CLIMATE CHANGE AND TREND OF RAINFALL IN THE SOUTH-EAST PART OF COASTAL BANGLADESH

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Abstract

Rainfall has been widely considered as one of the starting point towards the apprehension of climate change courses. Various studies have indicated due to climate change rainfall pattern in Bangladesh is most likely to change which would have adverse impacts on lives and livelihoods of millions of people. This study investigates temporal variability of precipitation of the south-east coast of Bangladesh over the period of 1949-2011. The Mann-Kendall test and the Sen's slope estimators have been used to detect rainfall trends and to understand magnitude of changes. We find that after 1990 mean annual rainfall has increased significantly in the south east part of Bangladesh compare to the period between 1949 and 1989. The rate of increase is 10% that is 463 mm/year. However, this pattern of increase in rainfall is not evenly distributed among all the four seasons. Sixty three years (1949-2011) trend analysis shows that rainfall has increased significantly during pre-monsoon season. The rate of increase in rainfall during pre-monsoon season is 3 mm/year. Trend analysis of rainfall for the last two decades (1990-2011) reveals a bit different trend. It shows increasing trend of rainfall in monsoon season and decreasing trend of rainfall in pre monsoon and post monsoon season. Although these trends are not statistically significant. Sen's test reveals rainfall during monsoon is increasing at the rate of 10 mm/year.

Keywords: Bangladesh, rainfall, climate change, trend analysis, Mann-Kendall test

1. Introduction

Bangladesh is considered to be one of the top ten most vulnerable countries in the world due to adverse impacts of climate change. Vulnerabilities include but not limited to sea level rise, changing rainfall patterns, increase in intense precipitation events, changes in seasonality patterns, increase temperature and frequency of extreme climatic events like floods and cyclones (Gov.UK, 2011, Smith et al., 2009).

Rainfall is an important factor for the population living in coastal Bangladesh. Erratic rainfall and associated extreme events could have negative impacts on the ecosystem, agriculture, business, health and the overall livelihoods of the common people. According to the IPCC 4th assessment report there will be a 5% to 6% increase in rainfall in Bangladesh by 2030 (Shahid, 2011). A better understanding of the rainfall pattern is important for formulating efficient resource management and climate change adaptation policies.

This study reports the outcome of an annual and seasonal trend analysis of a time series daily rainfall data from the two weather stations located in the south-east part of coastal Bangladesh. The Mann-Kendall test and Sen's slope estimator have been used to detect trends and to understand magnitude of changes.

2. Rainfall and seasonality pattern of Bangladesh

In Bangladesh, four distinct seasons can be recognized from a climatic point of view. These four seasons are as follows:

1. Dry winter season (December to February)
2. Pre- monsoon hot summer season (March to May)
3. Rainy monsoon season (June to September)
4. Post monsoon autumn season (October to November) (Rashid, 1991, Ahmed and Kim, 2003).

Climate of the south-eastern region, like rest of Bangladesh is characterised by moderately warm temperatures, high humidity and wide seasonal variations in rainfall. More than 72% of the total annual rainfall occurs during the monsoon season. Depending on locations mean annual rainfall in Bangladesh varies from 1901- 4193 mm (Shahid, 2011).

3. Data

The Bangladesh Meteorological Department (BMD) collect everyday surface data through weather stations situated all over Bangladesh. Data from 11 weather stations from the southern part of Bangladesh have been collected. Considering long term availability of data and their suitability for objectives of the study data of 2 stations, namely Chittagong and Cox's Bazar, have been selected for this study. Figure 1 and Table 1 show the specific location of the two weather stations. Percentage of missing data in the two weather stations is a little less than 2% (Table 1). The portion of missing data is high during the months of November and December 1971 and July 1976 for both Chittagong and Cox's Bazar station. In most of the cases missing data are replaced by recorded data from the nearest weather station.

