STATISTICAL ANALYSIS OF RAINFALL VARIABILITY AND ITS TRENDS IN THE COASTAL ZONES OF BANGLADESH DUE TO CLIMATE CHANGE

Nusrat Jahan

Shahriar Iqbal

ISLAMIC UNIVERSITY OF TECHNOLOGY

2021

STATISTICAL ANALYSIS OF RAINFALL VARIABILITY AND ITS TRENDS IN THE COASTAL ZONES OF BANGLADESH DUE TO CLIMATE CHANGE

Nusrat Jahan

Student ID: 160051006

Shahriar Iqbal

Student ID: 160051056

A THESIS SUBMITTED

FOR THE DEGREE OF BACHELOR OF SCIENCE IN CIVIL ENGINEERING

DEPARTMENT OF CIVIL AND ENVIRONMENTAL ENGINEERING

ISLAMIC UNIVERSITY OF TECHNOLOGY

2021

APPROVAL

This is to certify that the thesis submitted by Nusrat Jahan and Shahriar Iqbal entitled as "Statistical analysis of rainfall variability and its trends in the coastal zones of Bangladesh due to climate change" has been approved, in partial fulfillment of the requirements for the Bachelor of Science degree in Civil Engineering.

SUPERVISOR

Prof. Dr. Md. Rezaul Karim

Professor
Department of Civil and Environmental Engineering (CEE)
Islamic University of Technology (IUT)
Board Bazar, Gazipur-1704, Bangladesh

APPROVAL

This is to certify that the thesis submitted by Nusrat Jahan and Shahriar Iqbal entitled as "Statistical analysis of rainfall variability and its trends in the coastal zones of Bangladesh due to climate change" has been approved, in partial fulfillment of the requirements for the Bachelor of Science degree in Civil Engineering.

SUPERVISOR

Prof. Dr. Md. Rezaul Karim

Professor

Department of Civil and Environmental Engineering (CEE)

Islamic University of Technology (IUT)

Board Bazar, Gazipur-1704, 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).

March 2021

Nusrat Jahan
Student ID: 160051006

Shahriar Iqbal
Student ID: 160051056

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).

March 2021

Nusrat

Nusrat Jahan

Student ID: 160051006

শাহরিয়ার

Shahriar Iqbal

Student ID: 160051056

DEDICATION

We dedicate our thesis work to our beloved parents and family.

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 wish to express our sincere gratitude to Professor Dr. Md. Rezaul Karim for providing us with all the necessary facilities, giving undivided attention and fostering us all the way through the research. His useful comments, remarks and engagement helped us with through the learning process in the thesis. We are extremely obliged and indebted to him for sharing expertise, sincere and valuable guidance and encouragement extended to us.

We also express our earnest regards to our honorable teachers, seniors and friends who supported us throughout the work.

Table of Contents

List of Figures

List of Tables

Abstract

The coastal area of Bangladesh is highly vulnerable to climate change. Unpredictable rainfall or changes in rainfall patterns might have negative impacts on its socio-economic culture along with its ecosystem. Therefore, the aim of this study is to investigate the spatial distribution and trends of rainfall in the Coastal region of Bangladesh for the period 1980-2019. The Coefficient of Variation (CV) and Precipitation Concentration Index (PCI), Seasonality Index (SI), Standardized Anomaly Index (SAI) are calculated to observe the spatial variability and distribution of rainfall in the coastal region. For visualizing with a geographic information system, Inverse Distance Weighting method was used. To identify the trend of rainfall and its magnitude of changes Mann-Kendall and Sen's slope method are used respectively. The results show that the minimum annual rainfall of 1674 mm is observed in the coast of South-West which rises up to 4191 mm in the South-East coast. Above 70% of annual rainfall occurs during Monsoon with a uniform distribution and low variability. Maximum values of annual PCI are observed in the South-East coast and majority of the study area is characterized by irregular rainfall distribution. SI shows a significant increasing trend for the entire coastal area. SAI indicates a longer drier period for the South-West in recent years. The annual rainfall trend analysis shows mainly the zones exposed to the Bay of Bengal have an increasing trend at 95% level of confidence among which the South-East coast is experiencing a significant increasing trend. The seasonal rainfall trend analysis shows that the South-East region shows an increasing trend for Pre-Monsoon, Monsoon and Post-Monsoon whereas the South-West region has the increasing trend for Monsoon and Post-Monsoon. For the winter season, both regions show a negative trend.

Chapter One : Introduction

1.1 Background of the Study

Coastal zone of Bangladesh is geomorphologically and hydrologically dominated by the Ganges Brahmaputra Meghna (GBM) river system and Bay of Bengal (Ahmad H, 2019) . The coastal areas of Bangladesh is different from rest of the country not only because of its unique geo-physical characteristics but also for different socio political consequences that often limits people's access to endowed resources and perpetuate risk and vulnerabilities. Coastal areas include coastal plain islands, tidal flats, estuaries, neretic and offshore waters. It extends to the edge of a wide (about 20 km) continental self. A vast river network, a dynamic estuarine system and a drainage basin intersect the coastal zone, which made coastal ecosystem as a potential source of natural resources, diversified fauna, and flora composition, though there also have immense risk of natural disasters (M. Shamsuddoha & R. K. Chowdhury, 2007).

Bangladesh is considered to be highly vulnerable in the context of climate change. It is frequently at the mercy of the forces of nature, especially water from the sky, land, and sea (R. Kabir et al., 2014). The coastal region of Bangladesh covers about 20% of total land area and over 30% of the cultivable lands of the country. It includes highly diverse ecosystems e.g., the world's largest single tract of mangroves (the Sundarbans), beaches, coral reefs, dunes, and wetlands (M.H. Minar et al., 2013).

The total population of the coastal area is almost 35.07 million, which is around 29% of the total population of the country and more than half of them (around 52%) are poor. The people of this region use the land areas for agriculture, livestock rearing, fishing, shrimp culture, and salt production. Unpredictable rainfall and associated extreme events could have negative impacts on the ecosystem, agriculture, business, health, and the overall livelihoods of the common people. (Hasan et al., 2014). However, the areas are extremely prone to natural disasters like coastal flooding, cyclones, storm surges, erosion, salinity, arsenic contamination (Parvin et al., 2008).

The people in the coastal region are highly dependent on the natural resources for their livelihood. Increasing trends of climate change related vulnerabilities and natural disasters gradually making people's life more helpless. Change in rainfall patterns can affect the overall livelihood of the residents in the area.

1.2 Objective and purpose of the Study

- To understand the annual and seasonal rainfall variations and trends in the Coastal zones
- To observe the trends of the extreme rainfall events in the Coastal zones
- To comprehend the changes in rainfall distribution among the seasons
- To identify the vulnerable regions in the Coastal zones

1.3 Scope of work

This study aims to provide information about the mean annual rainfall, seasonal rainfall, spatial annual rainfall variability, and inter seasonal rainfall variability in the coastal region of Bangladesh. Analysis of the precipitation concentration index for both annual and seasonal rainfall is also a pursuit of the study. Using the seasonality index and trend analysis, the study will provide a picture of the ongoing change in the rainfall pattern in the past few decades.

1.4 Limitation

The study is done with s secondary data set. Moreover, some of the stations have missing rainfall data. For example, Rainfall data for Ambagan gauge station was available from the year 1999. For Mongla gauge station, it was available from the year 1991and Chittagong has missing data from 2004 to 2007. For the study, these missing data were skipped.

1.5 Thesis Book layout

In Chapter 2 the previous work on the context of rainfall variability and trend analysis has been reviewed for Bangladesh and other parts of the world. The Chapter 3 consists of the declaration of our study area and the methodology we have followed to conduct the work. The results and findings of the study are presented in Chapter 4. The data tables, the GIS figures, and bar charts are displayed to illustrate the findings on this chapter. In Chapter 5 the overall conclusions and the summary of the research is drawn along with the recommendations for future studies and the reference we have used to complete the thesis work.

Chapter Two : Literature Review

2.1 General

Rainfall variability in space and time is one of the most relevant characteristics of the climate of Bangladesh. From the previous studies on the variability and trend of rainfall due to the continuous climate change in the past several decades helps us to evolve the understanding of the rainfall pattern. The summary of such studies related to Bangladesh and foreign countries are detailed in this chapter.

2.2 Rainfall studies in Bangladesh

2.2.1 Analysis of Rainfall Trends in the South-East Bangladesh:

For the period of 1980 to 2011, the annual and seasonal trends of rainfall in the South-East region of Bangladesh was conducted in the paper. For the analysis, Non-parametric tests such as Mann-Kendall for detecting the rainfall trends and Sen's Slope for estimating the trends were used in the study.

