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Long-Term Trend and Variability of Rainfall in Bangladesh

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Abstract

The study of long-term rainfall data is significantly important for the country, whose food security and economy depend on the timely availability of water. In this study, spatial and temporal rainfall variability in Bangladesh were analysed for seasonal and annual trends by using monthly rainfall data for 40 years (1981–2020) from 34 stations of Bangladesh Meteorological Department. Linear regression analysis and Mann-Kendall (MK) test were used to identify trends and magnitude of the change and Sen's slope to estimate the slope of the trend line. The Coefficient of Variation (CV) was used to examine the variability of rainfall. Spatial interpolation technique was done by a Kriging method using Surfer for interpolating the spatial pattern over Bangladesh. With the exception of a few stations, the findings of both parametric and non-parametric tests and trend tests were insignificant for most stations, and these stations revealed a falling trend in annual rainfall. Sen's test showed a decreasing trend for both annual and monsoon rainfall in almost all stations. Over the 40-year periods, among the seasons, the highest percentage of variability was observed in winter rainfall (148.6%) while the lowest percentage variability was observed in annual series (12.1%). The analysis of rainfall data could help irrigation and agricultural management plan for the most efficient use of water resources in Bangladesh.

Keywords: Trend Analysis; Mann–Kendall Test; Sen's Test; Rainfall; Rainfall Variability.

Introduction

Bangladesh is a small country with an area of about 147,570 square kilometres located in the north-eastern part of South Asia within 88.02-92.68oE and 20.57-26.63oN. Land of Bangladesh is very flat: elevation is about 1-37 meters above sea level except for small parts of it. The southeast (about 200 m altitude) part which borders Myanmar and, in the northeast, (height of about 100 m) part which is on the border of Shillong Hill in India.

Bangladesh being an agricultural country, rice is the staple food and success or failure of the crops and water shortage are always considered the most important. A major portion of annual rainfall over Bangladesh is received during the summer monsoon season (June–September). Summer monsoon is also known as southwest monsoon in Bangladesh as well as in South Asia. Summer monsoon rainfall contributes about 70% of its annual rainfall over Bangladesh [1]. In addition, the summer monsoon season in Bangladesh is characterized by the occurrence of severe floods due to heavy rainfall causing extensive damage to crops, road, livestock, and properties associated with loss of valuable lives. Any change or variation in climate and climatic scenarios affecting the summer monsoon rainfall over Bangladesh as well as South Asia is considered to be a direct threat to the economy of Bangladesh. Annual variations in monsoon rainfall cause extreme hydrological events (widespread droughts and floods) from time to time, resulting in a dangerous reduction in agricultural production and affecting the country's large population and economy. A normal monsoon rainfall that is evenly distributed across the country is a benefit, but an extreme occurrence such as floods or droughts that affect the entire country or a smaller area is a natural hazard. As a result, monsoon and annual rainfall and temperature variability can be used to assess climatic variability and change in Bangladesh in the context of global warming. Thus, the availability of appropriate water for irrigation under changing climatic situations is critical for Bangladesh, where agriculture has a huge impact on both the economy and people's lives. The timely supply of water is critical to agricultural output. Population expansion, as well as increased demand for irrigation water and industry, will place more pressure on the environment in the future.

Water is essential to almost every part of the biosphere and human societies; the most severe effects of global warming are expected to be seen through changes in the hydrologic cycle [2]. The idea of global warming causing the hydrological cycle to accelerate is of particular relevance. As a result, the intensity of both wet and dry extremes has increased [3-10]. However, the factors regulating the increase in wet and dry episodes are likely to be closely interrelated, and manifestations of the same underlying hydroclimatic reaction [5, 7].

Agriculture production, flood control, and efficient water resource management have all become key priorities for any development or planning project. The uneven distribution of water supplies across Bangladesh is one of the major challenges facing water resource management in the country. This is due to the natural pattern (temporal and spatial) of rainfall, which varies greatly in time and location and climate change is exacerbating this variability [11].

Changes in rainfall response as a result of climate change are alarming hydrologists and water resource managers because these changes in rainfall quantity and frequency are currently altering the pattern of streamflow and demands, spatial and temporal distribution of runoff, soil moisture, and groundwater reserves [11-13]. Changes in rainfall have had a substantial impact on society, thus current data is required to determine the geographical distribution and variability at all places across India [14]. Floods and droughts would be more likely as a result of the substantial change in rainfall patterns [15]. The amount of rainfall affects aquifer recharging and soil moisture levels for agricultural crop production [16]. As a result, regular rainfall monitoring is essential for improved food security, as changes in rainfall distribution over time have an impact on cropping patterns and productivity [17].

The agriculture sector appears to be the worst hit, with rain falling when it isn't supposed to, and frequently accompanied by violent winds and hail, resulting in massive crop losses and crushing farmers that rely solely on their crops. Another irony is that floods are occurring in one location while drought is occurring in another. As a result, it's critical to determine whether rainfall has a trend or a pattern in its variability.

To understand the nature of rainfall fluctuations more research is needed for Bangladesh. In light of the foregoing, the purpose of this research is to examine rainfall patterns and variability over Bangladesh.

Data used

Monthly rainfall data of the 34 stations of Bangladesh were collected from Bangladesh Meteorological Department (BMD) and used to investigate the spatial and temporal variability of rainfall data series for the period 1981 to 2020 (40 years). Fig. 1 depicts the locations of meteorological stations of BMD.

There are four distinct seasons in Bangladesh, according to the Bangladesh Meteorological Department, namely (1) pre-monsoon (March–May), (2) monsoon (June–September), (3) post-monsoon (October–November) and (1) winter (December–February), are prevailing in Bangladesh. Fig. 1 depicts the spatial distribution of stations, and lists of the station characteristics and data availability are presented in Table 1.

