STATISTICAL ANALYSIS OF RAINFALL TREND AND VARIABILITY DUE TO CLIMATE CHANGE IN BANGLADESH

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ABSTRACT

Bangladesh is considered as one of the worst vulnerable country affected by global climate change, which may cause a significant shift in the rainfall pattern and trend of the country. Variation in quantities of precipitation is often assessed by detecting and characterizing trends in available metrological data. This study was undertaken to analyze the historic annual rainfall data of the country and observe the trend for annual, seasonal and extreme rainfall. Daily rainfall data of 11 metrological stations from 1965-2015 distributed all over the country was collected and analyzed for seasonal and annual rainfall variation. Co-efficient of variation (CV) and standardized anomaly index (SAI) were used to evaluate rainfall variability, while Mann-Kendall test and Sen's Slope model were used to detect the trend and magnitude of rainfall change, respectively. It was observed that about 69% of rainfall occurs during the Monsoon season throughout the country. Post-Monsoon season shows a significant increasing trend in rainfall, whereas Pre-Monsoon, Monsoon and Dry season show significant decrease in rainfall. Mean annual rainfall was highest in Sylhet; whereas Rajshahi has the least mean annual rainfall. Annual mean rainfall in Bangladesh was found to be 2347 mm/year. Moreover, a non-significant trend has been found in annual mean rainfall all over the country. Monthly mean and extreme rainfall were also analyzed and it was found a decreasing trend for the extreme event. In case of annual, seasonal and extreme rainfall, most of the stations show negative treads, thus indicating that the rainfall is decreasing all over the country over 51 years study period.

Keywords: Climate change, rainfall trend, extreme events, statistical analysis, Bangladesh.

1. INTRODUCTION

Global warming and climate change are recognized worldwide as the most crucial environmental dilemma that the world is experiencing today (Rahman et al., 2017). It has been indicated that rainfall is changing due to global warming on both the global (Hulme et al., 1998; Lambert et al., 2003; Dore, 2005) and the regional scales (Rodriguez-Puebla et al., 1998; Gemmer et al., 2004; Kayano and Sansigolo, 2008). Bangladesh is one of the top most nations vulnerable to climate change and IPCC also recognized Bangladesh as one of the most vulnerable countries in the world to the negative impacts of climate change, this is due to its geographical location which is highly vulnerable to natural disaster such as floods, landslides, waterlogging, salinity, erosion etc. Furthermore, the climate of Bangladesh is greatly influenced by the presence of the Himalayan mountain range and the Tibetan plateau in the north, the Bay of Bengal in the south (Rahman et al., 2017). Bangladesh relies heavily on agriculture which is the single largest producing sector of the economy since it comprises about 18.6% of the country's GDP and employs around 45% of the total labor force (BBS, 2010).

The climate of a region is determined by the long-term average, frequency and extremes of several meteorological variables, most notably temperature and precipitation (Rutherford and Maarouf, 2005). Analysis of the spatial distribution and temporal trends of rainfall is crucial in understanding the impact of climate change in a region. This study was conducted to evaluate the trends in annual and seasonal rainfall and extreme rainfall events from all over Bangladesh using historical rainfall data for 51 years. The study findings can be used to understand the impact of climate changes on rainfall pattern and also to serve as a necessary input for predicting, decision-making, and planning processes to mitigate any adverse consequences of changing climate in Bangladesh.

2. STUDY AREA AND DATA USED

Bangladesh is a low-lying plain of about 143,998 km^2, situated on deltas of large rivers flowing from the Himalayas. Geographically, it extends from 20°34'N to 26°38'N latitude and from 88°01'E to 92°41'E longitude. The daily rainfall data of 11 stations (Dhaka, Cox's Bazar, Khulna, Mymensingh, Rajshahi, Rangpur, Sylhet, Barisal, Comilla, Rangamati and Sreemangal) from 1965-2015 were collected from Bangladesh Meteorological Department (BMD). The stations were selected in such a way to get a representative spatial distribution of the stations all over Bangladesh as shown in Figure 1. When rainfall data were arranged, it was found that around one or two years of rainfall data were missing for each station. The missing rainfall data were not taken into considerations. For this analysis, four seasons were considered: Pre-monsoon (March-May), Monsoon (June-September), Post-monsoon (October-November), Dry (December-February).

