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

AHMED FARHAN MAHABUB
SAKIB SHADMAN PROSUN

ISLAMIC UNIVERSITY OF TECHNOLOGY
2018

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

AHMED FARHAN MAHABUB
SAKIB SHADMAN PROSUN

A THESIS SUBMITTED

FOR THE DEGREE OF BACHELOR OF SCIENCE IN CIVIL ENGINEERING

DEPARTMENT OF CIVIL AND ENVIRONMENTAL ENGINEERING
ISLAMIC UNIVERSITY OF TECHNOLOGY

2018

PROJECT REPORT APPROVAL

The thesis titled "STATISTICAL ANALYSIS OF RAINFALL TREND AND VARIABILITY DUE TO CLIMATE CHANGE IN BANGLADESH" submitted by Ahmed Farhan Mahabub and Sakib Shadman Prosun with St. ID: 145437 and 145449 has been found as satisfactory and accepted as partial fulfillment of the requirement for the Degree, Bachelor of Science in Civil Engineering.

Supervisor

Prof. Dr. Md. Rezaul Karim

Professor,

Head of Department of Civil and Environmental Engineering (CEE)

Islamic University of Technology (IUT)

Board Bazar, Gazipur, Bangladesh

DECLARATION OF CANDIDATE

We hereby declare that the undergraduate research work reported in this thesis has been performed by us under the supervision of Professor Dr. Md. Rezaul Karim and this work has not been submitted elsewhere for any purpose (except for publication).

Prof. Dr. Md. Rezaul Karim
Professor,
Head of Department of Civil and Environmental Engineering (CEE)
Islamic University of Technology (IUT)
Board Bazar, Gazipur, Bangladesh

Ahmed Farhan Mahabub
St. ID: 145437
Academic Year: 2017-2018

Sakib Shadman Prosun
St. ID: 145449
Academic Year: 2017-18

DEDICATION

We dedicate our thesis work to our family. A special feeling of gratitude to our loving parents. In addition, we express our deep gratitude towards our respected thesis supervisor Professor Dr. Md. Rezaul Karim

We also dedicate this thesis to our many friends who have supported us throughout the process. We will always appreciate what they have done.

ACKNOWLEDGEMENTS

"In the name of Allah, Most Gracious, Most Merciful"

All the praises to Allah (SWT) for giving us the opportunity to complete this book. We would like to express our sincere gratitude to our supervisor, Professor Dr. Md. Rezaul Karim. We are grateful for his patient guidance and valuable advice as without his help, diligence, insights, and enthusiasm, this work would never have been possible.

We would also like express gratitude to all of the departmental faculty members for their help and support from the beginning.

We are ever so grateful to our parents for their lifelong encouragement, support and attention and for being ravished patrons. We dedicate this work to them for their endless love and support.

To our batch mates and friends, we thank for everything they have done for us.

We also place on record, our sense of gratitude to one and all, who directly or indirectly, have contributed to this venture.

TABLE OF CONTENTS

LIST OF TABLES

LIST OF FIGURES

ABSTRACT

Climate change is a dominant environmental factor that has been affecting Bangladesh by causing a significant shift in the rainfall trend of the country. Variation in quantities of precipitation is often assessed by detecting and characterizing trends in available meteorological data. A study period from 1965-2015 has been taken in which daily rainfall records of 8 stations, distributed all over the country has been examined. The objective of the study is to analyse historic annual rainfall data of different locations from all over the country and observe the trend. These studies aim to understand the trend of change in rainfall patterns by analysing long term historical rainfall data, which then forms the basis of forecasting future scenarios. Seasonal and annual rainfall variation has been assessed. Mann-Kendall test and Sen's Slope model is used to detect the trend and estimate the magnitude of change, respectively. It has been observed that about 69% of rainfall occurs in the Monsoon season throughout the country. Monsoon and Post-Monsoon season shows a significant increasing trend whereas Pre-Monsoon and Dry season shows significant decrease. Mean annual rainfall is highest in Sylhet whereas Rajshahi has the least mean annual rainfall. It has been revealed that Khulna has a significant increase in mean annual rainfall trend. Annual mean rainfall in Bangladesh is found to be 2388 mm/year from this study. Moreover, a non-significant trend has been found in annual mean rainfall all over the country. Monthly mean and extreme event indices are also analyzed where the trend is decreasing for the extreme event. This study also aims to analyse some of the extreme rainfall indices using reliable, consistent and sufficient amount of rain gauge station data. Extreme rainfall analysis was also performed to study the changes in the intensity of extreme weather events. In case of annual, seasonal and extreme rainfall, most of the stations have negative trend so it is seen that the rainfall is decreasing all over the country in the 51 years study period.

Keywords: Climate change, rainfall trend, Mann-Kendall, Sen's Slope.

CHAPTER ONE

INTRODUCTION

1.1 Background of the Study

Climate change is the change in earth's climatic pattern. Change in climate is caused by factors such as biotic processes, variations in solar radiation received by Earth, plate tectonics, and volcanic eruptions and certain human activities. 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).

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 et al., 2005).The fluctuation in rainfall trend is analyzed in this study.

Bangladesh is one of the most affected country in the Asian region due to change in climate, this is down to its geographical location which is highly vulnerable to natural disaster such as floods, landslides, waterlogging, salinity, erosion. 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). The country is one of the most flood prone countries in the world due to its geographic position. Severe floods in the years of 1974, 1984, 1987, 1988, 1998, 2004 and 2007 ravaged the country. Drought in the northern part of the country has also become a growing concern in the recent years. The country experienced eight droughts of severe magnitude in last forty years (Shahid, 2008; Shahid and Behrawan, 2008. All parts of the country face erratic behavior of rainfall that includes early rainfall, late rainfall, and excessive rainfall in short period of time. (Huq, 2011). The potential magnitude and range of impacts of climate change makes it prudent to translate the trends in hydrologic variables into effects experienced by ecosystems, populations and infrastructure. Reliably detecting and characterizing these trends is a necessary first step in such an analysis. The objective of the study is to evaluate trends in the rainfall pattern from all over Bangladesh. The results can be used to check whether further analysis is required, and, if so, serve as a necessary input for predicting, decision-making, and planning processes to mitigate any adverse consequences of changing climate. The importance of the study is to analyze the extreme rainfall indices as the extreme event directly affects the flood risks and also to predict the future scenarios of rainfall pattern throughout Bangladesh.

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 (Bangladesh Bureau of Statistics, 2010). About 80% of total population of Bangladesh are directly or indirectly engaged in a wide range of agricultural activities

(Banglapedia, 2003).Rainfall is the most important factor that determines the agricultural production in Bangladesh. (Shahid, 2010).

1.2 Purpose and Objective of the Study

The purpose of the study is to understand and have a proper knowledge about the changes in rainfall trend over the years in Bangladesh. The specific objectives are:

- Analyze historic annual and monthly rainfall data and the extreme event of different locations from all over Bangladesh and observe the trend.

- To analyse the data statistically for verifying the trend.

1.3 Outline of the Thesis

The rest of the thesis chapters will be organized as follows:

- **Chapter 2: Literature Review**, discusses about the past works on this subject
- **Chapter 3: Study area and data collection**, identifying the location of the study and collecting of data
- **Chapter 4: Methodology**, Discusses about the procedural steps of the study.
- **Chapter 5: Results and Discussions**, analysis of the data
- **Chapter 6: Conclusions and Recommendations**, discuss about the effectiveness of the study and recommendations of the future studies.

CHAPTER TWO

LITERATURE REVIEW

2.1 Historical rainfall trends in South Africa: 1921–2015

The study which was conducted by Kruger and Nxumalo and the aim was to update the analysis of historical rainfall trend. Study period for this study was from 1921-2015. Two interlinked datasets, namely the district rainfall and individual rainfall stations datasets were used for the trend analyses, namely, daily time series of 60 individual rainfall stations and the daily district rainfall of 88 of 94 rainfall districts in South Africa. The extreme precipitation indices defined by the World Meteorological Organization Expert Team on Climate Change Detection and Indices were applied. The results show an increase in rainfall for most rainfall stations in the southern interior of South Africa, and indications of decreases in rainfall in the far northern and north-eastern parts. The increase in the annual rainfall in the south is reflected in the seasonal trends, where summer rainfall shows a similar increase, but also extends into the central interior. For other seasons, most of the country shows no significant historical trends in annual total rainfall. From the extreme rainfall analyses, an increase in daily rainfall extremes in the southern to western interior is apparent. Also, most of the country experienced increases in the intensity of daily rainfall, which confirms global results in general. Decreases in rainfall from wet spells were noted in most places over the east and north-east, while the southern and eastern parts along the escarpment experienced shorter annual dry spells. (Kruger and Nxumalo, 2017)

2.2 Rainfall variability and the trends of wet and dry periods in Bangladesh

The spatial patterns of annual and seasonal rainfall trends of Bangladesh over the time period 1958 – 2007 was assessed using rainfall data recorded at 17 stations distributed over the country by Shahid. Mann – Kendall trend test and the Sen’s slope method are used to detect the significance and the magnitude of rainfall change, respectively. The dry and wet months are identified by using standardized precipitation index method and their trends are analyzed to assess the possible change in wet and dry events in Bangladesh. The result shows a significant increase in the average annual and pre-monsoon rainfall of Bangladesh. The number of wet months is found to increase and the dry months to decrease in most parts of the country. Seasonal analysis of wet and dry months shows a significant decrease of dry months in monsoon and pre-monsoon. (Shahid, 2010)

2.3 Analysis of Rainfall Trends in the South-East Bangladesh

An analysis by Hasan on the annual and seasonal trends of rainfall in the South-East part of coastal Bangladesh over the period between 1980 and 2011 was done. Non-parametric- Mann-Kendall and Sen's test estimate is applied for detecting and estimating rainfall trends respectively. An assessment of rainfall data indicate amount of annual rainfall in South-East Bangladesh is increasing although this trend is not statistically significant. Seasonal analysis reveals least amount of rainfall occurs in winter and it is getting drier. However, trends analysis indicates the other three seasons, e.g. Pre-Monsoon, Rainy Monsoon and Post Monsoon, are becoming wetter. It is important to note that among all the seasons rainfall in Pre-Monsoon is increasing significantly (significant at *p= 0.05 level*) and the rate of increase is 8.5 mm/year.(. (Hasan[1] *et al (2014))*

2.4 Precipitation and Temperature Trend Analyses in Samsun, Turkey

An analysis was done by Karabulut on the precipitation and temperature trend in Samsun, Turkey. In this study, trends in precipitation and temperature at annual, seasonal and monthly time scales for the periods of 1931-2006 and 1974-2006 were examined for the Samsun which is located in the Black sea region of Turkey. Non-parametric tests (such as Mann -Kendall and