An assessment of rainfall data indicates the amount of annual rainfall in South-East Bangladesh is increasing although this trend is not statistically significant. Seasonal analysis reveals the 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 et al 2014)

2.2.2 Spatial and Temporal Variability of Rainfall over the South-West Coast of Bangladesh:

This study examined the spatial and temporal rainfall variability from the 1940s to 2007 in the south west coastal region of Bangladesh. The rate of change was found in the exposed zone and interior zone are +12.51 and +4.86 mm/year, respectively, over post monsoon and +0.9 and +1.86 mm/year, respectively, over winter. These trends intensified both in the exposed zone (+45.81 mm/year) and the interior zone (+27.09 mm/year) 1990 onwards. Winter rainfall does not exhibit significant change ($p > 0.1$) over the exterior or interior zone, though individual stations like Jessore, Satkhira and Bhola show significant negative trends after the 1990s. Although the trends were observed to weaken in the monsoon and pre-monsoon seasons, they are not significant. Moreover, an 11-year cyclicity was found within these two seasons, whilst no cyclicity was observed in the post-monsoon and winter seasons. These changes may have a detrimental effect on rain-fed agriculture in Bangladesh. The application of palaeo-environmental techniques, threshold determination and rainfall analysis across the whole country could be useful to support adaptation planning of the rain-fed agro-economy in Bangladesh (Hossain et al., 2014)

2.2.3 Precipitation Concentration in Bangladesh over Different Temporal Periods

The purpose of this study was to analyze precipitation concentration rates in different regions of Bangladesh using the precipitation concentration index (PCI) and the inverse distance weighting method. In this study, the rainfall data from 30 meteorological observation stations across Bangladesh were collected for the period 1980 to 2011. We defined periods of varying lengths (i.e., annual, supraseasonal, seasonal, and three- and two-month rainfall concentrations) and compared their PCI values. The results showed that precipitation concentrations were mostly irregular when rainfall was concentrated within two to four months of the year. Higher PCI values were mainly identified in the eastern region and have strong seasonal influences, whereas lower PCI values were mostly observed in the northern region. The analyses of periodic variation and precipitation in Bangladesh generally follow through the SW–NE direction due to the summer monsoon, while during the winter monsoon, they follow the N–S direction where JAS and JFM showed higher and lower PCI values. At a two-month scale, significant changes were identified during transition periods where PCI values were lower from 2000 to 2011 than those in the earlier decades (Mondol et al., 2018).

2.2.4 Rainfall variability and changes in Bangladesh during the last fifty years

The results of this study show that rainfall in Bangladesh varies from 1527 mm in the west to 4197 mm in the east with a mean of 2488 mm. More than 89% of rainfall occurs during May to October. Coefficient of variation of annual rainfall shows a moderate inter-annual variability of rainfall in most parts of the country. The trend analysis using Mann-Kendall method reveals the presence of a positive trend in annual rainfall of Bangladesh at 90% level of confidence. The magnitude of change of annual rainfall estimated by Sen's slope estimator shows that the annual rainfall of Bangladesh has increased at a rate of +5.53 mm yr-1 in the last fifty years (1958-2007). A significant increase in pre-monsoon rainfall at a rate of 2.47 mm yr-1 at 99% level of confidence is also observed over Bangladesh. (Shahid, Shamsuddin. 2012)

2.2.5 Detection of changes and trends in climatic variables in Bangladesh during 1988–2017

Due to the importance of climatic variability, an assessment detecting the changes and trends has been carried out over different time series of major climatic variables from the records of meteorological stations over Bangladesh from 1988-2017. The results show that the average monthly maximum temperature (T max) and minimum temperature (T min) have increased significantly by 0.35 °C/decade and 0.16 °C/decade, respectively. However, the increase in T max is comparatively higher than T min and caused significant increases in the monthly temperature range (MTR) at a higher rate in winter than in the monsoon season. The monsoonal and annual precipitation have decreased by 87.35 mm/decade and 107 mm/decade, respectively. The monsoonal T max and T min (0.47 °C/decade and 0.38 °C/decade, respectively) have increased significantly in the NW; consequently, this region has been warmed by 0.27 °C/decade. Humidity changes are not significant except in the monsoon season across the country. Precipitation, WS, and humidity are negatively correlated with the temperature variables. (Md. H. R. Khan et al 2019)

2.2.6 Spatiotemporal trends in the frequency of daily rainfall in Bangladesh during 1975–2017

This study aims to explore the spatiotemporal trends in the frequency of daily rainfall using different statistical models based on 23 station data from 1975 to 2017 in Bangladesh. The statistical results show that the frequency of rainfall ranges of < 5 mm, > 10 to ≤ 15 mm, > 15 to ≤ 20 mm, and > 25 to ≤ 30 mm exhibited an increasing trend while rainfall ranges of > 5 to ≤ 10 mm, > 20 to ≤ 25 mm, > 30 to ≤ 35 mm, and > 35 mm displayed a decreasing trend ($p > 0.10$). The jump test results indicate that only one jump occurred in the average rainfall ranges of > 15 to ≤ 20 mm ($p < 0.10$). The changes in temporal trends of different rainfall frequency ranges show an irregular pattern during the study period. The spatial map of trends among various rainfall ranges over sub-climatic regions is heterogeneous in nature which varies from region wise and station wise. The probability density function (PDFs) of rainfall frequency ranges will move upward in the future and broaden with an increase in the forthcoming period. (A. R. Md. T. Islam et al 2020)

2.2.7 Climatic feature of heavy rainfall activities in monsoon season and its socio-economic impact in Bangladesh

An attempt has been made to understand the heavy rainfall situation of Bangladesh by using rainfall data during the period 1951-2006. Daily rainfall data has been analysed as because heavy rainfall within a short period creates water logging as well as deteriorate flood situations by disrupting the capacity of drain canals and rivers. It has been found that in June, July, August and September the country averaged frequencies of moderately heavy rainfall are 3.30, 3.54, 3.08 and 2.48

respectively; frequencies of heavy rainfall are 2.20, 2.31, 1.82 and 1.34 respectively and frequencies of very heavy rainfall are 0.98, 1.02, 0.68 and 0.47 respectively. But the frequencies of total heavy rainfall are 6.17, 6.57, 5.54 and 4.29 respectively. The linear trends of all the categories of rainfall are mostly positive during the period. The higher frequencies of heavy rainfall are found either in the northeastern or in the southeastern parts but the lower frequencies are mainly concentrated in the central or west-central regions of Bangladesh. (Md. Mannan 2008)

2.2.8 Rainfall variability and seasonality in northern Bangladesh

This paper aimed at the analysis of rainfall seasonality and variability for the northern part of South-Asian country, Bangladesh. The coefficient of variability was used to determine the variability of rainfall. While rainfall seasonality index (SI) and mean individual seasonality index (SIi) were used to identify seasonal contrast. We also applied Mann-Kendall trend test and sequential Mann-Kendall test to determine the trend in seasonality. The lowest variability was found for monsoon among the four seasons whereas winter has the highest variability. Observed variability has a decreasing tendency from the northwest region towards the northeast region. The mean individual seasonality index (0.815378 to 0.977228) indicates that rainfall in Bangladesh is Markedly seasonal with a long dry season. (Bari et al., 2016)

2.2.9 Trends in extreme rainfall events of Bangladesh

A study of the variability of the extreme rainfall events in Bangladesh during the time period 1958–2007 has been carried out in this paper. Quality-controlled homogeneous daily precipitation records of nine stations distributed over Bangladesh are used for the study. A total of 15 annual and seasonal indices of rainfall are examined. A significant increase of annual and pre monsoon rainfall in Bangladesh is observed. In general, an increasing trend in heavy precipitation days and decreasing trends in consecutive dry days. (Bari et al., 2016)

2.2.10 Statistical Analysis of Rainfall Trend and Variability Due to Climate Change in Bangladesh

A study period from 1965-2015 has been taken in which daily rainfall records of 8 stations, distributed all over the country have been examined. 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. 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. Monthly mean and extreme event indices are also analyzed where the trend is decreasing for the extreme event. In case of annual, seasonal and extreme rainfall, most of the stations have a negative trend so it is seen that the rainfall is decreasing all over the country in the 51 years study period. (Md. R. karim et al, 2020)

2.2.11 Application of Standardized Precipitation Index to assess meteorological drought in Bangladesh

The present research has been carried out to examine the frequency of meteorological droughts in Bangladesh using the long-term rainfall data of 30 meteorological observatories covering the period of 1948–2011. The results indicate that droughts were a normal and recurrent feature and it occurred more or less all over the country in virtually all climatic regions of the country. Bangladesh experienced drought in the years 1950, 1951, 1953, 1954, 1957, 1958, 1960, 1961, 1962, 1963, 1965, 1966, 1967, 1972, 1973, 1975, 1979, 1980, 1983, 1985, 1992, 1994, 1995, 2002, 2004, 2006, 2009 and 2011 during the period 1948–2011. The eastern southern sides of the districts Chittagong, Rangamati, Khagrachhari, Bandarban and Teknaf were vulnerable. In the central regions, the districts of Mymensingh and Faridpur were more vulnerable than other districts. (Islam et al., 2019)

2.3 Global Studies on Rainfall analysis

2.3.1 Analysis of spatial variability and temporal trends of rainfall in Amhara region, Ethiopia

This study investigated the spatial distribution and temporal trends of rainfall in the Amhara region using time series rainfall data of Climate Hazards Group Infrared Precipitation with Stations (CHIRPS) for the period 1981–2017. Results showed that the region has been experiencing variable rainfall events that cause droughts and floods over different years. SAI also witnessed the presence of inter-annual variability of rainfall with negative and positive anomalies in 59.46% and 40.54% of the analyzed years, respectively. PCI and SI results implied that the area had irregular and strong irregular rainfall distribution. Trend analysis results showed an overall increase in the annual and seasonal rainfall (except winter) during the study period. (Alemu, M. M. & Bawoke, G. T., 2019)

2.3.2 Rainfall Trend Analysis By Mann-Kendall Test: A Case Study Of North-Eastern Part Of Cuttack District, Orissa

The present study is mainly concerned with the changing trend of rainfall of a river basin of Orissa near the coastal region. The Z_c value of MK Test represents both positive and negative trend in the area although not much significant. Individually months of January, May, June, September, October and November are showing positive trend and months of February, March, April, July, August and December are depicting negative trend in the Z_c value. Sen's Slope is also indicating increasing and decreasing magnitude of slope in correspondence with the MK Test values. (Mondal et. al., 2012).

