear regression have been used to discover the incidence of abrupt changes, compare the significant difference in monthly and annual rainfall data, multiple comparisons amidst mentioned stations to find changes, and to investigate the changeover on dry and rainy days, respectively. The analysis showed a statistically significant decreasing trends in monthly and annual rainfall series. As well, changes from positive to negative direction have been recognized in the February, May, July, September, and annual rainfall time sequence. Besides, ANOVA and Tukey's range tests revealed a statistically substantial difference in all monthly and annual rainfall volume excluding January, March, and June. Additionally, these two tests demonstrated momentous differences in all monthly and annual frequency of rainfall categories excepting January and April. However, Linear regression analysis revealed that the number of dry days gradually reduced at the end of the dry winter, though the number of rainy days decreased during the rainy season. As in, the number of rainy days replaces the number of dry days during the dry season and vice versa during the rainy season. Even though, with very few exceptions, the volume of rainfall decreases throughout the year. The outcomes of this research might helpful for implementing the planning and evaluating hydrological projects on Sirajganj district.

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1. Introduction

1.1. Literature review

Climate change has now become a worldwide concern. Heat waves, hurricanes, flooding, wildfires, and drought are already being felt as a result of climate change [1]. It is referred to as large variations in climate averages which exist for decades or even longer periods [2]. Despite the fact that climate change is a worldwide phenomenon, its effects frequently differ from one place to another [3]. The fluctuation of hydro-meteorological variables, such as rainfall, can be significantly impacted by climate change. Fluctuation of rainfall, a crucial element of the water cycle, can have a significant impact on agriculture, ecosystems, and the management of water resources [4]. Rainfall variation trend analysis could be useful in preserving environment and socioeconomic structure. Accurate monitoring of long-term rainfall trends has therefore become an increasingly important research part for effective provincial management of water resources and related hazards [4–8]. Now a days, rainfall variability and trend analysis is also becoming a progressively predominant form of decision-making study [5,6,8,9]. Researchers [10] examined rainfall variability and trend in the Shimsha basin area with daily rainfall data after 1989 to 2018. Observed historical weather data from Guwahati, Assam, India, since 1970–2019 has also been used to evaluate rainfall and temperature patterns [11]. Besides, time-series trends and variability were inspected in the observation of rainfall and temperature records for 16 stations from 1985 to 2015 [12]. Using data from 45 rainfall stations dating back more than 90 years, rainfall and drought features were investigated in southeastern Australia (New South Wales and Victoria) [13]. Some researchers studied daily rainfall data from 9 rain gauge stations for more than 30 years and used trend statistical analysis for rainfall and watercourse movement patterns in the Birr River watershed in the northwestern area of Ethiopia's highlands [14]. Spatial and temporal patterns of trends on seasonal and annual rainfall time series data were studied from 1966 to 2015 at 13 stations in India's Uttarakhand state's central Himalayan region [15]. The spatial distribution of changes in rainfall extremes in Sarawak, Malaysia, was also examined from 1980 to 2014 [16]. Above mentions are some examples of a latest worldwide research work, mostly in the field of rainfall trend and variability. Recently this issue has gained attention since environmental catastrophes can be easily evaluated by researching rainfall variability and trend. Natural disasters caused by climate change in Bangladesh's Sirajganj areas have an extensive history of affecting the local economy and community. Alike to prior researchers, the Sirajganj district's economy and locality can be maintained with greater success by using studies based on historical time series rainfall data analysis.

Several researchers analyzed the climate of Sirajganj district with a prominence on the risk of flooding and the morphological management of rivers in the vicinity [17–21]. But, in the long run, rainfall variability is the real cause of flooding, river bank erosion, drought, and other problems and it is quite challenging to analyze this rainfall phenomenon because Sirajganj's rainfall is extremely variable as a result of climate change. To meet the challenges, specialized mathematical techniques are desirable to explore time series data of this district with a level of variability which are not normally distributed. A data set is considered to have a normal distribution when its values are evenly distributed around one typical value [22]. A normal distribution is a requirement for a parametric statistical study [23]. Likewise, a number of researchers favor various types of non-parametric statistical tests for rainfall trend and variability analysis. In one of the research works, statistical non-parametric tests like the Mann-Kendall (MK) test and Sen's slope are preferred to be used to determine the extent of changes in India's rainfall trend over 141 years, from epochs 1871 to 2011 [24]. In another research work, both parametric and non-parametric tests such as Mann-Kendall (MK), Modified Mann-Kendall (MMK), Kendall Rank Correlation (KRC), Theil-Sen's Slope (TSS), Simple Linear Regression (SLR) etc. were used to investigate the spatial and temporal patterns of trends and magnitude of rainfall on monthly, seasonal, and annual time scales for 13 districts of Uttarakhand State in India's Central Himalayan region [25]. Correspondingly, the pattern of rainfall and temperature behavior in the Hadejia River Basin (HRB) have been analyzed by ANOVA and the Mann-Kendall trend test [26]. Statistical techniques such as regression and analysis of variation (ANOVA) were also used to investigate the variability of temperature-rainfall (TR) and land use/land cover (LULC) on the hydrological regime of a wooded watershed [27]. However, in Bangladesh no inclusive study has been accompanied on Sirajganj district based on non-normally distributed time series meteorological data for example rainfall time series consequently the present research is precise essential.

1.2. Research goal

The main target of this study to analyze the variability of rainfall patterns at five stations located between the administrative boundaries of Bangladesh's Sirajganj district for 57 years since 1965 to 2021. In addition, the study's specific objectives are (i) to examine rainfall's variation and trend characteristics on a broad scale; (ii) to detect significant trend in rainfall time series after removing the influence of significant lag-1 serial correlation from the time series using the Mann-Kendall test and the Sen's slope estimator; (iii) to identify the appearance of abrupt changes in time series using cumulative sum charts and bootstrapping; (iv) to find significant variance in rainfall using ANOVA and Tukey's range tests; (v) to observed the transition between dry and rainy days by using linear regression. All goals are addressed by properly interpreting and evaluating rainfall data by means of the nonparametric and linear approaches castoff by the aforementioned numerous researchers.

2. Resources and technique

2.1. Study areas and source of data

Sirajganj district is a developed city and administrative area in northwestern Bangladesh's Rajshahi Division that was selected for the present study. This district's residents depend primarily on agriculture, and a large area of grazing land is located inside the Jamuna River [28]. It covers an area of 2497.92 square kilometers and is located between 24°22′ and 24°37′ north latitude and 89°36′ and 89°47′ east longitude [17,29] (Fig. 1). The climate is commonly referred to as tropical monsoon climate which is distinguished by heat, wind pressure, humidity, mild temperatures, and significant seasonal fluctuations. The contrasting winds that characterize the summer and winter seasons, which are an intrinsic element of the South Asian sub-continental circulation system, are the most remarkable aspect of the climate of this area. The area's climate is in between that of the Am and Aw type (Köppen climate classification scheme) [30]. Tropical-monsoon and tropical-savannah climate reasons are indicated by the Am and Aw respectively. The Köppen climate classification scheme states that the area's coldest month has a temperature of at least 18°C and the driest month has an average rainfall of roughly 93 cm. But the facts is that there are instances when there is no rain at all during the dry months. Three distinct seasons can be identified based on rainfall and temperature, namely the dry winter, which lasts from November to February; the pre-seasonal monsoonal summer, which lasts from March to May; and the rainy season, which lasts from June to October [31].

The daily rainfall data from five rain gauge stations that established by Bangladesh Water Development Board (BWDB) has been castoff in this investigation from periods 1957 to 2021 (Table 1).

2.2. Data pre-processing

By using the Inverse Distance Weighting (IDW) Interpolation method, missing values from the rainfall time series are estimated. IDW is a deterministic approach for multivariate interpolation with a known distributed set of points followed by various researchers [32–35]. The IDW approach is beneficial when the distribution of the estimated parameters is not normal [36]. Then, to ensure the consistency of rainfall data, double mass analysis is utilized [37,38]. Double mass analysis is a straightforward graphical method for determining the consistency of hydrological data. It is a standard data analysis method for analyzing the behavior of records made of hydrological or meteorological data at multiple locations [39].

In time-series investigations, serial correlation occurs when errors from one period spill over into subsequent periods. The series should be pre-whitened before applying the Mann-Kendall test to remove serial correlation [40]. In this study, the serial correlation is checked using Bartlett's test to determine the null hypothesis [41–44]. The Bartlett's test compares the null hypothesis, H_0, that all k population variances are equal, to the alternative that at least two are different. If there are k samples with sizes n_i and sample variances S_i^2 then Bartlett's test statistic is calculated by Eq. (1).

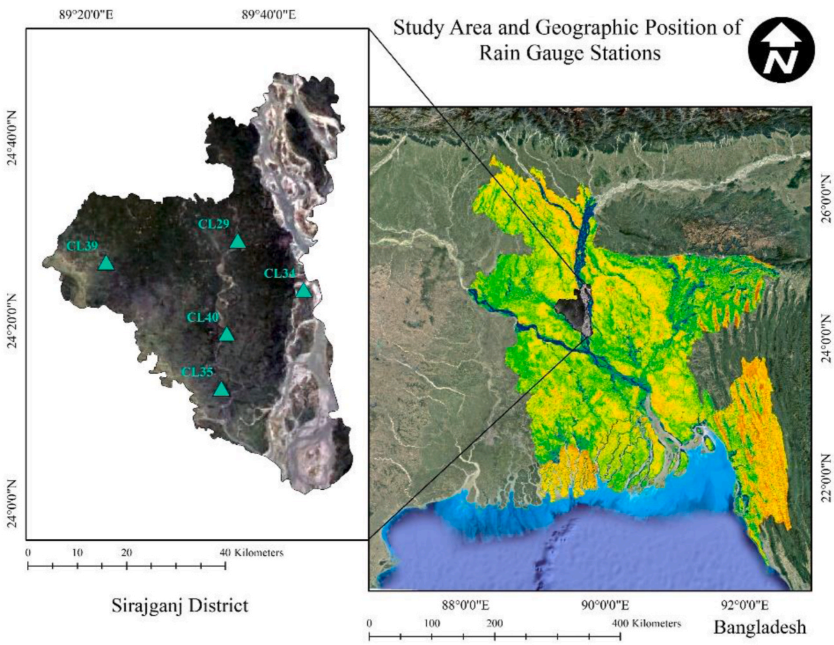

Fig. 1. Study region and geographic position of rain gauge stations.