Sen’s Slope), linear regression, cumulative deviation curve techniques were used to determine climatic trends. The results showed that there is no negative or positive statistically significant trend in the study area, despite of slight precipitation decrease in winter for the period of 1931-2006. In contrast, 1974-2006 seasons represent slight precipitation increase (which are not statistically significant) annually and seasonally. Temperature data showed slight increase annually even though results are not statistically significant during the period of 1931-2006. On the other hand, results of temperature trend analyses represent statistically significant trend for the period of 1974-2006. The temperature data for summer months represent statistically significant trends during the last 32 years.(Karabulut et al 2008)

2.5 Climatic changes and trends over a Mahanadi river basin in India

A study was conducted by Rao on the climatic changes and trends over Mahanadi River basin in India. The study represents long-term changes of seasonal and annual surface air temperatures and precipitation of the Mahanadi river basin in India. The long-term trends in these 2 important climatic elements were evaluated by linear trend analysis. The results indicate that there is a highly significant warming trend in the mean maximum, mean minimum and average mean temperatures of the basin based on data from 7 stations for the period 1901-80. Results of the trend analysis of surface air temperatures of individual stations are also presented and discussed. Increase in greenhouse gases in the atmosphere over India, recent land-use pattern changes and agricultural practices in the region appear to have a bearing on the observed varying trend. For rainfall, monsoon and annual series were subjected to trend analysis. Basin rainfall series based on data from 125 stations for the period 1901-80 did not show any significant trend. Moreover, none of 10 selected stations in the basin was characterized by a significant increasing or decreasing tendency in either monsoon or annual rainfall. (Rao, 1993)

2.6 Trend analysis of rainfall and temperature data for India

Regarding trends in temperature, the mean maximum temperature series showed a rising trend at most of the stations; it showed a falling trend at some stations. The mean minimum temperature showed a ris-ing as well as a falling trend. At most of the stations in the south, central and western parts of India a rising trend was found. Some stations located in the north and northeastern India showed a falling trend in annual mean temperature. Most of the data used in trend analysis pertained to the stations located in urban areas and these areas are sort of heat islands. This article also highlights the need of a network of baseline stations for climatic studies. (Jain and Kumar, 2012)

CHAPTER THREE

STUDY AREA AND DATA COLLECTION

3.1 General

This section discusses about the location of the study and the collection of data related to the study.

3.2 Study Area

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' longitude. (Shahid and Khairulmaini, 2014)

3.3 Data Collection

The daily rainfall data were extracted from Bangladesh Meteorological Department (BMD) of 8 stations (Dhaka, Sylhet, Rajshahi, Rangpur, Cox's Bazar, Barisal, Khulna, Mymensingh) from 1965-2015. The locations of the stations are being displayed in figure 1.

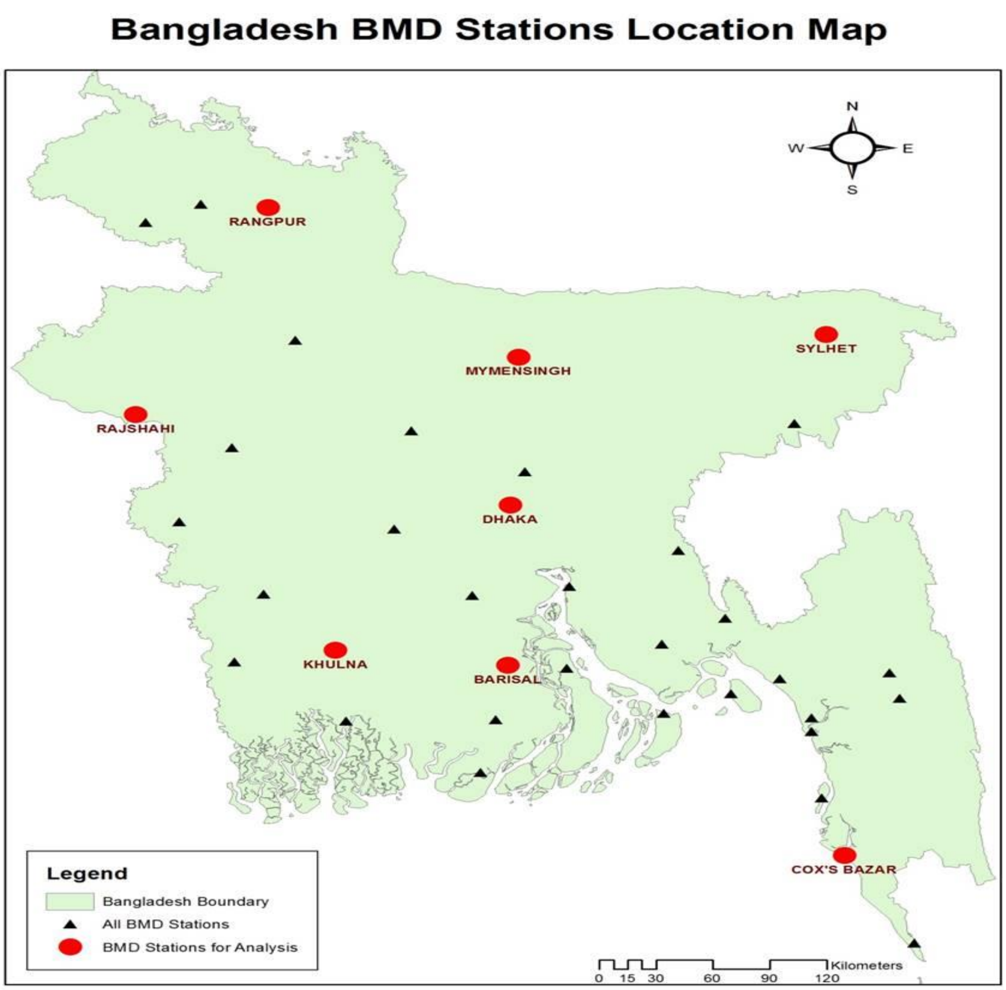

Figure 1: BMD station locations

CHAPTER FOUR

METHODOLOGY

4.1 General

This section describes the method to be followed one after another for the analysis of rainfall pattern throughout the country.

4.2 Forms of Analysis

To conduct the study, the analysis was broken down into four different parts.

4.2.1 Mean Monthly Rainfall

The mean monthly rainfall of a specific month is the average of the monthly values for certain years. Based on the study, the daily rainfall values were converted to monthly rainfall values which were later used to calculate the mean monthly rainfall.

4.2.2 Annual Mean Rainfall

Annual mean rainfall is the arithmetical average of total amount of precipitation recorded during calendar year. For this study, the daily rainfall values were converted to annual rainfall values which were later used to calculate the mean annual rainfall.

4.2.3 Extreme Rainfall Event

Extreme rainfall event is defined as the daily maximum rainfall for a specific year. For this study, the maximum value of daily rainfall from each year for each station is evaluated to estimate the extreme event.

4.2.4 Seasonal Rainfall

Seasonal rainfall is total the amount of rainfall in a specific season. The seasons in Bangladesh are divided into four parts. Such as:

1. Pre-monsoon
2. Monsoon
3. Post-Monsoon
4. Dry Season

For this study, daily rainfall is converted to monthly ones. Later seasonal rainfall is estimated by the sum of rainfall amount of all the months in that season.

4.3 Statistical Analysis

In this section the Trend analysis is evaluated by using the statistical non-parametric tests i.e. Mann-Kendall test and Sen's Slope Estimator test. The collected data have been compiled, tabulated and analyzed by 'MS Excel' and Excel template "MAKESENS" Application.

4.3.1 Mann-Kendall Test

In the Mann–Kendall test (Mann, 1945; Kendall, 1975) the data are evaluated as an ordered time series. Each data are compared to all subsequent data. The initial value of the Mann–Kendall statistic, *S*, is assumed to be 0 (e.g. no trend). If data from a later time period is higher than data from an earlier time period, *S* is incremented by 1. On the other hand, if the data from a later time period is lower than data sampled earlier, *S* is decremented by. (Shahid, 2010)

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

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

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,

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

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

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

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,

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

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

4.3.2 Sen's Slope Estimator

Some trends may not be evaluated to be statistically significant while they might be of practical interest (Yue Hashino, 2003; Basistha *et al*., 2007). Even if climate change component is present, it may not be detected by statistical tests at a satisfactory significance level (Radziejewski and Kundzewicz, 2004). 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.

To evaluate the slope estimate Q in equation 5 we first calculate the slopes of all data value pair

$$Q_i = \frac{x_j - x_i}{j - i} \tag{6}$$

Where j > k.

If there n values x_j in the time series we get as many as N= n(n-1)/2 slope estimates Q_i. The median of these N values of Q_i is the Sen's estimator of the slope. The N values of Q_i are ranked from the smallest to the largest and the Sen's estimator is

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

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

CHAPTER FIVE

RESULTS AND DISCUSSIONS

5.1 General

Many researchers have done linear trend analysis on rainfall pattern and this linear trend analysis is used because of its better acceptance. By analyzing the trend, the pattern of rainfall and characteristics of climate change can be observed and predicted. In this section, trends of various forms of rainfall in the different stations in Bangladesh is analyzed and detected. After evaluating station base analysis, the rainfall trends in overall Bangladesh is also analyzed.

.

5.2 Analysis of Mean Monthly rainfall

The daily rainfall data of each month from 1965-2015 is converted to monthly data. The mean is the average of the all the data of a specific variable and the Standard deviation is the dispersion of a particular data from the mean. For a specific month, monthly data for 51 years is taken into account and mean monthly rainfall for that month is calculated. In the table 1 the mean monthly rainfall of the 8 stations is shown:

Table 1: Mean monthly rainfall (mm/yr) for the 8 stations

Station	Rainfall in (mm/yr)											
	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
Cox's Bazar	13.3	24.7	75.5	233.9	715.8	885.1	765.5	431.6	259.3	137.4	17.7	8.2
Barisal	8.2	20.5	49.5	101.3	209.3	398.3	404.1	347.3	287.0	176.5	40.0	10.2
Dhaka	6.6	19.8	50.4	126.5	273.1	360.4	374.9	315.0	288.7	165.6	29.5	9.5
Khulna	11.7	28.7	44.7	70.6	184.1	330.9	327.7	312.5	262.6	125.7	27.3	4.8
Mymensingh	8.5	15.9	33.3	124.5	291.5	360.1	411.8	339.7	288.0	156.2	12.8	4.5
Rangpur	8.9	10.4	25.9	99.5	276.9	405.2	424.7	349.2	341.2	149.9	8.3	5.9
Rajshahi	9.8	13.8	26.6	56.7	129.6	261.2	307.7	258.1	258.8	106.6	13.0	7.4
Sylhet	9.1	43.0	133.0	359.3	550.3	782.2	771.6	636.8	506.8	207.4	25.3	6.7
Average	**9.5**	**22.1**	**54.9**	**146.6**	**328.8**	**472.9**	**473.5**	**373.8**	**311.5**	**153.2**	**21.8**	**7.1**
ST DEV	2.1	10.3	35.4	101.3	200.3	228.7	186.5	116.8	83.3	31.2	10.6	2.1

The maximum mean monthly rainfall was found in Cox's Bazar at an amount of 885.1 mm/yr occurring in the month of June whereas in Mymensingh the minimum mean monthly rainfall was found in December at an amount of 4.5 mm/yr.