2.3.3 Seasonal Rainfall Trend Analysis

This study aims to detect the trend in seasonal rainfall of four rainy months i.e., June, July, August, and September. The Z value of Mann-Kendall test showed positive and negative trend for the rainy months. Among the four rainy months, negative trend was observed for June and September, but for July and August positive trend was observed. From all statistical tests result it was indicated that there was some change in the trend of rainfall of the rainy months (Pandit, D. V., 2016).

2.3.4 Trend in Standardized precipitation Index and Standardized anomaly index in context of climate change in southern Togo

This study aimed to investigate the temporal trend analysis in annual temperature and rainfall in the Southern Togo for the 1970-2014 period. Mann-Kendall statistical test for the mean annual, mean annual minimum and maximum temperature from 1970 to 2014 showed significant warming trends for all stations except Kouma-Konda where mean annual maximum temperature had exhibited nonsignificant cooling trend ($P = 0.01$). Standardized Precipitation Index in the 12-month time scale, drying tendency dominates Atakpamé (55.7%) and Kou-ma-Konda (55.5%) while wet tendency dominates slightly Lomé (50.9%) and Tabligbo (51.4%) (Koudahe et. al., 2017).

2.3.5 Changes in Seasonality Index Over Sub-Divisions of India During 1951-2015

In the study, trend analysis clearly showed the climate change impact on northwest sub-divisions of the country showing increase in SI values leading to dryness during the monsoon season. The negative trend in SI values was observed in Sub- Himalayan West Bengal, Haryana-Delhi-Chandigarh, Punjab, Jammu & Kashmir, West and east Rajasthan, coastal Andhra Pradesh showing increasing wetness for an already wet months although rainfall occurs in a very short period of just a month or two (Nandargi, S. S., et. al., 2017).

As most of the previous studies on rainfall variability and trend analysis in Bangladesh were done for either the whole country or a certain portion of coastal regions, we have decided to do our study on whole coastal regions of Bangladesh from 1980 to 2019.

Chapter Three : Study Area And Methodology

3.1 General

In this section the location of the study area and the data collection method will be described.

3.2 Study Area

The coastal zones of Bangladesh is towards the Southern region of the country. Covering an area of 47,201 km^2, which is almost 32% of the country's land area. It is geomorphologically and hydrologically dominated by the Ganges Brahmaputra Meghna (GBM) river system and Bay of Bengal (Ahmad, 2019). The landward coastal zone consists of 19 districts (Bagerhat, Barguna, Barisal, Bhola, Chandpur, Chittagong, Cox's Bazar, Feni, Gopalgonj, Jessore, Jhalakhati, Khulna, Lakshmipur, Narail, Noakhali, Patuakhali, Pirojpur, Sarkhira, Shariatpur) constituting 147 upazilas (Abu et al., 2003).

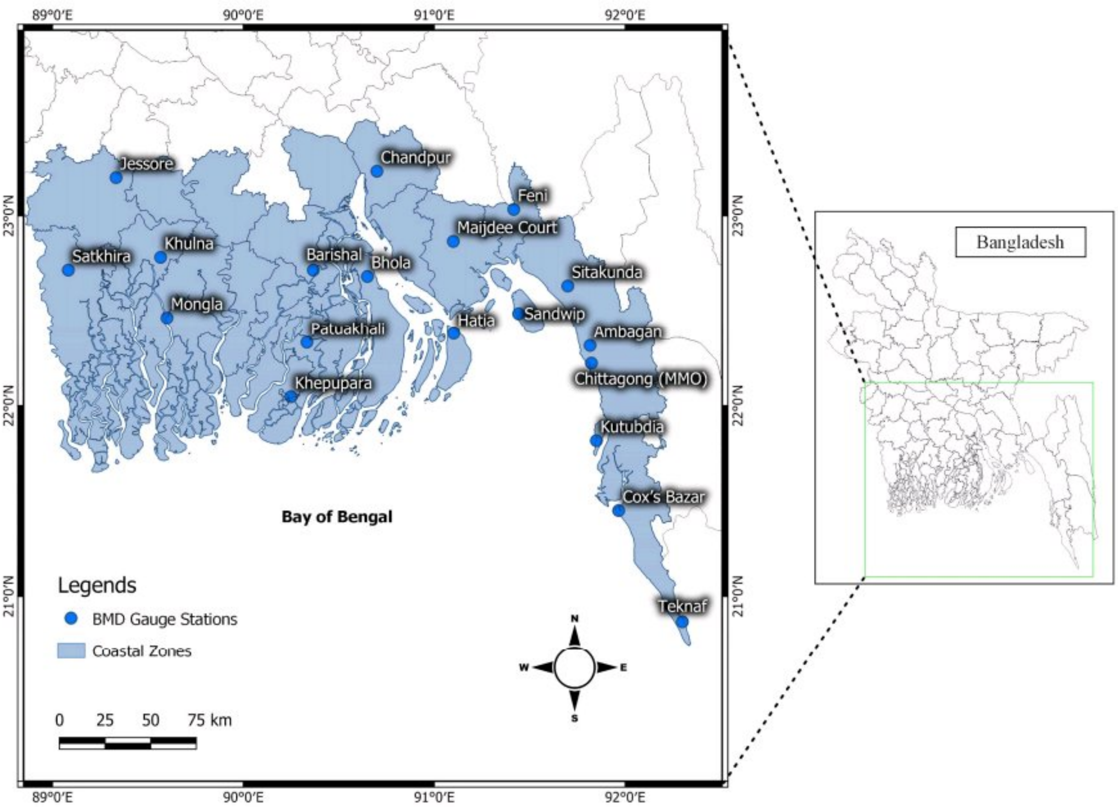


Figure 1: The study area and the distribution of meteorological stations

Reference:

Abu M, Kamal U, Rob K. *Delineation of the coastal zone Dhaka*, PDO-ICZMP, Bangladesh (2003)

3.3 Data Collection

Daily rainfall data is purchased from Bangladesh Meteorological Department (BMD) for 19 (Sitakunda, Sandwip, Chittagong, Cox's Bazar, Hatiya, Feni, Kutubdia, M. Court, Teknaf, Chandpur, Ambagan, Bhola, Patuakhali, Jossore, Barisal, Khepupara, Satkhira, Khulna, Mongla) coastal stations from the year 1980 to 2018.

3.4 Parts of Analysis

For the study, the coastal area is divided into 2 regions, namely South-East Region and South-West Region.

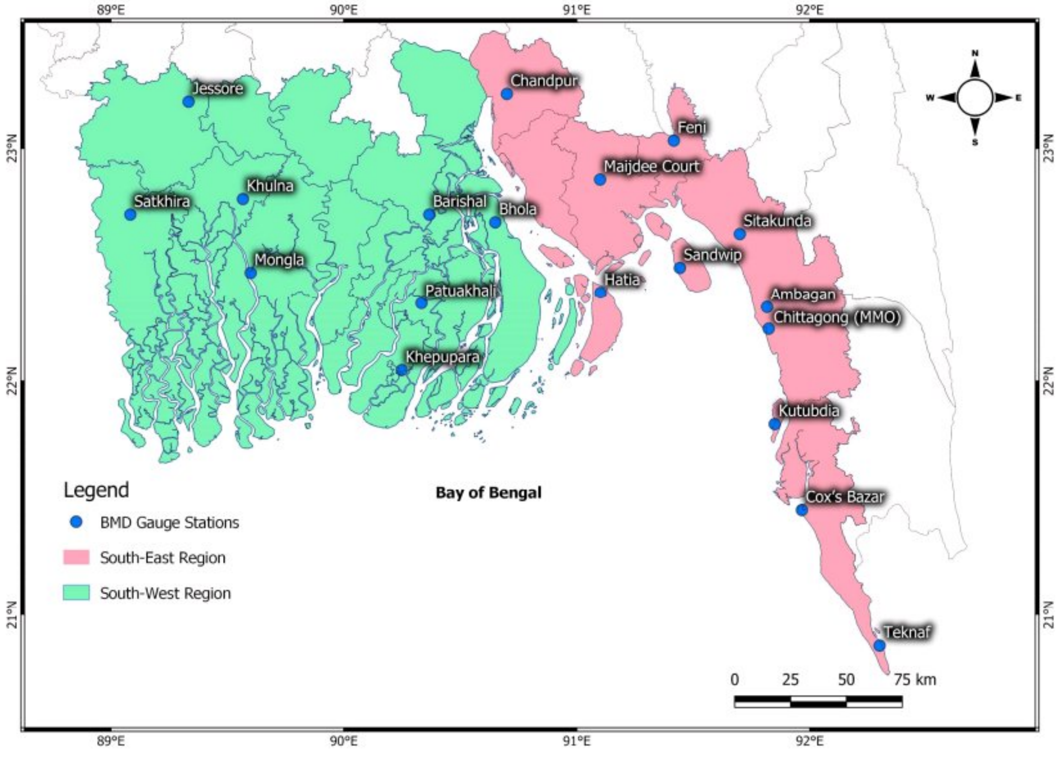


Figure 2: South-East and South-West Region of study area

For these regions, Mean Monthly Rainfall, Annual Mean Rainfall and Seasonal Mean Rainfall are calculated and statistical analysis is performed. For Seasonal Rainfall analysis, 4 seasons are considered. They are:

i. Pre-monsoon
ii. Monsoon
iii. Post-Monsoon
iv. Dry Season

3.5 Statistical Analysis

For the statistical analysis of our study, we have conducted the variability analysis and the trend analysis of the rainfall data.