Table 1
Geographic properties of the rainfall stations used in the study.

Station ID	Station Name	District	Latitude	Longitude	Elevation, m (from MSL)
CL29	Raiganj	Sirajganj	24.48	89.61	14.33
CL34	Sirajganj	Sirajganj	24.39	89.73	11.28
CL35	Shazadpur	Sirajganj	24.21	89.58	10.06
CL39	Taras	Sirajganj	24.44	89.37	13.11
CL40	Ullapara	Sirajganj	24.31	89.59	8.84

$$\chi^2 = \frac{(N-k)\ln\left(S_p^2\right) - \sum_{i=1}^{k}(n_i-1)\ln\left(S_i^2\right)}{1+\frac{1}{3(k-1)}\left(\sum_{i=1}^{k}\left(\frac{1}{n_i-1}\right)-\frac{1}{N-k}\right)} \tag{1}$$

Where, $N=\sum_{i=1}^{k}n_i$ and $S_p^2=\frac{1}{N-k}\sum_i(n_i-1)S_i^2$ is the pooled estimate for the variance. The test statistic has approximately a χ_{k-1}^2 distribution. Thus, the null hypothesis is rejected if $\chi^2>\chi_{k-1,\alpha}^2$ (where $\chi_{k-1,\alpha}^2$ is the upper tail critical value for the χ_{k-1}^2 distribution).

Cochrane-Orcutt Regression is employed in the study to remove serial correlation from the series [45,46]. The Cochrane-Orcutt Regression approach for tackling autocorrelation is an iterative variation of the Feasible generalized least squares (FGLS) method.

Finally, the monthly and yearly rainfall volume is computed by adding the daily rainfall for each month and year at each station. Daily rainfall is then divided into six categories, as mentioned in Table 2 [47]. In this study, trace and light rain are grouped together as trace tiny to measure. It is generally not a detectable amount, but only enough to moisten the rain gauge in which it is seen [48]. Basically the category described below is adopted from Bangladesh Meteorological Department (BMD).

2.3. Non-parametric and linear approach

2.3.1. Mann-Kendall test

When analyzing long-term temporal data, the Mann-Kendall trend test is used to identify statistically significant decreasing or increasing trends. It is predicated on the existence of two hypotheses: the null hypothesis, which states that there is no trend, and the alternative hypothesis, which reflects a significant increasing or decreasing trend in the data over time [49,50]. The Mann-Kendall trend test is based on the relationship between a time series' rank and its chronological sequence. The Mann-Kendall test statistic S is calculated as mentioned by the following Eq. (2) [49,50].

$$S=\sum_{i=1}^{n-1}\sum_{j=i+1}^{n}\mathrm{sgn}\left(x_j-x_i\right) \tag{2}$$

Where n is the number of data points, x_i and x_j are the data values in time series i and $j(j>i)$, respectively and $\mathrm{sgn}\left(x_j-x_i\right)$ is the sign function as shown in Eq. (3).

$$\mathrm{sgn}\left(x_j-x_i\right)=\begin{cases}+1, \text{if } x_j-x_i>0\\ 0, \text{if } x_j-x_i=0\\ -1, \text{if } x_j-x_i<0\end{cases} \tag{3}$$

The variance is computed by Eq. (4).

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

Where, n denotes number of data points, m denotes number of tied groups and t_i denotes number of ties of extent i. A tied group is a set of sample data having the same value. In cases where the sample size $n>10$, the standard normal test statistic Z_S is computed from Eq. (5).

Table 2
Classification of rainfall category in Bangladesh.

Category of rainfall	Intensity (mm)
No rain	0.0 mm
Light rain	4.57–9.64 mm
Moderate rain	9.65–22.34 mm
Moderately heavy rain	22.35–44.19 mm
Heavy rain	44.20–88.90 mm
Very heavy rain	≥89 mm

$$Z_S = \begin{cases} \frac{S-1}{\sqrt{Var(S)}}, \text{if } S > 0 \\ 0, \text{if } S = 0 \\ \frac{S+1}{\sqrt{Var(S)}}, \text{if } S < 0 \end{cases} \tag{5}$$

Positive values of Z_S indicate increasing trends while negative Z_S values show decreasing trends. Testing trends is done at the specific α significance level. When, $|Z_S| > Z_{1-\alpha/2}$, the null hypothesis is rejected and a significant trend exists in the time series. $Z_{1-\alpha/2}$ is obtained from the standard normal distribution table. In this study, significance levels $\alpha = 0.01$ and $\alpha = 0.05$ were used. At the 5% significance level, the null hypothesis of no trend is rejected if $|Z_S| > 1.96$ and rejected if $|Z_S| > 2.576$ at the 1% significance level

It is common practice to employ the Mann-Kendall statistical test to evaluate the significance of trends in hydrometeorological time series [51–54].

2.3.2. Sen's slope estimator

There is a non-parametric way for estimating the slope of trend in the sample of pairs of data by Eq. (6) [55].

$$Q_i = \frac{x_j - x_k}{j - k} \text{ for } i = 1, ...N \tag{6}$$

where, x_j and x_k are the data values at times j and k $(j > k)$ respectively. If there is only one datum in each time period, then $N = \frac{n(n-1)}{2}$; where, n is the number of time periods. If there are multiple observations in one or more time periods, then $N < \frac{n(n-1)}{2}$; where, n is the total number of observations.

The N values of Q_i are ranked from smallest to largest and the median of slope or Sen's slope estimator is computed by Eq. (7) as below.

$$Q_{med} = \begin{cases} Q_{[(N+1)/2]} \text{ if } N \text{ is odd} \\ \frac{Q_{[N/2]} + Q_{[(N+2)/2]}}{2} \text{ if } N \text{ is even} \end{cases} \tag{7}$$

The Q_{med} symbol represents the data trend, and its value represents how steep the trend is. Obtaining the confidence interval of Q_{med} at a certain probability will allow one to assess whether the median slope is statistically distinct from zero.

The confidence interval about the time slope can be computed from Eq. (8) as follows [56,57].

$$C_\alpha = Z_{1-\alpha/2}\sqrt{Var(S)} \tag{8}$$

Where, $Var(S)$ is defined in Eq. (3) and $Z_{1-\alpha/2}$ is obtained from the standard normal distribution table. In this study, the confidence interval was computed at two significance levels ($\alpha = 0.01$ and $\alpha = 0.05$).

Then, $M_1 = \frac{N-C_\alpha}{2}$ and $M_2 = \frac{N+C_\alpha}{2}$ are computed. The lower and upper limits of the confidence interval, $Q_{\min}$ and $Q_{\max}$, are the $(M_2 + 1)$ th largest and the M_1 th largest of the N ordered slope estimates [57]. Sen's slope estimator has been widely used in hydro-meteorological time series [2,58,59].

2.3.3. CUSUM and bootstrapping

For the purpose of identifying abrupt change points in rainfall time series, cumulative sum charts (CUSUM) and bootstrapping [60] are employed. The study's entire analysis is based on 1000 bootstrap samples. The cumulative sums $S_0, S_1, ..., S_n$ of sample data $(x_1, x_2, ..., x_n)$, where n is the sample size, are calculated iteratively as follows:

i. calculate the average of sample data $(\overline{x})$, ii. Set $S_0 = 0$, iii. Calculate S_i from Eq. (9) recursively as

$$S_i = S_{i-1} + (x_i - \overline{x}), i = 1, 2, ...n \tag{9}$$

While a sudden change in the direction of the CUSUM suggests a sudden shift in the average, a period where the CUSUM chart follows a generally straight line indicates a period where the average does not change. Making use of bootstrap analysis, one can ascertain the confidence level. First, the magnitude of change S_{diff} is calculated by $S_{diff} = S_{\max} - S_{\min}$ where $S_{\max} = \max_{i=1...n} S_i$ and $S_{\min} = \min_{i=1...n} S_i$ and then, the bootstrap analysis can be performed as illustrated in the following steps:

a. Create a bootstrap sample of n units, denoted as $x_1^0, x_2^0, ..., x_n^0$, by randomly reorganizing the original n values.
b. Based on the bootstrap sample, calculate the bootstrap CUSUM, represented as $S_1^0, S_2^0, ..., S_n^0$.
c. Compute the maximum, the minimum and the difference of the bootstrap CUSUM, $S_{\max}^0$, $S_{\min}^0$ and S_{diff}^0
d. Determine whether the bootstrap difference S_{diff}^0 is less than the original difference S_{diff} or not.
e. Iterate the above procedure (a) – (d) n times

f. Let X be the number of bootstraps for which $S^0_{diff} < S_{diff}$, then, the confidence level (CL) at which a change point occurred from Eq. (10) is

$$CL = 100\frac{X}{n}\% \tag{10}$$

To guess the position of the change point, define m such that by Eq. (11).

$$|S_m| = \max_{i=1,\ldots,n}|S_i| \tag{11}$$

which is the point furthest from 0 in the CUSUM chart. The point m estimates the last point before the incidence of the change point.