From these stations, the rainfall in overall Bangladesh is evaluated. In July month, mean monthly rainfall in Bangladesh is found to maximum. On the other side, December shows the less mean monthly rainfall. The fluctuation in rainfall is the most significant in June. Mean monthly rainfall throughout Bangladesh is shown in Figure 1 as a bar chart:

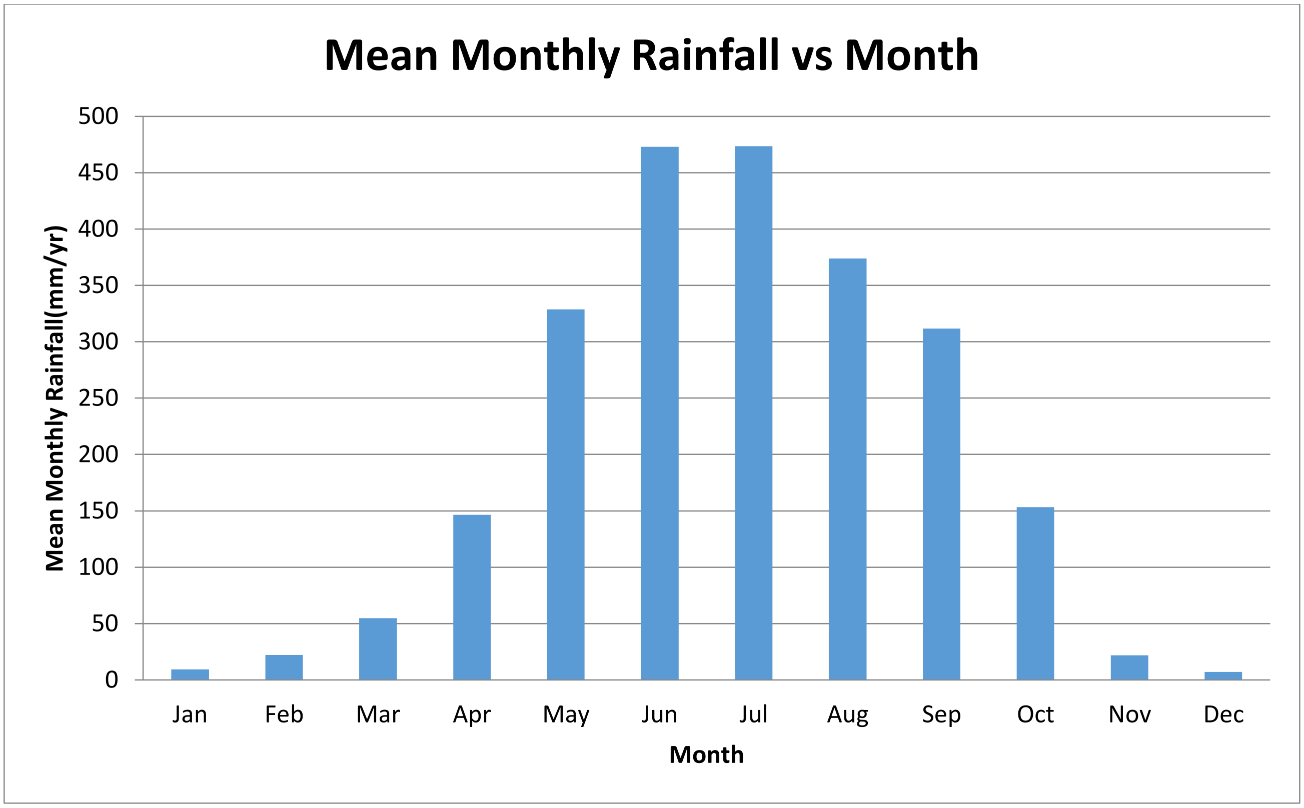

Figure 2: Bar chart of Mean Monthly Rainfall in Bangladesh

5.3 Analysis of Annual Mean Rainfall

The daily rainfall data is converted to annual data for each year from 1965-2015 for each station. Annual Rainfall trend for each station is determined by MS Excel and Excel template 'MAKESENS' application. The bar chart showing the trend with trend line equation and the z value for all the 8 stations is represented below:

Khulna Station:

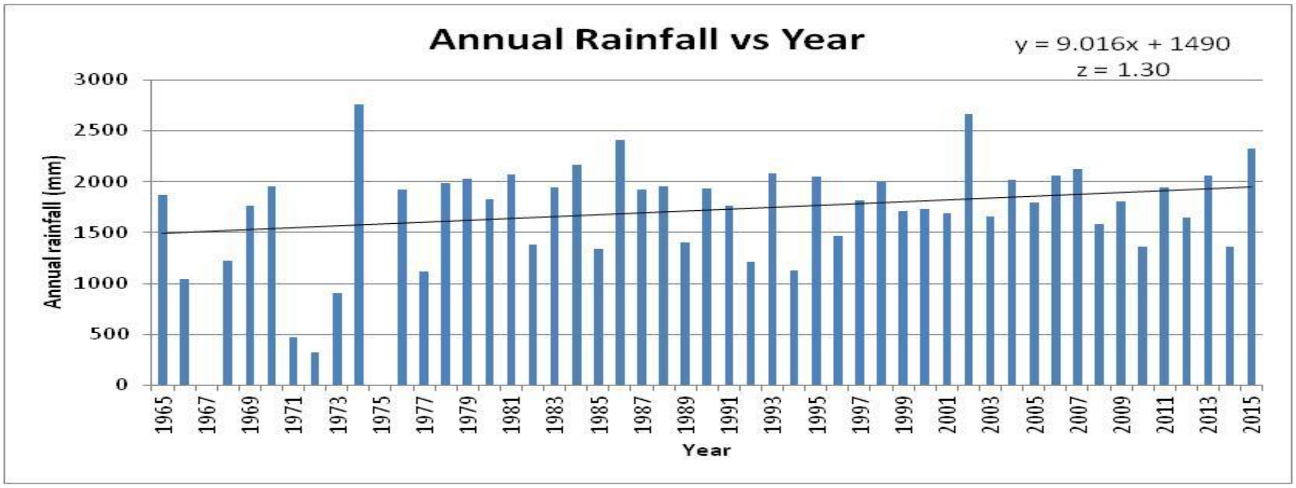

Figure 3: Annual Rainfall Trend in Khulna Station

For Khulna, annual rainfall is increasing significantly over the years as the z value is seen to be positive and for each year, the rainfall is increasing about 5.657 mm/yr.

Cox's Bazar Station:

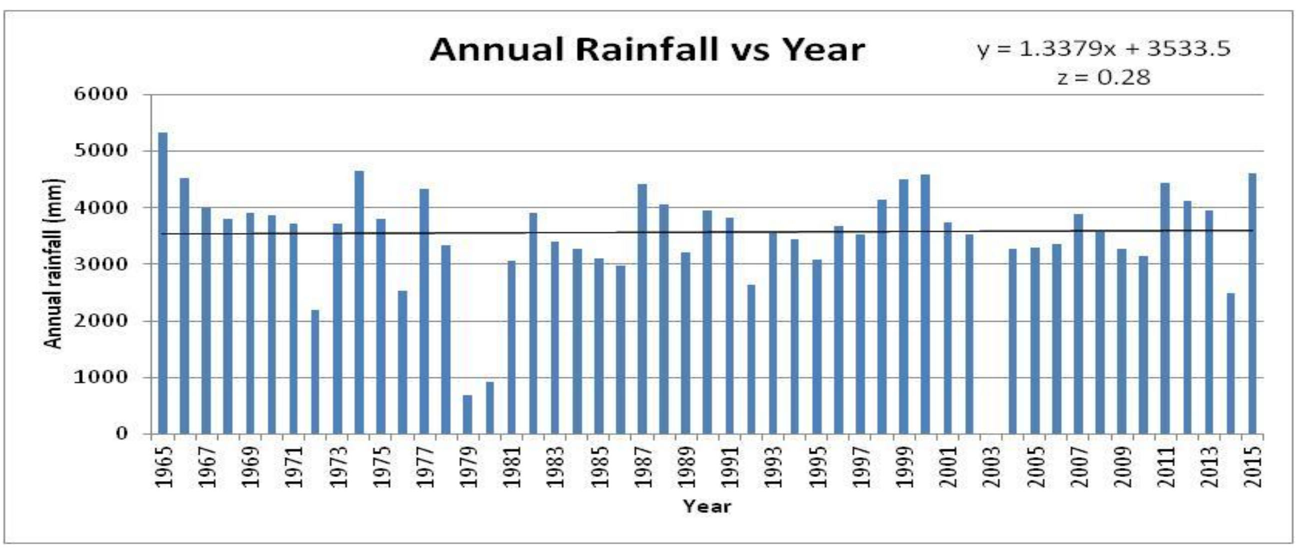

Figure 4: Annual Rainfall Trend in Cox's Bazar Station

In Cox's Bazar, the rainfall trend is seem to be insignificant. From the analysis, the z value becomes 0.28. As the value is positive, the trend will be also positive. As the z value is very small, so the trend is not significant. The rainfall is increasing about 1.889 mm/yr over 51 years.