Table 1: Location of the stations

Station name	Latitude (DD)	Longitude (DD)	Missing data
Chittagong	+22350	+091817	2.32%
Cox's Bazar	+21433	+091967	1.85%

DD = Decimal degrees

Figure 1: Map of Bangladesh and location of the two stations used in this study (Source: http://commons.wikimedia.org/wiki/File:Map_Bangladesh_RoadRail.png)

4. Research method

For this study sixty-three years (1949-2011) daily rainfall data from the two weather stations, namely Chittagong and Cox's Bazar, have been obtained through the Bangladesh Metrological Department (BMD). Sixty three year time period is divided into two categories. A period between 1949 and 2011 is termed as 'long term' and 1990 and 2011 is termed as 'recent term'. Annual and seasonal rainfall trends are investigated for both the long term and the recent term period (Table 2). Mann-Kendall test method is used to investigate rainfall trends for each time period. To find out the magnitude of the changes Sen's slope test is applied.

Two periods are created to compare and understand the rainfall trend in different period and to find out if there is any dramatic changes in trend of rainfall in the last two decades in relation to past sixty three years (1949-2011).

Table 2: Time period and investigation

Time period	Investigation
Long term rainfall trend	• Annual trend • Seasonal trend
Recent term rainfall trend	• Annual trend • Seasonal trend

Everyday rainfall data was entered into Excel 2010 spread sheet. After that, a daily time series for every station, for every single month and year is plotted. Visual examinations are done to identify the outliers. Suspected outliers are cross-checked with the neighbouring weather stations. No significant anomalies are found in this process. Missing rainfall data values are replaced by the recorded data from the closest weather station.

In this study, five rainfall indices are defined, based on total daily rainfall (Table 2). These five indices of the two weather stations are subject to a non-parametric Mann- Kendall test to detect the annual trend over the period of 1949-2011 and 1990-2011. Sen's method is used to understand the magnitude of the trends.

Table 2: Annual and seasonal rainfall indices

Index name	Measurement
Long term rainfall trend	Time period between 1949 and 2011
Recent rainfall trend	Time period between 1990 and 2011
Annual rainfall	Total rainfall from January to December
Dry winter season	Total rainfall (mm) from December to February
Pre- monsoon hot summer season	Total rainfall (mm) from March to May
Rainy monsoon season	Total rainfall (mm) from June to September
Post monsoon autumn season	Total rainfall (mm) from October to November

Mann-Kendall test and Sen's test are widely popular methods for detecting rainfall trends, and for understanding the magnitude of changes over time (Yue et al., 2002, Xu et al., 2003, TUeRKEŞ, 1996, Partal and Kahya, 2006, Nasher, 2013). The excel template application MAKESENS is used to do the Mann-Kendall test and the Sen's slope estimate. MAKESENS was developed by the Finnish Meteorological institute for detecting and estimating trends in the time series of annual values of atmospheric and precipitation concentrations (Salmi, 2002, Lü and Tian, 2007). Since then, various studies have used this tool to analyse rainfall trends (Río et al., 2011, Fagerli and Aas, 2008, van der Swaluw et al., 2010, Abbas et al., 2013).

4.1 Mann-Kendall test

Mann-Kindall test is a test of significance where the X variable is a time as a test for trend and x_i of a time series is assumed to obey the following model

$x_i = f(t_i) + \varepsilon_i$ ………………………..(1)

where f(t) is a continuous monotonic increasing or decreasing function of time and the residuals ε_i can be assumed to be from the same distribution with zero mean. It is therefore assumed that the variance of the distribution is constant in time. No assumption of normality is required for this test. This test is performed to determine whether the central value or the median changes over time (Helsel and Hirsch, 2002).

We want to test the null hypothesis of no trend, H_o i.e. the observations x_i are randomly ordered in time, against the alternative hypothesis, H_1, where there is an increasing or decreasing monotonic trend. In the computation of this statistical test MAKESENS exploits both the so called S statistics given in Gilbert (1987) (Gilbert, 1987) and the normal approximation (Z statistics). For a time series with 10 or more data points the normal approximation is used. N represents the annual data values in the data series. Missing values are allowed and n can thus be smaller than the number of years in the studied time series.

The Mann-Kendall test statistic S is calculated using the formula

$S = \sum_{k=1}^{n-1} \sum_{j=k+1}^{n} sgn\,(x_j - x_k)$ ……………………(2)

where x_j and x_k are the annual values in years j and k, j > k, respectively, and

$$sgn(x_j - x_k) = \begin{cases} 1 & if\ x_j - x_k > 0 \\ 0 & if\ x_j - x_k = 0 \\ -1 & if\ x_j - x_k < 0 \end{cases}$$

If n is at least 10 the normal approximation test is used.