2.3.4. ANOVA and Tukey's range tests

One of the most well-known statistical tools for identifying if there is variation between two or more groups of observations is one-way analysis of variance (ANOVA) [26]. It is employed to examine the equality of the means of two or more independent groups. This statistical tool examines the null hypothesis that samples from the same population were used in at least two groups [61]. Anova results that are significant show that at least one group is different from the other groups. However, the omnibus test does not reveal the pattern of mean differences. The anova is frequently followed by particular comparisons, the most popular of which compares two means, in order to understand the pattern of difference between means. Tukey's range tests, named after Tukey, are a simple and popular pairwise comparison method [62].

2.3.5. Linear regression

The foundation of statistical modeling is linear regression [63]. When modeling the relationship between a scalar answer and one or more explanatory factors (also known as dependent and independent variables) in statistics, linear regression is a linear approach. The slope of the regression equation is utilized in this study to illustrate how specific types of rainfall events spread in either a negative or positive manner. It is possible to distinguish between dry and rainy days by comparing these negative or positive propagations.

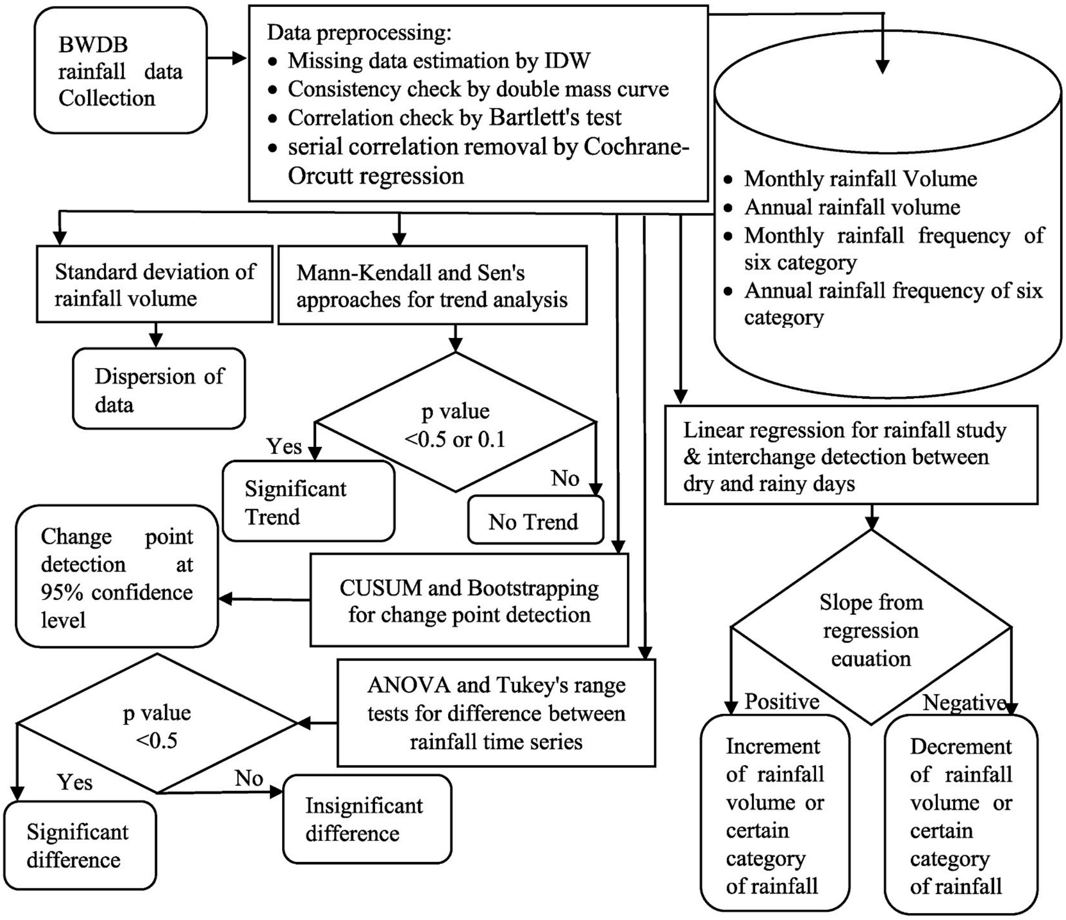

Fig. 2. Flow diagram of methodology adopted in the current study.

Flow diagram of methodology is adopted in the current study is presented in Fig. 2. IDW, double mass curve analysis, Bartlett's test, and Cochrane-Orcutt regression procedures are used to preprocess data from the BWDB. The final database of monthly and annual rainfall volume and frequency of six categories is enlisted for further investigation. To observe data dispersion, the standard deviation of rainfall volume is estimated. Mann-Kendall and Sen's techniques are designed for analyzing rainfall volume trends. CUSUM and Bootstrapping are used to detect change points. ANOVA and Tukey's range tests are used to compare rainfall time series from different stations. Linear regression is used to examine the transition between dry and rainy days.

3. Result and discussion

3.1. Standard deviation

The standard deviations of the mean monthly and annual rainfall of five stations have been used in this study to show sample data characteristics. It is the dispersion of data in a normal distribution and reflects how well the mean represents sample data [22]. When estimating the variability of the population from which the sample was taken, we use the standard deviation of a sample [64]. In this study, January's rainfall's standard deviations (mm) have been calculated as 8.74, 14.07, 8.18, 7.4 and 12.51 and January's monthly mean rainfall (mm) as 4.39, 8.59, 4.89, 3.12 and 6.79 at five stations namely CL29, CL34, CL35, CL39 and CL40 (Table 3). According to earlier study, in the case of data with a normal distribution, approximately 95 % of individuals will have values within 2 standard deviations of the mean, with the remaining 5 % evenly distributed above and below these boundaries [64]. Hence, the standard deviations of January rainfall at five stations reveal that 57 values of each station's rainfall quantity at January of 57 years are not normally distributed. Other values of standard deviation of five stations in the next eleven months likewise suggest that rainfall quantity measurements for each station over the span of 57 years are not normally distributed (Table 3). Correspondingly, the standard deviations of annual rainfall quantity at five stations over a 57 years are exceptionally large, indicating a non-normal distribution.

Fig. 3 shows that the standard deviations of five stations are at their highest from July to September. This indicates the variability of monthly rainfall quantity at five stations over a 57 years are maximum in these three months. These three months are part of the rainy season. An increase in the amount of rainfall in a given period increases the variability of the amount of rainfall in that period over time [8].

3.2. Serial correlation

The Bartlett's test is employed in this study to exclude serial correlation from the series. The Mann-Kendall test and Sen's slope estimator are applied to the initial values of the time series if the calculated Bartlett's test statistic is not significant at the 5 % level. Bartlett's test statistic is significant at 5 % confidence level if the p value is less than 0.05 [65]. Table 4 below shows the p values for five stations at monthly and annual intervals. The p values with a star next to them indicate significance for Bartlett's test statistic. Serial correlation effect exists in time series with significant Bartlett's test statistic. Cochrane-Orcutt Regression is used in the study to eliminate serial correlation from the series suggested by a significant Bartlett's test result.

3.3. Trends in the monthly and annual rainfall volume

Table 5 highlights statistically significant monthly annual rainfall trends at the 5 % and 1 % significance levels, as well as some non-significant trends. The number of stations with significant decreasing trends in the rainfall of August and September (i.e. end of the rainy season) is greater than for the other seasonal series. Excluding CL34, the other four stations had a significant Mann-Kendall test statistic in January with a zero slope, which is found in other research work [66]. It doesn't actually point to a trend. Mann–Kendall test only considers the signs of differences while analyzing time series, whereas Sen considers the actual numerical slopes. Sen's slope

Table 3
Mean and standard deviation for different months and years (in mm).

Time Range	CL29		CL34		CL35		CL39		CL40	
	Mean	Standard deviation	Mean	Standard deviation	Mean	Standard deviation	Mean	Standard deviation	Mean	Standard deviation
January	4.39	8.74	8.59	14.07	4.89	8.18	3.12	7.40	6.79	12.51
February	11.05	19.1	21.07	31.9	11.00	14.85	2.46	5.91	34.51	58.90
March	32.98	46.28	28.19	32.41	31.53	36.11	15.33	38.07	42.57	84.22
April	78.48	77.72	116.61	84.43	56.92	42.84	97.24	163.51	99.36	78.18
May	160.77	110.92	254.26	134.27	185.92	114.87	121.92	121.34	260.49	140.7
June	274.88	188.9	300.58	149.94	288.60	164.51	285.86	192.52	316.09	151.24
July	283.54	212.22	311.33	138.16	320.35	183.87	407.98	260.72	339.37	155.09
August	218.44	162.27	305.94	198.18	205.31	180.15	358.19	276.15	293.96	157.41
September	202.55	135.18	276.94	148.92	217.87	184.75	247.90	187.52	377.37	226.18
October	78.50	74.41	199.23	135.02	98.80	106.43	79.71	167.86	164.35	135.14
November	11.15	20.6	21.35	33.49	7.21	17.27	17.04	34.27	21.10	35.52
December	2.76	6.63	19.24	46.52	7.72	22.72	5.94	14.55	15.04	37.91
Annual	**416.40**	**144.82**	**1448.51**	**306.76**	**1189.63**	**481.83**	**4035.43**	**1718.33**	**1915.67**	**440.55**

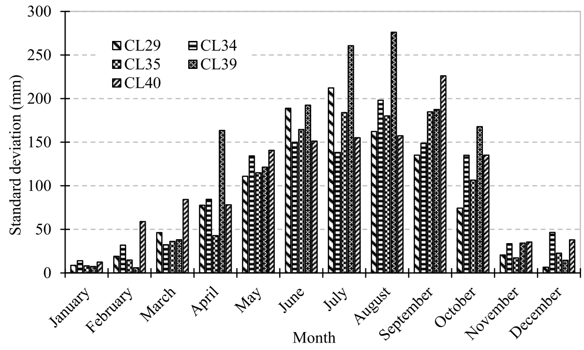

Fig. 3. Standard deviation of five stations at different Month.