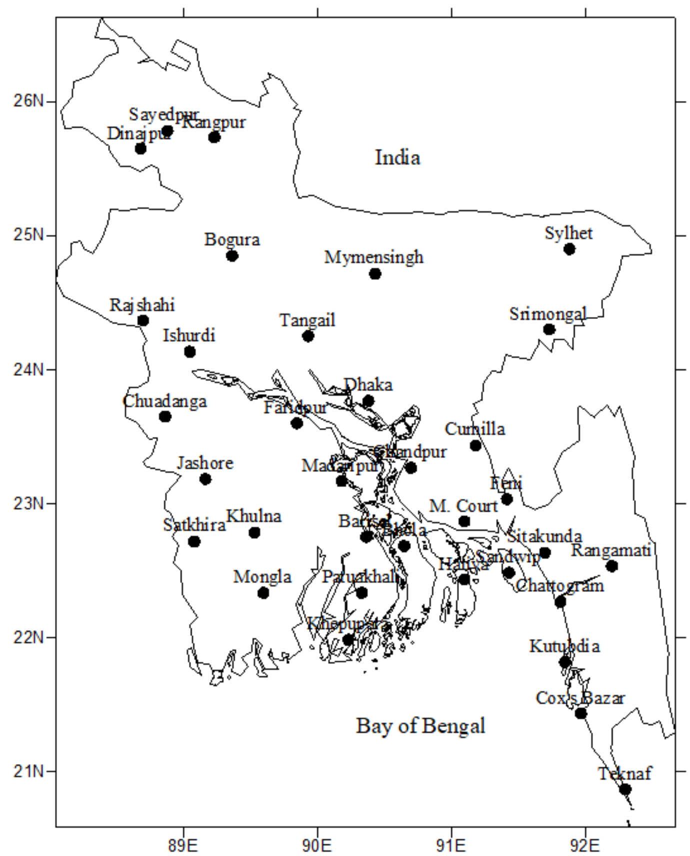


Figure 1: Map showing Bangladesh Meteorological Department observational rain-gauge stations.

Table 1: Statistical summary of seasonal and annual rainfall over Bangladesh

Stations	Pre-monsoon			Monsoon			Post-monsoon			Winter			Annual		
Name	Mean	SD	CV	Mean	SD	CV	Mean	SD	CV	Mean	SD	CV	Mean	SD	CV
Dinajpur	318.1	136.0	42.8	1486.2	413.6	27.8	149.2	157.3	105.5	28.0	25.1	89.7	1980.3	483.4	24.4
Sayedpur	358.6	161.5	45.0	1557.1	410.8	26.4	154.9	152.6	98.5	21.2	18.0	85.1	2091.8	505.2	24.2
Rangpur	444.3	154.1	34.7	1643.4	442.1	26.9	166.6	138.6	83.2	28.0	21.3	76.0	2281.2	507.7	22.3
Bogura	327.3	132.3	40.4	1232.0	329.1	26.7	157.6	118.4	75.1	29.0	27.2	93.9	1743.8	396.6	22.7
Rajshahi	237.4	99.5	41.9	1030.0	270.3	26.2	125.1	83.7	66.9	33.7	39.4	116.7	1423.9	298.9	21.0
Ishurdi	286.9	134.0	46.7	1051.7	247.5	23.5	131.8	109.3	82.9	35.7	34.8	97.5	1504.9	303.1	20.1
Tangail	426.7	148.5	34.8	1178.8	294.4	25.0	171.7	119.9	69.8	41.9	36.4	87.0	1818.3	360.2	19.8
Mymensingh	522.6	179.6	34.4	1513.3	345.6	22.8	203.2	146.7	72.2	35.4	31.9	89.9	2272.5	479.1	21.1
Sylhet	1137.2	328.7	28.9	2684.9	466.3	17.4	229.2	136.3	59.4	55.6	42.4	76.2	4106.2	661.7	16.1
Srimangal	783.9	289.3	36.9	1407.7	269.8	19.2	196.4	118.3	60.3	51.3	48.7	95.0	2438.6	481.3	19.7
Dhaka	479.4	181.0	37.8	1328.5	362.2	27.3	193.7	123.6	63.8	40.3	35.3	87.6	2041.0	475.0	23.3
Chuadanga	246.6	124.2	50.4	1054.6	267.3	25.3	138.5	102.0	73.6	47.4	48.7	102.7	1487.0	283.5	19.1
Faridpur	385.8	155.7	40.4	1177.9	285.4	24.2	178.5	102.6	57.5	45.0	43.7	97.1	1784.8	362.8	20.3
Jashore	305.0	110.3	36.2	1175.1	281.3	23.9	161.5	114.2	70.7	52.4	55.3	105.5	1690.3	320.9	19.0
Satkhira	285.9	107.5	37.6	1215.5	237.9	19.6	173.1	118.4	68.4	56.2	51.5	91.8	1728.2	258.3	14.9
Mongla	277.3	99.7	35.9	1397.5	286.8	20.5	209.4	125.3	59.8	41.5	35.5	85.7	1925.6	313.5	16.3
Khulna	313.8	138.5	44.2	1279.0	322.1	25.2	181.7	111.8	61.5	56.1	58.8	104.9	1828.9	364.6	19.9
Madaripur	409.7	184.9	45.1	1337.0	327.7	24.5	186.5	116.5	62.5	39.9	39.6	99.2	1971.7	392.1	19.9
Khepupara	387.3	150.4	38.8	2074.6	326.5	15.7	340.9	214.8	63.0	41.0	37.7	92.0	2843.5	400.0	14.1
Chandpur	494.6	293.8	59.4	1455.8	454.2	31.2	201.0	112.3	55.9	37.9	36.0	95.0	2188.2	558.3	25.5
Cumilla	534.1	204.9	38.4	1329.0	298.9	22.5	180.0	102.0	56.7	40.9	44.4	108.7	2083.3	407.9	19.6
M. Court	556.9	187.8	33.7	2275.2	473.6	20.8	259.5	157.2	60.6	41.8	38.6	92.4	3132.9	514.0	16.4
Feni	592.7	226.0	38.1	2135.2	388.1	18.2	259.0	159.6	61.6	39.6	38.3	96.8	3026.2	572.1	18.9
Hatiya	479.1	191.2	39.9	2477.4	427.3	17.2	336.9	181.5	53.9	39.2	43.0	109.7	3331.0	546.4	16.4
Sandwip	567.5	251.4	44.3	2738.8	631.8	23.1	324.1	187.4	57.8	37.9	38.4	101.4	3667.6	786.1	21.4
Sitakunda	567.7	215.2	37.9	2364.2	571.7	24.2	299.0	209.4	70.0	36.3	53.9	148.6	3267.0	678.8	20.8
Rangamati	523.4	214.7	41.0	1781.5	476.5	26.7	222.8	123.1	55.3	36.8	42.1	114.5	2564.5	572.6	22.3
Kutubdia	443.5	215.3	48.6	2386.6	586.3	24.6	263.2	147.0	55.8	36.6	40.1	109.4	3130.0	630.9	20.2
Cox's Bazar	450.2	204.7	45.5	2931.7	491.7	16.8	308.3	158.2	51.3	34.6	33.5	96.9	3724.0	520.6	14.0
Teknaf	361.0	192.2	53.3	3518.5	503.7	14.3	325.5	181.7	55.8	28.8	40.9	142.4	4232.9	513.2	12.1
Bhola	379.1	189.6	50.0	1556.8	332.0	21.3	224.9	138.9	61.8	39.3	37.6	95.6	2228.7	407.8	18.3
Chattogram	387.9	192.8	49.7	2153.0	501.4	23.3	269.9	164.2	60.9	36.9	39.4	106.7	2966.5	549.1	18.5
Barishal	408.4	164.4	40.3	1444.5	294.1	20.4	229.9	143.0	62.2	40.1	41.6	103.8	2092.7	364.9	17.4
Patuakhali	506.9	203.7	40.2	1922.0	397.4	20.7	268.6	144.7	53.9	36.6	36.7	100.1	2615.0	475.0	18.2