Barisal Station:

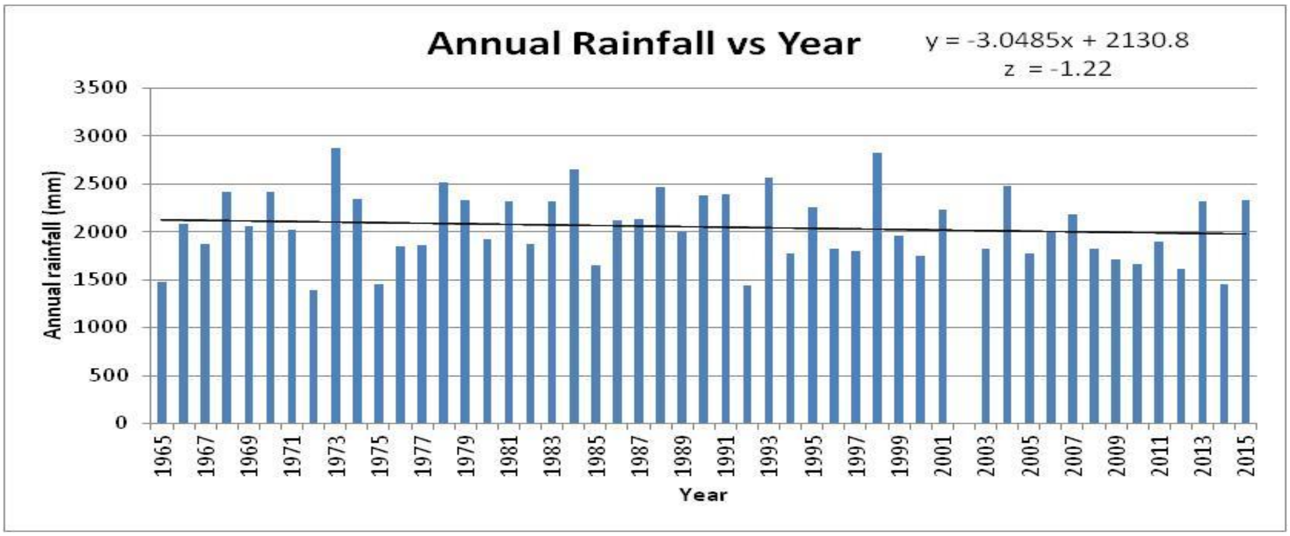

Figure 5: Annual Rainfall Trend in Barisal Station

In Barisal, the annual mean rainfall trend is negative as the z value is negative. From fig. the slope of trend line equation is also negative. Here, the rainfall is decreasing and the amount is 4.083 mm/yr.

Dhaka Station:

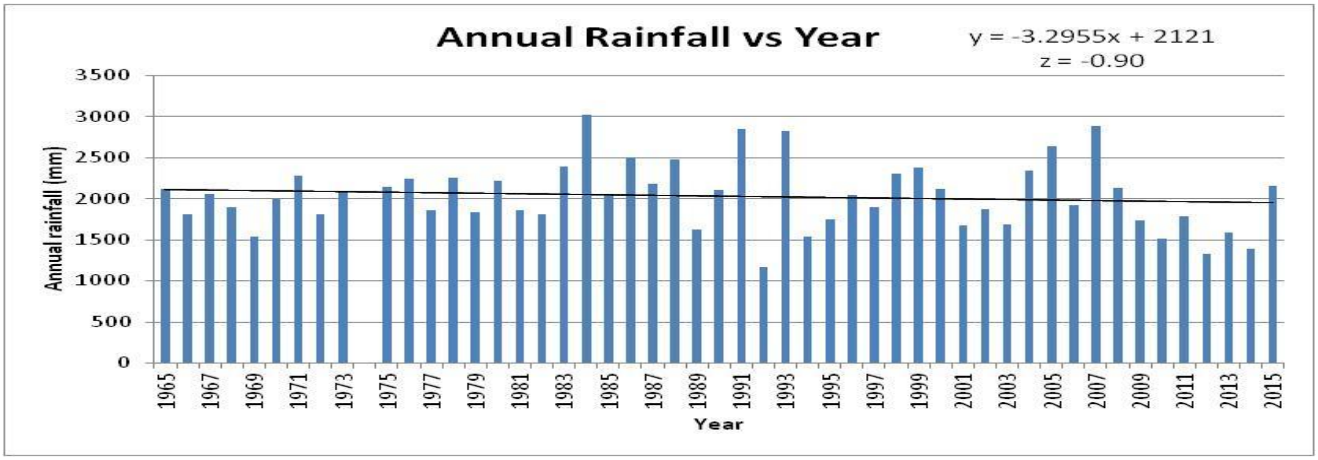

Figure 6: Annual Rainfall Trend in Dhaka Station

In Dhaka station, the rainfall trend is decreasing. From the analysis, the z value becomes -0.90. As the value is negative, the trend will be also negative. The rainfall is decreasing about 4.078 mm/yr over 51 years.

Mymensingh Station:

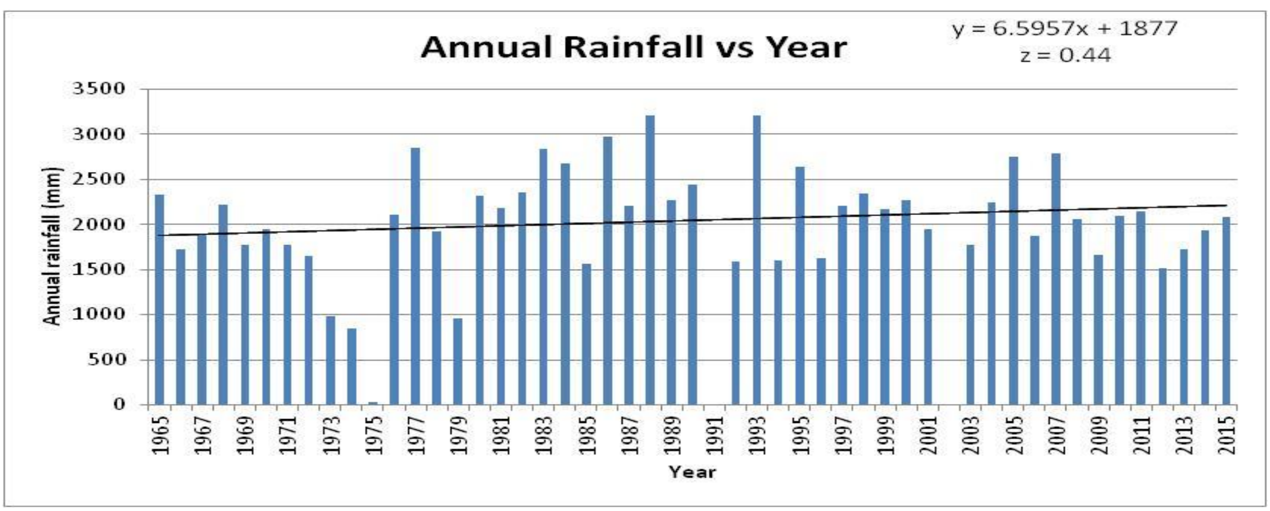

Figure 7: Annual Rainfall Trend in Mymensingh Station

From the analysis, the z value becomes 0.44. As the value is positive, the trend will be also positive. The rainfall is increasing about 3.279 mm/yr over 51 years.

Rajshahi Station:

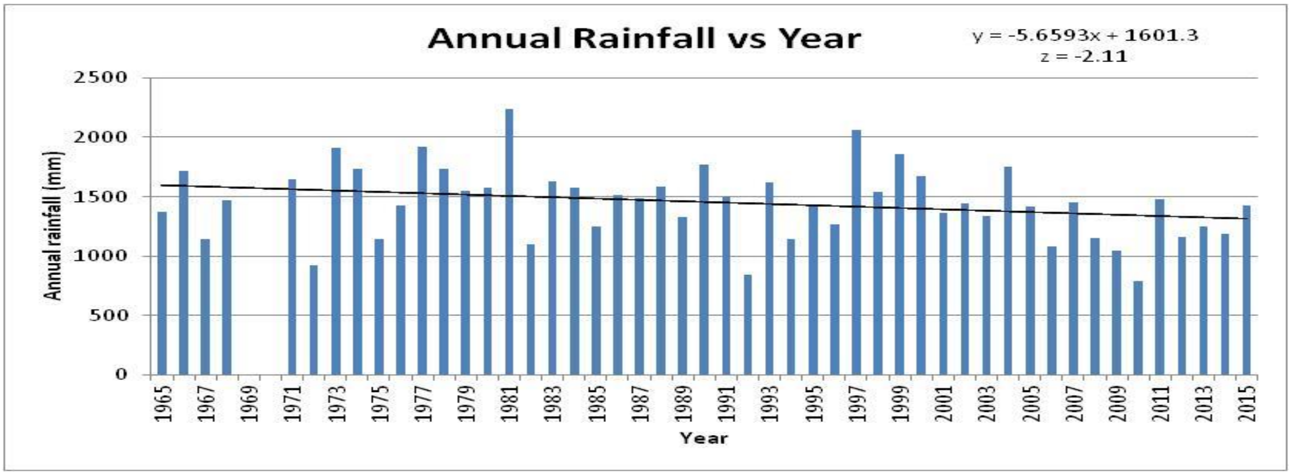

Figure 8: Annual Rainfall Trend of Rajshahi Station

In Rajshahi, the annual mean rainfall trend is negative as the z value is negative. From fig. the slope of trend line equation is also negative. Here, the rainfall is decreasing and the amount is 6.88 mm/yr.

Rangpur Station:

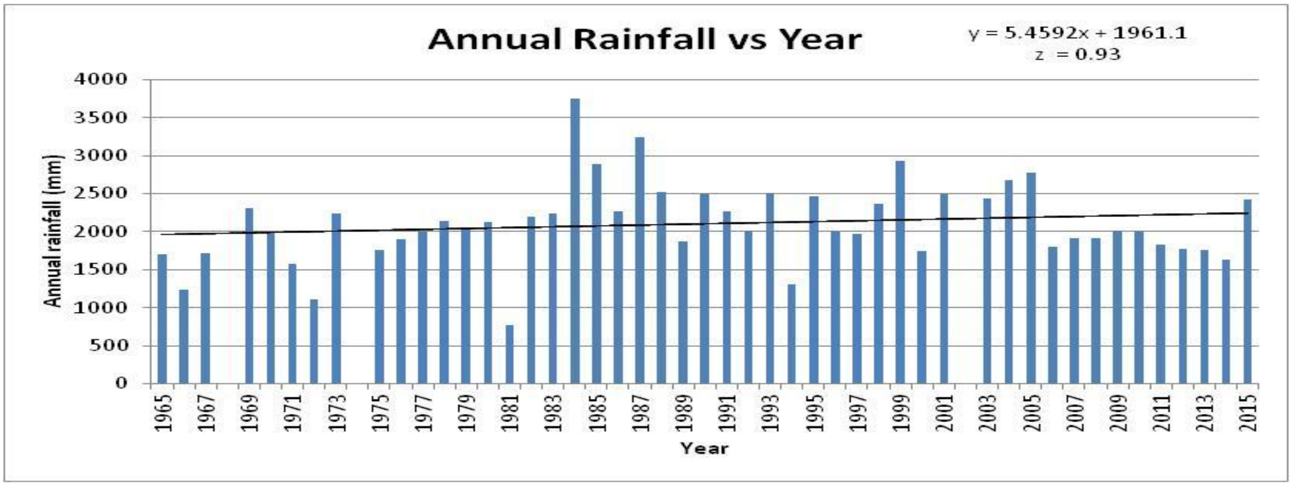

Figure 9: Annual Rainfall Trend of Rangpur Station

From the analysis, the z value becomes 0.93. As the value is positive, the trend will be also positive. The rainfall is increasing about 4.909 mm/yr over 51 years.