Table 4
p values for five stations at monthly and annual time series from Bartlett's test statistic.

Time Range	CL29	CL34	CL35	CL39	CL40
January	0.723	0.544	0.669	0.593	0.313
February	0.648	0.063	0.260	0.682	0.366
March	0.777	0.939	0.894	0.726	**0.006***
April	0.825	0.731	0.263	0.452	0.606
May	0.088	0.827	0.175	**0.001**[a]	0.443
June	0.376	0.164	0.533	**0.004**[a]	0.608
July	0.277	0.586	0.305	0.572	0.501
August	0.200	0.669	**0.0001**[a]	0.508	0.101
September	**0.024**[a]	0.175	**0.024**[a]	0.110	0.318
October	0.787	0.311	0.406	0.673	0.819
November	0.683	0.334	0.505	0.763	0.916
December	0.888	0.843	0.589	0.886	0.850
Annual	0.723	0.926	**0.006**[a]	**0.0001**[a]	0.895

[a] Statistically significant at the 5 % significance level.

Table 5
Results of the statistical tests for monthly and annual trend of rainfall volume (1965–2021).

Time Range	Test	CL29	CL34	CL35	CL39	CL40
January	Z_s	−2.649[b]	−1.696	−2.068[a]	−2.494[a]	−2.574[a]
	Q_{med}	0.000[b]	0.000	0.000[a]	0.000[a]	0.000[a]
February	Z_s	−1.255	−0.885	−1.298	−2.018[a]	0.126
	Q_{med}	0.000	0.000	0.000	0.000[a]	0.000
March	Z_s	−0.478	−0.511	−1.142	−1.626	−0.991
	Q_{med}	0.000	−0.026	−0.194	0.000	−0.250
April	Z_s	−1.281	−0.241	0.764	−1.915	0.537
	Q_{med}	−0.521	−0.232	0.239	−0.802	0.306
May	Z_s	−1.976[a]	−0.489	0.468	−1.232	−0.613
	Q_{med}	−1.628[a]	−0.625	0.397	−0.493	−0.715
June	Z_s	−1.990[a]	−0.860	−0.124	−0.750	−0.475
	Q_{med}	−2.130[a]	−1.076	−0.203	−0.773	−0.511
July	Z_s	−2.609[b]	−1.033	0.654	−0.785	−0.585
	Q_{med}	−3.188[b]	−0.953	0.824	−1.747	−0.839
August	Z_s	−2.974[b]	−2.802[b]	−0.757	−2.361[a]	−2.767[b]
	Q_{med}	−3.390[b]	−2.910[b]	−0.400	−4.607[a]	−2.866[b]
September	Z_s	−3.050[b]	−2.402[a]	−2.492[a]	−1.459	−2.533[a]
	Q_{med}	−2.223[b]	−2.130[a]	−1.920[a]	−1.426	−3.791[a]
October	Z_s	−0.945	−1.728	−2.113[a]	−2.249[a]	−2.031
	Q_{med}	−0.289	−1.517	−1.001[a]	−0.695[a]	−1.703
November	Z_s	−1.627	−1.391	−2.923[b]	−3.391[b]	−0.889
	Q_{med}	0.000	0.000	0.000[b]	0.000[b]	0.000
December	Z_s	−1.371	−1.244	−2.763[b]	−2.175[a]	−0.710
	Q_{med}	0.000	0.000	0.000[b]	0.000[a]	0.000
Annual	Z_s	−0.406	−0.682	−0.695	−4.523[b]	−1.232
	Q_{med}	−0.370	−1.694	−2.889	−66.531[b]	−4.520

[a] Statistically significant trends at the 5 % significance level.
[b] Statistically significant trends at the 1 % significance level.

calculates the median of all the two-point slopes. When there are a lot of the same tied values in the dataset, it produces a lot of zero slope. If more than half of the two-point slopes are zero, then the median of the two-point slopes is also zero. In this study, there is a lot of zero rainfall at every station in January, which brings the zero Sen's slope to a significant Mann-Kendall test statistic where the actual trend is zero. But, in October, both CL35 and CL39 have a significant decreasing trend. While these stations have significant test statistic with zero slope means no trend at all in November and December. Except for April and May, most stations exhibit an insignificant decreasing trend throughout the year. Considerably decreasing annual rainfall trend is shown by station CL39 in an immense extents.

3.4. Abrupt change point

An abrupt changes in monthly and annual rainfall data from five stations are displayed in Table 6. Any station's confidence level with a star indicates statistically significant monthly and annual data signifying a change point at 5 % range [65]. Station CL35 has 98.8 % of the CUSUM runs, indicating an abrupt change in the direction of February rainfall in 2003 from positive to negative. Among all monthly data, this station has the highest confidence level change point of 98.8 %. Several stations have abrupt changes over the whole data record with statistical significance, in February, May, July, and September. Throughout May, station CL35 and CL29 show statistically significant abrupt change in 2001 and 2003, respectively over the total data of each station. While CL29 shows statistically significant abrupt change in 2008 and 2010 during July and September respectively. Stations CL35 and CL39 both have statistically significant change points in annual rainfall data in 2002 and 1998, respectively from positive to negative direction. Including February, rainy season and its subsequent months exhibit the most statistically significant reduction in rainfall at various stations. The reduction in rainfall occurred between 2001 and 2010. Stations with statistically insignificant confidence levels in annual and monthly rainfall data have several change points. This frequent change in phase reduces confidence level [9].

3.5. ANOVA, Tukey's range tests and linear regression

ANOVA can be used to determine whether differences between sets of time series data are statistically significant. The difference in monthly and annual rainfall amounts, as well as the number of different rainfall kinds, is examined in this study by ANOVA. Table 7 shows the significant difference in monthly and annual rainfall volumes among various stations. Except for January, March, and June, the table shows that there is a significant difference in all monthly rainfall amounts as well as annual rainfall volumes among all stations. Tukey's range tests in Table 8 show a position of significant difference among stations in monthly and annual rainfall, which is comparable to Table 7. Table 7 shows the lowest p value in May and annual rainfall; however, Table 8 shows the maximum variations between two separate stations throughout those time periods, which is comparable to the findings of other research work [67]. Five stations with such huge variations in rainfall volume are located around Sirajganj, covering a 2897.92 square kilometer area. Table 9 demonstrate the monthly and annual rainfall volume's R-square statistic and the slope of the regression equation. It is noticed that almost in every instance the R-square statistic value is low denotes a high variety of rainfall patterns along the time period. Alarmingly, almost every time period all stations exhibit a negative slope, particularly during the annual rainfall, when this is the case for every station. This indicates a progressive decrease in rainfall over time. With the exception of June, CL29 and CL34 exhibit the highest amount of negative slope almost every month and year. June is the only month during which rainfall increases at all stations except for CL39.

In January, according to Table 10 and Table 11, there are no significant differences between the stations in each category of rainfall assessed by ANOVA and Tukey's range tests. Because the dry season in Bangladesh lasts from November to February, rain is not a regular occurrence in January. There are many years amongst 1965 to 2021 where there was no rain in January. This is also observed in the case of January having zero slope when using Sen's slope estimator method (Table 5). Table 12 shows that low R-square statistic values indicate a poor proportion of variance for a dependent variable in a regression model that is explained by an independent variable, where time and the frequency of various types of rainfall are the respective independent and dependent variables in this case. The regression model explains just 10.99 % of the variability observed in the no rain event, with the highest value of R-square statistic being 0.1099, present at Cl29. Regardless of whether the R-square statistic is very low in each instance, a positive slope of the regression equation in the no rain event suggests a decrease in rainfall in January. In this case, a negative slope in practically every event, with the exception of no rain, is very relevant and denotes a gradual reduction in rainfall. In February, there is a noticeable

Table 6
Change-point in mean of the total rainfall volume of monthly and annual time period during 1965–2021.

Time period	Stations	Change Point	Confidence Level
February	CL35	2003+→-	98.8[a]
May	CL29	2003+→-	96.3[a]
	CL35	2001+→-	96.9[a]
July	CL29	2008+→-	95.7[a]
September	CL29	2010+→-	97.8[a]
Annual	CL35	2002+→-	98.2[a]
	CL39	1998+→-	99.9[a]

+→− = change from positive to negative direction.
[a] Statistically significant at the 5 % significance level.

Table 7
ANOVA test of five stations on monthly and annual rainfall volume.

