Analysis of Long-term Rainfall Trends in Bangladesh

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Abstract

The study of rainfall trends is critically important for Bangladesh whose food security and economy are dependent on the timely availability of water. Trends in monthly, seasonal, and annual rainfall on the eight divisions as well as all Bangladesh were examined in this study using a monthly data series of 40 years (1981–2020). Most of the divisions showed decreasing trend in monsoon seasonal rainfall but for only three divisions namely Dhaka, Rajshahi and Rangpur were statistically significant except in Chattogram division, whereas rainfall trend showed positive but not significant. On an annual scale, all divisions also showed a decreasing trend with insignificant exceptions in Dhaka and Rajshahi divisions, which showed a statistically significant trend. For all Bangladesh, no significant trend was detected for seasonal rainfall. Annual, pre-monsoon, monsoon and winter rainfall decreased, while post-monsoon rainfall increased at the national scale but was not significant. Only annual rainfall was detected as statistically significant for all Bangladesh.

Key words: Rainfall, divisions, trend analysis, Bangladesh.

1 **Introduction**

Bangladesh extends from 20°34'N to 26°38'N latitude and from 88°01'E to 92°41'E longitude. Except the hilly southeast, most of the country is a low-lying plain land with elevation is about 1-37 m above sea level except small portions in the southeast (elevation about 200 m) which is border with Myanmar and in the northeast (elevation about 100 m) which is border with Shillong hill of India. It is surrounded by the Assam Hills in the east, the Meghalaya Plateau in the north, the lofty Himalayas lying farther to the north. To its south lies the Bay of Bengal, and to the west lie the plain land of west Bengal and the vast tract of the Gangetic Plain. It is mentioned that there are 8(eight) administrative divisions in Bangladesh, in terms of meteorology, these divisions can also be called meteorological divisions for research purpose.

Bangladesh has a subtropical monsoon climate characterized by wide seasonal variations in rainfall, high temperatures and humidity. There are three distinct seasons in Bangladesh: a hot, humid summer from March to June; a cool, rainy monsoon season from June to October; and a cool, dry winter from October to March. Heavy rainfall is characteristic of Bangladesh. With the exception of the relatively dry western region of Rajshahi, where the annual rainfall is about 1500 mm, most parts of the country receive at least 1800 mm of rainfall per year. Because of its location just south of the foothills of the Himalayas, where monsoon winds turn west and northwest, the regions in north eastern Bangladesh receive the highest annual rainfall, sometimes over 4800 mm per year (Rahman 2006).

Bangladesh being an agricultural country, rice is the main food and the success or failure of the crops and water scarcity in any year is always viewed with the greatest concern. Agriculture sector plays an important role in the overall economic development of Bangladesh. The agricultural sector (crops, animal farming, forests and fishing) contributes 14.74 percent to the country's GDP, providing employment to about 41 percent of the labour force according to Quarterly Labour Force Survey 2015-16. A major portion of annual rainfall over Bangladesh is received during summer monsoon season (June–September). Seasonal variation in rainfall is one of the most distinctive features of monsoon regions in the world. About 70% of the rainfall in Bangladesh occurs during the four monsoon months from June to September with large spatial and temporal variations over the country (Rahman 2006). Such a heavy concentration of rainfall results in a scarcity of water in many parts of the country during the non-monsoon period. Annual fluctuations in monsoon rainfall from time to time lead to extreme hydrological events (widespread droughts and floods) which lead to dangerous decline in agricultural production and affect the huge population and the national economy. A normal monsoon with rainfall evenly distributed across the country is a wealth, while an extreme event of floods or droughts across the country or a smaller area poses a natural hazard. Hence, the variability in monsoon and annual rainfall and temperature can be considered as a measure to examine climate variability / change over Bangladesh in the context of global warming. Therefore, for Bangladesh, where agriculture has a significant influence on both the economy and livelihood, the availability of adequate water for irrigation under changed climatic scenarios is very important. The agricultural output is primarily governed by timely availability of water. In future, population growth along with a higher demand for water for irrigation and industries will put more pressure on water resources.