3.5.1 Variability Analysis

For the parametric analysis, we choose the tests, Coefficient of Variation (CV), Standardized Anomaly Index (SAI), Precipitation Concentration Index (PCI), and Seasonality Index (SI). All the calculations and analysis are completed using Microsoft Excel. For visualization of the results, we have used an open-source GIS software, QGIS and Microsoft Excel.

3.5.1.1 Coefficient of Variation

According to (Alemu & Bawoke, 2019, p. 1505), the coefficient of variation measures the overall variability of the rainfall in the area of interest. A higher value of CV indicates a rainfall greater variability and vice versa. It is computed using the formula:

$$CV = \frac{\sigma}{\mu} \times 100$$

where σ is the standard deviation and μ is the mean rainfall for the chosen temporal scales. Generally, CV is used to classify the degree of variability of rainfall events into three:

Table 1 | Classification of Coefficient of Variation

Coefficient of Variation (%)	Category
< 20	Low
20 ~ 30	Moderate
> 30	High

3.5.1.2 Standardized anomaly index

According to (Alemu & Bawoke, 2019, p. 1505), standardized anomaly index of rainfall has been calculated to examine the nature of the trends. It enabled the determination of the dry and wet years in the record and is used to assess frequency and severity of droughts and it is computed as:

$$SAI_i = \frac{x_i - \bar{x}}{\sigma}$$

where, Xi is the annual rainfall of the particular year; $\bar{x}$ is the long-term mean annual rainfall over a period of observation and σ is the standard deviation of annual rainfall over the period of observation. Negative values indicate a drought period as compared to the chosen reference period while the positive ones indicate a wet situation. SAI is also computed for seasonal scale. SAI value classification is presented in:

Table 2 | SAI value Classification

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

3.5.1.3 Precipitation concentration index (PCI)

The PCI indicates the distribution of monthly rainfall and can be used as an indicator of hydrological hazard risks such as floods and droughts. In other words, intensive rainfall is considered to be uniform if it occurs throughout the time period, but if it occurs within a narrow subset of the time period, then its distribution is considered to be irregular. PCI was calculated on an annual scale for each grid point according to the equation:

$$PCI = \frac{\sum_{i=1}^{12} P_i^2}{\left(\sum_{i=1}^{12} P_i\right)^2} \times 100$$

Where P_i is the monthly precipitation in month i. According to Oliver (1980), the suggested categories for the PCI are tabulated below:

Table 3 | PCI Value Classification

PCI	**Category**
< 10	Uniform Rainfall distribution
10 ~ 15	Moderate Rainfall Distribution
16 ~ 20	An irregular Rainfall distribution

> 20	Strong Irregular Rainfall Distribution

3.5.1.4 Seasonality index (SI)

SI is an index which helps to identify the rainfall regimes on the monthly distribution of rainfall. Moreover, this index quantifies the degree of variability in monthly rainfall through the year. The higher the seasonality index of a region the greater the water resource variability and scarcity in time, the more vulnerable the area to desertification. SI is simply the sum of absolute deviations of mean monthly rainfall from the overall monthly mean, divided by the mean annual rainfall. The computation of SI is done using the formula:

$$SI = \frac{1}{P}\sum_{i=1}^{12}\left|\overline{P_i} - \frac{\overline{P}}{12}\right|$$

where, $\overline{P_i}$ is the mean rainfall (mm) of the i^{th} month, and $\overline{P}$ is the mean annual rainfall (mm). The index varies from zero, if all the months have equal rainfall, to 1.83 if all the rainfall occurs in a single month. Kanellopoulou (2002) suggests the following rainfall regime for different SI values:

Table 4 | SI Value Classification

SI	**Rainfall regime**
≤0.19	Very equable
0.20 to 0.39	Equable but with a definite wetter season
0.40 to 0.59	Rather seasonal with a short drier season
0.60 to 0.79	Seasonal
0.80 to 0.99	Markedly seasonal with a long drier season
1.00 to 1.19	Most rain in 3 months or less
≥1.20	Extreme, almost all rain in 1–2 months

3.5.2 Trend Analysis

For trend analysis we have conducted the Mann-Kendall (MK) test and Sen's Slope Estimator to detect and quantify the possible trends in the time series data.

3.5.2.1 Mann-Kendall (MK) test

According to the MK test, this study tested the null hypothesis (H_o) of no trend, that is the observations xi are randomly ordered in time, against the alternative hypothesis (H_1), where there is a monotonic (increasing or decreasing) trend in the time series. The MK statistics S is calculated using the formula

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

where n is the length of the dataset, x_i and x_j are two elements of the considered time series at the time step i and j, respectively,

$$sng(x_j - x_i) = \begin{cases} -1, & (x_j - x_i) < 0 \\ 0, & (x_j - x_i) = 0 \\ 1, & (x_j - x_i) < 0 \end{cases}$$

If the dataset is identically and independently distributed, then the mean of S is zero and the variance of S is given by

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

where n is the length of the dataset, m is the number of tied groups (a tied group is a set of sample data having the same value) in the time series and it is the number of data points in the i-th group.

$$Z = \begin{cases} \frac{S+1}{\sqrt{Var(S)}} & for\ S < 0 \\ 0 & for\ S = 0 \\ \frac{S-1}{\sqrt{Var(S)}} & for\ S > 0 \end{cases}$$

A significant level α is also utilized for testing either an upward or downward monotone trend. The trend is significant at the 90% confidence level if $|Z| > 1.65$, at the 95% confidence level if $|Z| > 1.96$, and at the 99% confidence level of $|Z| > 2.58$ (Mandale et al.). The positive and negative Z values indicate increasing and decreasing trends, respectively (Alemu & Bawoke, 2019).

3.5.2.2 Sen's slope estimator

This study used Sen's slope estimator to calculate the actual slope of time series data trends. 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 using the following equation:

$$\beta = median\left(\frac{x_j - x_i}{j - i}\right)$$

where β represents the median value of the slope values between data measurements x_i and x_j at the time steps i and j ($i < j$), respectively. Positive value of β indicates an increasing trend whereas negative value of β indicates a decreasing trend. The sign of β reflects data trend direction, whereas its value indicates the steepness of the trend. The advantage of this method is that it limits the influence of missing values or the outliers on the slope in comparison with linear regression According to (Alemu & Bawoke, 2019).

3.6 Analysis of Extreme Rainfall Events

Extreme rainfall events of a year were determined by considering the maximum amount of rainfall occurring in a single day for the specific year. After determining the events for every station for the entire study period, the variability analysis and trend analysis were conducted.

Chapter Four : Results and Analysis

4.1 General

In this section the rainfall variability and trend analysis are upheld for the collected rainfall data from the two coastal regions.

4.2 Analysis of Mean Monthly Rainfall

The mean monthly rainfall analysis has been conducted separately for the two regions.

Table 5 | Results of mean monthly rainfall in the South-West region

South West region						
Month	**Mean Rainfall (mm)**	**SD (mm)**	**CV (%)**	**Z-Value**	**Slope**	**Contribution to Annual Rainfall (%)**
Jan	9.45	13.30	140.79	-1.80	-0.04	0.46
Feb	26.40	28.90	109.47	-1.05	-0.26	1.30
Mar	41.85	47.80	114.22	-1.03	-0.38	2.06
Apr	83.56	55.40	66.30	-1.11	-0.79	4.11
May	202.60	88.40	43.63	-0.27	-0.26	9.97
Jun	370.94	134.60	36.29	-0.20	-0.45	18.25
July	432.02	123.30	28.54	2.71	3.79	21.25
Aug	348.46	102.30	29.36	0.07	0.09	17.14
Sep	293.80	122.90	41.83	1.43	1.91	14.45
Oct	175.10	105.50	60.25	1.62	2.11	8.61
Nov	41.58	60.80	146.22	0.12	0.00	2.05
Dec	7.13	13.00	182.33	-0.78	0.00	0.35

In the South-West region maximum mean monthly rainfall is found for July with a rainfall of 3456.18 mm and a Standard Deviation of 986.53 mm. Whereas, December has a minimum rainfall of only 57 mm with a relatively high Standard Deviation of 103.64 mm. June (2967.50 mm), July (3456.18 mm) and August (2787.70 mm) contributed the maximum share to the annual rainfall, 18.25%, 21.25%, and 17.14% respectively. On the other hand January and December received less rainfall and contributed 0.46% and 0.35% of the annual rainfall.

The coefficient of variation of July and August are 28.54% and 29.35% which indicate moderate rainfall variability. The coefficient of variation for the remaining months is greater than 30 , indicating higher rainfall variability in these months.

From the trend analysis, the results of the MK test shows a statistically significant increasing trend for July at 5% level of significance. August, September, October and November have non-significant increasing trends and the remaining months have non-significant decreasing trends.

Table 6 | Results of mean monthly rainfall in the South-East region

South East region						
Month	**Mean Rainfall (mm)**	**SD (mm)**	**CV (%)**	**Z-Value**	**Slope**	**Contribution to Annual Rainfall (%)**
Jan	5.35	9.04	169.04	-1.15	0.00	0.18
Feb	17.84	21.81	122.28	-0.86	-0.11	0.60
Mar	46.34	46.85	101.11	-0.86	-0.29	1.56
Apr	113.05	75.52	66.80	-1.20	-1.37	3.81
May	294.23	138.87	47.20	0.92	1.60	9.93
Jun	593.98	218.57	36.80	1.36	5.30	20.04
July	737.65	220.06	29.83	2.44	7.95	24.89
Aug	534.87	166.25	31.08	0.89	2.10	18.05
Sep	348.38	127.29	36.54	2.64	3.87	11.75
Oct	216.20	112.50	52.04	2.39	3.46	7.29
Nov	46.93	55.12	117.44	-1.07	-0.44	1.58
Dec	9.11	14.21	155.93	-0.63	-0.004	0.31

For the rainfall variability analysis the South-east region also shows the same Monthly characteristics like the South-West region. But among them more rainfall has occurred in the South-East region.