SD means standard deviation and CV means coefficient of variation (%)

Methodology

Annual series were prepared from monthly data, and then trend analysis was undertaken. The monthly rainfall data was divided into four seasons for seasonal analysis: pre-monsoon season, monsoon season, post-monsoon season, and winter season, respectively. Spatial interpolation technique was done by a Kriging process using Surfer. For rainfall trend analysis, the following tests were utilized.

In this study, Sen's estimator was used to determine the magnitude of trend in a time series, and the statistical significance of the trend in the time series was determined using the Mann–Kendall (MK) test [18-20].

Magnitude of trend

Sen's method assumes a linear trend in the time series and has been widely used for determining the magnitude of trend in hydro-meteorological time series [21-23]. In this method, the slopes (T_i) of all data pairs are first calculated by

$$T_i = \frac{x_j - x_k}{j-k} \; for \; i = 1, 2, \ldots\ldots, N, \qquad (1)$$

where x_j and x_k are data values at time j and k (j > k), respectively. The median of these N values of T_i is Sen's estimator of slope, which is calculated as follows:

$$\beta = \begin{cases} T_{\frac{N+1}{2}} & N \text{ is odd} \\ \frac{1}{2}\left(T_{\frac{N}{2}} + T_{\frac{N+2}{2}}\right) & N \text{ is even} \end{cases} \qquad (2)$$

A positive value of β indicates an upward (increasing) trend and a negative value indicates a downward (decreasing) trend in the time series.

Linear regression method

Linear regression is a parametric statistical tool that is frequently used to investigate data trends over time. Trends may be covered in data dispersion coming from non-perfect hydrogeologic circumstances, testing and examination conditions, and so on, if the traditional practice of translating the log slope of the regression line is used. The most common strategy for detecting trends is to create a linear model between data and time.

Gadgil and Dhorde utilized linear regression to determine long-term changes in seasonal and annual rainfall [25]. The mean temporal change in the studied variable is the fundamental statistical metric. A positive slope value denotes an upward tendency, whereas a negative one denotes a downward trend. The total change throughout the time period is calculated by multiplying the slope by the number of years [26].

Significance of trend

The statistical significance of the trend in monthly, seasonal and annual series was analysed using the non-parametric Mann-Kendall (MK) test [19]. The MK test has been employed by a number of researchers to ascertain the presence of statistically significant trend in hydrological climatic variables such as temperature, precipitation, and stream flow with reference to climate change [23, 27-30]. The MK test checks the null hypothesis of no trend versus the alternative hypothesis of the existence of increasing or decreasing trend. Following Bayazit & Onoz no pre-whitening of the data series was carried out, as the sample size was large (n ≥ 50) and the slope of trend was high (>0.01) [31].

The statistic (S) is defined as (Salas, 1993) follows:

$$S = \sum_{i=1}^{N-1} \sum_{j=i+1}^{N} sgn(x_j - x_i) \quad (3)$$

where N is the number of the data points. Assuming $(x_j - x_i) = \theta$, the value of sgn(θ) is computed as follows:

$$\text{sign}(\theta) = \begin{cases} 1 & if\ \theta > 0 \\ 0 & if\ \theta = 0 \\ -1 & if\ \theta < 0 \end{cases} \quad (4)$$

This statistic represents the number of positive differences minus the number of negative differences for all the differences considered. For large samples (N > 10), the test is conducted using a normal distribution with the mean and the variance as follows:

$$E[S]=0 \quad (5)$$

$$\text{Var}(S) = \frac{N(N-1)(2N+5) - \sum_{k=1}^{n} t_k(t_k - 1)(2t_k + 5)}{18} \quad (6)$$

where N is the number of tied (zero difference between compared values) groups and t_k the number of data points in the kth tied group [32]. The standard normal deviate (Z-statistics) is then computed as (Hirsch et al. 1993) follows [32]:

The standardized test statistic Z is given by:

$$Z = \begin{cases} \frac{S-1}{\sqrt{Var(S)}} & if\ s > 0 \\ 0 & if\ s = 0 \\ \frac{S-1}{\sqrt{Var\ (S)}} & if\ s < 0 \end{cases} \quad (7)$$

If the computed value of $|Z| > z_{\alpha}/2$, the null hypothesis (H_0) is rejected at α level of significance in a two-sided test. In this analysis, the null hypothesis was tested at 95% confidence level.

Rainfall Variability Analysis (Coefficient of Variation)

Variance is a statistical measure of how different data points differ from the mean. The coefficient of variation (CV) is a normalized measure of spread around the mean that may be calculated as follows:

$$CV(\%) = \frac{S}{X} \times 100$$

Where the mean is X, and the standard deviations are S. CV is a dimensionless number that is preferable to standard deviation. When evaluating the middle of datasets with different units or normally different means, the coefficient of variation should be used instead of the standard deviation. A higher CV value indicates greater spatial variability, and vice versa. Using CV, the annual and occasional rainfall variability for 34 locations in Bangladesh was investigated.