Time Range	Sources	SS	df	MS	F	p value
February	Between Groups	34259.65634	4	8564.914086	8.384938576[a]	2.11167E-06[a]
	Within Groups	286009.9597	280	1021.464142		
April	Between Groups	118254.1157	4	29563.52893	3.089082555[a]	0.016379283[a]
	Within Groups	2679691.446	280	9570.326594		
May	Between Groups	819848.3396	4	204962.0849	13.13092374[a]	8.14385E-10[a]
	Within Groups	4370551.906	280	15609.11395		
July	Between Groups	498003.3129	4	124500.8282	3.277018872[a]	0.012001269[a]
	Within Groups	10637787.96	280	37992.09986		
August	Between Groups	928139.9607	4	232034.9902	5.827295891[a]	0.000161627[a]
	Within Groups	11149218.86	280	39818.63879		
September	Between Groups	1093315.451	4	273328.8627	8.493695281[a]	1.75796E-06[a]
	Within Groups	9010457.643	280	32180.20587		
October	Between Groups	681398.3778	4	170349.5944	10.44676083[a]	6.68933E-08[a]
	Within Groups	4565806.303	280	16306.45108		
November	Between Groups	8874.598377	4	2218.649594	2.591873393[a]	0.036936812[a]
	Within Groups	239680.6449	280	856.0023032		
December	Between Groups	10531.56839	4	2632.892097	3.010583812[a]	0.018641651[a]
	Within Groups	244872.7001	280	874.5453576		
Annual	Between Groups	422994965	4	105748741.2	151.3291949[a]	9.85899E-69[a]
	Within Groups	195663814.7	280	698799.3382		

[a] Statistically significant at the 5 % significance level.

Table 8
Tukey's range tests of monthly and annual rainfall volume of five stations.

Month	Group 1	Group 2	Mean	p-value	Month	Group 1	Group 2	Mean	p-value
February	CL29	CL40	23.456[a]	0.001[a]	October	CL29	CL34	120.728[a]	0.000[a]
	CL34	CL39	18.612[a]	0.018[a]		CL29	CL40	85.849[a]	0.004[a]
	CL35	CL40	23.503[a]	0.001[a]		CL34	CL35	100.435[a]	0.000[a]
	CL39	CL40	32.049[a]	0.000[a]		CL34	CL39	119.517[a]	0.000[a]
April	CL34	CL35	59.688[a]	0.011[a]		CL39	CL40	84.637[a]	0.004[a]
May	CL29	CL34	93.499[a]	0.001[a]	November	CL34	CL35	14.148[a]	0.037[a]
	CL29	CL40	99.726[a]	0.000[a]	December	CL29	CL34	16.482	0.026[a]
	CL34	CL35	68.349[a]	0.031[a]	Annual	CL29	CL34	1032.107	2.15E-09[a]
	CL34	CL39	132.349[a]	0.000[a]		CL29	CL35	773.230	1.33E-05[a]
	CL35	CL40	74.576[a]	0.014[a]		CL29	CL39	3619.029	6.21E-15[a]
	CL39	CL40	138.575[a]	0.000[a]		CL29	CL40	1499.277	6.43E-15[a]
July	CL29	CL39	124.436[a]	0.007[a]		CL34	CL39	2586.922	6.21E-15[a]
August	CL29	CL39	139.751	0.002[a]		CL34	CL40	467.171	0.026[a]
	CL35	CL39	152.872	0.001[a]		CL35	CL39	2845.799	6.21E-15[a]
September	CL29	CL40	174.813[a]	0.000[a]		CL35	CL40	726.047	5.31E-05[a]
	CL34	CL40	100.423[a]	0.025[a]		CL39	CL40	2119.751	6.21E-15[a]
	CL35	CL40	159.498[a]	0.000[a]					

[a] Statistically significant at the 5 % significance level.

difference in the frequency of light rain (Table 10) between stations CL39 and CL40 (Table 11). In this month for a dependent variable like the frequency of rainfall, the value of the R-square statistic (Table 12) is too low to explain any amount of variance. However, various rainfall events in different stations have both very mild positive and negative slopes of regression equations. The straight lines that these regression equations can plot on graphs with time and rainfall frequency as the independent and dependent variables respectively, will be roughly parallel to the x-axis.

In March with the beginning of the pre-seasonal monsoonal summer (March to May) the frequency of no rain events, as well as light and very heavy rain events, significantly changed (Table 10). Positions of significant differences are detected only between CL34 and CL39 in each scenario of no rain and light rain events (Table 11). However, in the case of very heavy rainfall frequency, there is a considerable difference between CL29 and four other stations. Similar to February, this month's R-square statistic (Table 12) value is too low to provide any context. According to Table 12, however the R-square statistic is very low in no rain, three out of five stations have a mild negative slope, which indicates an increase in rainfall. The slope of the regression equation for the various types of precipitation is both negative and positive. However, more light and heavy rainfall occur since four out of five stations have a positive slope. In April, significant differences between stations are absent in terms of all types of rainfall frequency. During this month R-square statistics are low as in prior months combined with both a negative and positive slope for the regression equation. A particular

Table 9
Slope of Regression equation and R-square statistic of monthly and annual rainfall volume of five stations.

Month	CL29		CL34		CL35		CL39		CL40	
	Slope	R^2	Slope	R^2	Slope	R^2	Slope	R^2	Slope	R^2
January	−0.1169	0.0493	−0.1955	0.0532	−0.1153	0.0548	−0.0222	0.0025	−0.221	0.0861
February	−0.1703	0.0219	−0.127	0.0044	−0.1129	0.0159	0.0102	0.0008	0.2856	0.0065
March	−0.4227	0.023	−0.0734	0.0014	−0.1705	0.0061	0.0161	0.00005	1.0374	0.0418
April	−0.607	0.0168	−0.4572	0.0081	0.3036	0.0138	0.2493	0.0006	0.625	0.0176
May	−1.2363	0.0342	−0.6448	0.0064	0.3127	0.002	1.1596	0.0252	−0.9032	0.0114
June	0.574	0.2816	0.2691	0.0823	0.9487	0.3702	−0.0387	0.0008	0.1775	0.0332
July	−2.0585	0.0259	−0.8567	0.0106	1.9462	0.0309	0.832	0.0028	−0.826	0.0078
August	−2.6463	0.0733	−3.3967	0.0809	−1.1201	0.0107	−2.0812	0.0156	3.715	0.1534
September	−2.3703	0.0847	−2.0222	0.0508	−2.0356	0.0334	−0.2831	0.0006	−4.3566	0.1022
October	−0.4794	0.0114	−1.838	0.0511	−0.8944	0.0195	0.8431	0.007	−2.2441	0.076
November	−1.2363	0.0342	−0.6448	0.0064	0.3127	0.002	1.1596	0.0252	−0.9032	0.0114
December	−0.0548	0.0188	−0.4739	0.0286	−0.2716	0.0394	−0.0802	0.0084	−0.2569	0.0127
Annual	−0.4156	0.0023	−1.8339	0.0098	−1.812	0.0039	−57.046	0.3036	−4.258	0.0257

Table 10
ANOVA test of frequency of different rainfall category at five stations in Monthly and Annual Time period.

Time Range	Type of Rain	Sources	SS	df	MS	F	P value
February	Light rain	Between Groups	21.944	4	5.486	2.834	**0.025**[a]
		Within Groups	542	280	1.936		
March	No rain	Between Groups	70.961	4	17.740	2.565	**0.039**[a]
		Within Groups	1936.702	280	6.917		
	Light rain	Between Groups	39.698	4	9.925	2.461	**0.046**[a]
		Within Groups	1129.298	280	4.033		
	Very heavy rain	Between Groups	2.211	4	0.553	8.596	**1.478E-06**[a]
		Within Groups	18	280	0.064		
May	No rain	Between Groups	359.944	4	89.986	3.271	**0.012**[a]
		Within Groups	7704.035	280	27.514		
June	No rain	Between Groups	480.758	4	120.189	5.8199	**0.0002**[a]
		Within Groups	5782.421	280	20.652		
	Light rain	Between Groups	472.793	4	118.198	8.9855	**7.684E-07**[a]
		Within Groups	3683.193	280	13.154		
July	No rain	Between Groups	506.442	4	126.611	6.321	**6.972E-05**[a]
		Within Groups	5608	280	20.029		
	Light rain	Between Groups	637.088	4	159.272	12.054	**4.716E-09**[a]
		Within Groups	3699.719	280	13.213		
	Heavy rain	Between Groups	39.214	4	9.804	2.916	**0.022**[a]
		Within Groups	941.298	280	3.362		
August	No rain	Between Groups	621.916	4	155.479	5.475	**0.0002**[a]
		Within Groups	7951.263	280	28.397		
	Light rain	Between Groups	663.663	4	165.916	11.832	**6.786E-09**[a]
		Within Groups	3926.316	280	14.023		
September	No rain	Between Groups	438.105	4	109.526	5.320	**0.0004**[a]
		Within Groups	5764.281	280	20.587		
	Light rain	Between Groups	387.775	4	96.944	9.053	**6.867E-07**[a]
		Within Groups	2998.526	280	10.709		
	Moderate rain	Between Groups	48.477	4	12.119	3.238	**0.013**[a]
		Within Groups	1048.035	280	3.743		
October	No rain	Between Groups	149.172	4	37.293	2.850	**0.024**[a]
		Within Groups	3664.140	280	13.086		
	Light rain	Between Groups	87.839	4	21.960	3.410	**0.010**[a]
		Within Groups	1802.947	280	6.439		
November	Light rain	Between Groups	17.874	4	4.468	5.007	**0.001**[a]
		Within Groups	249.895	280	0.892		
December	Light rain	Between Groups	4.547	4	1.137	3.052	**0.017**[a]
		Within Groups	104.281	280	0.372		
Annual	No rain	Between Groups	21112.856	4	5278.214	13.238	**6.85E-10**[a]
		Within Groups	111644.597	280	398.731		
	Light rain	Between Groups	16692.119	4	4173.030	16.162	**6.38E-12**[a]
		Within Groups	72295.123	280	258.197		
	Moderate rain	Between Groups	629.102	4	157.275	3.474	**0.009**[a]
		Within Groups	12675.684	280	45.270		

[a] Statistically significant at the 5 % significance level.