To perform the test first the variance of S is computed by the following equation

$$VAR\ (S) = \frac{1}{18}\left[n\ (n-1)(2n+5) - \sum_{p=1}^{q} t_p\left(t_p - 1\right)(2t_p + 5\right] \text{ ………….(3)}$$

Here q is the number of tied groups and t_p is the number of data values in the p^{th} group.

The values of S and VAR(S) are used to compute the test statistic Z as follows

$$Z = \begin{cases} \frac{S-1}{\sqrt{VAR(S)}} & if\ S > 0 \\ 0 & if\ S = 0 \\ \frac{S+1}{\sqrt{VAR(S)}} & if\ S < 0 \end{cases} \text{ ………………(4)}$$

The presence of a statistically significant trend is evaluated using the Z value. A positive (negative) value of Z indicates an upward (downward) trend. The statistic Z has a normal distribution. To test for either an upward or downward monotone trend (a two-tailed test) at α level of significance, H_0 is rejected if the absolute value of Z is greater than $Z_{1-\alpha/2}$, where $Z_{1-\alpha/2}$ is obtained from the standard normal cumulative distribution tables. In MAKESENS the tested significance levels α are 0.001, 0.01, 0.05 and 0.1.

For the four tested significance levels the following symbols are used in the table:

*** if trend at α = 0.001 level of significance

** if trend at α = 0.01 level of significance

* if trend at α = 0.05 level of significance

+ if trend at α = 0.1 level of significance

If the cell is blank, the significance level is greater than 0.1.

4.2 Sen's method

Some trends may not be evaluated as statistically significant even while they might have practical interest (Yue et al., 2002). Linear trend analysis, Sen's slope method is used in this study to estimate the magnitude of the trend. Here f(t) in equation (1) is equal to

$$f(t) = Qt + B \text{……………………(5)}$$

where Q is the slope and B is a constant.

To get the slope estimate Q in equation (5) MAKESENS calculate the slopes of all data value pairs by using the following formula

$$Q_i = \frac{x_j - x_k}{j-k} \text{ ……………………(6)}$$

where j>k .

If there are n values x_j in the time series we get as many as N = n(n-1)/2 slope estimates Q_i .

The Sen's estimator of slope is the median of these N values of Q_i. The N values of Q_i are ranked from the smallest to the largest and the Sen's estimator is

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

or

$Q = \frac{1}{2}(Q_{[\frac{N}{2}]} + Q_{[\frac{N+2}{2}]})$, if N is even……………………..(7)

A 100(1-α)% two-sided confidence interval about the slope estimate is obtained by the nonparametric technique based on the normal distribution. The procedure in MAKESENS computes the confidence interval at two different confidence levels; α = 0.01 and α = 0.05, resulting in two different confidence intervals.

$C_\alpha = Z_{\frac{1-\alpha}{2}}\sqrt{VAR\,(S)}$ ……………………(8)

where VAR(S) has been defined in previous equation, and $Z_{1-\alpha/2}$ is obtained from the standard normal distribution.

5. Results and discussion

5.1 Annual long term trend (1949-2011)

Table 3 shows minimum, maximum and mean annual rainfall (mm) for Chittagong and Cox's Bazar for 63 years (1949 to 2011). Mean annual rainfall during the period of 1949-2011 for Chittagong and Cox's Bazar are 2891mm and 3595mm respectively. Minimum and maximum amount of annual rainfall for Chittagong varies from 1780 mm to 4380 mm and for Cox's Bazar 751mm and 4988mm. Cox's Bazar receives 24% higher rainfall than Chittagong. At Chittagong 32 counts of more than the annual mean rainfall are observed during the time period between 1949 and 2011 (Figure 1) and for Cox's Bazar it is 35 counts (Figure 2). 35% observations of more than the average rainfall fall after 1990s.