Results and Discussions

Statistical Characteristics of Annual and Seasonal Rainfall

Basic statistical features, such as mean, standard deviation (SD), coefficient of variation (CV), of annual and seasonal (pre-monsoon, monsoon, post-monsoon and winter) rainfall events during the period 1981-2020 of 40 years of Bangladesh were analysed as shown in Table 2. Annual rainfall data of various stations in Bangladesh varied from 1423.9 to 4232.9 mm and 258.3 to 786.1 mm, in mean and SD, respectively. In the case of seasonal rainfall, their values varied from 237.4 to 1137.2 mm in pre-monsoon, 1030.0 to 3518.5 mm in monsoon, 125.1 to 340.9 mm in post-monsoon, and 21.2 to 56.2 mm in winter and SD from 99.5 to 328.7 in pre-monsoon, 237.9 to 631.8 in monsoon, 83.7 to 214.8 in post-monsoon, and 18.0 to 58.8 in winter, respectively, for the period 1981–2020.

This fundamental statistic shows that locations with higher rainfall have less variability than the regions with relatively lower rainfall. The scrutiny of annual and seasonal rainfall records showed that the maximum rainfall was 5412.0 mm in Teknaf (located in south-eastern coastal region) in the year 2008, and minimum rainfall of 894.0 mm in Rajshahi (located in western region) in the year 2010. In general, the mean annual rainfall of Bangladesh indicated a long-term decreasing trend as shown in Fig. 2(a).

Trend analysis

Linear regression, Mann–Kendall, Sen's slope estimator has been used for the determination of the trend. The brief details of the results are presented in the following subsections.

Linear regression analysis of mean annual and seasonal rainfall series

Fig. 2 demonstrates mean annual and seasonal rainfall trends (pre-monsoon, monsoon, post-monsoon and winter) of all available stations in Bangladesh. At 95% confidence level tests were examined. At all stations, the monsoon season contributes the most to annual rainfall in Bangladesh. During the monsoon season, more rainfall occurs (June, July, August, and September) in the country. Annual and seasonal rainfall series observed decreasing trends except post-monsoon rainfall series, whereas post-monsoon rainfall series showed increasing trends. The annual, pre-monsoon, monsoon, post-monsoon, and winter rainfall series had slopes by -5.36, -2.65, -3.15, 0.91, and -0.56, respectively (Fig 2). It means that most of the seasonal and annual rainfall showed a slightly decreasing trend over Bangladesh and it may be happened due to climate change. The significance test indicated that annual and seasonal (pre-monsoon, monsoon, post-monsoon, and winter) rainfall trends in Bangladesh were insignificant.

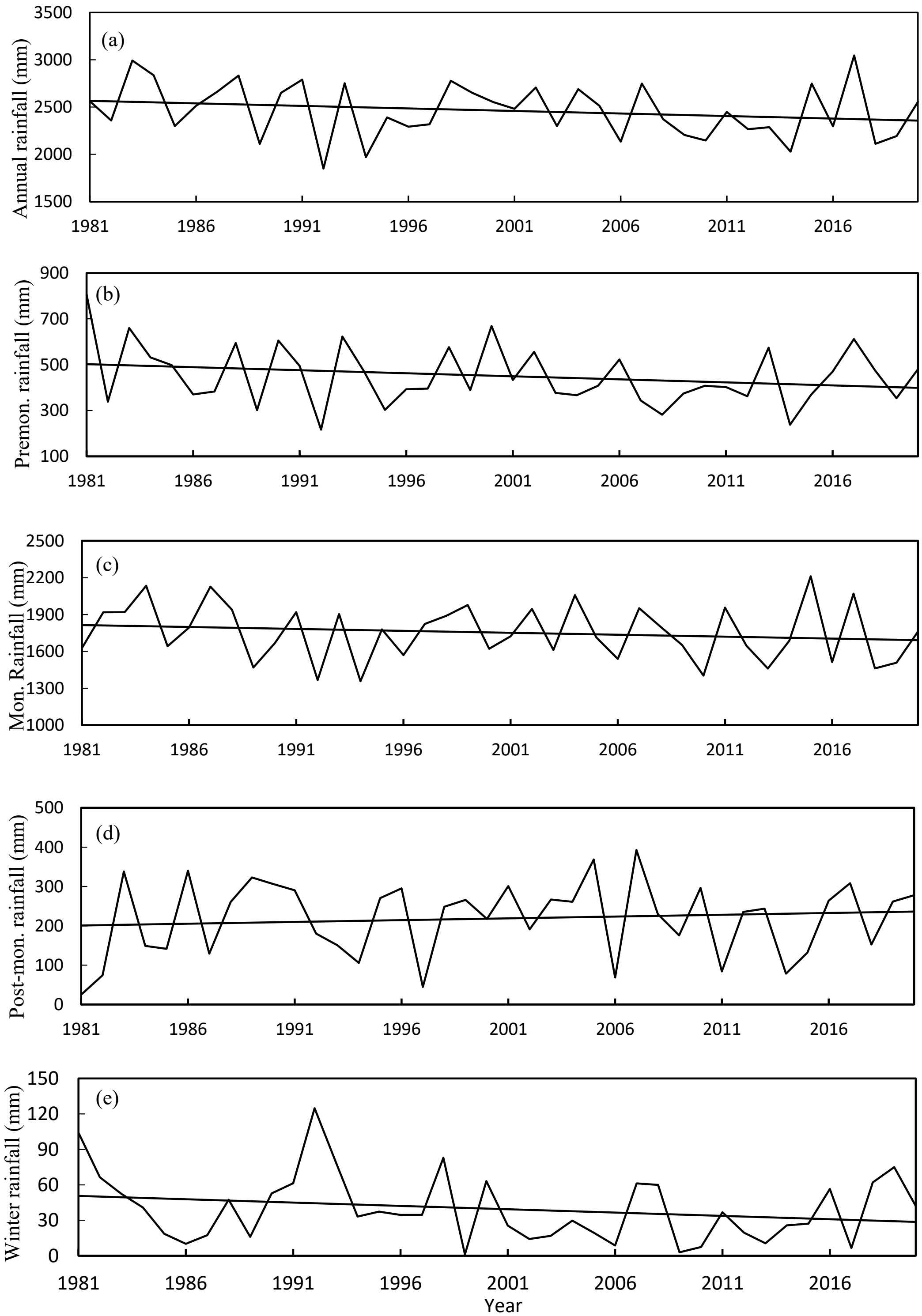


Figure 2: The temporal plot of (a) mean annual rainfall (b) pre-monsoon rainfall (c) monsoon rainfall (d) post-monsoon rainfall and (e) winter rainfall trend over Bangladesh during the period 1981-2020.