Water is critical for most aspects of the earth's biosphere and human societies, and thus the most acute impacts of global warming are likely to be felt through changes in the hydrological cycle (Bates et al. 2008) of particular concern is the possibility that global warming causes the hydrological cycle to accelerate, thereby increasing the intensity of both wet and dry extremes (Hennessy et al. 1997; Dai et al. 1998; Trenberth 1999; Allen and Ingram 2002; Trenberth et al. 2003; Christensen and Christensen 2003; Held and Soden 2006; Allan and Soden 2008). However, it is likely that the processes governing the increase in wet and dry events are deeply interconnected, and manifestations of the same underlying hydroclimatic response (Trenberth 1999; Trenberth et al. 2003).

Recent studies (Khan et al. 2000; Shrestha et al. 2000; Mirza 2002; Lal 2003; Min et al. 2003; Goswami et al. 2006; Dash et al. 2007) show that, in general, the frequency of more intense rainfall events in many parts of Asia has increased, while the number of rainy days and total annual amount of precipitation has decreased.

The global average precipitation is projected to increase, but both increases and decreases are expected at the regional and continental scales (Dore 2005). Higher or lower rainfall or changes in its spatial and seasonal distribution would influence the spatial and temporal distribution of runoff, soil moisture and groundwater reserves, and would affect the frequency of droughts and floods. Further, temporal change in precipitation distribution will affect cropping patterns and productivity.

According to the Intergovernmental Panel on Climate Change (IPCC 2007), future climate change is likely to affect agriculture, increase the risk of hunger and water scarcity, and lead to more rapid melting of glaciers.

Freshwater availability in many river basins in India is likely to decrease due to climate change (Gosain et al. 2006). This decrease, along with population growth and rising living standards, could adversely affect many people in India by the 2050s. Accelerated glacier melt is likely to cause an increase in the number and severity of glacier melt related floods, slope destabilization and a decrease in river flows as glaciers recede (IPCC 2007).

Under the conditions of skewed water availability and its mismatch with demand, large storage reservoirs may be needed to redistribute the natural flow of streams in accordance with the requirements of a specific region (Vijay Kumar et al. 2010). The general practice of designing a reservoir is based on the assumption that climate is stationary. Changes in rainfall due to global warming will influence the hydrological cycle and the pattern of streamflow. With the growing recognition of the possibility of adverse impacts of global climate change on water resources, an assessment of future water availability at various spatial and temporal scales is needed. It is expected that the response of hydrological systems, erosion processes and sedimentation could significantly alter due to climate change.

In Bangladesh, first time attempts have been made in the recent past to determine trends in the rainfall at divisional scales. In the present study, a much wider view has been taken, and changes in rainfall have been studied on seasonal and annual scales for 8 (eight) divisions. Intra-seasonal variability in rainfall has also been studied by analysing the trends in monthly rainfall over the eight divisions in Bangladesh.

2. Methodology

Each year was divided into four meteorological seasons namely pre-monsoon (March-May), monsoon (June-September), post-monsoon (October-November) and winter (December-January-February) for seasonal analysis. Analysis of the data was carried out season-wise as well as year-wise for rainfall during the period 1981-2020. Long time series for rainfall analysis were performed to detect local trends by dividing it into smaller timescales like 1981-2000 and 2001-2020 respectively.

In this study, the magnitude of trend in a time series was determined using a nonparametric method known as Sen's estimator (Sen 1968) and statistical significance of the trend in the time series was analysed using Mann–Kendall (MK) test (Mann 1945; Kendall 1975).