Table 3: 63 years (1949-2011) minimum, maximum and mean annual rainfall (mm) for Chittagong and Cox's Bazar

Station	Rainfall (mm)			
	Minimum annual	Maximum annual	Mean annual	Std. Deviation
Chittagong	1780	4340	2891	548
Cox's Bazar	751	4988	3595	759

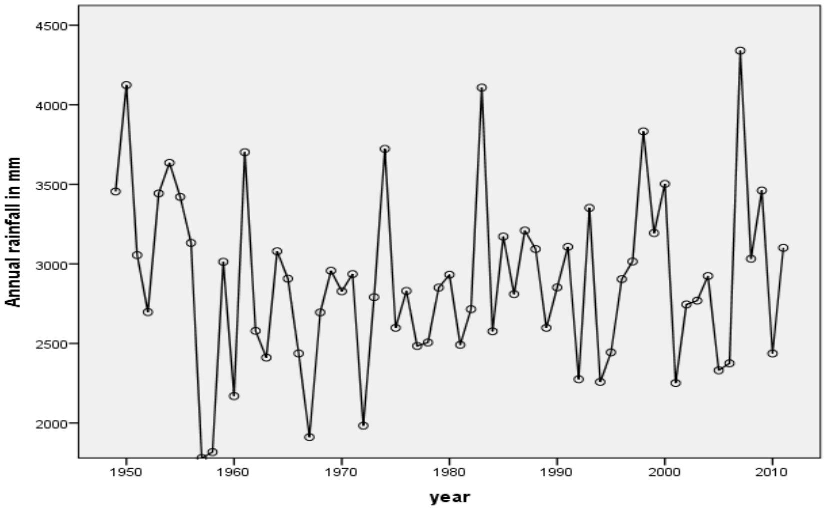

Figure 1: Annual rainfall trend for Chittagong, total observation period 1949-2011

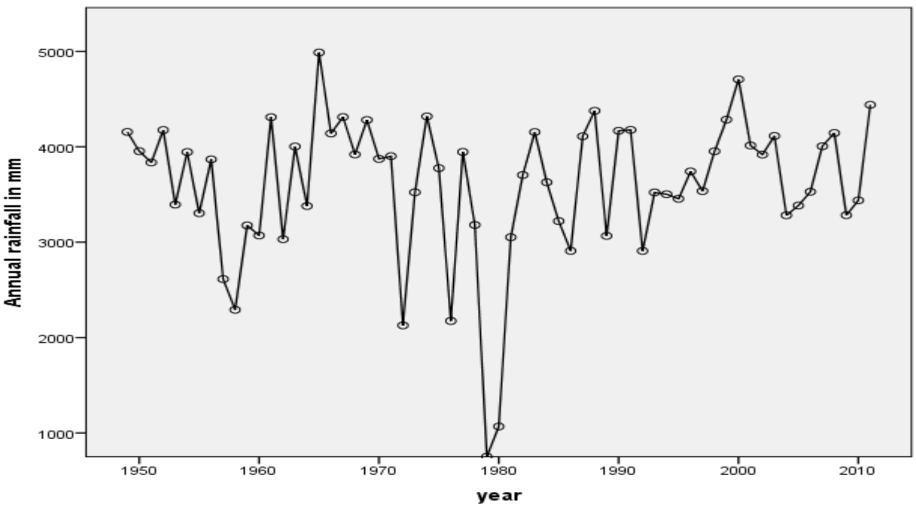

Figure 2: Annual rainfall trend for Cox's Bazar, total observation period 1949-2011

The Mann-Kendall test result of the annual rainfall trend shows an increasing pattern of rainfall at Chittagong and Cox's Bazar, though this increase is statistically not significant (Table 4).

Table 4: Mann-Kendall test for annual rainfall trend at Chittagong and Cox's Bazar, 1949-2011

Station	Period	Test Z	Significance
Chittagong	1949-2011	0.00	Not significant
Cox's Bazar	1949-2011	0.49	Not significant

Sen's slope estimate shows that change of per unit rainfall over time. The analysis of annual rainfall by Sen's slope method shows that at Cox's

Bazar annual rainfall is increasing at a rate of 1.75 mm/ year. The result of trend analysis for each station is given in Table 5.