Spatial variation of mean annual and seasonal rainfall analysis

The spatial variation in annual rainfall trend values across the country shows a nearly falling tendency, with a few exceptions in the southeast region (Fig. 3). Pre-monsoon seasonal rainfall variation trend shows a slight increase, with the exception of the centre to southeast region, where it has shown a tendency to decline. The spatial variation of monsoon and post-monsoon rainfall patterns there demonstrates a declining trend, with the exception of the southern regions of Bangladesh where there is a rising tendency. Therefore, rainfall trends diversity in south-eastern zone is observed due to orographic lift as it can be seen from the measurements shown in Figs.3&4 [33]. The potential demonstration of that significant rainfall differs due to monsoonal blowing of wind originating from the coastal Bay [34]. Similarly, Ahmed and Kim (2003) explained that monsoonal winds might be the possible cause of rainfall variations as its depression path is south to northward [35]. The spatial pattern of Bangladesh's winter season rainfall shows decreasing, over Bangladesh (Fig. 4). The decreased amount of winter rainfall over Bangladesh is influenced by the weak depression of Bay of Bengal (BoB) [36].

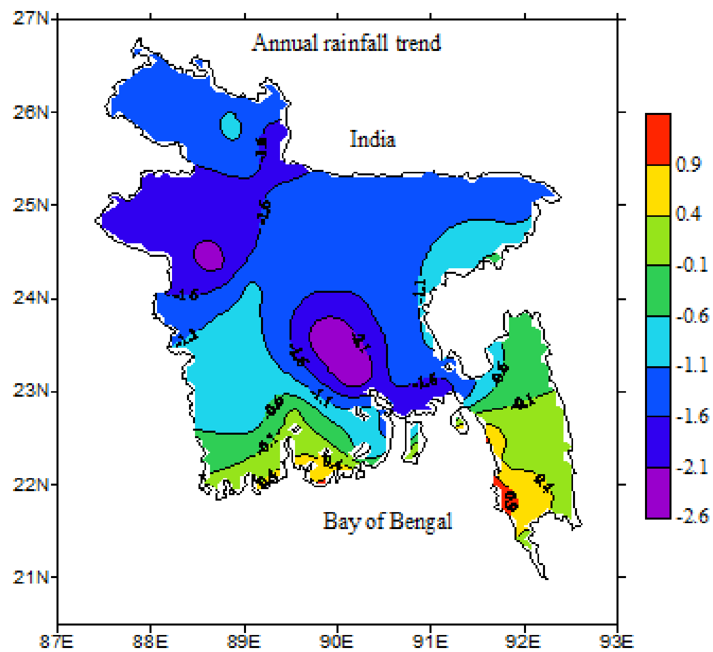
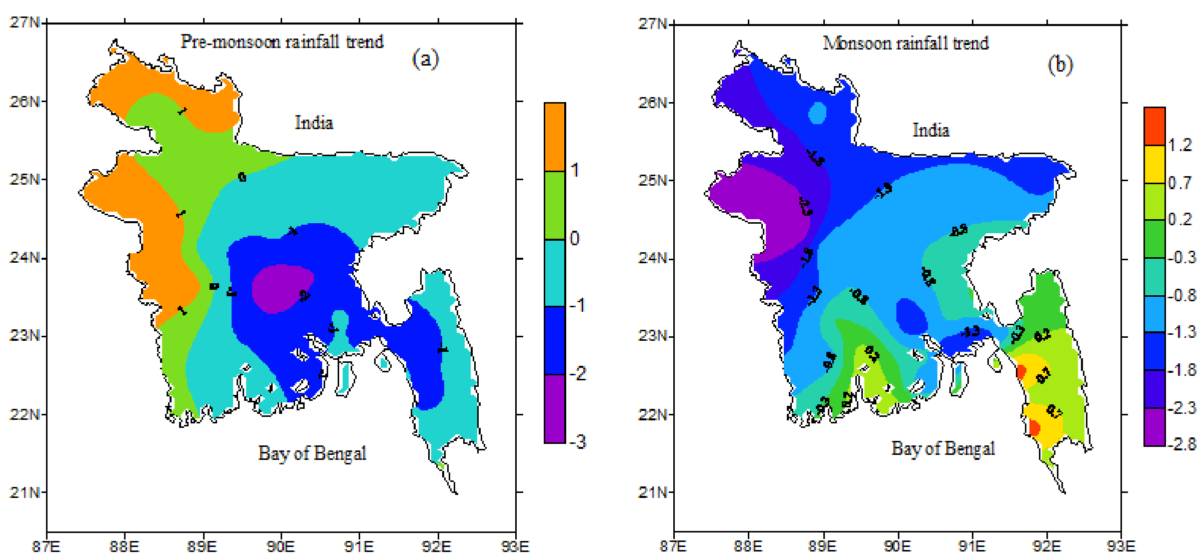


Figure 3: Plot of Mann Kendall Z statistics for the annual rainfall trend during the period 1981–2020.