2.1 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 (Lettenmaier et al. 1994; Yue and Hashino 2003; Partal and Kahya 2006). In this method, the slopes (*Ti)* of all data pairs are first calculated by

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

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:

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

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

2.2 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 (Mann 1945; Kendall 1975). The MK test has been employed by a number of researchers (e.g. Yu et al. 1993; Douglas et al. 2000; Yue et al. 2003; Burn et al. 2004; Singh et al. 2008a, b) to ascertain the presence of statistically significant trend in hydrological climatic variables such as temperature, precipitation, and stream flow with reference to climate change. 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 (2007), no pre-whitening of the data series was carried out, as the sample size was large ($n \geq 50$) and the slope of trend was high (>0.01).

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

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

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

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

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 (Helsel and Hirsch, 1992) with the mean and the variance as follows:

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

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

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. The standard normal deviate (Z-statistics) is then computed as (Hirsch et al. 1993) follows:

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.

3. Data used

As a whole, the Bangladesh has 8(eight) divisions namely Rangpur, Mymensing, Rajshahi, Dhaka, Khulna, Barishal, Chattogram and Sylhet. The station rainfall data were collected from Bangladesh Meteorological Department (BMD). The data has been quality checked for analysis and design. This data may be considered the most reliable long series of data for this study. The data were used during the period 1981-2020. In addition, general statistical features of the different divisions and the whole study area are given in Table I. The weighted-average monthly rainfall series for each division were done and the same way was also done for eight divisions along with the combined data of 34 rain-gauge stations in Bangladesh.

It is noted that the density of the stations is low in Bangladesh. Furthermore, the coefficient of variations of the rainfall for the different divisions is quite low and it is still lower for the whole divisions.

4. Results and discussions

The results of rainfall trend analysis are presented for the monthly, seasonal, and annual data in the following sections.

4.1 Trend analysis of monthly rainfall data

Rainfall trend analysis shows large variability in magnitude and direction of trend from one division to another. When the entire available data time series for the period 1981–2020 was considered for trend detection at monthly scale, of 96 values (12 months × 8 divisions), 59 values were negative and 37 were positive (Table 2). Among the divisions, four divisions namely Dhaka, Chattogram, Rangpur and Barishal, the value of Sen's estimator is statistically significant for only two months each and other three divisions namely Sylhet, Rajshahi and Khulna for one month each only is statistically significant. Remaining one division, Mymensingh is not statistically significant of Sen's estimator values for one month also. Of these, one month has large positive value and one month has large negative value among the divisions. The Gangetic western part division (Rajshahi) has one month with rising trend, which is statistically significant. Another division namely Mymensingh, it lies on the north bank of the old Brahmaputra River, has no statistically significant trend among the twelve months. For all Bangladesh, most of the negative values (declining trend) except one month (October) showed positive value (increasing trend) but not statistically significant and for only one month is statistically significant among the twelve values of all Bangladesh (Table 2).

Since the available data series was long (40 years), it was split in two parts, 1981–2000 and 2001–2020, to ascertain the temporal variation in trends in the time series. For the period 1981–2000, of the 96 slope values, 47 were negative (declining trend) and 49 were positive (increasing trend). Although the values of Sen's estimator are comparatively larger, the values for very few months are statistically significant. Sylhet division has a large negative value of the Sen's estimator for the months of April and this was statistically significant; Dhaka, Sylhet, Rangpur and Khulna had declining trends which were statistically significant and no trend value was statistically significant for Chattogram, Rajshahi and Barishal divisions. Sen's estimator value of Mymensingh division had no trend but was statistically significant. For all Bangladesh, positive and negative values were evenly balanced and the declining trend for only two months was statistically significant as shown in Table 2.

For the period 2001–2020, of the 96 slope values, only 31 had negative signs and many values were not statistically significant. Chattogram and Rangpur divisions had high positive as well as high negative values of the Sen's estimator; high positive values of Chittagong division were not statistically significant whereas three negative values were statistically significant for Rangpur division. Rangpur division had very high negative significant value for the month of June and October, respectively. No statistically significant values for the Mymensingh, Chattogram, Sylhet, Barishal divisions but had high magnitude. For Gangetic western part division (Rajshahi), eight values were positive and four values were negative, the positive value for one month (May) was statistically significant as shown in Table 2. The data for all Bangladesh had ten months of positive Sen's estimator value and two months of negative value for this period, the negative value for the month of June were highly statistically significant.