Table 5: Sen's slope estimate for annual rainfall trend at Chittagong and Cox's Bazar, 1949-2011

Station	Q	B
Chittagong	0.000	2852.00
Cox's Bazar	1.750	3730.50

Q= Estimator for the true slop of linear trend
B= Estimator of the constant

5.2 Comparison of mean annual rainfall between two periods (1949-1989 and 1990-2011)

A comparison for the two periods, 1949-1989 and 1990-2011, has been done to understand the change of mean annual rainfall between the two periods.

Table 6 shows mean annual rainfall for Chittagong and Cox's Bazar during two periods, 1949-1989 and 1990-2011. Mean annual rainfall has increased in Chittagong by 21% and Cox's Bazar by 8% during the period of 1990-2011 compare to the period of 1949-1989.

Table 6: Mean annual rainfall of two periods (1949-1989 and 1990-2011) for Chittagong and Cox's Bazar

Station		Period 1 1949-1989 n= 41	Period 2 1990-2011 n= 22	Changes (%) (Increase/ Decrease)
Chittagong	Mean annual rainfall (mm)	2870	3488	21%
Cox's Bazar	Mean annual rainfall (mm)	3488	3796	8%

5.3 Long term seasonal rainfall trend

Table 7 shows the minimum, maximum and mean seasonal rainfall in millimetre (mm) for Chittagong and Cox's Bazar during the period 1949 to 2011. According to the table a little more than 70% rainfall occurs the monsoon season. The lowest amount of rainfall occurs during the dry season (a little less than 1%). Pre and post monsoon seasons receive an almost equal amount of rainfall for both Chittagong and Cox's Bazar. During monsoons Cox's Bazar receives 33% more rainfall than Chittagong. Figure 3 and 4 shows annual rainfall trend for Chittagong and Cox's Bazar during the period of 1949 to 2011.

Table 7: Seasonal minimum, maximum, and mean rainfall for Chittagong and Cox's Bazar, Period 1949-2011, N= 63

Station	Season	Rainfall in mm				
		Range	**Minimum**	**Maximum**	**Mean**	**Std. Deviation**
Chittagong	Dry season	107	0	107	16	23
	Pre-monsoon	927	63	990	444	198
	Monsoon	2421	921	3342	1857	492
	Post monsoon	796	21	817	267	143
Cox's Bazar	Dry season	124	0	124	18	28
	Pre-monsoon	895	25	920	415	215
	Monsoon	3161	597	3758	2485	603
	Post monsoon	967	0	967	313	184