But for trend analysis there are some differences between the South-East and South-West region like, a significant increasing trend is found for July, September and October at 5% level of significance and November shows non-significant decreasing trend for South-East.

4.3 Analysis of Mean Annual Rainfall

Table 7 | Results of mean annual rainfall in the South-East region

South East region						
Station	**Mean Annual Rainfall (mm)**	**STD (mm)**	**CV (%)**	**Z-Value**	**p-Value**	**Sen's Slope**
sitakunda	3214	791	24.61	0.91	0.36	10.07
sandwip	3646	718.2	19.70	1.54	0.12	14.64
chittagong	2967	487	16.41	0.56	0.58	8.10
cox's bazar	3652	697	19.09	0.594	0.55	6.86
hatiya	3165	769.7	24.32	2.16	0.03	25.77

feni	2958	642.5	21.72	-0.606	0.54	-6.70
kutubdia	3071	737	24.00	0.99	0.32	9.23
M.court	3121	515	16.50	-1.771	0.08	-12.88
teknaf	4191	693.6	16.55	1.5	0.12	12.47
chandpur	2188	558.2	25.51	-1.23	0.22	-9.50
ambagan (from 1999)	3000.05	561.98	18.73	0.332	0.74	6.12

For the SouthEast region, the maximum amount of mean annual rainfall is observed in Teknaf, 4191 mm with a Standard deviation of 693.6 mm. But the Coefficient of Variation for this station is low compared to the other stations (only 16.55%). The lowest mean annual rainfall is received by Chandpur with only 2188 mm of rainfall. It also has the highest Coefficient of Variation (25.51%).

Hatiya has a significant increasing trend at 5 % level of significance and other stations, except for Chandpur, M. Court, and Feni, have non-significant increasing trends.

Table 8 | Results of mean annual rainfall in the South-West region

South West region						
Station	**Mean Annual Rainfall (mm)**	**STD (mm)**	**CV (%)**	**Z-Value**	**p-Value**	**Sen's Slope**
Bhola	2243.85	418.89	18.67	-2.37	0.02	-13.48
patuakhali	2613.59	476.97	18.25	-1.23	0.22	-9.80
jessore	1674.58	320.84	19.16	-0.75	0.44	-4.50
barisal	2080.3	361.42	17.37	-0.85	0.39	-4.60
khepupara	2783.075	415.55	14.93	2.25	0.03	14.34
satkhira	1710.35	277.59	16.23	-0.489	0.62	-2.29
khulna	1825.68	349.58	19.15	0.38	0.70	2.32
mongla (from 1991)	1926.17	303.98	15.78	0.131	0.89	0.63

In the South-West region, all the stations have relatively similar mean annual rainfall with exceptions in Patuakhali and Khepupara. Khepupara has the maximum mean annual rainfall of 2783.1 mm and a Standard deviation of 415.55 mm. Jessore has the lowest value of mean annual rainfall, 1674.58 mm.

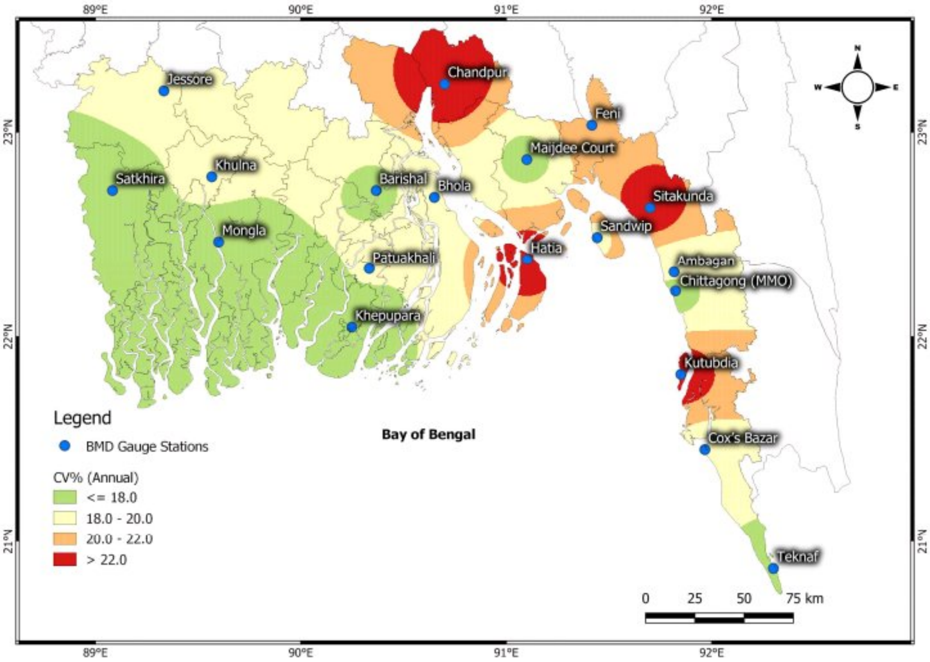


Figure 3 | Spatial distribution of CV (%) of annual rainfall of the coastal region

Spatial distribution of the CV of annual rainfall shows that the South-West region has low rainfall variability, whereas the South-East is characterized by moderate rainfall variability. Most of the South-East stations (Sandip, Chittagong, Cox's bazar, M.court, Teknaf, Ambagan) have a coefficient of variation less than 20% , indicating low rainfall variability. Other stations show moderate rainfall variability.

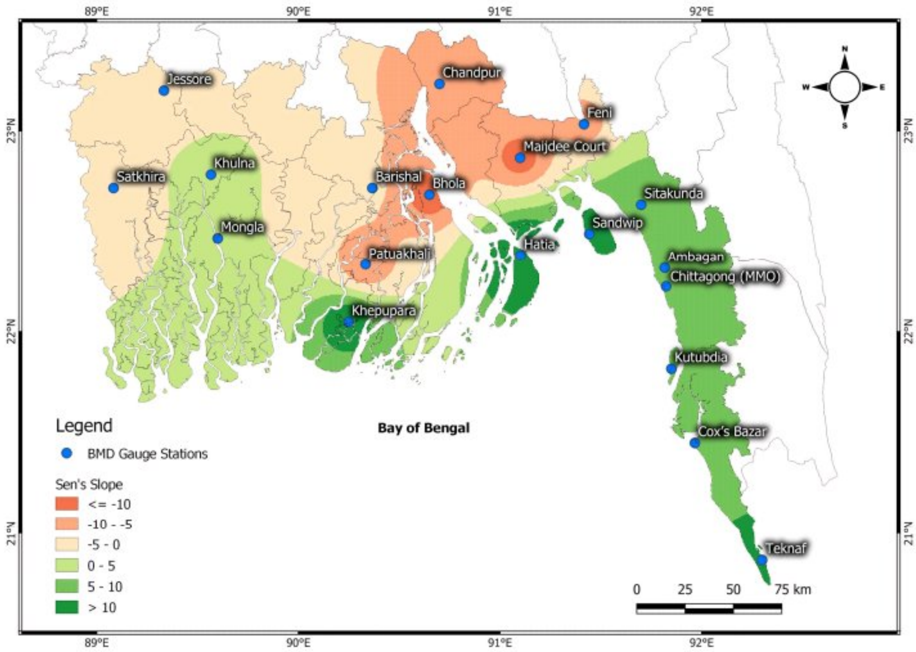


Figure 4 | Spatial distribution of Sen's Slope for annual rainfall (mm/year) in coastal region

The trend analysis reveals that decreasing trends are observed at the upper portion of both South-East and West regions. The rate of changes of annual rainfall for Khepupara, Hatia, Sandwip and Tekanf are more than 10 mm per year.

Annual rainfall anomalies:

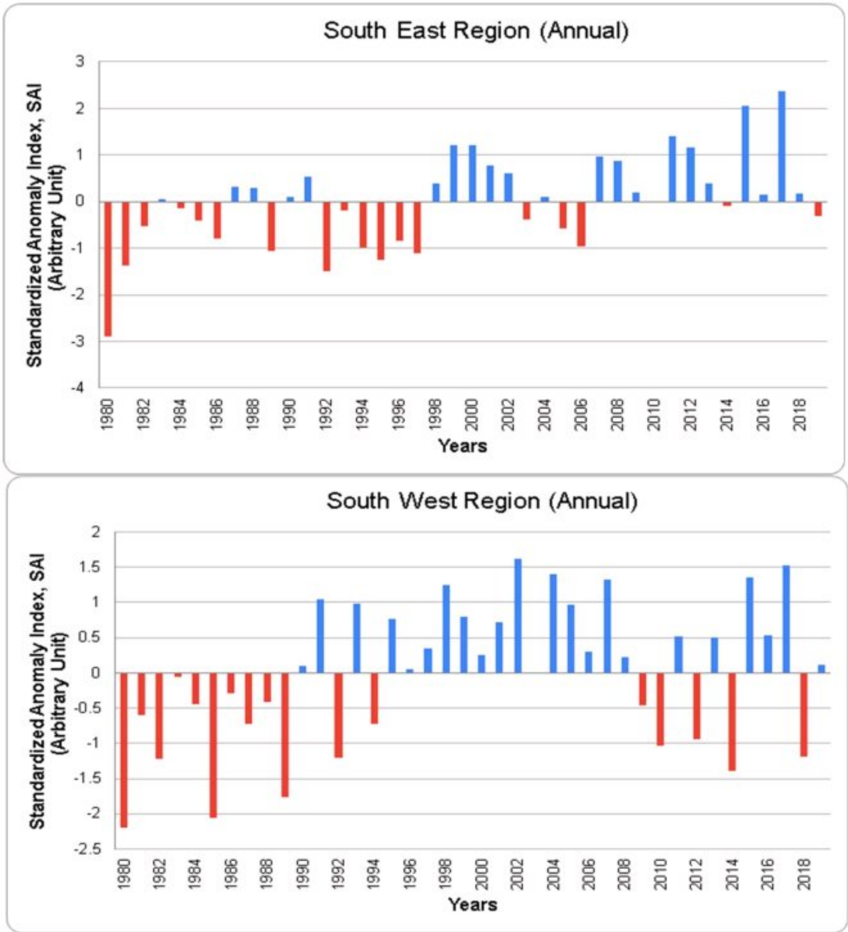


Figure 5 | Annual rainfall anomalies of coastal region for 1980 - 2019 period

In the South-West region the negative anomalies became more pronounced in the 1980s and 2010s. But for South-East, from 1998 there is a wet period with strong positive anomalies for all the stations. Maximum values of negative values are observed in the 1980s for the South-West.