4.2 Trend analysis of seasonal rainfall

Trend analysis was also performed on a seasonal scale to examine if there are trends in the data at this scale. Fig. 2 shows the plots of seasonal and annual rainfall for all Bangladesh for the period 1981–2020; trend lines for the data have also been drawn. It is noticed from the figures that the rainfall for the monsoon season has the least scatter among all the seasons. Annual rainfall also does not show much scatter but rainfall for winter and post-monsoon seasons have large variation from one year to the other. For the period 1981–2020, the various divisions had small positive or negative trends in different seasons, but the trends were not significant, only one in the post-monsoon season (Table 3). Of 32 slope values, 07 were positive but not statistically significant. Among the negative values, five had a declining trend with statistically significant. In the monsoon season, Rajshahi and Rangpur (Gangetic western part) as well as Dhaka divisions had high negative slopes which are statistically significant. Dhaka and Rangpur division also had a negative significant slope in the pre-monsoon and winter season, respectively.

For the period 1981–2000, of 32 slope values, only 17 were negative and 15 were positive. Only the Sylhet division had a significant slope with declining trend in the pre-monsoon season and none of the divisions had a significant slope, although some of the values had high magnitude. None of the slope values for all Bangladesh was statistically significant.

Data for the period 2001–2020 showed high negative slope values for the various divisions. Rajshahi (Gangetic western part) were the statistically significant positive slopes in the winter season. This result is very similar with Jain, S. K. et al. (2012). They showed rainfall were the statistically significant positive slopes for Gangetic West Bengal in India. Among the eight divisions, one seasonal slope value was positive in the winter season and one was negative slope value in the post-monsoon season. Thus, for all Bangladesh, seasonal slopes were mostly negative for the period 1981–2020, these were mostly positive for the period 1981–2000, and were both positive and negative for 2001–2020. But none of the slopes for all Bangladesh was statistically significant.

4.3 Trend analysis of annual rainfall

For the annual rainfall data of different divisions, all divisional values were negative for the period 1981–2020, six values were negative and two were positive for the period 1981–2000 and 2001-2020 respectively. Among these, only two negative values were statistically significant as shown in Table 3.

For the entire time series for all Bangladesh, the value of the Sen's estimator was -7.79, while it was -7.41 for the period 1981–2000 and -8.88 for the period 2001–2020 (Table 3). Among these values only one negative value (-7.79) was statistically significant for the period 1981-2020. From the analysis, it is seen that the time series shows a declining trend over all divisions in Bangladesh when it is split into two parts then it is also seen a declining trend, it may have happened due to climate change. To explore this behaviour, the statistical properties of the Sen's estimators were examined. In the Sen's method, the slopes of all data points are calculated and their median value is the Sen's estimator of slope. When the statistical properties of the data are determined, it is seen that these data have high skewness and they cannot be considered to be normally distributed. If we compute the mean values of the slopes for the entire series and the two parts of the series, these turn out to be -2.79, -3.40, and -3.03, respectively. These values give a naturally reasonable estimate because the whole time series has a decreasing trend, whereas the first and the second part also have a falling slope (negative slope).

Trends and magnitude of change in annual rainfall in eight divisions of Bangladesh and Sen's estimator of slope per year with statistical significance are shown in Fig. 3. All divisions' time series values have a decreasing trend with statistically insignificant but only two negative values were statistically significant for Dhaka and Rajshahi for the period 1981-2020 as shown in Fig. 3.