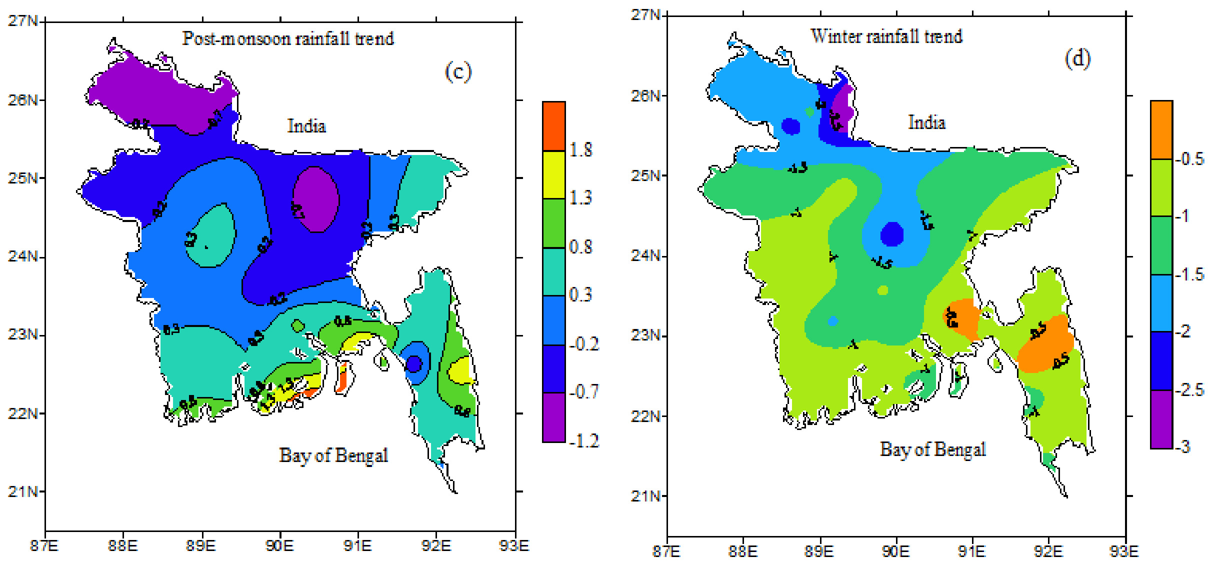


Figure 4: Plot of Mann Kendall Z statistics for the (a) pre-monsoon rainfall (b) monsoon rainfall (c) post-monsoon rainfall (d) winter rainfall trend during the period 1981-2020.

Mann–Kendall test of rainfall series

Seasonal and annual trends the Z statistic values for rainfall time series of all stations of Bangladesh for the seasonal (pre-monsoon, monsoon, post-monsoon, winter) and annual time scales are seen in Table 2 and Figs. 3 and 4. In terms of seasonality, 28 stations showed negative or decreasing trends in rainfall in the pre-monsoon seasons and 6 stations showed positive or increasing trends, but only two stations out of 34 stations showed significant trends in the same season. In the monsoon season, 24 stations out of 34 stations are seen to have decreasing trends and the rest of the 10 stations showed increasing trends using the MK test at 95% confidence level that seem to be erratic. In the post-monsoon season, 12 stations showed decreasing insignificant trends and others 22 stations showed increasing trends including three stations had statistically significant trend (Table 2). All stations showed a decreasing insignificant trend in the winter season except three stations where these stations had statistically significant at 95% confidence level. For the annual time scale, out of 34 stations, 23 stations showed negative or decreasing trends and 11 stations showed positive or increasing trends. Among the 34 stations, seven stations had statistically significant in which six (6) had decreasing trends and one (1) had increasing trend in the annual time series.

Table 2: Z statistic values of seasonal and annual rainfall data using MK in Bangladesh during the period 1981-2020.

Stations Name	Pre-monsoon	Monsoon	Post-monsoon	Winter	Annual
Dinajpur	0.36	**-1.74**	-0.66	**-2.18**	-1.43
Sayedpur	1.25	-1.16	-1.23	-1.25	-0.89
Rangpur	1.24	-1.50	-0.54	**-3.09**	**-1.74**
Bogura	-0.20	-1.57	0.27	-0.70	-1.48
Rajshahi	1.35	**-2.75**	-0.10	-0.91	**-2.30**
Ishurdi	-0.80	-0.82	0.86	-0.96	-1.01
Tangail	-0.91	-0.84	-0.24	**-2.33**	-1.36
Mymensingh	-0.72	-1.15	-1.06	-1.33	-1.43
Sylhet	-0.27	-1.43	0.69	-0.94	-1.25
Srimangal	-0.28	-0.55	0.77	-0.63	-0.28
Dhaka	**-2.11**	-0.78	-0.49	-1.34	-1.62
Chuadanga	1.64	-1.50	-0.11	-0.47	-0.79
Faridpur	**-2.83**	-1.22	-0.72	-0.92	**-2.52**
Jashore	-0.55	-0.24	0.22	-1.63	-0.80
Satkhira	-0.61	-1.17	0.76	-0.79	-0.94
Mongla	-0.30	0.71	0.54	-0.63	0.39
Khulna	-0.84	0.52	0.30	-0.80	0.01
Madaripur	-1.51	**-1.81**	0.91	-1.36	**-2.67**
Khepupara	-1.05	0.58	2.42	-0.64	1.62
Chandpur	-0.90	-0.57	0.70	-0.31	-1.11
Cumilla	-1.04	-0.07	-0.14	-0.49	-0.98
M. Court	-1.26	**-1.99**	**1.90**	-0.44	**-2.12**
Feni	-1.46	-1.11	1.05	-0.99	-1.24
Hatiya	-0.44	0.97	**2.42**	-0.87	1.43
Sandwip	-0.38	**1.85**	0.51	-1.46	**1.70**
Sitakunda	-1.20	1.27	-0.64	-0.08	0.35
Rangamati	-0.80	0.65	1.56	-0.60	0.29
Kutubdia	-0.71	1.40	0.31	-0.68	1.14
Cox's Bazar	-0.05	0.43	0.37	-1.11	0.29
Teknaf	0.40	-0.02	-0.21	-0.94	0.31
Bhola	-0.65	**-1.74**	1.07	-1.14	**-1.90**
Chattogram	-1.36	0.34	0.58	-1.21	0.17
Barishal	-1.56	-0.59	0.54	-0.68	-0.69
Patuakhali	-1.26	-1.20	**1.75**	-1.34	-1.05

Bold values indicate statistically at 95% confidence level.