Table 11
Tukey's range tests of frequency of different rainfall category at five stations in Monthly and Annual Time period.

Time Range	Rainfall category	G1	G2	Mean	p-value	Time Range	Rainfall category	G1	G2	Mean	p-value
February	Light rain	CL39	CL40	0.807	**0.018**[a]	August	Light rain	CL29	CL34	2.737	**0.001**[a]
March	No rain	CL34	CL39	1.421	**0.034**[a]		Light rain	CL34	CL35	3.702	**2.61E-06**[a]
	Light rain	CL34	CL39	1.088	**0.033**[a]		Light rain	CL34	CL39	4.316	**2.62E-08**[a]
	Very heavy rain	CL29	CL34	0.211	**0.00013**[a]		Light rain	CL34	CL40	3.649	**3.77E-06**[a]
	Very heavy rain	CL29	CL35	0.228	**2.52E-05**[a]	September	No rain	CL29	CL34	2.719	**0.013**[a]
	Very heavy rain	CL29	CL39	0.228	**2.52E-05**[a]		No rain	CL34	CL35	3.667	**0.0002**[a]
	Very heavy rain	CL29	CL40	0.211	**0.00013**[a]		No rain	CL34	CL39	2.895	**0.007**[a]
May	No rain	CL34	CL39	3.263	**0.009**[a]		Light rain	CL29	CL34	2.228	**0.003**[a]
June	No rain	CL29	CL34	2.491	**0.030**[a]		Light rain	CL34	CL35	2.719	**0.000**[a]
	No rain	CL34	CL35	3.649	**0.000**[a]		Light rain	CL34	CL39	3.421	**0.000**[a]
	No rain	CL34	CL39	3.316	**0.001**[a]		Light rain	CL34	CL40	2.649	**0.000**[a]
	No rain	CL34	CL40	2.947	**0.006**[a]		Moderate rain	CL35	CL39	1.105	**0.021**[a]
	Light rain	CL29	CL39	1.877	**0.048**[a]	October	No rain	CL34	CL35	1.895	**0.0436**[a]
	Light rain	CL34	CL35	3.053	**0.000**[a]		No rain	CL34	CL39	2.053	**0.022**[a]
	Light rain	CL34	CL39	3.667	**0.000**[a]		Light rain	CL34	CL35	1.421	**0.025**[a]
	Light rain	CL34	CL40	2.860	**0.000**[a]		Light rain	CL34	CL39	1.491	**0.016**[a]
	Moderate rain	CL35	CL39	1.140	**0.011**[a]	November	Light rain	CL29	CL34	0.579	**0.010**[a]
July	No rain	CL29	CL34	3.281	**0.001**[a]		Light rain	CL34	CL39	0.754	**0.000**[a]
	No rain	CL34	CL35	3.491	**0.000**[a]	December	Light rain	CL34	CL35	0.351	**0.020**[a]
	No rain	CL34	CL39	3.316	**0.001**[a]		Light rain	CL34	CL39	0.316	**0.048**[a]
	No rain	CL34	CL40	3.211	**0.001**[a]	Annual	No rain	CL29	CL34	18.702	**9.99E-06**[a]
	Light rain	CL29	CL34	2.491	**0.003**[a]		No rain	CL34	CL35	22.912	**3.04E-08**[a]
	Light rain	CL29	CL39	2.000	**0.029**[a]		No rain	CL34	CL39	23.667	**9.83E-09**[a]
	Light rain	CL34	CL35	3.246	**0.000**[a]		No rain	CL34	CL40	15.228	**0.001**[a]
	Light rain	CL34	CL39	4.491	**0.000**[a]		Light rain	CL29	CL34	12.965	**0.0002**[a]
	Light rain	CL34	CL40	3.281	**0.000**[a]		Light rain	CL29	CL39	9.754	**0.012**[a]
	Heavy rain	CL29	CL39	1.088	**0.015**[a]		Light rain	CL34	CL35	18.175	**4.91E-08**[a]
August	No rain	CL29	CL34	3.175	**0.014**[a]		Light rain	CL34	CL39	22.719	**6.23E-12**[a]
	No rain	CL34	CL35	4.263	**0.0003**[a]		Light rain	CL34	CL40	15.544	**4.54E-06**[a]
	No rain	CL34	CL39	3.649	**0.003**[a]		Moderate rain	CL34	CL35	3.877	**0.019**[a]
	No rain	CL34	CL40	3.070	**0.019**[a]		Moderate rain	CL35	CL40	3.649	**0.033**[a]

[a] Statistically significant at the 5 % significance level.

characteristic that stands out is that four of the five stations have a negative slope when there is no rainfall, meaning that the dry days of April are replaced by rainy days. Only the no rain event (Table 10) in CL34 and CL39 (Table 11) showed a significant difference in May. Table 12 shows, the slope of the regression equation nearly parallel to x-axis and the R-square statistic is very low. Here, three of the five stations have a mildly negative slope when there is no rain, and all five have a mildly positive slope when there is light rain. Whereas in May, all five stations have both a mildly negative and positive slope when there is moderate, moderately heavy, heavy or very heavy rain. Pre-seasonal monsoonal summer's two of three months show a significant difference in the number of dry days across five stations. While in most cases throughout this season, dry days gradually give way to rainy days.

The rainy season in this region lasts from June through October. In June at the beginning of rainy season, the p values of no rain, light rain, and moderate rain events demonstrate significant differences (Table 10). In each scenario of no rain and light rain of this month, positions of significant differences are found between CL34 and the same three other stations, such as CL35, CL39, and CL40 (Table 11). Also, there are significant differences between other two pair of stations in both the no rain and light rain scenarios. There is a significant differences between CL35 and CL39 with moderate rain. According to Table 12, negative slope in regression equation and a low R-square statistic in the no rain are detected at one of the five stations. In other type of rainfall, all of the stations have low R-square statistics and both positive and negative slopes. The significant difference between events with no rain or light rain in July and those with rain in June is relatively similar (Tables 10 and 11). The difference is that in July, there is a significant difference in heavy rainfall. The value of the R-square statistic in July is relatively higher than in June (Table 12). The nature of the slope at no rain is comparable to June, but most other types of rainfall have an increasing quantity of negative slope at different stations. Also there is a significant difference in no rain and light rain throughout August (Tables 10 and 11), similar to June and July. Table 12 indicates that the value of the R-square statistic grew in August, notably in the no rain. In the no rain, every station has a positive slope of the regression equation, however in other rainfall events, the majority of the stations have a negative slope. September has a significant difference in No rain, Light rain, and Moderate rain, as shown in Table 10. And the rainfall variations of the stations responsible for this difference are shown in Table 11. Like August, September has relatively high R-square statistic values, as shown in Table 12. When there is no rain, the slope of the regression equation is positive, indicating a rise in dry days similar to August rainfall. The slope of the majority of the other types of rainfall is also negative. Tables 10 and 11 show the same type of substantial difference between no rain and light rain in October compared to previous months. The nature of the regression equation is also relatively similar to September

Table 12
Slope of Regression equation and R-square statistic of frequency of different rainfall category at five stations in Monthly and Annual Time period.