5. Analysis of annual rainfall variability pattern

The variation in rainfall represents a general characteristic of the data series. However, from an agricultural point of view, it is essential to understand the annual variation for precise assessment of supplemental water requirements. The study of rainfall variability patterns using CV during the period 1981–2020 (40 years) for eight divisions indicate that the inter-annual variability was the highest for Rangpur division only (Table 1). Among the eight values, minimum value of CV was found for Chattogram (0.12), whereas the annual rainfall variability was found maximum in Rangpur (0.22) as shown in Table 1. Overall a high variation in annual rainfall was seen which indicated that the areas with higher inter-annual variability in rainfall are more susceptible to floods and droughts.

6. Box and Whisker plots analysis

Fig. 4 shows the Box and Whisker plots of the seasonal and annual rainfall data series. The lower and upper ends of the box denote the 25 and 75 percentile values, the line inside the box represents the median, and the whiskers show the minimum and the maximum values. For all the data series, the median line is close to zero, implying that there is a clear trend in the data. For all the five series in Fig. 4, the distance between the median to minimum is less than the distance between the median to maximum. Thus, the variability of the Sen's slopes till the median is more at all timescales. Overall, clear pattern of the values of the Sen's estimator for seasonal and annual rainfall for all Bangladesh has a declining trend, either spatially or temporally, and thus, one can conclude that the seasonal rainfall series for all Bangladesh for the period 1981–2020 does not have any significant trend but annual rainfall has a significant trend.

Summary and conclusions

Climate change is likely to affect all surface of life. Decreasing rainfall, as expected due to climate change, will result in decreased water availability. An understanding of the spatial and temporal distribution and changing patterns in rainfall is a basic and important requirement for the planning and management of water resources. This study has examined trends in monthly, seasonal, and annual rainfall at different divisional scales as well as for all Bangladesh. A long data set was used, consisting of 34 observed raingauge stations with the length of data series of 40 years (1981-2020).

As expected, the divisional rainfall trends show a large variability –all divisional (eight) rainfalls have shown a decreasing trend in annual rainfall with insignificant exceptions in Dhaka and Rajshahi divisions, where the decreasing trend is statistically significant. The maximum and minimum decrease was -13.91 and -0.25 mm/year for Dhaka and Chattogram, respectively. On an all-Bangladesh basis, the annual rainfall showed a large (7.79 mm/year) decreasing trend, which is statistically significant.

Seasonal analysis showed that pre-monsoon rainfall decreased over 7(seven) divisions and the remainder have shown the opposite trend, i.e. increasing trend but not significant, only for one division (Dhaka) has a significant trend; monsoon rainfall decreased over 7 (seven) divisions and remaining one division (Chattogram) shown positive trend; post-monsoon rainfall increased over 5(five) divisions and three divisions namely Dhaka, Mymensingh and Rangpur decreased rainfall; and winter rainfall decreased over 8(eight) divisions. Pre-monsoon, Monsoon, winter and annual rainfall has decreased and post-monsoon rainfall increased on an all Bangladesh basis. All Bangladesh annual rainfall has a significant trend during the period 1981-2020.

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.

Ethics approval

Our manuscript has submitted in Theoretical and Applied Climatology solely but didn't submit any Journal for publication.