<u>Sylhet Station:</u>

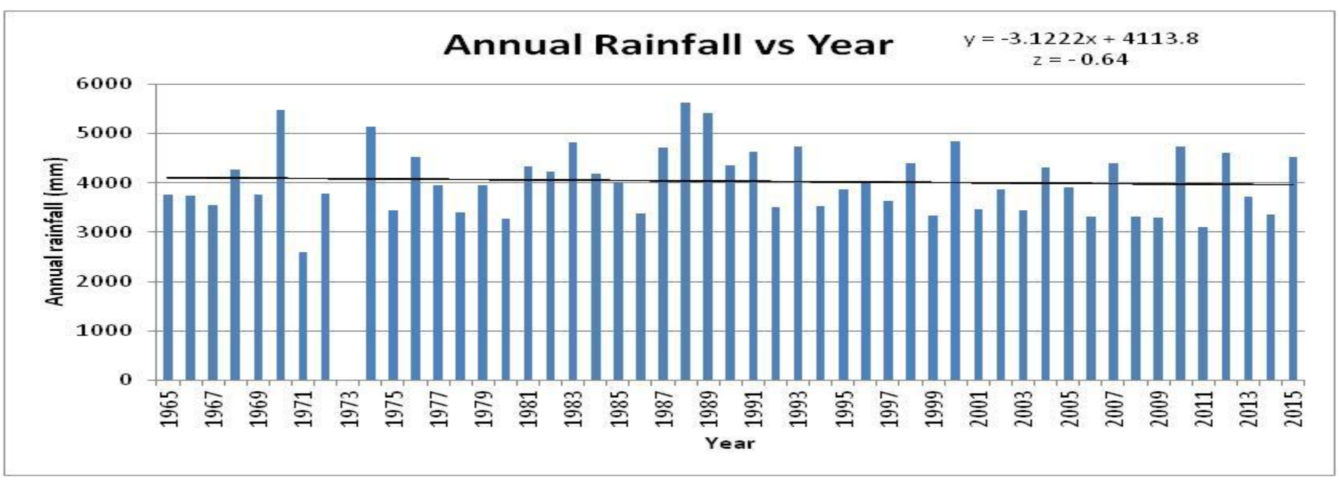

Figure 10: Annual Rainfall Trend of Sylhet Station

In Sylhet, the annual mean rainfall trend is negative as the z value is negative. From fig. the slope of trend line equation is also negative. Here, the rainfall is decreasing and the amount is 3.933 mm/yr.

5.4 Extreme Rainfall Event Analysis

The daily maximum rainfall of each year is evaluated from 1965-2015 and the trend of each station is detected by using MS Excel and the 'MAKESENS' application. The trend characteristics and the magnitude of extreme rainfall of each station are shown in the following figures:

Khulna Station:

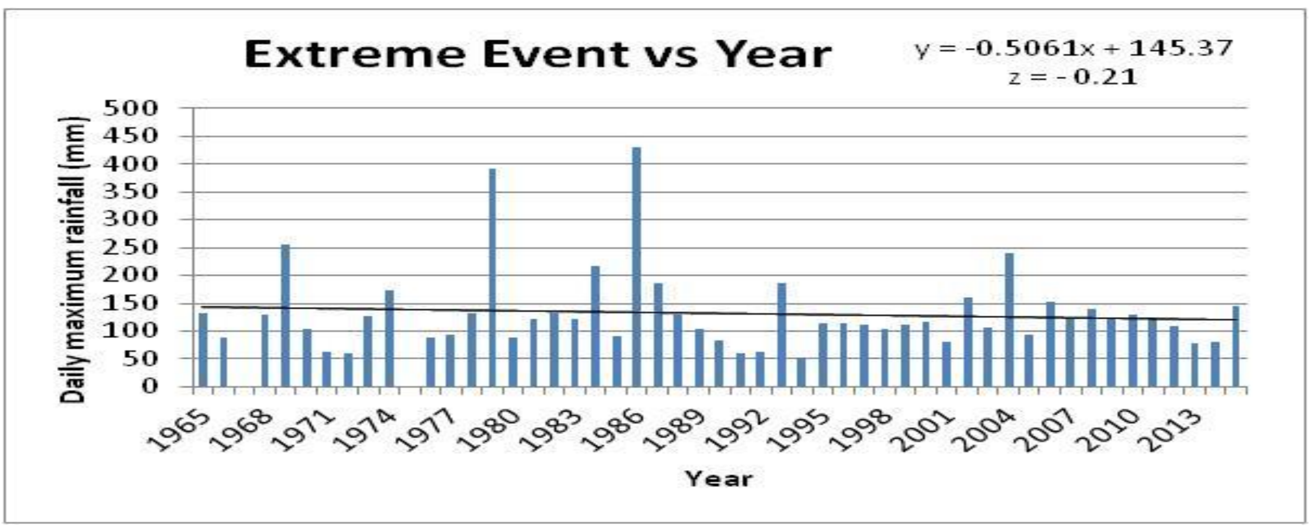

Figure 11: Extreme event trend of Khulna Station

In Khulna, the extreme event rainfall trend is negative as the z value is negative. From fig. the slope of trend line equation is also negative. The rainfall is decreasing 0.08mm/yr.

Cox’s Bazar Station:

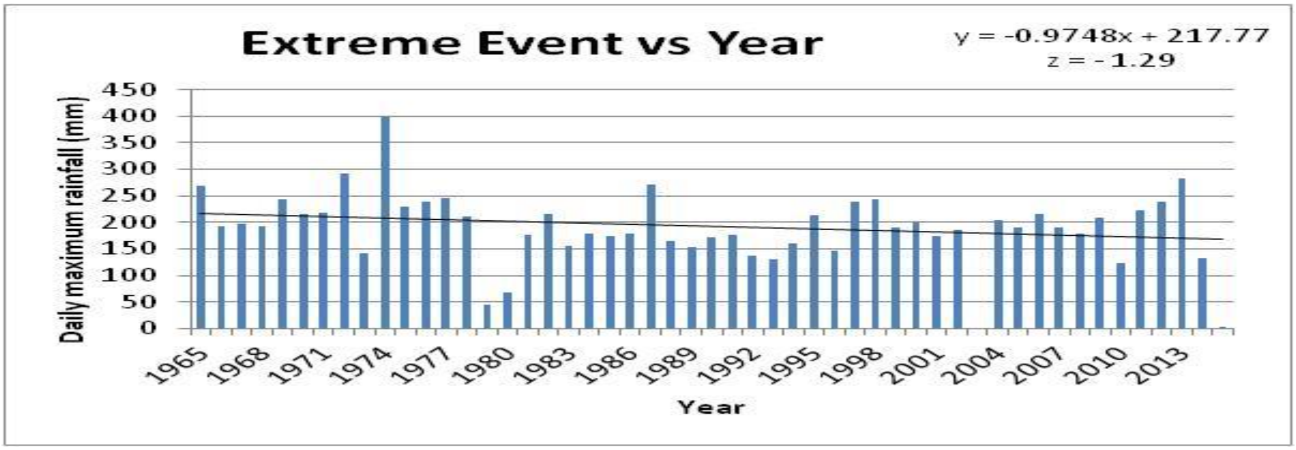

Figure 12: Extreme event trend of Cox’s Bazar Station

In Cox’s Bazar, the extreme event rainfall trend is negative as the z value is negative. From fig. the slope of trend line equation is also negative. Here, the rainfall is decreasing and the amount is -0.75 mm/yr.

Dhaka Station:

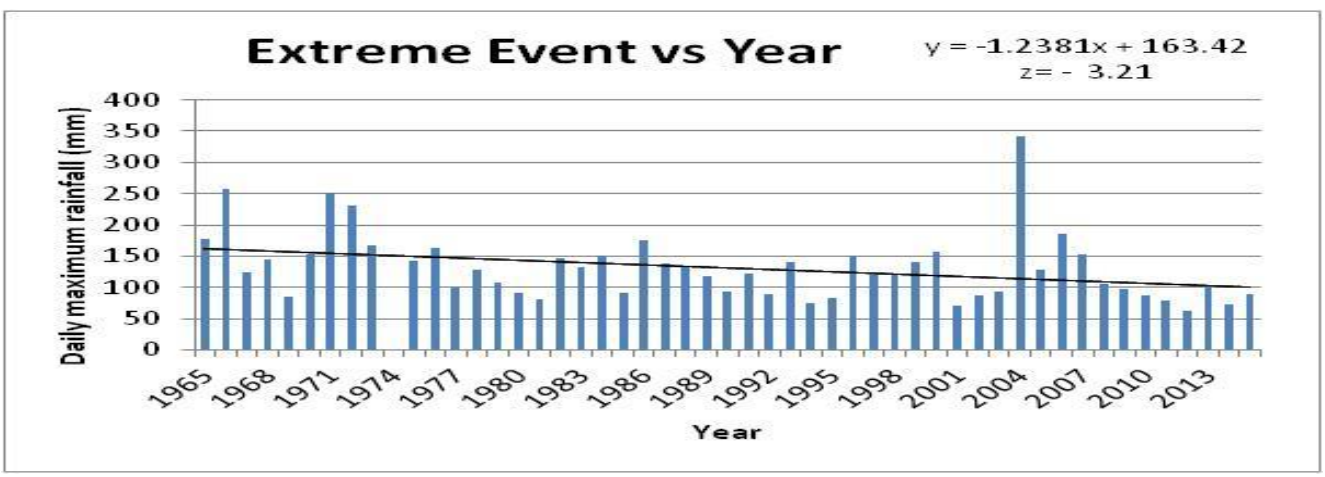

Figure 13: Extreme event trend of Dhaka Station

In Dhaka, the extreme event rainfall trend is negative as the z value is negative. From fig. the slope of trend line equation is also negative. Here, the rainfall is decreasing and the amount is -1.37 mm/yr.