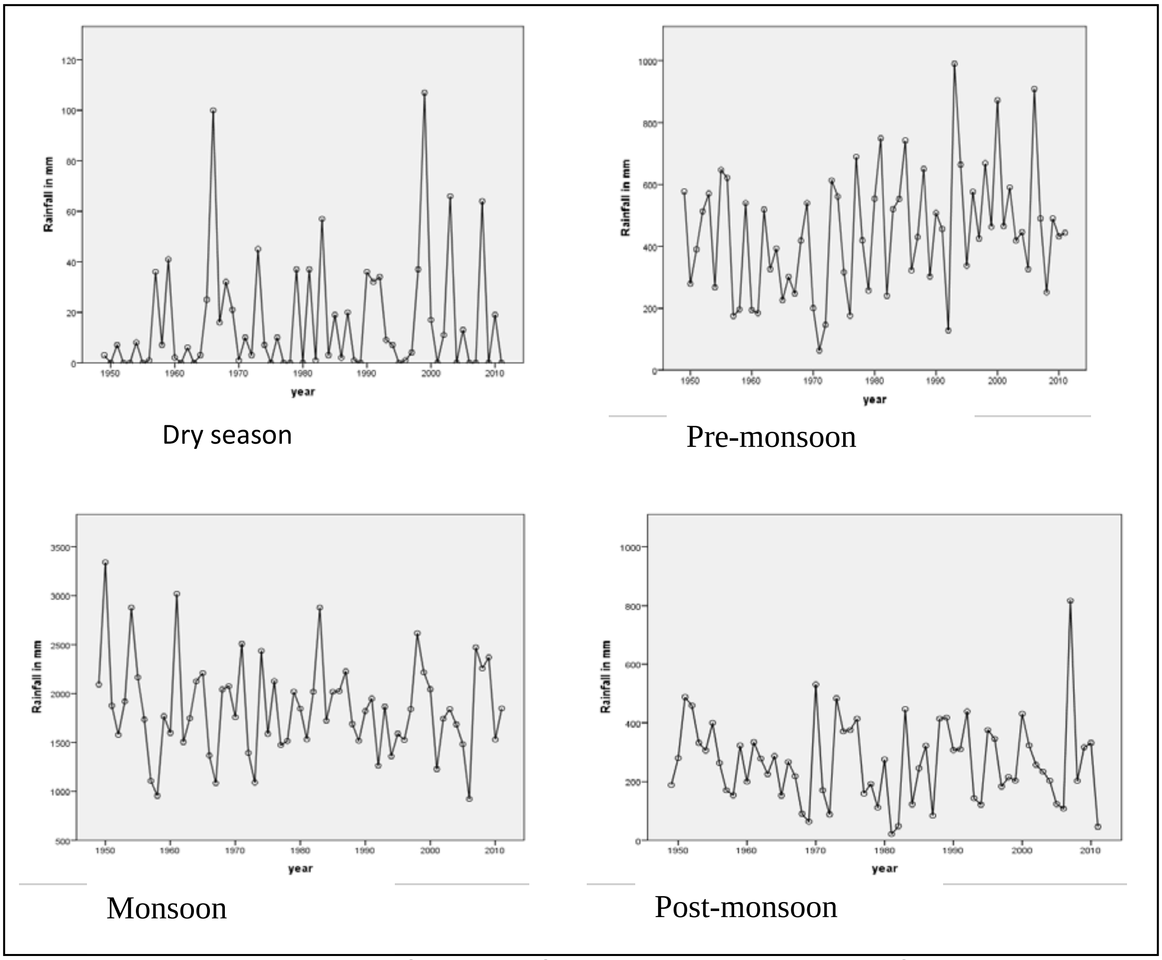

Figure 3: Seasonal rainfall pattern for Chittagong, 1949-2011 Rainfall in mm

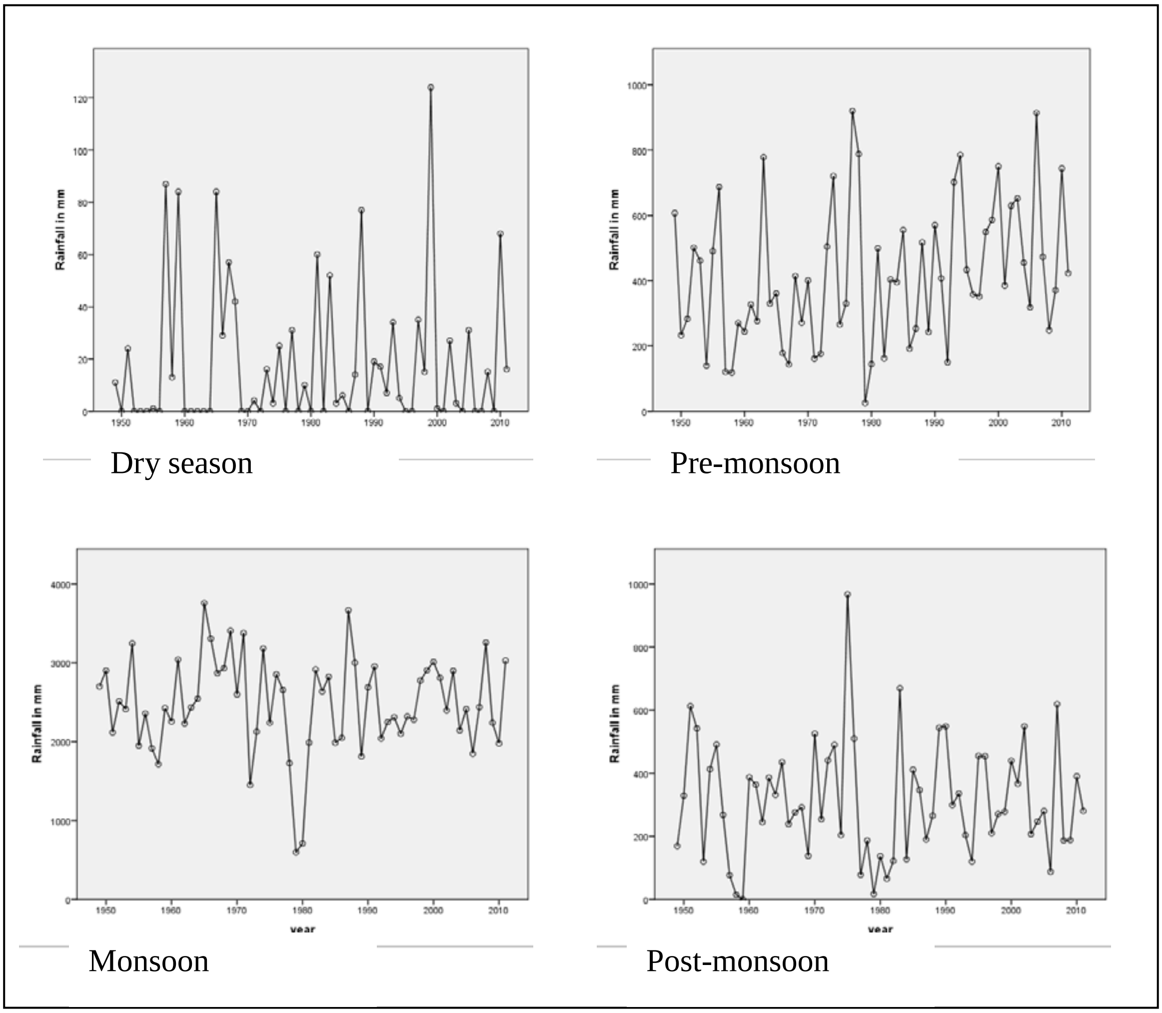

Figure 4: Seasonal rainfall pattern for Cox's Bazar, 1949-2011 Rainfall in mm

Table 8 shows results of Mann-Kendal test of seasonal rainfall for all the four seasons in Chittagong and Cox's Bazar during the period of 1949 to 2011. According to the table rainfall is increasing during the dry and pre-monsoon seasons and decreasing during the monsoon and post monsoon seasons at Chittagong (Table 8). Rainfall in pre-monsoons is increasing significantly (99% level of confidence) in Chittagong.

Table 8: Mann-Kendall test result for seasonal rainfall trend in Chittagong, Period 1949-2011

Seasons	**Test Z**	**Significance**
Dry season	0.62	Not significant
Pre-monsoon	1.77	Significant
Monsoon	-0.52	Not significant
Post monsoon	-0.80	Not significant

According to the Sen's test result (Table 9) rainfall is increasing at the pre-monsoon season at a rate of 2.3mm/year in Chittagong. During monsoon and post monsoon seasons, rainfall is decreasing at a rate of 1.6 mm/ year and 0.8 mm/year respectively.

Table 9: Sen's test result for seasonal rainfall trend in Chittagong, Period 1949-2011

Seasons	Q	B
Dry season	0.000	7.00
Pre-monsoon	2.300	352.00
Monsoon	-1.560	1884.96