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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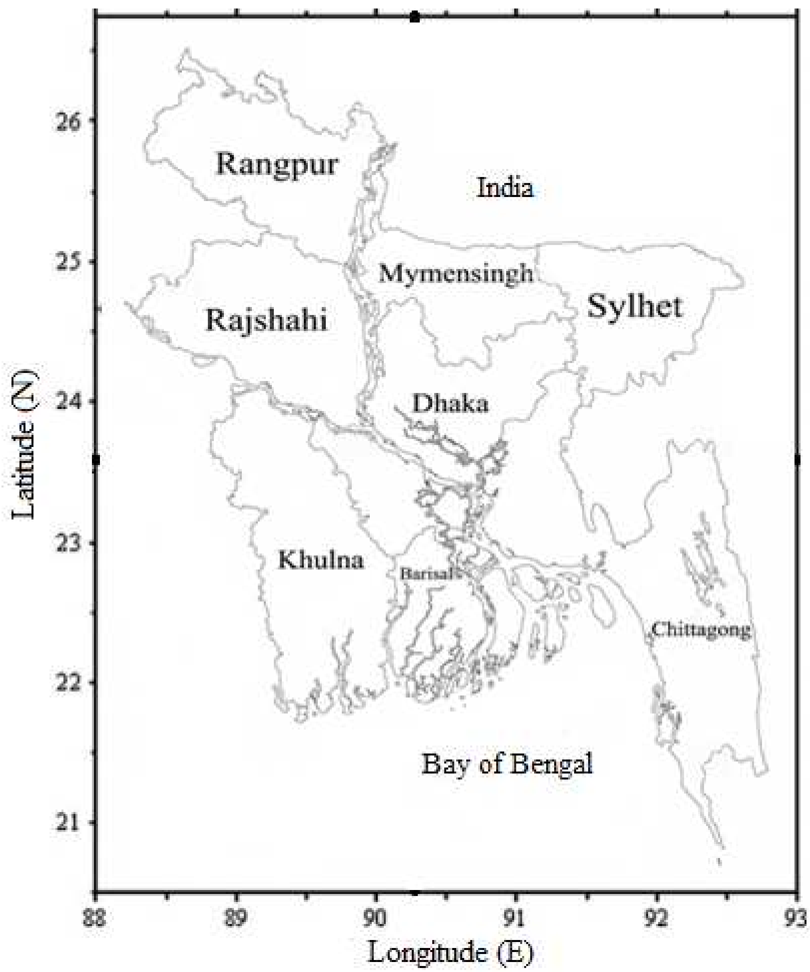