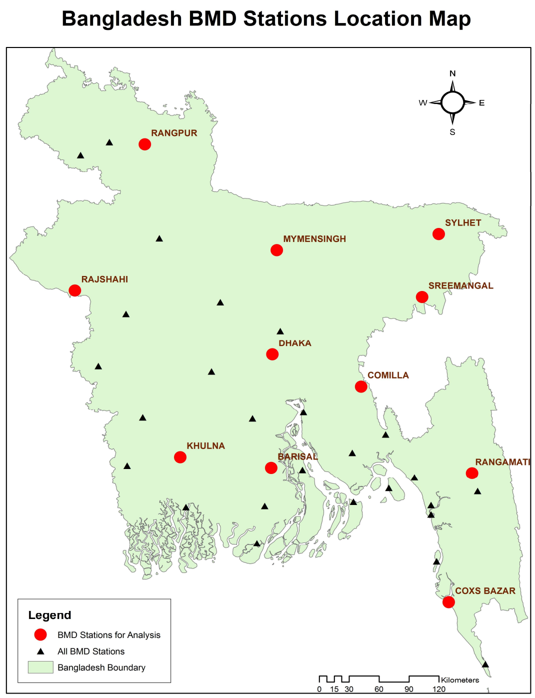


Figure 1. BMD station locations.

3. METHODOLOGY

3.1 Trend Analysis

Trend analysis of rainfall was conducted using the statistical non-parametric tests i.e. Mann-Kendall test and Sen's Slope Estimator test on annual, mean monthly, extreme event and seasonal rainfall. The collected data have been compiled, tabulated and analyzed by MS Excel and MAKESENS application.

3.1.1 Mann-Kendall test

The Mann-Kendall (MK) is a non-parametric test used for trend analysis. Mann (1945) first used this test and Kendall (1975) derived the test statistic distribution (Rustum et al., 2017).

The Mann-Kendall statistic S is given as (Swain et al., 2016):

$$\sum_{i=1}^{n-1} \sum_{j=i+1}^{n} sgn\,(x_j - x_i) \tag{1}$$

A time series x_i that is ranked from i = 1, 2, 3,…, n-1 and x_j, which is ranked from j=i+1,2,….,n. Each of the data point x_i is taken as a reference point which is compared with the rest of the data points x_j so that,

$$sgn\,(x_j - x_i) = \begin{cases} -1, (x_j - x_i) < 0 \\ 0, (x_j - x_i) = 0 \\ 1, (x_j - x_i) > 0 \end{cases} \tag{2}$$

For n > 8, S follows approximately normal distribution with mean i.e. E(S) =0. The variance statistic is given by

$$Var(S) = \frac{n(n-1)(2n+5) - \sum_{i=1}^{m} t_i(i)(i-1)(2i+5)}{18} \tag{3}$$

Where, t_i is considered as the number of ties up to sample i.

The test statistic Z_{mk} (Mann-Kendall co-efficient) is computed as

$$\sum Z_{mk} = \begin{cases} \frac{S-1}{\sqrt{Var(S)}}, & S > 0 \\ 0, & S = 0 \\ \frac{S+1}{\sqrt{Var(s)}}, & S < 0 \end{cases} \tag{4}$$

Z_{mk} here follows a standard normal distribution. A positive and negative value of Z_{mk} indicates an upward trend and downward trend, respectively.

3.1.2 Sen's slope estimator test

To estimate the true slope of an existing trend (as change per year) and in cases where the trend can be assumed to be linear, the Sen's Slope nonparametric method is used. The trend line equation is

$$f\ (t) = Qt + B \tag{5}$$

Where Q is the slope and B is the constant.

If a linear trend exists, the magnitude of the monotonic trend in hydrologic time series can be quantified by using the nonparametric Sen's estimator of slope Q, given by the following equation.

$$Q_i = \frac{x_j - x_i}{j - i} \text{ where j>k.} \tag{6}$$

$$Q = Q_{[(N+1)/2]}, \text{ if N is odd} \tag{7}$$

$$Q = 1/2\ (Q_{[(N/2]} + Q_{[(N+2)/2]}), \text{ if N is even} \tag{8}$$

3.2 Rainfall variability

3.2.1 Coefficient of variation (CV)

The coefficient of variation determines the variability of the rainfall in a specific region. A higher value of CV indicates that the rainfall variability is greater where a lower value means the opposite. CV is computed by

$$CV = \frac{\sigma}{\mu} * 100 \tag{9}$$

Where σ is the standard deviation and μ is the mean rainfall of for the chosen temporal scale. CV is used to classify the degree of variability of rainfall events into three categories: low (CV < 20), moderate (20 < CV <30) and high (CV > 30) (Asfaw et al., 2018).