Post monsoon	-0.830	280.83

The trend analysis for Cox's Bazar found that there are increasing trends of rainfall in all the three seasons except monsoons. The increasing trend of the pre-monsoon seasons is significant at the 10% level of confidence (Table 10). Sen's test result reveals pre-monsoon rainfall is increasing at a rate of 3.4mm/ year and monsoon rainfall is decreasing at a rate of 0.3mm/ year at Cox's Bazar (Table 11).

Table 10: Mann-Kendall test results for seasonal rainfall trends in Cox's Bazar, Period 1949-2011

Seasons	Test Z	Significance
Dry season	0.69	Not significant
Pre-monsoon	2.40	Significant
Monsoon	-0.04	Not significant
Post monsoon	0.15	Not significant

Table 11: Sen's test result for seasonal rainfall trend in Cox's Bazar, Period 1949-2011

Seasons	Q	B
Dry season	0.000	4.00
Pre-monsoon	3.394	276.21
Monsoon	-0.268	2439.76
Post monsoon	0.091	274.36

Q= Estimator for the true slop of linear trend

B= Estimator of the constant

5.4 Recent changes of seasonal mean rainfall

Further investigation in changes of mean rainfall in different seasons shows that there is a significant increase in rainfall in pre-monsoon seasons both for Chittagong and Cox's Bazar, 27% and 41% respectively. This trend is quite significant because 30% of the total annual rainfall occurs during pre-monsoon season.