Figure 1

Map showing divisions name of Bangladesh

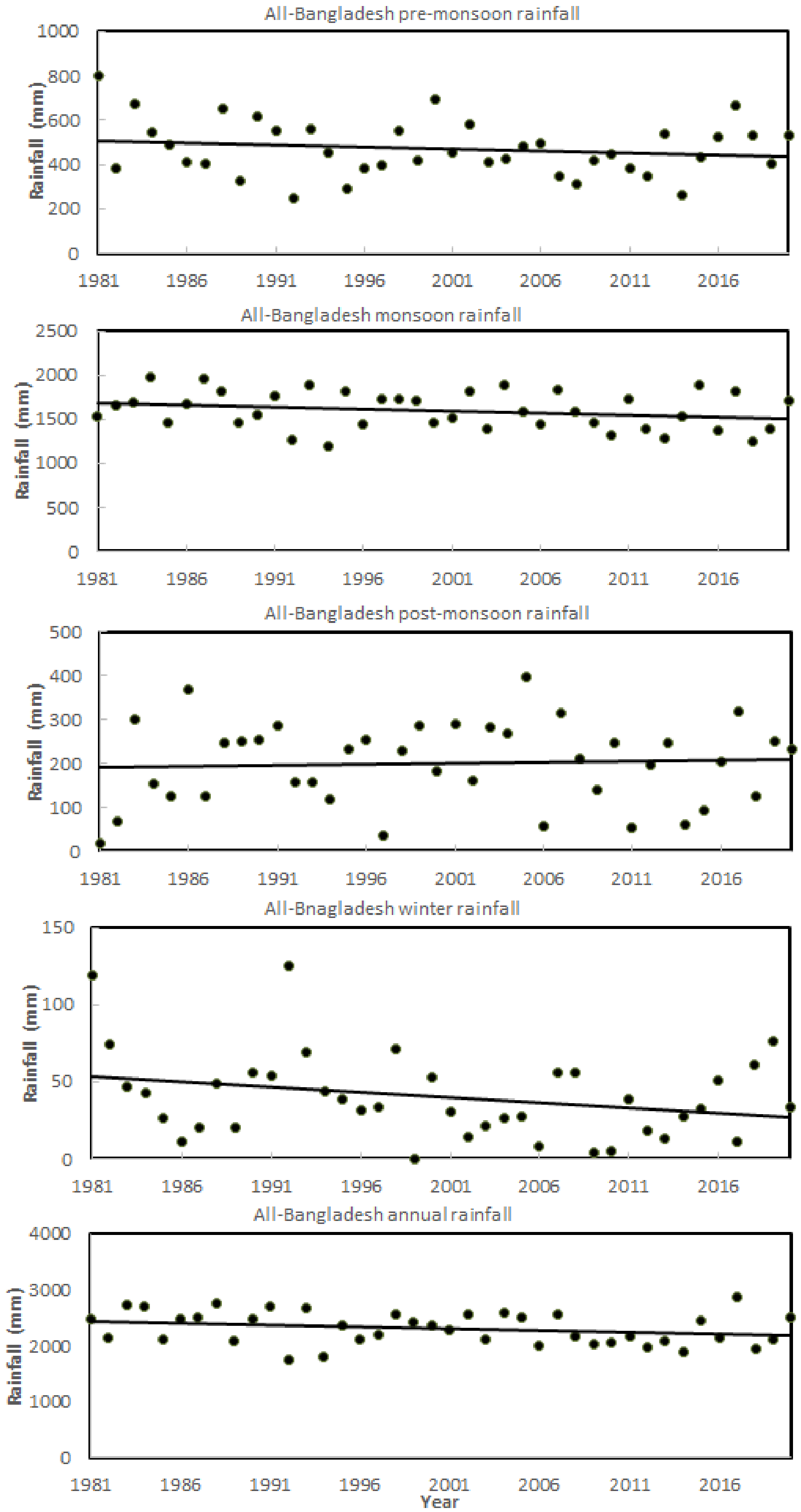

Figure 2

Seasonal and annual rainfall trends for all Bangladesh during the period 1981-2020.