3.2.2 Standardized Anomaly Index (SAI)

Standardized anomaly index of rainfall is used to observe the nature of the trends. It can determine the dry and wet years in the record and is used to measure the frequency and severity of droughts. SAI is computed as

$$SAI = \frac{X_i - X}{\sigma} \tag{10}$$

where X_i is the annual rainfall of the particular year; X is the long-term mean annual rainfall over a period of observation and σ is the standard deviation of annual rainfall over that period of observation. Positive values suggest a time of wet situation relative to the period of reference chosen while the negative ones imply a drought condition. It can be used also for seasonal scale. SAI value classification is presented in Table 1.

Table 1: SAI value classification (McKee *et al.* 1993)

SAI value	Category
Above 2	Extremely wet
1.5 to 1.99	Very wet
1.0 to 1.49	Moderately wet
-0.99 to 0.99	Near normal
-1.0 to -1.49	Moderately dry
-1.5 to -1.99	Severely dry
-2 or less	Extremely dry

4. RESULTS AND DISCUSSIONS

The results of analysis of rainfall trends of annual rainfall and extreme rainfall events for 11 stations located all over Bangladesh using Mann-Kendall Statistic and Sen's Slope over a period of 51 years are represented in Table 2 and Table 3, respectively.

Annual mean rainfall in all over Bangladesh was maximum (2958.72 mm) in 1993 and minimum (1594.81 mm) in 1972. It was found that annual average rainfall trend throughout Bangladesh is following a downward trend (Z_{mk} = -0.16) and the change in magnitude of rainfall is -0.61 mm/yr. The coefficient of variation of the annual rainfall is (13.24%), shown low inter-annual variability of annual rainfall over the study area. In Mymensingh and Khulna, there is a greater rainfall variability in comparison with other stations. Extreme events exhibited downward trends within few years in most of the stations except Rangpur. In Sreemangal, daily maximum rainfall was recorded in 1976 and the magnitude was 514 mm. Within last decade, extreme rainfall was highest in Cox's Bazar which was 330 mm in 2015. The coefficient of variation of the annual rainfall for all the stations revealed low to moderate inter-annual variability of annual rainfall in Bangladesh.

Table 2. Mann-Kendall and Sen's Slope values of Annual rainfall in Bangladesh from (1965-2015) period.

Station	Annual mean (mm/yr)	CV (%)	Z_{mk}	Q (mm/yr)	B
Khulna	1731.37	27.73	1.30	5.657	1698.38
Cox's Bazar	3567.97	23.49	-0.28	-1.889	3739.22
Barisal	2052.32	17.96	-1.22	-4.083	2088.28
Dhaka	2034.30	19.91	-0.90	-4.078	2098.88
Mymensingh	2046.75	29.23	0.44	3.279	1948.09
Rajshahi	1449.39	20.96	-2.11	-6.880	1640.71
Rangpur	2105.96	25.10	0.93	4.909	1962.14
Sylhet	4031.57	16.46	-0.64	-3.933	4005.37
Comilla	2058.21	19.83	-1.10	-4.769	2183.04
Rangamati	2497.12	21.54	0.81	4.741	2374.96
Sreemangal	2247.32	23.66	0.53	2.328	2141.64

Table 3. Mann-Kendall and Sen's Slope values of Extreme rainfall events in Bangladesh from (1965-2015) period.

Station	Z_{mk}	Trend	Q (mm/yr)	B
Khulna	-0.21	-	-0.08	119.63
Cox's Bazar	-1.29	-	-0.75	214.13
Barisal	-1.78	-	-0.89	152.34
Dhaka	-3.21	-	-1.37	156.78
Mymensingh	-0.84	-	-0.36	135.43
Rajshahi	-1.71	-	-0.67	120.03
Rangpur	1.52	+	1.18	133.03
Sylhet	-0.55	-	-0.36	185.80
Comilla	-0.59	-	-0.22	125.03
Rangamati	-0.12	-	-0.05	156.21
Sreemangal	-1.39	-	-0.46	131.69

Rainfall characteristics including mean, standard deviation (SD), coefficient of variation (CV) and percentage contributions of monthly rainfall to annual rainfall over the study area were determined for the period from 1965 to 2015 and the results are described in Table 4. June and July had the maximum contributions in annual rainfall budget (19.75% and 19.7%) respectively where January and December had the least contributions (0.36% and

0.34%) respectively. In November and December, amount of rainfall variation is higher than any other months. The coefficient of variation of the monthly rainfall revealed moderate to high variability of monthly rainfall in Bangladesh.