Barisal Station:

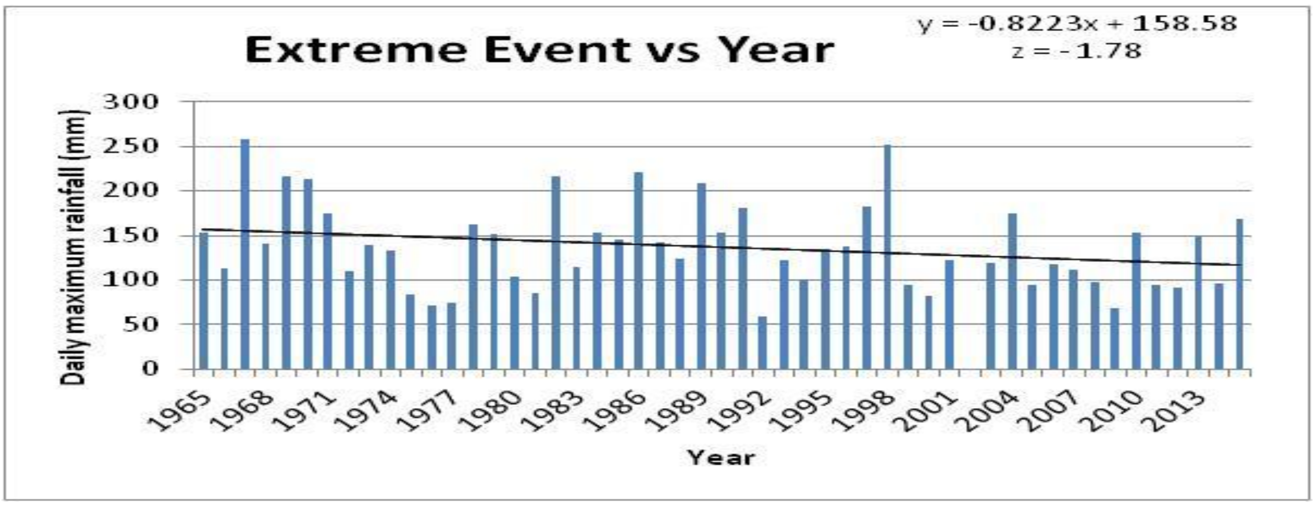

Figure 14: Extreme event trend of Barisal Station

In Barisal, the extreme event rainfall trend is negative as the z value is negative. From fig. the slope of trend line equation is also negative. Here, the rainfall is decreasing and the amount is -0.89 mm/yr.

Mymensingh Station:

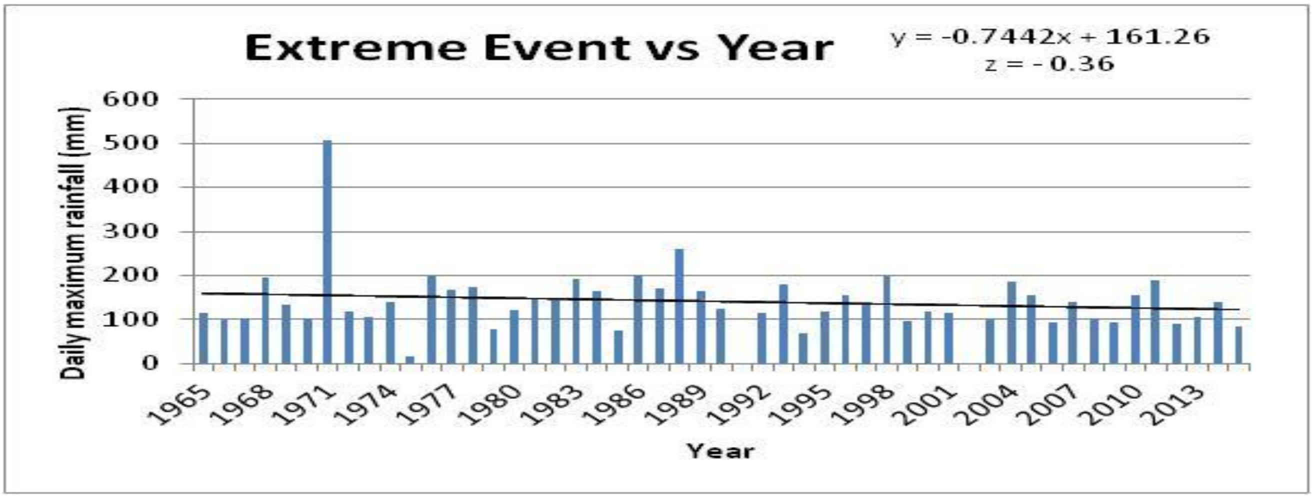

Figure 15: Extreme event trend of Mymensingh Station

In Mymensingh, the extreme event rainfall trend is negative as the z value is negative. From fig. the slope of trend line equation is also negative. Here, the rainfall is decreasing and the amount is -0.6 mm/yr.

<u>Rajshahi Station:</u>

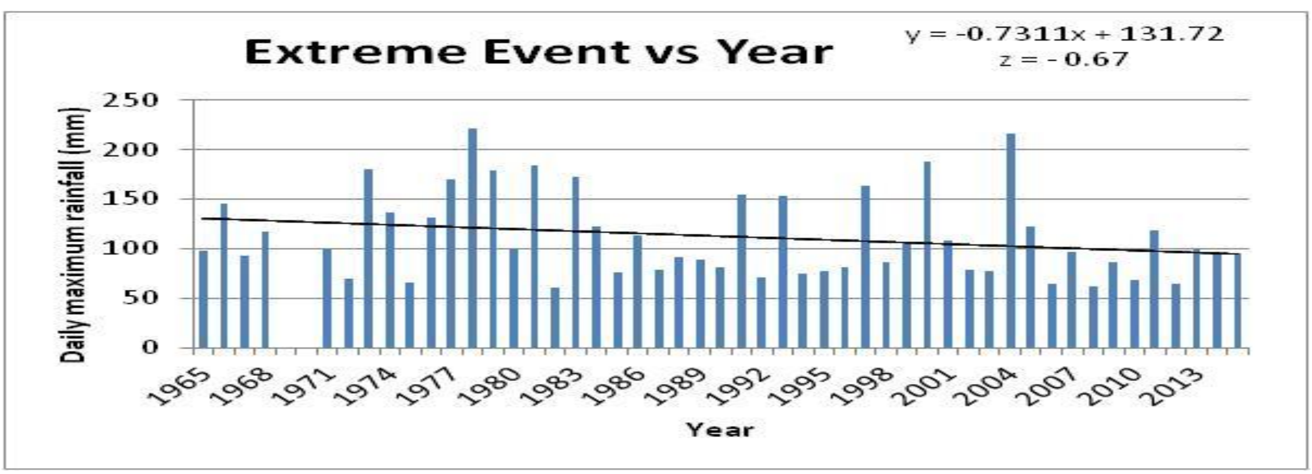

Figure 16: Extreme event trend of Rajshahi Station

In Rajshahi, the extreme event rainfall trend is negative as the z value is negative. From fig. the slope of trend line equation is also negative. Here, the rainfall is decreasing and the amount is -0.67 mm/yr.

Rangpur Station:

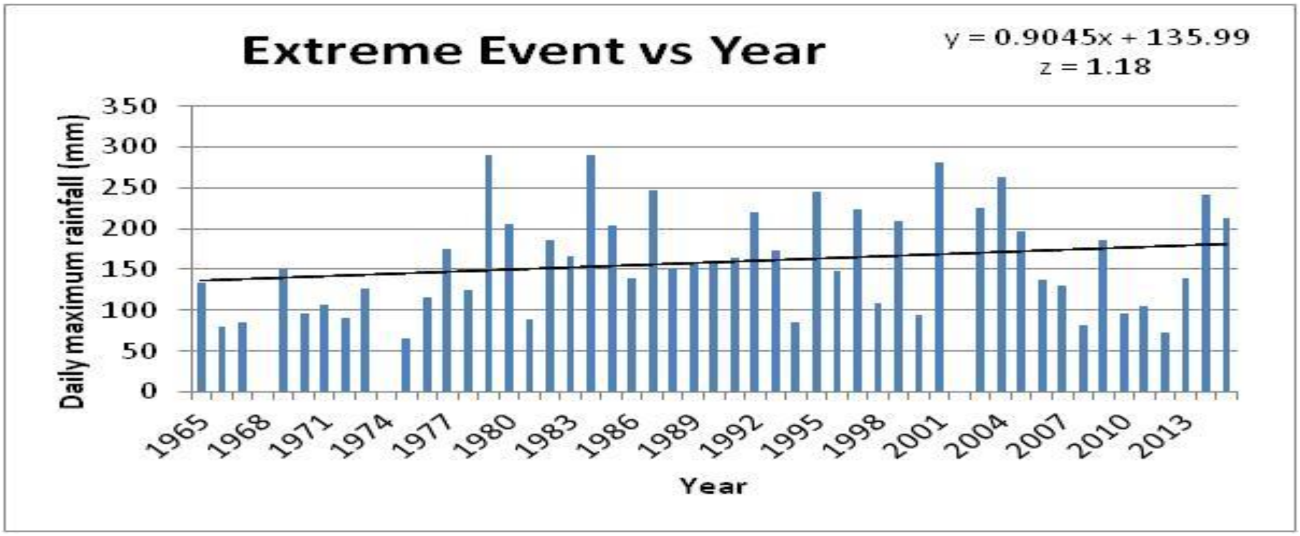

Figure 17: Extreme event trend of Rangpur Station

In Rangpur, the extreme event rainfall trend is positive as the z value is positive. From fig. the slope of trend line equation is also positive. Here, the rainfall is increasing and the amount is +2.8 mm/yr.

Sylhet Station:

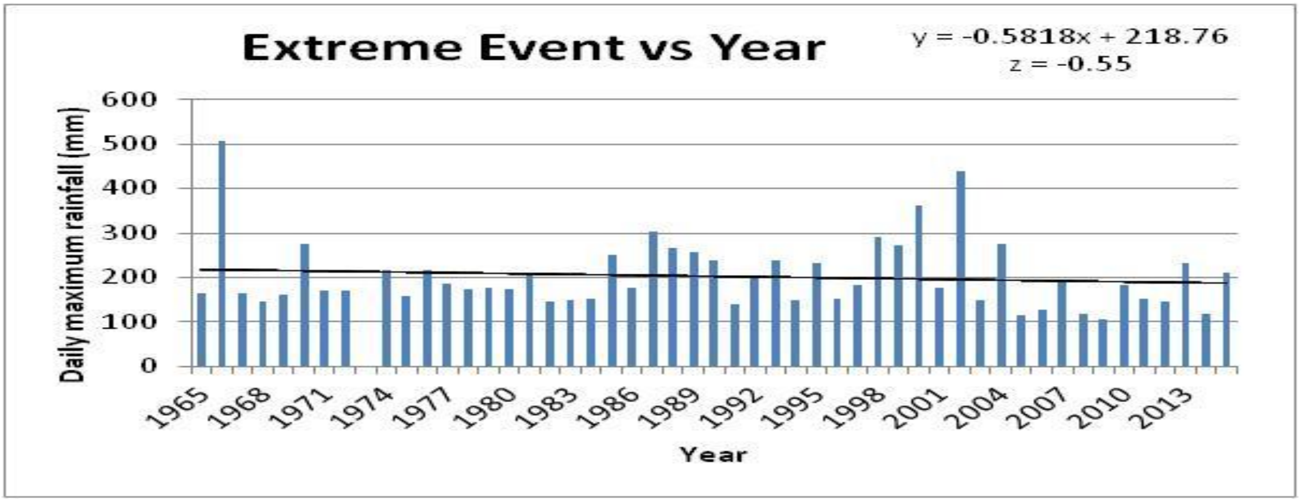

Figure 18: Extreme event trend of Sylhet Station

In Sylhet, the extreme event rainfall trend is negative as the z value is negative. From fig. the slope of trend line equation is also negative. Here, the rainfall is decreasing and the amount is -0.36 mm/yr.