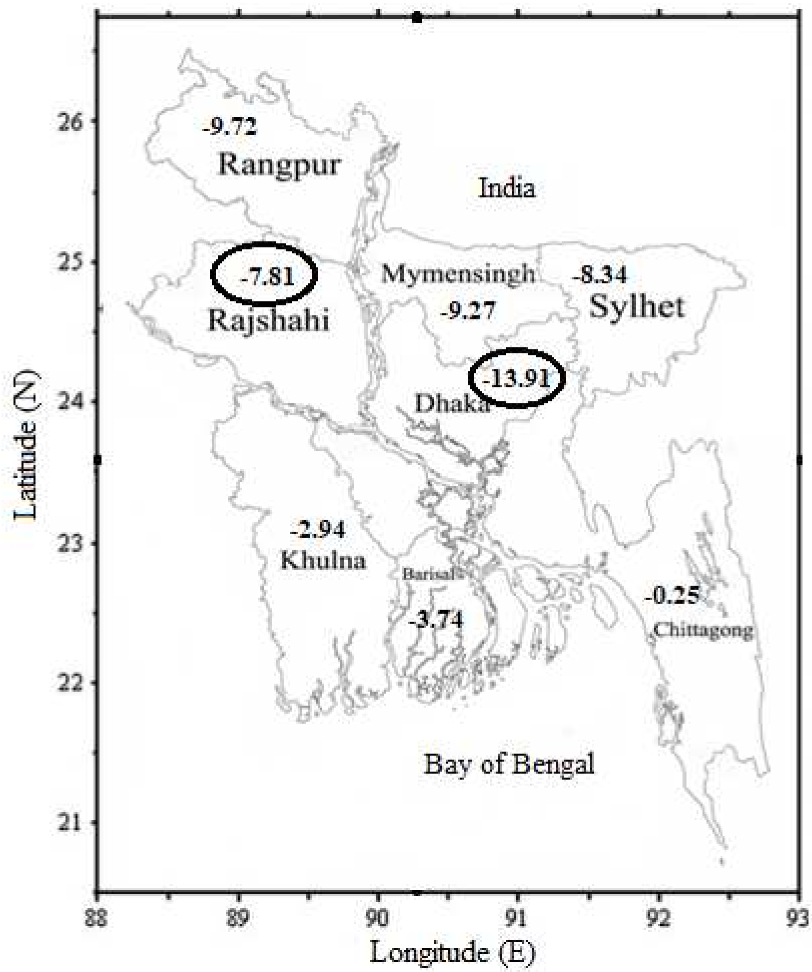

Figure 3

Trends and magnitude of changes in annual rainfall (mm/year) for different divisions in Bangladesh. Circles around values indicate divisions having significant trend.

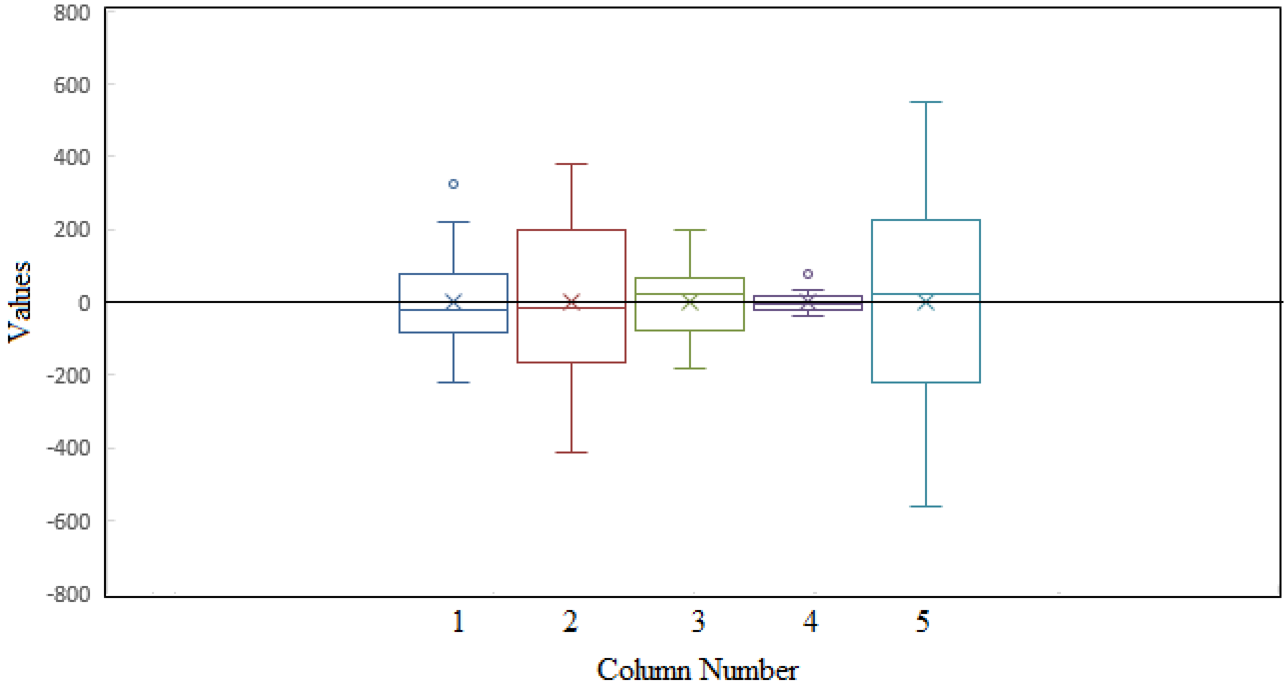

Figure 4

Box-Whisker plot of seasonal and annual rainfalls. Columns 1-5 refer to pre-monsoon, monsoon, post-monsoon, winter and annual, respectively.

Supplementary Files

This is a list of supplementary files associated with this preprint. Click to download.

- Table1.tif
- Table2.tif
- Table3.tif