Magnitude of trend in rainfall series (Sen's slope)

Table 3 shows the magnitude of the trend. The magnitude of the negative trend in the annual rainfall series was in the range of 1.98 in Srimangal station to 16.59 in Faridpur station (Table 3). The positive trend or increasing trend was found in Khulna station (0.24) and Sandwip station (16.17). Rainfall trends showed over India a large variability in the magnitude and direction from one station to another [37]. This result is very similar to Gajbhiye et al. [37]. Six, out of 34 stations showed positive trends and 28 stations showed negative trends or decreasing trends in the pre-monsoon season, in which two stations had statistically significant decreasing trends (Table 3). In the monsoon season, 24 out of 34 stations had negative decreasing trends and 10 stations exhibited positive trends in which 5 and 1(one) stations had positively and negatively statistically significant, respectively. The post-monsoon season had a positive value of Sen's estimator for 21 stations including three statistically significant and had a negative value for 13 stations, although they were non-significant. During the winter season, rainfall showed negative trends for all stations except one station which showed a positive trend. Three (3) out of 34 stations exhibited negatively statistically significant for the winter season and rest of the stations showed negative trends but it was non-significant.

Table 3: Sen's estimator of slope (mm/year) for seasonal and annual rainfall.

Stations Name	Pre-monsoon	Monsoon	Post-monsoon	Winter	Annual
Dinajpur	0.956	**-8.785**	-0.824	**-0.667**	-9.292
Sayedpur	3.400	-6.545	-2.154	-0.409	-11.462
Rangpur	3.230	-10.130	-0.605	**-0.944**	**-10.194**
Bogura	-0.408	-7.931	0.475	-0.236	-9.302
Rajshahi	1.694	**-9.388**	-0.074	-0.355	**-8.917**
Ishurdi	-1.236	-3.545	0.903	-0.362	-4.583
Tangail	-2.556	-5.400	-0.636	**-1.429**	-6.800
Mymensingh	-2.030	-5.842	-2.306	-0.528	-9.275
Sylhet	-1.902	-9.256	1.135	-0.500	-12.714
Srimangal	-1.669	-2.361	1.067	-0.240	-1.981
Dhaka	**-5.794**	-3.389	-0.860	-0.588	-10.477
Chuadanga	2.667	-7.722	-0.113	-0.211	-5.538
Faridpur	**-6.225**	-5.757	-0.977	-0.442	**-16.594**
Jashore	-0.817	-1.061	0.321	-0.956	-4.958
Satkhira	-0.559	-4.055	1.016	-0.439	-3.972
Mongla	-0.500	3.750	1.400	-0.240	4.063
Khulna	-1.812	2.736	0.667	-0.400	0.244
Madaripur	-3.573	**-7.400**	1.562	-0.643	**-14.214**
Khepupara	-2.437	3.487	7.263	-0.219	9.375
Chandpur	-2.593	-2.881	1.000	-0.156	-8.392
Cumilla	-2.959	-0.379	-0.200	-0.180	-5.437
M. Court	-3.583	**-9.303**	**4.928**	-0.196	**-13.660**
Feni	-3.359	-6.967	2.390	-0.347	-8.671
Hatiya	-1.125	6.731	**6.722**	-0.186	10.960
Sandwip	-1.285	**15.909**	1.286	-0.470	**16.173**
Sitakunda	-3.611	9.600	-1.114	0.000	3.424
Rangamati	-3.464	3.826	2.667	-0.167	3.333
Kutubdia	-2.000	11.051	0.829	-0.297	9.488
Cox's Bazar	-0.225	3.000	0.819	-0.333	2.463
Teknaf	1.369	-0.153	-0.483	-0.146	2.751
Bhola	-1.095	**-8.792**	2.581	-0.378	**-8.552**
Chattogram	-2.492	2.128	1.324	-0.410	2.067
Barishal	-3.841	-2.266	1.283	-0.250	-4.000
Patuakhali	-3.515	-6.182	**3.721**	-0.556	-6.688

Bold values indicate statistically at 95% confidence level.

Analysis of annual and seasonal rainfall variability (CV)

From an agricultural point of view, it is essential to understand the seasonal variations for precise assessment of supplemental water requirements for crops specially for rice. The rainfall variability pattern for Bangladesh utilizing CV during the period 1981–2020 revealed that the inter-annual and inter-seasonal variability was highest for the entire Bangladesh (Figs. 5 and 6). The minimum values of CV fell to 12.1% for annual rainfall. The seasonal rainfall variability was minimum in Sylhet (28.9%) for pre-monsoon, Teknaf (14.3%) for monsoon, Cox's Bazar (51.3 %) for post-monsoon, and Rangpur (76.0%) for winter rainfall whereas the seasonal rainfall variability was found maximum in Chandpur (59.4%) for pre-monsoon, Chandpur (31.2%) for monsoon, Dinajpur (105.5%) for post-monsoon, and Sitakunda (148.6%) for winter rainfall seasons (Table 1). The winter rainfall variability was greater than that of annual rainfall. Overall, there was a lot of variance in rainfall, indicating that places with more inter-annual variability in rainfall are more vulnerable to floods and droughts.

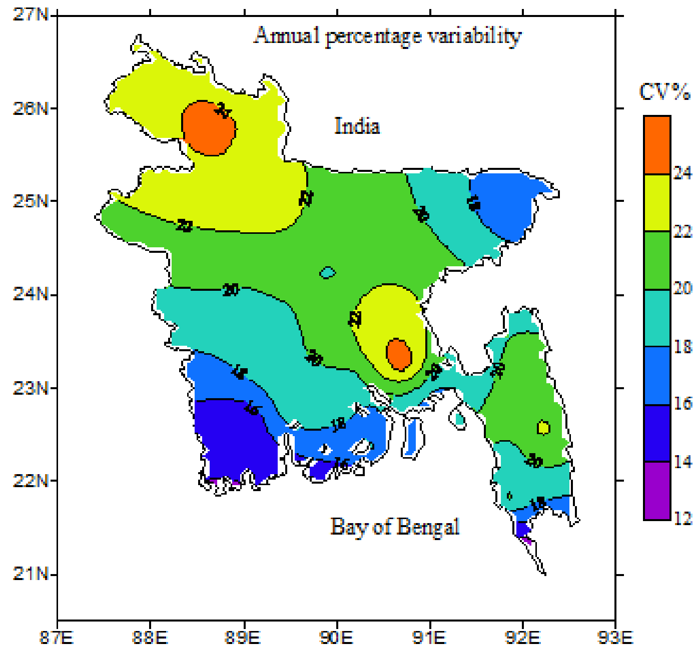


Figure 5: Spatial distribution of inter-annual variability of annual rainfall (CV) during the period 1981-2020.