5.5 Seasonal Rainfall

For seasonal rainfall analysis, the monthly rainfall values are calculated from daily rainfall amount. Later, for each season the rainfall amount the corresponding months are considered to sum up to estimate seasonal rainfall.

For all of the seasons in each station, the rainfall trend is represented in tabulated form:

Barisal Station

Table 2: Seasonal Rainfall Trend Statistics in Barisal

Time series	First year	Last Year	n	Test S	Test Z	Q	B
PreMonsoon	1965	2015	50		-0.42	-0.500	296.25
Monsoon	1965	2015	50		-0.89	-2.636	1488.76
PostMonsoon	1965	2015	50		-0.03	-0.030	200.45
Dry	1965	2015	50		-0.99	-0.226	26.36

Trend: For all the seasons, there is negative trend for seasonal rainfall from 1965 to 2015.

Dhaka Station

Table 3: Seasonal Rainfall Trend Statistics in Dhaka

Time series	First year	Last Year	n	Test S	Test Z	Q	B
PreMonsoon	1965	2015	50		-1.10	-2.462	526.44
Monsoon	1965	2015	50		-0.36	-0.983	1298.14
PostMonsoon	1965	2015	50		-1.01	-1.083	214.71
Dry	1965	2015	50		-0.44	-0.125	32.88

Trend: For all the seasons, there is negative trend for seasonal rainfall from 1965 to 2015.

Khulna Station:

Table 4: Seasonal Rainfall Trend Statistics in Khulna

Time series	First year	Last Year	n	Test S	Test Z	Q	B
PreMonsoon	1965	2015	49		-0.41	-0.486	294.87
Monsoon	1965	2015	49		1.06	4.911	1065.93
PostMonsoon	1965	2015	49		2.64	3.118	72.21
Dry	1965	2015	49		1.41	0.294	10.70

Trend: For Pre-monsoon, seasonal rainfall trend is negative .For Monsoon, Post-monsoon and Dry season the trend is positive.

Mymensingh Station

Table 5: Seasonal Rainfall Trend Statistics in Mymensingh

Time series	First year	Last Year	n	Test S	Test Z	Q	B
PreMonsoon	1965	2015	49		0.71	1.377	386.99
Monsoon	1965	2015	49		0.47	2.461	1359.77
PostMonsoon	1965	2015	49		0.89	0.973	124.29
Dry	1965	2015	49		0.52	0.125	20.13

Trend: For all the seasons, there is positive trend for seasonal rainfall from 1965 to 2015.

Rajshahi Station:

Table 6: Seasonal Rainfall Trend Statistics in Rajshahi

Time series	First year	Last Year	n	Test S	Test Z	Q	B
PreMonsoon	1965	2015	49		1.08	1.000	170.00
Monsoon	1965	2015	49		-2.84	-8.167	1281.50
PostMonsoon	1965	2015	49		-0.19	-0.120	123.48
Dry	1965	2015	49		-1.52	-0.312	30.74

Trend: For Pre-monsoon , seasonal rainfall trend is positive.For Monsoon, Post-monsoon and Dry season the trend is negative.

Rangpur Station:

Table 7: Seasonal Rainfall Trend Statistics in Rangpur

Time series	First year	Last Year	n	Test S	Test Z	Q	B
Pre	1965	2015	48		0.64	1.155	354.31
Moon	1965	2015	48		0.06	0.431	1509.67
Post	1965	2015	48		1.27	1.779	86.15
Dry	1965	2015	48		-0.12	0.000	23.80

Trend: For Dry season,the seasonal rainfall trend is positive. For Monsoon, Post-monsoon and Dry season the trend is positive.

Sylhet Station:

Table 8: Seasonal Rainfall Trend Statistics in Sylhet

Time series	First year	Last Year	n	Test S	Test Z	Q	B
Pre	*1965*	*2015*	*50*		0.96	3.391	971.39
Moon	*1965*	*2015*	*50*		-0.87	-4.692	2791.29
Post	*1965*	*2015*	*50*		-0.95	-1.813	263.38
Dry	*1965*	*2015*	*50*		-0.79	-0.288	48.16

Trend: For Pre-monsoon, seasonal rainfall trend is positive. For Monsoon, Post-monsoon and Dry season the trend is negative.

Here, for Monsoon season Khulna, Mymensingh, Rangpur, Cox’s Bazar show positive trend where Barisal, Dhaka, Sylhet, Rajshahi show the opposite. For Post-monsoon Khulna, Mymensingh, Rangpur, Cox’s Bazar show positive trend where Barisal, Dhaka, Sylhet, Rajshahi Show negative trend. For Dry season Khulna and Mymensingh show positive trend where Cox’s Bazar, Barisal, Dhaka, Sylhet, Rajshahi, Rangpur show negative trend.

For Pre-monsoon season Mymensingh, Rajshahi, Rangpur, Sylhet show positive trend where Cox's Bazar, Barisal, Dhaka, Khulna show the opposite.

Seasonal Rainfall in overall Bangladesh is estimated by combining the seasonal rainfall in each station.The seasonal rainfall trend is given below as bar chart:

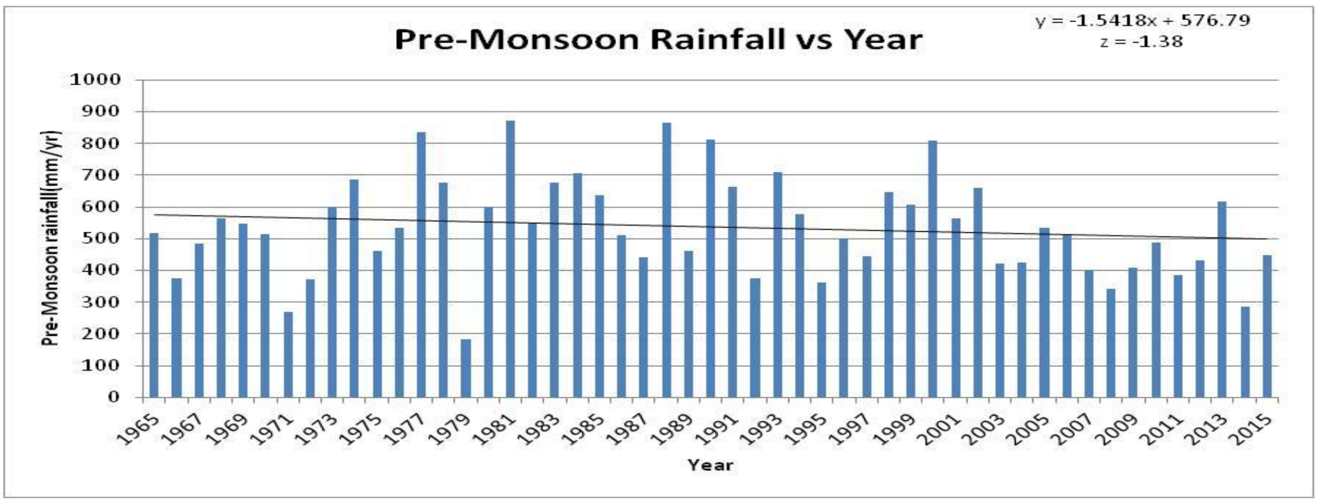

Figure 19: Pre-Monsoon rainfall trend in Bangladesh

The Pre-Monsoon trend in Bangladesh is negative as the z value is negative. From fig. the slope of trend line equation is also negative. Here, the rainfall is decreasing and the amount is -2.203 mm/yr.

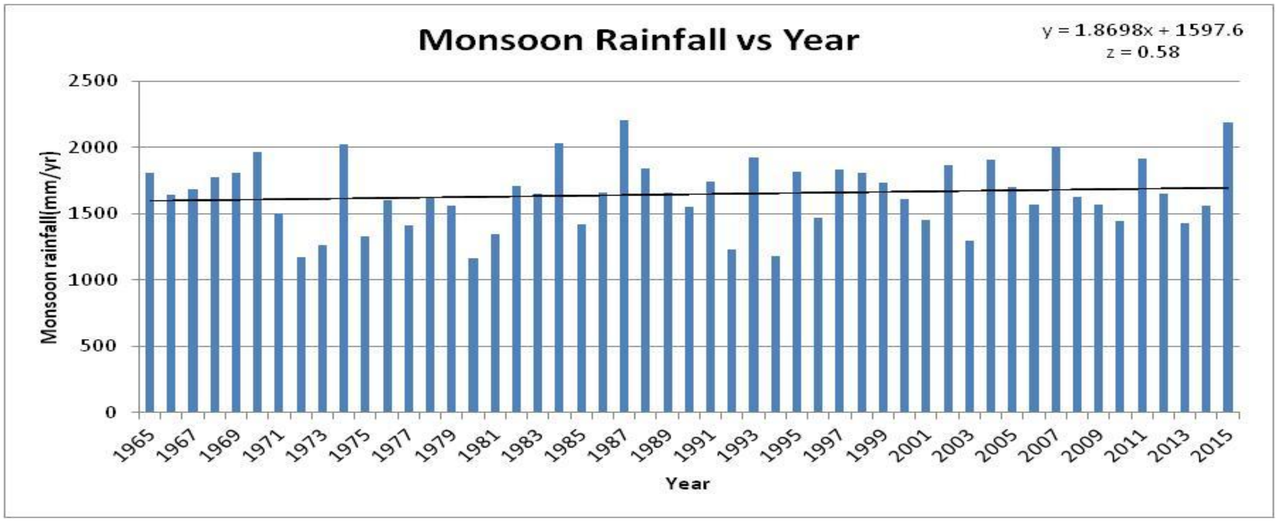

Figure 20: Monsoon Rainfall trend in Bangladesh

The Monsoon trend in Bangladesh is positive as the z value is positive. From fig. the slope of trend line equation is also positive. Here, the rainfall is increasing and the amount is +1.438 mm/yr.