Station	No rain		Light rain		Moderate rain		Moderately heavy rain		Heavy rain		Very heavy rain	
	Slope	R^2	Slope	R^2	Slope	R^2	Slope	R^2	Slope	R^2	Slope	R^2
January												
Cl29	0.0185	0.1099	−0.0139	0.0945	−0.0029	0.0115	−0.0017	0.0227	–	–	–	–
CL34	0.006	0.0059	−0.0035	0.0029	−0.0017	0.0046	−0.0008	0.0033	–	–	–	–
CL35	0.0063	0.0115	−0.0148	0.0559	−0.0051	0.0659	−0.0032	0.084	–	–	–	–
CL39	0.012	0.0465	0.0021	0.0016	−0.0023	0.0296	−0.001	0.0045	–	–	–	–
CL40	0.021	0.0745	−0.0086	‘0.0317	−0.004	0.0208	−0.0023	0.0279	–	–	–	–
February												
Cl29	0.0005	3E-05	0.0109	0.0182	−0.0086	0.0281	0.0004	0.0012	–	–	−0.0013	0.0264
CL34	0.0014	0.0002	−0.0026	0.0009	−0.0002	3E-05	0.0036	0.025	−0.0013	0.0091	–	–
CL35	0.0172	0.028	−0.0069	0.007	0.0002	0.002	−0.0011	0.0029	−0.0011	0.0097	–	–
CL39	0.0138	0.0452	−0.0135	0.0522	0.0023	0.0053	−0.0047	0.0469	−0.0002	0.0003	–	–
CL40	0.0328	0.0527	0.0218	0.0443	0.0102	0.0387	−0.0028	0.0223	0.001	0.0036	0.0034	0.0943
March												
Cl29	−0.0221	0.0217	0.0305	0.0668	0.0023	0.0017	−0.0101	0.0984	−0.0006	0.0005	−0.0101	0.0984
CL34	−0.013	0.0066	0.0243	0.0349	−0.0051	0.0075	−0.0069	0.037	0.0007	0.0012	–	–
CL35	0.0113	0.0088	0.0018	0.0003	−0.0075	0.0284	−0.0084	0.0404	0.0027	0.0134	–	–
CL39	0.0091	0.003	−0.005	0.002	−0.0016	0.0009	−0.0044	0.0233	0.0019	0.0113	–	–
CL40	−0.0355	0.0351	0.0255	0.0369	−0.0034	0.0054	0.0012	0.0007	0.0105	0.0562	0.0018	0.0481
April												
Cl29	−0.0362	0.0211	0.0751	0.1117	−0.024	0.0873	−0.013	0.043	−0.0014	0.0014	−0.0005	0.0015
CL34	−0.0022	8E-05	−0.0101	0.0028	0.0126	0.0277	-6E-05	5E-07	−0.0006	0.0003	0.0005	0.0016
CL35	0.0293	0.0108	−0.0108	0.0017	−0.0034	0.0027	−0.0056	0.0075	−0.0089	0.065	−0.0005	0.0015
CL39	−0.1048	0.1128	0.0771	0.116	0.0183	0.0454	−0.0046	0.0059	0.0062	0.0125	0.0078	0.0253
CL40	−0.0773	0.0664	0.0549	0.0448	0.005	0.0039	0.0119	0.0328	0.007	0.0209	−0.0015	0.0178
May												
Cl29	0.008	0.0007	0.0642	0.0506	−0.022	0.0349	−0.0346	0.1394	−0.0169	0.0832	0.0012	0.0013
CL34	−0.0009	1E-05	0.0016	5E-05	−0.0136	0.022	0.0019	0.0005	0.0139	0.0263	−0.0029	0.006
CL35	0.0158	0.0022	0.0002	4E-07	−0.0215	0.0343	−0.0058	0.0035	0.0097	0.0327	0.0017	0.0024
CL39	−0.0854	0.0586	0.0754	0.069	0.0181	0.0281	−0.0025	0.0007	−0.0106	0.0247	0.005	0.041
CL40	−0.0751	0.0646	0.055	0.0364	−0.0017	0.0003	0.008	0.0079	0.0145	0.0436	0.0048	0.04
June												
Cl29	0.0519	0.0347	0.0165	0.0049	−0.0404	0.0995	−0.0112	0.0148	−0.0128	0.0183	−0.004	0.0059
CL34	0.0428	0.0266	−0.0175	0.007	−0.0078	0.0059	−0.0026	0.0006	−0.0099	0.0152	−0.0049	0.011
CL35	0.1213	0.1747	−0.095	0.1589	−0.0305	0.1001	−0.0056	0.0051	−0.0027	0.0009	0.0124	0.0736
CL39	−0.0487	0.0312	0.0027	0.0004	0.0191	0.0238	0.0015	0.0004	0.0316	0.0633	−0.0062	0.0279
CL40	0.0161	0.0038	0.0036	0.0002	−0.026	0.0546	0.003	0.0011	0.0034	0.0021	−0.0002	2E-05
July												
Cl29	0.1184	0.1614	−0.0363	0.0224	−0.0244	0.028	−0.0326	0.1014	−0.02	0.0418	−0.0051	0.0062
CL34	0.045	0.0367	−0.0429	0.0453	0.0212	0.0346	−0.0023	0.0006	−0.0166	0.0385	−0.0044	0.0093
CL35	0.1698	0.2874	−0.1372	0.2799	−0.046	0.144	−0.0161	0.0236	0.0136	0.0235	0.0159	0.0814

(*continued on next page*)

Table 12 (*continued*)

January												
Station	No rain		Light rain		Moderate rain		Moderately heavy rain		Heavy rain		Very heavy rain	
	Slope	R^2	Slope	R^2	Slope	R^2	Slope	R^2	Slope	R^2	Slope	R^2
CL39	−0.024	0.0096	−0.038	0.0415	0.0172	0.0253	−0.0041	0.0011	0.0474	0.0783	0.0015	0.0016
CL40	0.0533	0.0467	−0.0413	0.0444	−0.0137	0.0129	−0.0062	0.0052	0.007	0.0063	0.0008	0.0005
August												
Cl29	0.1816	0.3116	−0.0549	0.0618	−0.0573	0.1661	−0.0322	0.0904	−0.0226	0.0412	−0.0145	0.1275
CL34	0.0905	0.1115	−0.0434	0.0413	−0.0285	0.0686	−0.0123	0.0145	−0.0039	0.0029	−0.0025	0.0019
CL35	0.2386	0.391	−0.1275	0.2368	−0.0697	0.2422	−0.0141	0.0197	0.0427	0.0654	0.0049	0.0113
CL39	0.066	0.0408	−0.0843	0.1473	−0.0145	0.0157	−0.0148	0.023	−0.019	0.0622	−0.0073	0.0417
CL40	0.1403	0.2351	−0.0758	0.1325	−0.0448	0.1154	0.0065	0.0034	−0.0244	0.0621	−0.0029	0.0035
September												
Cl29	0.1821	0.359	−0.0506	0.0649	−0.0641	0.2046	−0.0426	0.1705	−0.0204	0.0439	−0.0044	0.0154
CL34	0.0159	0.0056	0.0117	0.0042	−0.0114	0.0125	−0.0161	0.0384	−0.0002	1E-05	0.0001	1E-05
CL35	0.1762	0.3279	−0.0716	0.096	−0.0433	0.1813	−0.0345	0.1339	−0.0296	0.1264	0.0027	0.0024
CL39	0.0244	0.0068	−0.0387	0.038	−0.002	0.0002	0.011	0.0104	0.0098	0.0078	−0.0045	0.0137
CL40	0.0986	0.1843	−0.0453	0.0686	−0.0323	0.1058	−0.016	0.0329	−0.0081	0.0109	0.0032	0.0043
October												
Cl29	0.0018	7E-05	0.0468	0.0693	−0.0098	0.0168	−0.0228	0.1451	−0.0095	0.0465	−0.0065	0.069
CL34	0.0108	0.0033	−0.0235	0.023	0.003	0.0026	0.0073	0.0125	−0.0032	0.0039	0.0056	0.0367
CL35	0.0683	0.0847	−0.0204	0.0175	−0.0257	0.0857	−0.0113	0.0535	−0.0108	0.0265	−0.0001	2E-05
CL39	0.0136	0.0026	−0.0233	0.026	0.0071	0.0107	−0.0005	3E-05	0.0099	0.0085	−0.0069	0.0711
CL40	0.0119	0.0046	−0.0062	0.0023	−0.0043	0.0038	0.0009	0.0002	−0.0008	0.0003	−0.0016	0.0026
November												
Cl29	0.0135	0.0306	−0.0044	0.0071	−0.0015	0.0064	−0.0051	0.033	−0.0025	0.0252	–	–
CL34	0.0169	0.0374	−0.0107	0.0227	−0.003	0.0181	−0.0023	0.0184	−0.0009	0.0014	–	–
CL35	0.0343	0.1621	−0.0245	0.1501	−0.0069	0.0595	−0.0019	0.0054	−0.0012	0.0074	0.0001	0.0003
CL39	0.0206	0.0599	−0.0095	0.0462	−0.0064	0.0303	−0.0058	0.0548	0.0005	0.0015	0.0006	0.0053
CL40	0.0073	0.0105	−0.0007	0.0002	−0.0069	0.0392	6E-05	1E-05	0.0002	0.0001	–	–
December												
Cl29	0.0098	0.0438	−0.0047	0.0203	−0.002	0.0137	−0.0022	0.0388	−0.0009	0.0066	–	–
CL34	0.0087	0.016	−0.0078	0.0233	−0.0018	0.0041	0.0006	0.0018	0.0003	0.0008	–	–
CL35	0.0164	0.1106	−0.01	0.1413	−0.0024	0.0239	−0.0014	0.0148	−0.0027	0.0166	–	–
CL39	0.0143	0.0578	−0.0116	0.1152	−0.0005	0.0004	−0.0013	0.0026	−0.0009	0.0129	–	–
CL40	0.0025	0.0022	−0.0025	0.005	0.0018	0.0053	−0.0027	0.02	0.001	0.0076	–	–
Annual												
Cl29	0.574	0.2816	0.0792	0.0062	−0.2546	0.2684	−0.2078	0.2932	−0.1075	0.1278	−0.0453	0.141
CL34	0.2691	0.0823	−0.1244	0.027	−0.0364	0.013	−0.0299	0.0127	−0.0216	0.0109	−0.0086	0.0065
CL35	0.9487	0.3702	−0.4997	0.1815	−0.2692	0.332	−0.1089	0.1263	−0.0554	0.0439	0.0292	0.0355
CL39	−0.0387	0.0008	−0.0773	0.0071	0.055	0.0188	−0.0314	0.0063	0.1382	0.0547	0.0023	0.0003
CL40	0.1775	0.0332	−0.0257	0.0007	−0.1201	0.1468	0.0016	4E-05	0.0167	0.0071	0.0034	0.0016

except that the R-square statistic value is lower than in prior months. During this study, it is clear that the number of dry days during the rainy season is gradually increasing while the number of rainy days decreases.

In November and December during the start of the dry winter, Table 10 shows nearly identical results. ANOVA test revealed a significant difference in light rain in both November and December. Tukey's range tests, on the other hand, reveal a significant difference in different positions throughout November and December. Furthermore, the majority of the rainfall occurrences during these two months have a negative slope. The R-square statistic values for these two months are also poor.

In the case of an ANOVA test of five stations' annual varied rainfall categories, a significant difference is found in the no rain, light rain, and moderate rain (Table 10). In Table 11 Tukey's range tests show that station CL34 has a significant difference with other stations in the no rain and light rain categories. In the category of moderate rainfall, CL35 differs significantly from CL34 and CL40. According to Table 12, dry days gradually take the place of rainy days throughout the year especially in rainy season. R-square statistic value is low but substantially stronger than monthly one when seen from an annually perspective. The number of dry day increases throughout the year for all stations, with the exception of CL39, have negative slopes in the regression equation for the no rain category. In the instance of CL39, the R-square statistic is very small, and the slope of the regression equation reflects a line that is nearly parallel to the x-axis. Almost every category of rainfall has a negative slope in the regression equation. In a case of very heavy rain, two of the three stations show a positive slope, but the R-square statistic is quite low.