Table 4. Mann-Kendall and Sen's Slope values of monthly rainfall in Bangladesh from (1965-2015) period.

Month	Mean(mm)	SD(mm)	CV (%)	Z_{mk}	Q (mm/yr)	Contribution to annual rainfall (%)
January	8.59	9.03	105.12	-1.42	-0.09	0.36
February	21.72	16.44	75.68	-0.50	-0.06	0.92
March	58.10	41.81	71.96	-0.57	-0.16	2.47
April	149.08	69.46	46.59	-0.34	-0.26	6.33
May	333.46	112.87	33.84	-0.34	-0.38	14.17
June	464.78	103.83	22.33	-0.16	-0.26	19.75
July	463.67	123.82	26.70	-0.86	-0.95	19.70
August	367.17	91.38	24.88	0.96	0.87	15.60
September	299.35	78.36	26.17	1.02	0.66	12.72
October	153.59	70.89	46.15	1.22	0.873	6.53
November	26.11	29.66	113.62	-1.57	-0.30	1.11
December	8.04	13.46	167.39	-0.56	-0.003	0.34

Monsoon season contributed a major amount (68.81%) of total annual rainfall in all over the study area. Pre-monsoon, Post-monsoon and Dry season had 23.4%, 7.75% and 1.61% respectively. Monsoon season showed the moderate rainfall variability where rest of the seasons had high rainfall variability. Rainfall trend had been increasing in Post-monsoon season by the influence of the increasing rainfall in the months of September and October. Dry season had a significant decreasing trend in recent years. Characteristics of seasonal rainfall is shown below in the Table 5.

Table 5. Mann-Kendall and Sen's Slope values of seasonal rainfall in Bangladesh from (1965-2015) period.

Season	Mean (mm)	SD(mm)	CV (%)	Z_{mk}	Q (mm/yr)	B
Premonsoon	402.3146	154.6625	38.44319	-0.71	-0.834	558.93
Monsoon	1520.227	461.8826	30.38247	-0.02	-0.049	1604.93
PostMonsoon	158.225	132.7104	83.87446	1.01	0.922	158.25
Dry	25.10833	18.96717	75.54134	-1.23	-0.258	39.64

Figure 2 displays the annual rainfall anomalies over Bangladesh from 1965 to 2015 that determines the presence of inter-annual variability of rainfall. The percentages of positive and negative anomalies were 52.9% and 47.1%, respectively. The highest positive anomaly (2.15) was observed in the year 1987 whereas the highest negative anomaly (-3.04) was observed in the year 1971. Since 2008, SAI of annual rainfall had been showing negative value determining drought conditions in the study area.

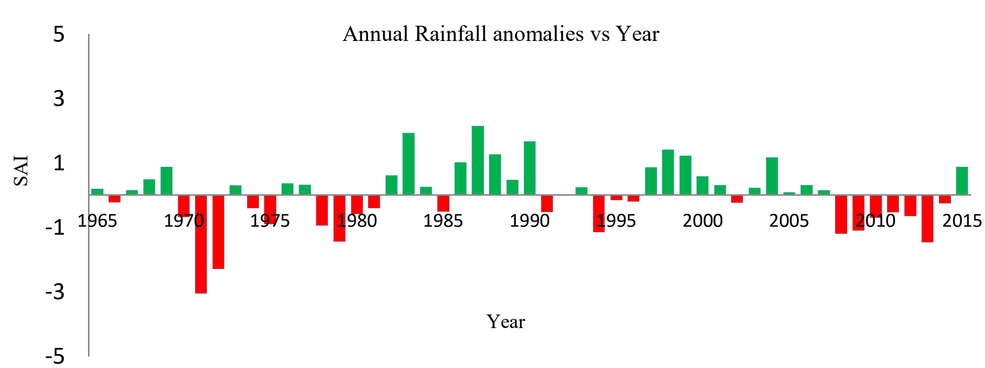
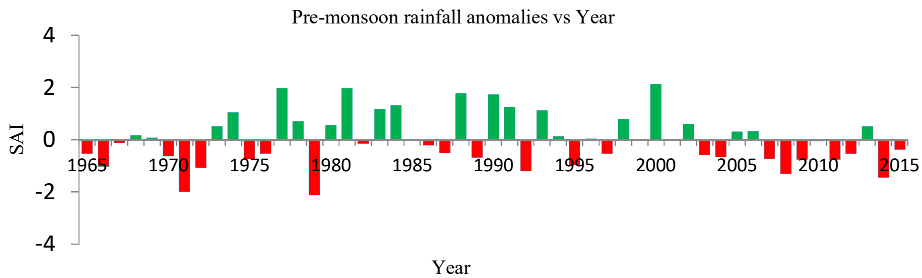
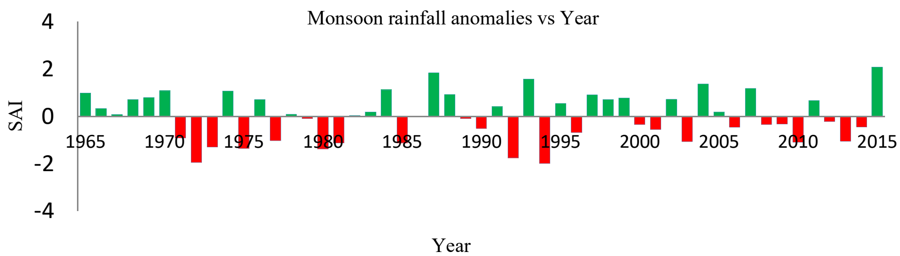