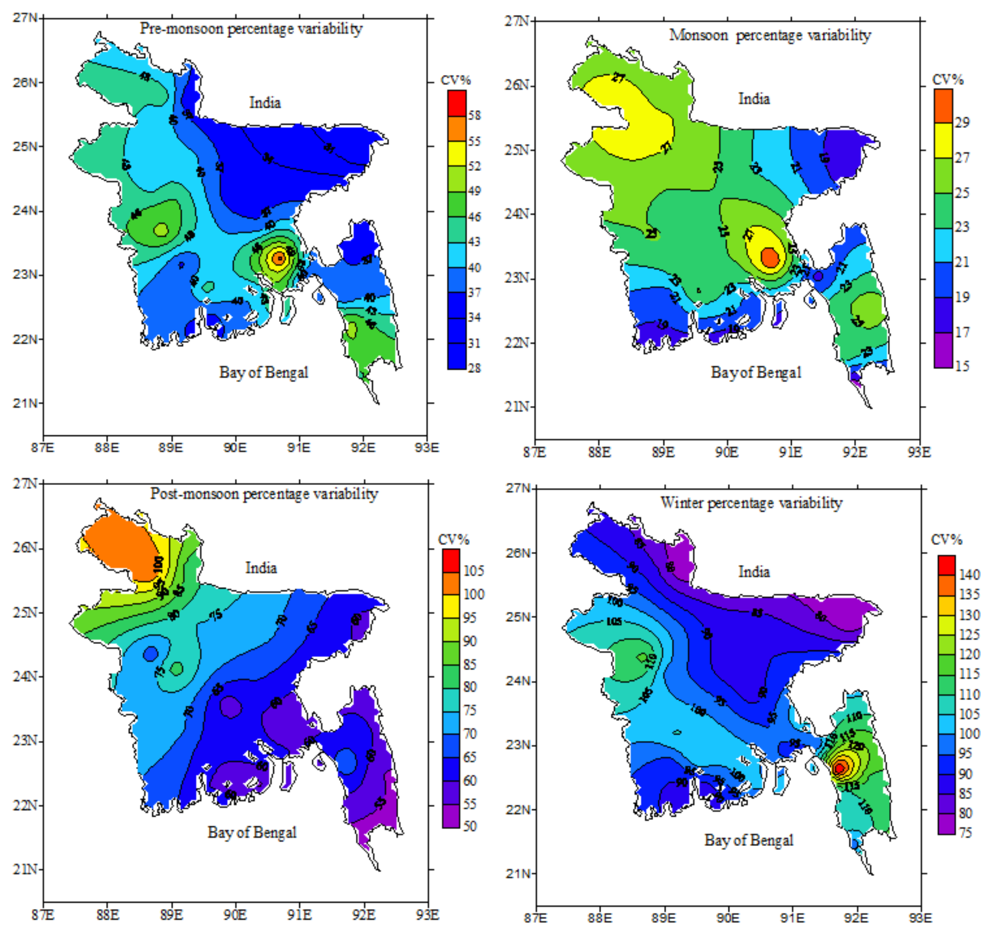


Figure 6: Spatial distribution of inter-seasonal variability of seasonal rainfall (CV) during the period 1981-2020.

Conclusions

Linear regression, Mann–Kendall test, and Sen's slope estimator were used to examine trends in annual and seasonal rainfall time series for 34 stations in Bangladesh from 1981 to 2020. The Z-value of MK test represents both positive and negative trends of rainfall in Bangladesh. Annual rainfall series results reveal non-significant upward (increasing) and downward (decreasing) trends for most of the stations, with the exception of Rangpur, Rajshahi, Faridpur, Madaripur, M. Court, Bhola and Sandwip, which exhibit statistically significant downward and upward trends (Z-value). Winter season rainfall in Bangladesh showed a decreasing insignificant trend for all stations except three stations namely Dinajpur, Rangpur and Tangail, where these stations had downward statistically significant. In the monsoon season, more than one-third out of 34 stations seen negative or decreasing trends with non-significant except five stations like as Dinajpur, Rajshahi, Madaripur, M. Court, Bhola and Sandwip stations whereas, these stations showed statistically significant downward and upward trends. Praveen et al. demonstrated that reanalysis data (ECMWF ERA5) exhibit that increasing/ decreasing precipitation convective rate, elevated low cloud cover and inadequate vertically integrated moisture divergence might have influenced on change of rainfall in India [37]. The same may have happened for Bangladesh.

Irrigation for a man rice and agricultural management could benefit from the analysis of rainfall data, which could help them plan for the most efficient use of water resources because a man rice is dependent on monsoonal rainfall. Similarly, in the present exploration mostly shows decreasing tendency, which varies seasonally so crop transplanting time period may change to reduce food scarcity as well as water availability for agricultural production.

Therefore, the water resource is essential part of the progressive economy of Bangladesh and its economy is totally dependent on the rainfall either it is agriculture or industry. However, the global rainfall pattern has been altered as a result of climate change. Therefore, many studies were carried out in the developed countries to quantify the pattern of the rainfall changes and formulate the management plan accordingly. However, very few researches were conducted in the case of Bangladesh to do this. The present study provides information in all aspects like rainfall variability and trend for overall and change station wise for annual and seasonal rainfall, rainfall change rate, year wise departure, and most importantly this study analyses the causes of rainfall changes in Bangladesh. Technically, the present study used several sophisticated techniques which have been admired worldwide by the scientists for providing high precision results. This type of studies has not been conducted for Bangladesh. Therefore, the present study can be the full package and should be very much helpful to the Bangladesh planners to proposing plans for small- and large-scale regions.

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Conflict of Interest

The authors declare that they have no conflict of interest.

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Author's Contribution

All authors involved in data screening, testing, designed as well as analysis, wrote this manuscript. Both authors read and approved the final manuscript.

Availability of data and material

All rainfall data and material are available in Agro-Meteorological Information Systems Development Project (AMISDP), Department of Agricultural Extension, Dhaka, Bangladesh.

Code availability

Presently there is no code.

Consent to participate

All authors have a consent to participate.

Consent for publication

All authors have a consent to publication for this Journal.

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