One distinguishing feature is that the number of dry days decreases throughout the pre-monsoonal summer and increases during the rainy season. Overall number of dry day and rainy day increases and decreases respectively throughout the year. Figs. 4 and 5 show the temporal propagation nature of annual dry day and rainy day. Wherever CL29, CL34, and CL35 have sharp positive and negative regression equation slope, indicating an increase and decrease in the number of dry and rainy days, respectively, which is the graphical depiction of the prior claim.

4. Discussion

The present study assesses the climate change convinced rainfall trend and changeability through non-parametric and linear technique for Sirajganj district in Bangladesh for total time span 57 years after 1965 to 2021. The key goal of this study to investigate the trends and variability for the monthly and annual rainfall. The main findings of this research work are as follows:

The standard deviation begins to rise towards the beginning of the pre-monsoonal summer and peaks in the midst of the rainy season. The variability of the quantity of rainfall in a specific period rises and the highest variability is observed during the annual rainfall. But, in rainy season, the station CL39 displays the maximum rainfall variability. The district Bogra, which is located just north of the administrative boundary of the study area, shows the similarity in case of the mean monthly rainfall variability period [68]. In the present study area, stations CL29, CL34, CL35, CL39 and CL40 have monthly standard deviations ranging from 6.63 - 212.22 mm, 14.07–198.18 mm, 8.18–184.75 mm, 5.91–276.15 mm and 12.51–226.18 mm respectively, whereas in Bogra, the standard deviation of mean monthly rainfall is 167.79 mm [68]. In addition, a study [69] found significant variations in rainfall in Rajshahi division during January, February, March, April, May, June, July, August, September, October, November, and December with respect to standard deviation ranges of 14.6 mm, 15.3 mm, 26.0 mm, 56.9 mm, 67.4 mm, 120.8 mm, 136.8 mm, 101.1 mm, 129.1 mm, 81.3 mm, 20.7 mm, and 20.5 mm respectively. On the other hand, the standard deviations for the stations CL29, CL34, CL35, CL39 and CL40 from January to December are in the range of 7.40–14.07 mm, 5.91–58.90 mm, 32.41–84.22 mm, 42.84–163.51 mm, 110.92–140.7 mm, 149.94–192.52 mm, 138.16–260.72 mm, 157.41–276.15 mm, 135.18–226.18 mm, 74.41–167.86 mm, 17.27–35.52 mm and 6.63–46.52 mm respectively. So, the results of [69] and present study mostly match well, as Sirajganj is a district of Rajshahi Division.

Different stations display a statistically significant negative trend in rainfall from the end of the pre-monsoonal summer to the rainy season at both the 1 % and 5 % significance levels. Maximum four out of five stations exhibit a significant negative trend in August and September. In terms of annual rainfall, CL39 exhibits a maximum negative trend with a steep slope. Bogra district in the north of the study area has a positive rainfall trend in May, September and December, with a significant positive rainfall trend in April and other eight months face a negative trend with significance in March [68]. The results of both research works are comparable in both similarity and dissimilarity. Considering whole Bangladesh, a study [68] represents the mean result of country-wise different districts,

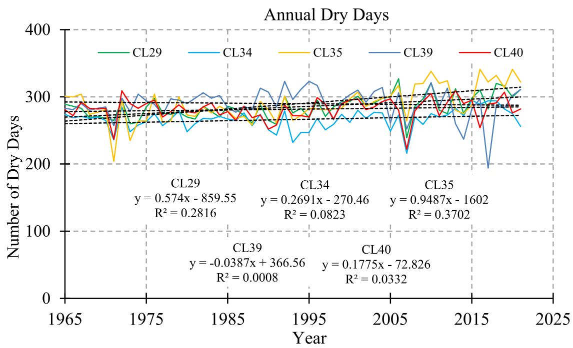

Fig. 4. Five stations' annual dry day count fluctuation over time.

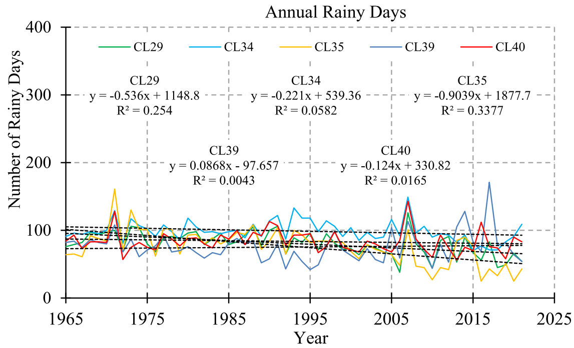

Fig. 5. Five stations' annual rainy day count fluctuation over time.

whereas the present work considers five stations in the same district. The overall trend pattern of these two districts matches well.

Maximum three abrupt shifts from a positive to a negative direction are found at Station CL29 in May, July, and September of 2003, 2008, and 2010, respectively. Two abrupt changes to CL35 were found in February and May of 2003 and 2001, respectively. During 1998, CL39 abruptly changes at total annual precipitation. For CL29 and CL35, there are rapid changes in the monthly rainfall, but for CL39, there are abrupt changes in the annual rainfall pattern. The worrisome fact is that the rainy season is when each significant negative trend and change point happens. This is a sign of climate change. There is research work on global historical rainfall observations to detect regions that have undergone large, sudden decreases in rainfall [71]. Their result show that in the 20th century, about 30 regions in the world have experienced such changes. This research work [71] discovered abrupt drops in rainfall in the current study zone.

Nine out of the twelve months, with the exception of January, March, and June, have shown a significant difference in the ANOVA test of five stations on monthly volume. Additionally, a significant difference was discovered during the testing of five stations' yearly rainfall volumes. In the case of monthly data, Tukey's range test shows that station CL34 has a significant amount of difference from other stations. However, in terms of annual data, Station CL29 differs significantly from all other stations, while Station CL34 differs from three other stations. During the rainy season, a meaningful significant difference between stations CL34 and other stations is seen in the ANOVA of monthly rainfall frequency. This significant difference is primarily seen during the rainy season and occurs in case of no rain and light rain events. It is also seen in case of annual time period when CL34 has the significant difference with others at no and light rain event. The outcome is consistent with that of previous research [26]. However, in terms of the catchment area of the current study area, this kind of study is infrequent. Therefore, further research is required to completely analyze the study area.

Annual rainfall is decreasing day by day in every station except station CL39, no rain has a positive slope in the regression equation, indicating that dry days generally rise during the year. Despite the fact that CL39 is an outlier, its slope is almost always parallel to the x-axis, implying that it responds to changes in state slowly. The frequency of dry days reduces during the pre-monsoonal summer and increases during the rainy season, which is one differentiating feature. CL29, CL34, and CL35 have a notable strong positive and negative regression slope, indicating an increase in the number of dry and decrease in the number of rainy days, respectively. The present results of the linear approach are mostly alike to those of past research [69] based on the rainfall pattern of Rajshahi Division.

The methodologies mentioned above and the types of data used in this study are nearly the same as those used by other researchers [2,26,67–70]. The primary distinction is the research area, which includes positions and regions such as tropical, arid desert and tundra regions. Rainfall trends can be both positive and negative depending on the position and region, which indicates an alteration in the LULC and climate and these researchers assert it as well. Additionally, the current study's pattern of outcomes aligns with the previously cited researchers. The current study's validity is assured based on the methodology used in comparison with other researchers.

5. Conclusion

This study assesses the variability of rainfall trends at five sites in Sirajganj. The Raiganj and Sirajganj areas, which are classified as CL29 and CL34 respectively by the BWDB, exhibit high rainfall variability. However, the Shazadpur area (CL35) and Raiganj (CL29) show a concerning quantity of decreasing rainfall. The Taras area, labeled as CL39, has a strong yearly negative rainfall trend. Because the region's vulnerability to slight climatic changes, all findings are critical for the planning and management of water-related activities and programs including water supply and agriculture. In overall, the findings of nonparametric techniques such as the Mann-Kendall test, Sen's slope estimator, ANOVA, Tukey's range tests, and linear approach highlight the consistency in results in the identification of the trend and variability for the rainfall of Sirajganj. Most of the study area's results are compared to those of the Bogra districts and Rajshahi division, which share the same catchment area. The results of this study will help in a deeper investigation of the fundamental causes of this district's rainfall's trend and variability. Even if some statistically significant findings appeared from the rainfall data analysis, it is still critical for planning water-related initiatives and projects given the region's vulnerability and fragility to slight rainfall variability. The present study focuses mostly on non-parametric procedures, however some rainfall patterns remain uninterpreted. More research is required to understand such a complicated rainfall pattern. The rainfall frequency pattern of various stations is not thoroughly investigated here. The movement of different rainfall categories throughout the year can be explored in depth. More research should be conducted in future on the frequency, central tendency, dispersion or variation, and position of the Sirajganj rainfall time series.

6. Data availability statement

The data associated with this study have not been deposited into a publicly available repository. The data associated with this study will be made available on request.

CRediT authorship contribution statement

Chandan Mondal: Writing – original draft, Visualization, Validation, Software, Methodology, Investigation, Formal analysis, Data curation, Conceptualization. **Md Jahir Uddin:** Writing – review & editing, Visualization, Supervision, Investigation, Data curation, Conceptualization.

Declaration of competing interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

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