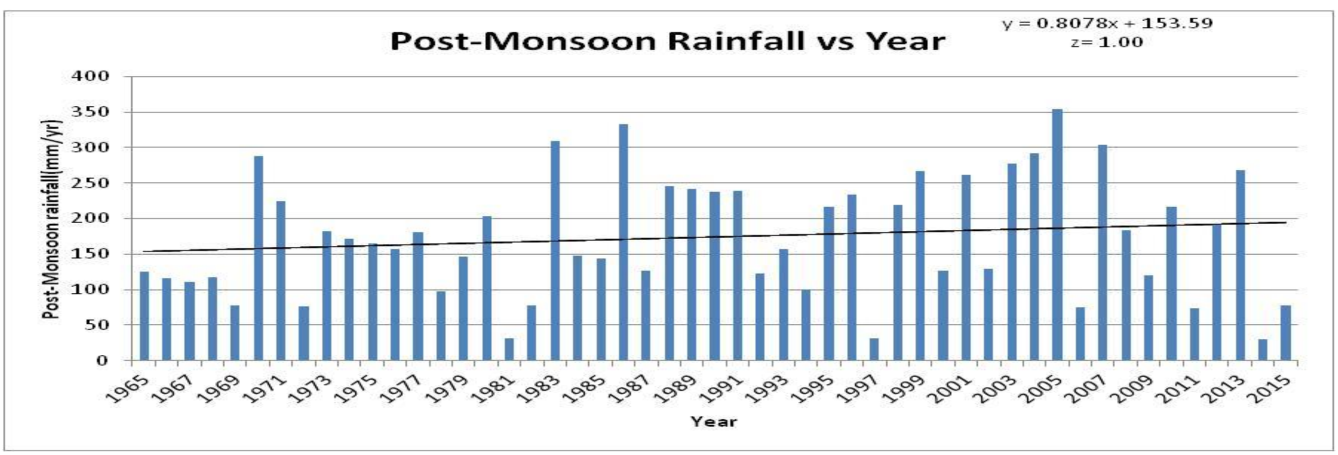

Figure 21: Post-Monsoon Rainfall trend in Bangladesh

The Post-Monsoon trend in Bangladesh is positive as the z value is positive. From fig. the slope of trend line equation is also positive. Here, the rainfall is increasing and the amount is +1.099 mm/yr.

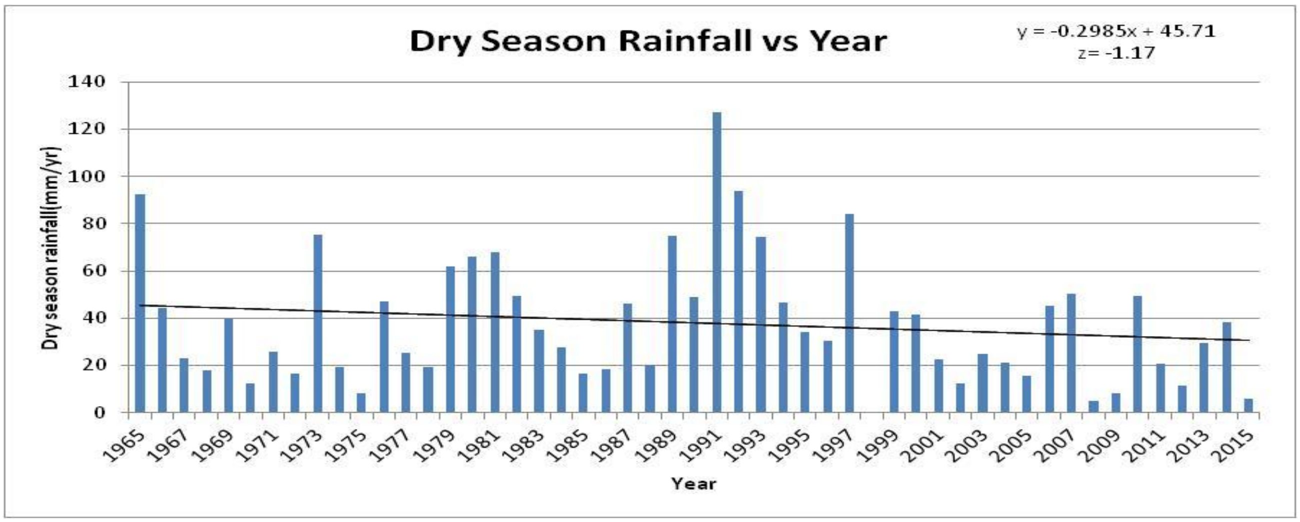

Figure 22: Dry Seasonal Rainfall trend in Bangladesh

The Pre-Monsoon trend in Bangladesh is negative as the z value is negative. From fig. the slope of trend line equation is also negative. Here, the rainfall is decreasing and the amount is -0.250 mm/yr.

CHAPTER SIX

CONCLUSIONS AND RECOMMENDATIONS

The objective of this study is to have a proper knowledge about rainfall pattern in Bangladesh. In this study, the main focus was to find the rainfall trend and variability. The data were carefully checked before analyzing. The trend analysis showed significant increase in annual rainfall for Khulna whereas Rajshahi had a significant decrease in annual rainfall over the course of these 51 years. In case of extreme rainfall event, Dhaka registered the significant decrease in trend due to temperature rise and land use factors. However, unlike the other 7 stations, Rangpur had an increase in extreme rainfall event trend. There is no significant change in annual mean rainfall trend all over the Bangladesh but for each of the station the trend is significant. From this study, it is also seen that in most of the stations the Dry season rainfall is decreasing over years.

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 such as dry days, rain days, and other climate change parameters. Moreover, the analysis could be done in regional basis by considering more stations to have a proper knowledge about a specific zone. This chapter gives an overview of the important findings of this research. Identifying the rainfall trends could have a wide range of applications in hydrology, engineering design and climate research.

REFERENCES

1) AC Kruger and MP Nxumalo.,2017: Climate Service, South African Weather Service, Private Bag X097, Pretoria, 0001, South Africa, Department of Geography, Geoinformatics and Meteorology, Faculty of Natural and Agricultural Sciences, University of Pretoria, South Africa

2) Bangladesh Bureau of Statistics (2010) Census of Agriculture Bangladesh. Bureau of Statistics, Statistics Division, Ministry of Planning, Govt. of the People's Republic of Bangladesh, Dhaka.

3) Dore, M.H.I., 2005: Climate change and changes in global precipitation patterns: What do we know. Env. Internl., 31(8), 1167-1181.

4) Gemmer, M., Becker, S., and Jiang, T., 2004: Observed monthly precipitation trends in China 1951–2002. Theor. Appl. Climatol., 77, 39–45.

5) Hulme, M., Osborn, T.J., Johns, T.C., 1998: Precipitation sensitivity to global warming: comparison of observations with HADCM2 simulations. Geophy. Res. Let., 25, 3379–3382.

6) IPCC (2007) Climate Change 2007: Synthesis Report. In: R.K. Pachauri and A. Reisinger, Eds., Contribution of Working Groups I, II and III to the Fourth Assessment Report of the Intergovernmental Panel on Climate Change (IPCC), Cambridge University Press, Cambridge.

7) IPCC (2007) Climate Change 2007: The Physical Science Basis. In: S. Solomon, D. Qin, M. Manning, Z. Chen, M. Marquis, K. B. Averyt, M. Tignor and H. L. Miller, Eds., Contribution of Working Group I to the Fourth Assessment Report of the Intergovernmental Panel on Climate Change (IPCC), Cambridge University Press, Cambridge.

8) IPCC (2007) Climate Change 2007: Impacts, Adaptation and Vulnerability. In: M. L. Parry, O. F. Canziani, J. P. Palutikof, P.J van der Linden and C. E. Hanson, Eds., Contribution of Working Group II to the Fourth Assessment Report of the Intergovernmental Panel on Climate Change (IPCC), Cambridge University Press, Cambridge.

9) Kayano, M.T., and Sansígolo, C., 2008: Interannual to decadal variations of precipitation and daily maximum and daily minimum temperatures in southern Brazil. Theor.Appl.Climatol., DOI 10.1007/s00704-008-0050-4

10) Lambert, F., Stott, P., and Allen, M., 2003: Detection and attribution of changes in global terrestrial precipitation. Geophy. Res. Abs., 5, 06140

11) Mearns, L.O., Rosenzweig, C., and Goldberg, R., 1996: The effect of changes in daily and interannual climatic variability on CERES-wheat: a sensitivity study. Clim. Change, 32, 257–292

12) Mohammad Anisur Rahman, Sunny Mohammed Mostafa Kamal, Mohammad Maruf Billah. Prediction and Trends of Rainfall Variability over Bangladesh. Science Journal of Applied Mathematics and Statistics. Vol. 5, No. 1, 2017, pp. 54-59. doi: 10.11648/j.sjams.20170501.18

13) Murat Karabulut, Mehmet Gűrbűz,Hüseyin Korkmaz. Precipitation and Temperature Trend Analyses in Samsun. J. Int. Environmental Application & Science,Vol. 3(5): 399-408 (2008)

14) P. Govinda Rao. Climatic changes and trends over a major river basin in India. CLIMATE RESEARCH Vol. 2: 215-223, 1993.

15) Radziejewski M, Kundzewicz ZW. 2004. Detectability of changes in hydrological records. Hydrological Sciences Journal 49(1): 39–51

16) Rodrı´guez-Puebla, C., Encinas, A.H., Nieto, S., Garmendia, J., 1998: Spatial and temporal patterns of annual precipitation variability over the Iberian Peninsula. Int. J. of Climatol., 18, 299–316

17) Rutherford., and Maarouf ., 2005: Standardized Precipitation Index Zones for México. Atmósfera vol.18 no.1 México ene. 2005

18) Shamsuddin Shahid.2010. Rainfall variability and the trends of wet and dry periods in Bangladesh. International Journal of Climatology Int. J. Climatol. 30: 2299–2313 (2010)

19) Shamsuddin Shahid and Osman Salleh Khairulmaini O.S. (2009) Spatio-Temporal variability of Rainfall over Bangladesh during the time period 1969-2003, Asia-Pacific Journal of Atmospheric Sciences 45 (3): 375-389.

20) Sabyasachi Swain, Manikant Verma, M.K. Verma(2016). Statistical trend analysis of monthly rainfall for Raipur district, Chattisgarh. International Journal of Advanced Engineering Research and Studies

21) Sharad K. Jain and Vijay Kumar., Trend analysis of rainfall and temperature data for India. Department of Water Resources Development and Management, Indian Institute of Technology, Roorkee 247 667, India.National Institute of Hydrology, Roorkee 247 667, India (Now at Ministry of Earth Sciences, New Delhi)

22) Yue S, Hashino M. 2003. Long term trends of annual and monthly precipitation in Japan. Journal of American Water Resources Association 39(3): 587–596.

23) Zaheed Hasan, Sabiha Akhter, Alamgir Kabir. Analysis of Rainfall Trends in the South-East Bangladesh. Journal of Environment (2014), Vol. 03, Issue 04, pp. 51-56.