There is a sharp increase (50% increases) in rainfall during the dry season for Chittagong. At this point of time this change is not significant because the total amount of rainfall is less. The dry season shares only 0.5% of the total amount of annual rainfall and the mean rainfall in the dry season is 21mm during the period of 1990-2011.

Another important trend in rainfall pattern is during monsoon. For Chittagong the mean rainfall during monsoon decreased by 5% where as there is a 1% increase in monsoon rainfall for Cox's Bazar.

Table 12: Seasonal mean rainfall during the period of 1949-1989 and 1990-2011 in Chittagong and Cox's Bazar

Station	**Season**	**Mean rainfall (in mm)**		**Changes in mean rainfall (increase/decrease)**
		Period 1949-1989	Period 1990-2011	
Chittagong	Dry season	14	21	50%
	Pre-monsoon	406	515	27%
	Monsoon	1892	1794	-5%
	Post monsoon	263	274	4%
Cox's Bazar	Dry season	18	19	6%
	Pre-monsoon	363	511	41%
	Monsoon	2474	2504	1%
	Post monsoon	309	319	3%

5.5 Recent trend of rainfall

The trend analysis of seasonal rainfall of Chittagong and Cox's Bazar shows decreasing trend of rainfall during dry season, post monsoon season and increasing trend for monsoon season (Table 13).

According to the Table 14 monsoon rainfall is increasing at the rate of 11mm/year at Chittagong and 9mm/year at Cox's bazar. Post monsoon rainfall is decreasing at the rate of 4mm/ year and 3mm/year respectively.

Table 13: Mann-Kendall test results for trend of rainfall in Chittagong and Cox's Bazar in between 1990 to 2011

Station	**Season**	**Mann-Kendall test**	
		Period 1990-2011, n=22	
		Z test	**Significance**
Chittagong	Dry season	-1.35	Not significant
	Pre-monsoon	-0.76	Not significant
	Monsoon	0.54	Not significant
	Post monsoon	-0.87	Not significant
Cox's Bazar	Dry season	-0.69	Not significant
	Pre-monsoon	0.00	Not significant
	Monsoon	0.45	Not significant
	Post monsoon	-0.68	Not significant

Table 14: Magnitude of per year changes in rainfall estimated by Sen's slope method for Chittagong and Cox's Bazar in between 1990 to 2011

Station	**Season**	**Q= Estimate of per year rain fall increase/decrease Period 1990-2011, n=22**
Chittagong	Dry season	-0.500
	Pre-monsoon	-3.167
	Monsoon	10.667
	Post monsoon	-4.600
Cox's Bazar	Dry season	-0.111

Pre-monsoon	0.800
Monsoon	8.600
Post monsoon	-3.000

6. Conclusion

Our analysis shows that in the south east part of Bangladesh mean annual rainfall has increased significantly in in the last two decades compare to a period between 1949 and 1989. At Chittagong percentage of increase in mean rainfall is 21% (618mm/year) and for Cox's Bazar it is 8% (308 mm/year). This increasing pattern of rainfall is not evenly distributed for all the four seasons. Sixty three years (1949-2011) trend analysis shows that rainfall is increasing significantly during pre-monsoon season. The rate of increase in rainfall during pre-monsoon season is 3 mm/year. This is quite significant because 17% of the total annual rainfall occurs during pre-monsoon (Ahasan et al., 2010). Moreover, trend analysis of rainfall of the last two decades (1990-2011) shows monsoon rainfall is increasing and pre-monsoon and post monsoon rainfall is slightly decreasing in the south east part Bangladesh. Sen's test reveals rainfall during monsoon is increasing at the rate of 10 mm/year. This trend is significant as 70% of the annual rainfall occurs in monsoon (Ahasan et al., 2010). However, these results are not statistically significant.

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