Figure 2. Annual rainfall anomalies from 1965-2015 in all over Bangladesh

Figure 3 shows the individual seasonal anomaly characteristics all over Bangladesh from 1965 to 2015 below. During the time period, the proportion of negative anomalies surpassed that of the positive anomalies in all seasons except Pre-monsoon. In the Monsoon season there is no value of SAI is less than 2 during those 51 years.



(a)



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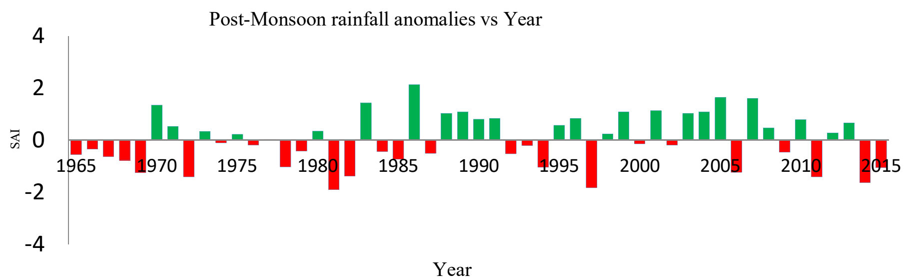
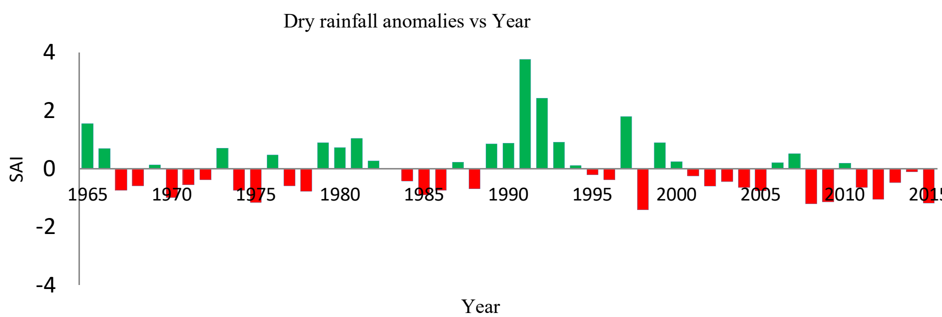


(c)



(d)

Figure 3. Seasonal rainfall anomalies from 1965-2015 in Bangladesh; (a) Pre-monsoon (b) Monsoon (c) Post-monsoon (d) Dry

5. CONCLUSIONS

The trend analysis showed significant increase in annual rainfall for Khulna whereas Rajshahi had a significant decrease in annual rainfall over 51 years' period. In case of extreme rainfall event, Dhaka registered the significant decrease in trend due to temperature rise and land use factor. However, unlike the rest of the stations, only Rangpur had an increase in extreme rainfall event trend. In terms of various rainfall parameters, it is revealed that the rainfall trend is declining all over the country. Further studies are recommended to be conducted in which analysis should be done in hourly basis and investigate other rainfall characteristics at temporal and spatial resolution, seasonality and other climate change parameters. The present study provides useful information to understand the spatial and temporal trends of rainfall in Bangladesh, which is a of great importance for management of mitigation measures adopted in the country in various sectors for securing sustainable developments under the global impacts of climate change.

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