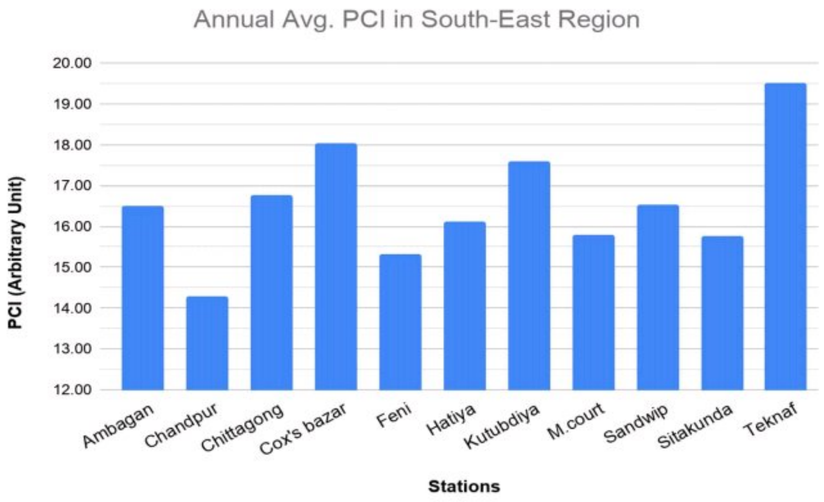


Figure 6 | Annual average PCI in South-East region

The South-East region is observing moderate to irregular rainfall distribution. Maximum PCI is found at the lower portion of that region.

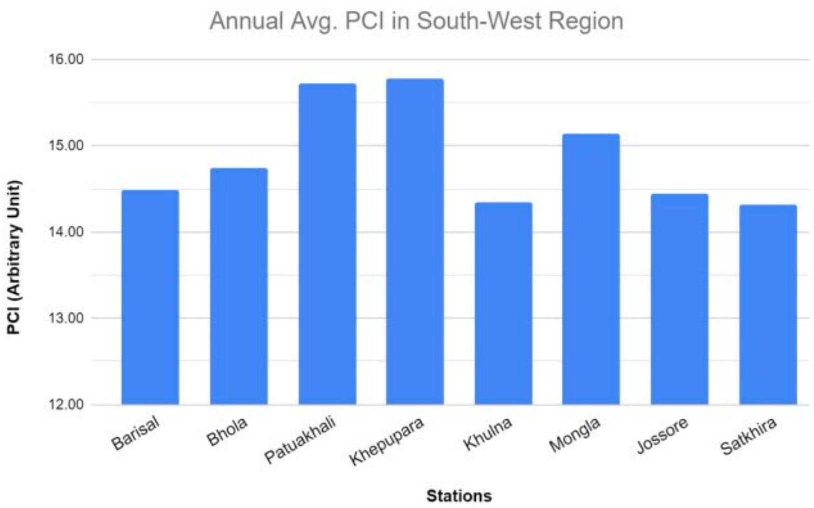


Figure 7 | Annual average PCI in South-West region

Annual precipitation concentration index shows that Both South-East and West regions are observing irregular annual rainfall distribution which indicates rainfall is occurring within a narrow subset of the time period.

Table 9 | *Results of annual Seasonality Index in the South-East region*

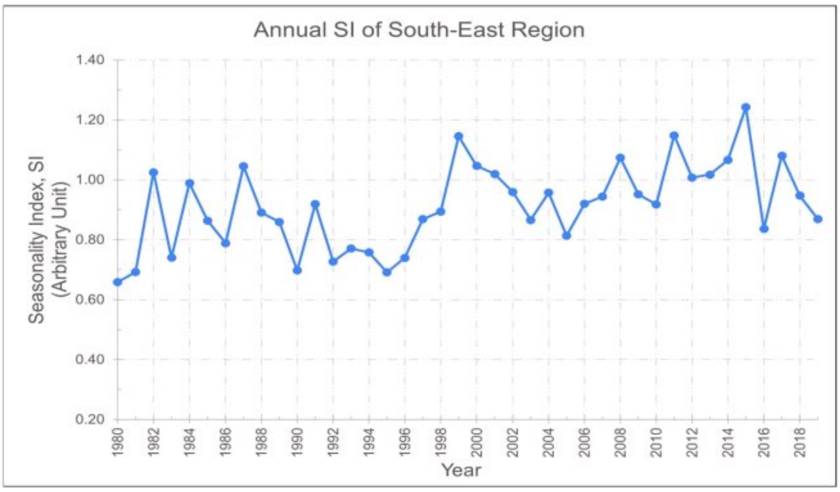
South- East Region		
Station	**Seasonality Index (SI)**	**Remark**
Ambagan (from 1999)	0.85	Markedly seasonal with a long drier season
Chandpur	0.77	Seasonal
Chittagong	0.84	Markedly seasonal with a long drier season
Cox's bazar	0.9	Markedly seasonal with a long drier season
Feni	0.81	Markedly seasonal with a long drier season
Hatiya	0.84	Markedly seasonal with a long drier season
Kutubdia	0.88	Markedly seasonal with a long drier season
M.court	0.84	Markedly seasonal with a long drier season
Sandwip	0.86	Markedly seasonal with a long drier season
Sitakunda	0.76	Seasonal
Teknaf	0.99	Markedly seasonal with a long drier season

Most of the South-East stations show SI over 0.80 which indicates Markedly seasonal with a long drier season which means these areas are more vulnerable to desertification. Only chandpur and sitakunda are showing seasonal rainfall.

Table 10 | Results of annual Seasonality Index in the South-West region

South- west Region		
Station	**Seasonality Index (SI)**	**Remark**
Barisal	0.766	Seasonal
Bhola	0.78	Seasonal
Patuakhali	0.82	Markedly seasonal with a long drier season
Khepupara	0.84	Markedly seasonal with a long drier season
Khulna	0.77	Seasonal
Mongla (from 1991)	0.81	Markedly seasonal with a long drier season
Jessore	0.77	Seasonal
Satkhira	0.75	Seasonal

For the South-West most of the stations have seasonal rainfall and remaining stations are facing a long drier season. So if the whole coastal area is considered it will be shown that the majority of the area has markedly seasonal rainfall with a long drier season.



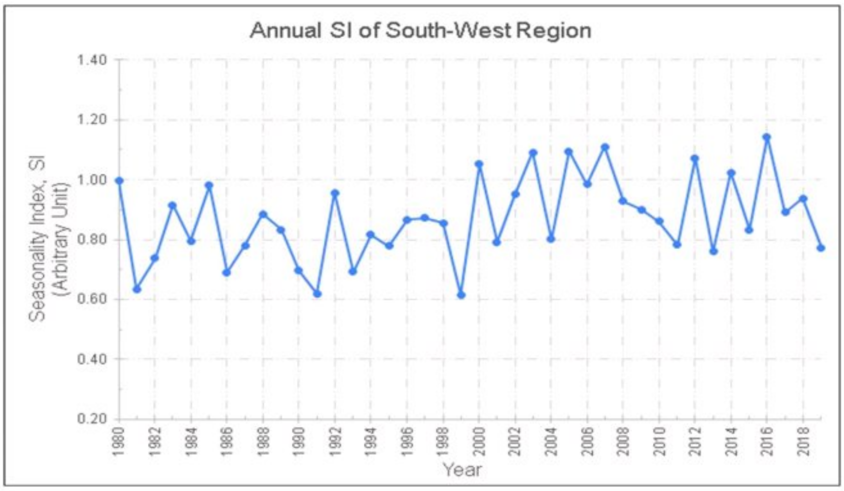


Figure 8 | Seasonality Index of annual rainfall of coastal region for 1980 – 2018 period

Both the South-East and West Region shows a significant increasing trend of SI throughout the study period. For the South-East Region, the value is above 0.85 from 2006. Which implies, the rainfall in the South-East Region is markedly seasonal with a long drier season.

4.4 Extreme Rainfall Analysis

Table 11 | Results of Extreme Rainfall in the South-East region

South East Region						
Station	**Year**	**month**	**Max rainfall**	**Z-Value**	**trend at 95% C.I.**	**Sen's Slope**
ambagan (from 1999)	2012	june	438	0.030	no	0.113
chandpur	1983	june	334	0.012	no	0.000
chittagong	1983	aug	511	-1.144	no	-1.406

cox's bazar	2015	june	467	2.646	yes	2.016
feni	2005	jul	420	-1.690	no	-1.182
hatiya	2016	oct	403	1.605	no	1.571
kutubdia	1998	jul	422	1.798	no	1.491
M.court	1981	jul	520	-0.781	no	-0.745
sandwip	2001	june	590	1.875	no	1.538
sitakunda	2017	jul	347	1.119	no	1.000
teknaf	2010	june	481	2.774	yes	2.254

Among all the stations of the South-East region, sandwip has the highest rainfall (590 mm) event occurred in June 2001.The Z-value of extreme events shows the significant increasing trend in Cox's Bazar and Teknaf. Other stations except Chittagong, Feni and M.court have the non-significant increasing trend.

Table 12 | Results of Extreme Rainfall in the South-West region

South West region						
Station	**Year**	**month**	**Max rainfall**	**Z-Value**	**trend at 95% C.I.**	**Sen's Slope**
barisal	2019	nov	262	0.13	no	0.07
Bhola	2010	oct	292	0.26	no	0.20
jessore	1986	sep	255	-0.83	no	-0.43
khepupara	1995	jul	373	1.56	no	1.38
khulna	1986	sep	430	0.58	no	0.37
mongla (from 1991)	1997	sep	204	0.56	no	0.53
patuakhali	1982	june	312	-1.49	no	-1.04
satkhira	1986	sep	302	0.09	no	0.02

In the South-West region the amount of rainfall which causes extreme events is less than in the South-East region. The Z-value of the different stations of the South-West region shows that every station has a non-significant increasing trend except Patuakhali and Jessore.

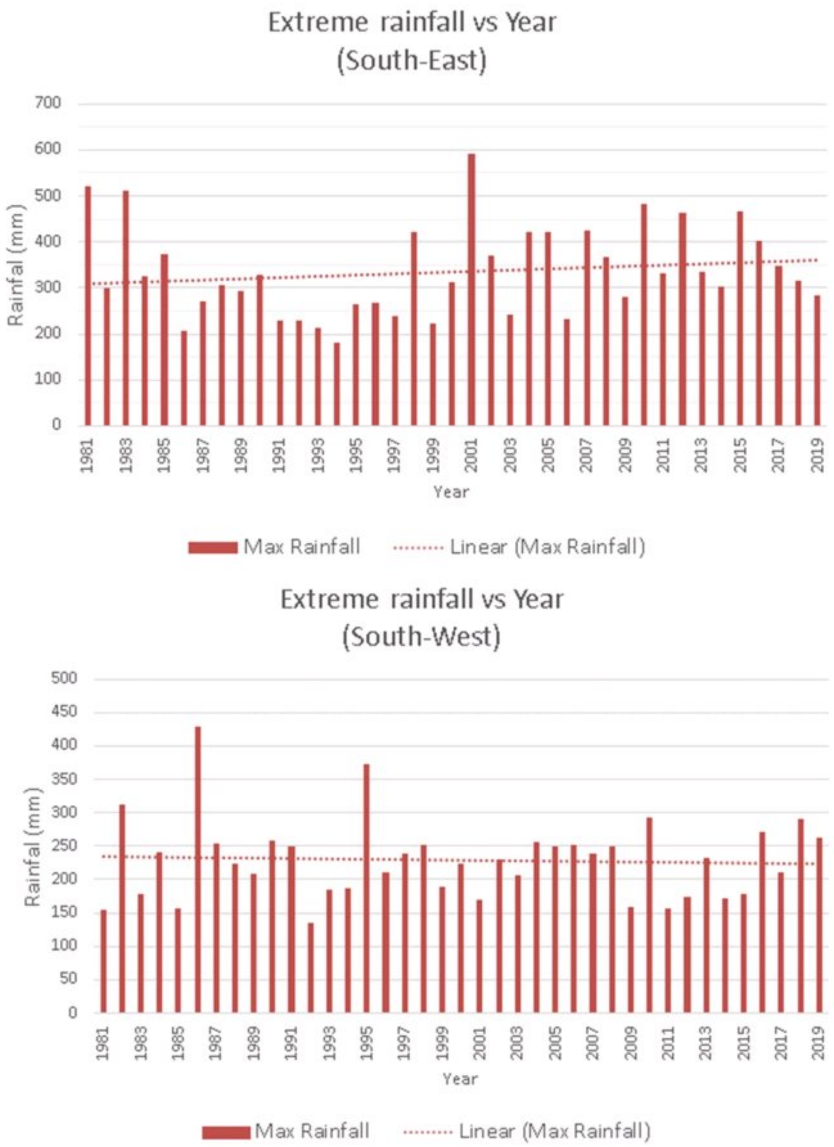


Figure 9 | Annual extreme rainfall (mm) for the coastal regions

The amount of rainfall causing extreme events is following an increasing trend for the South-East region.

4.5 Seasonal Rainfall Analysis

Table 13 | Seasonal rainfall results for South-East region

South East region						
Station	**Time period**	**Mean (mm)**	**STD (mm)**	**CV (%)**	**z- stat**	**Sen's slope**
Cox's Bazar	Pre-Monsoon	443.98	203.66	45.87	0.72	2.48

	Monsoon	2870.53	613.22	21.36	0.58	6.23
	Post-Monsoon	302.6	159	52.54	0.52	1.24
	Winter	36.11	33.87	93.80	-1.39	-0.47
Feni	Pre-Monsoon	582.63	217.11	37.26	-1.95	-4.44
	Monsoon	2075.63	510.35	24.59	-0.58	-3.71
	Post-Monsoon	261.1	156.51	59.94	0.68	1.36
	Winter	38.31	37.85	98.80	-1.29	-0.5
M. Court	Pre-Monsoon	554.08	180.18	32.52	-1.3	-3.97
	Monsoon	2269.03	479.65	21.14	-1.45	-9
	Post-Monsoon	258.33	156.07	60.41	1.93	4.72
	Winter	39.24	36.28	92.46	-0.89	-0.43
Sandwip	Pre-Monsoon	568.88	259.03	45.53	-0.45	-1.81
	Monsoon	2717.44	595.14	21.90	2.12	15.75
	Post-Monsoon	323.42	194.43	60.12	0.5	1.25
	Winter	35.9	38.78	108.02	-1.72	-0.5
Sitakunda	Pre-Monsoon	556.55	220.86	39.68	-0.38	-1.57
	Monsoon	2324.85	650.04	27.96	1.78	17.55
	Post-Monsoon	298.05	207.22	69.53	-0.42	-0.92
	Winter	34.67	54.05	155.90	-0.52	-0.11
Chandpur	Pre-Monsoon	486.16	284.92	58.61	-1.27	-4.55
	Monsoon	1463.98	450.19	30.75	-0.52	-3.25
	Post-Monsoon	201.39	112.04	55.63	0.24	0.54
	Winter	37.19	36.65	98.55	0.18	0.05
kutubdia	Pre-Monsoon	406.92	213.46	52.46	0.57	2.67
	Monsoon	2354.14	642.44	27.29	1.63	12.46
	Post-Monsoon	275.56	140.29	50.91	-0.07	-0.41
	Winter	58.75	147.73	251.46	-0.46	-0.13
ambagan (from 1999)	Pre-Monsoon	485.96	156.01	32.10	-1.03	-3.45
	Monsoon	2183.1	505.25	23.14	0.69	17.42

	Post-Monsoon	304.53	167.02	54.85	0.24	1
	Winter	27.4	32.36	118.10	-0.16	-0.08
Teknaf	Pre-Monsoon	354.35	189.59	53.50	1.35	3.8
	Monsoon	3481.73	657.96	18.90	1.08	7.79
	Post-Monsoon	325.08	181.03	55.69	0.31	1.1
	Winter	30.24	41.15	136.08	-1.148	-0.21
Chittagong	Pre-Monsoon	498.42	186.9	37.50	-0.99	-3.79
	Monsoon	2169.09	478.91	22.08	0.64	6.61
	Post-Monsoon	263.06	133.95	50.92	0.2	0.56
	Winter	36.52	43.78	119.88	-1.45	-0.47

For all stations it is shown that the major share of annual rainfall is received in Monsoon (JJAS) with low rainfall variability (CV<30) whereas the other seasons have higher rainfall variability. In the Monsoon, All the stations in the South-East region have a very high mean rainfall ranging from 2075.63 mm to 3481.73 mm. The slope of this season is also increasing for all the stations except for Chandpur, which means, the districts on the exposed coastal zones are experiencing increased rainfall in the Monsoon season. For the Winter season, however, all the stations have negative slope with extremely low mean rainfall between 27.4 mm to 58.75 mm with very high CV, almost all above 100%. This means that the Winter season rainfall is not very consistent during the winter months throughout the study period.

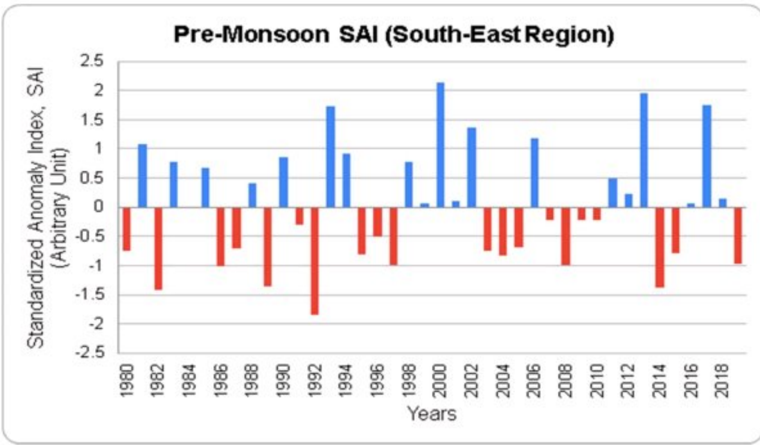
Table 14 | Results of Extreme Rainfall in the South-West region

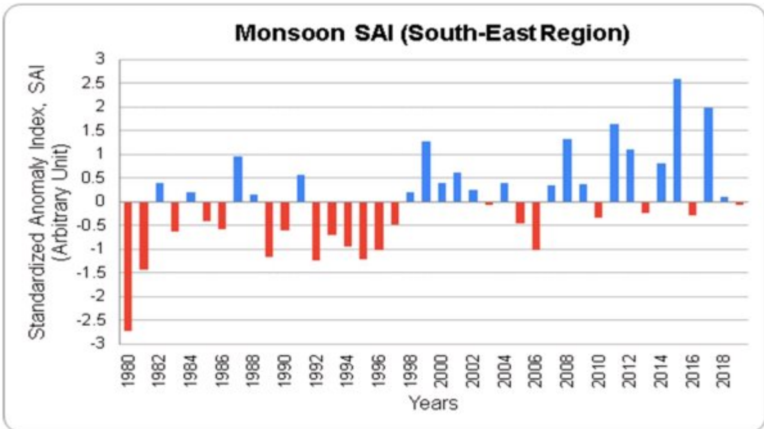
South West region						
station	**Time period**	**Mean (mm)**	**STD (mm)**	**CV (%)**	**p-value**	**Sen's slope**
Barisal	Pre-Monsoon	369.5	179.55	48.59	0.36	-1.3
	Monsoon	1440.45	291.11	20.21	0.25	-2.79
	Post-Monsoon	231.65	141.29	60.99	0.84	0.58
	Winter	37.98	39.9	105.06	0.36	-0.28
Bhola	Pre-Monsoon	416.1	177.75	42.72	0.03	-5.33
	Monsoon	1561.75	326.41	20.90	0.06	-8.83
	Post-Monsoon	225.98	136.53	60.42	0.56	1.17

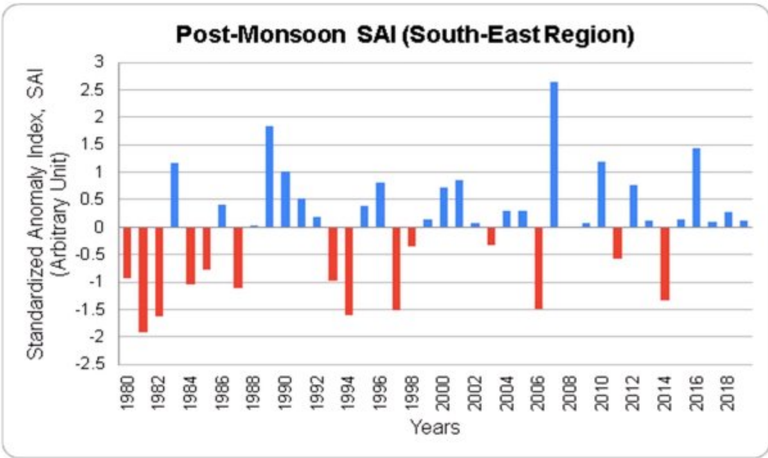
	Winter	36.9	35.73	96.83	0.13	-0.57
Khepupara	Pre-Monsoon	384.45	148.02	38.50	0.5	-1.56
	Monsoon	2026.58	350.68	17.30	0.1	7.65
	Post-Monsoon	332.93	199.42	59.90	0.06	5.33
	Winter	39.57	37.03	93.58	0.37	-0.3
Patuakhali	Pre-Monsoon	383.24	191.93	50.08	0.1	-2.9
	Monsoon	1922.54	401.02	20.86	0.14	-8.48
	Post-Monsoon	271.62	151.45	55.76	0.16	3.37
	Winter	35.58	36.76	103.32	0.21	-0.56
Khulna	Pre-Monsoon	307.93	135.18	43.90	0.14	-2.833
	Monsoon	1277.05	318.18	24.92	0.27	5.09
	Post-Monsoon	185.25	108.06	58.33	0.42	1.36
	Winter	53.9	57.04	105.83	0.52	-0.3
Satkhira	Pre-Monsoon	276	99.6	36.09	0.45	-0.79
	Monsoon	1202	255.99	21.30	0.61	-2.17
	Post-Monsoon	175.95	116.16	66.02	0.27	1.71
	Winter	53.24	47.73	89.65	0.56	-0.35
mongla (from 1991)	Pre-Monsoon	273.59	98.57	36.03	0.43	-1.8
	Monsoon	1397.45	286.28	20.49	0.58	3.49
	Post-Monsoon	214.38	122.57	57.17	0.82	0.68
	Winter	39.75	35.25	88.68	0.5	-0.28
Jessore	Pre-Monsoon	297.73	105.32	35.37	0.28	-1.47
	Monsoon	1166.43	279.83	23.99	0.78	-0.75
	Post-Monsoon	161.58	114.15	70.65	0.76	0.375
	Winter	48	44.99	93.73	0.1	-0.87

For the South-West region, we can find that the mean rainfall in the Monsoon season still contributes the most in the annual precipitation, but the values are significantly less than that of the South-East region, ranging from 1166.43 mm to 2026.58 mm with relatively low CV% compared to the other seasons. Here too, Winter season has the lowest mean rainfall with a decreasing trend for all the stations and the CV% for the season is much higher.

4.5.1 Seasonal rainfall anomalies for South-East region







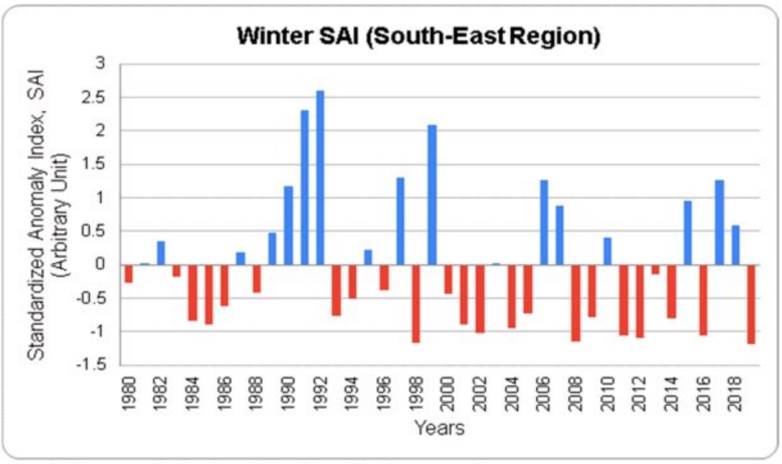
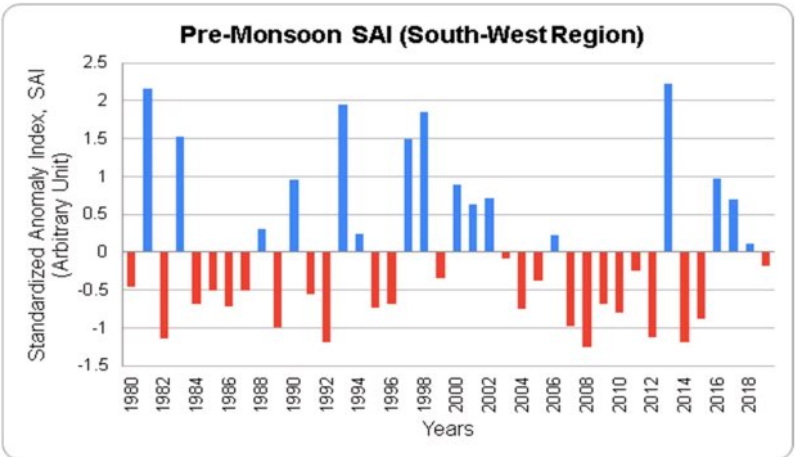
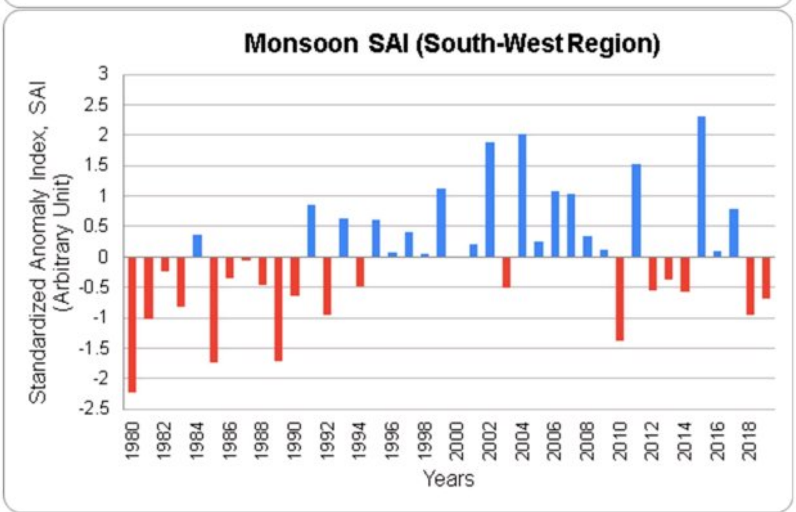


Figure 10 | Seasonal Anomaly Index for South-East region

For South-East seasonal SAI analysis shows that negative anomalies are mostly found at Winter and Pre-Monsoon. Monsoon and Pre-Monsoon are experiencing a wet period from 2000.

4.5.2 Seasonal rainfall anomalies for South- West region:





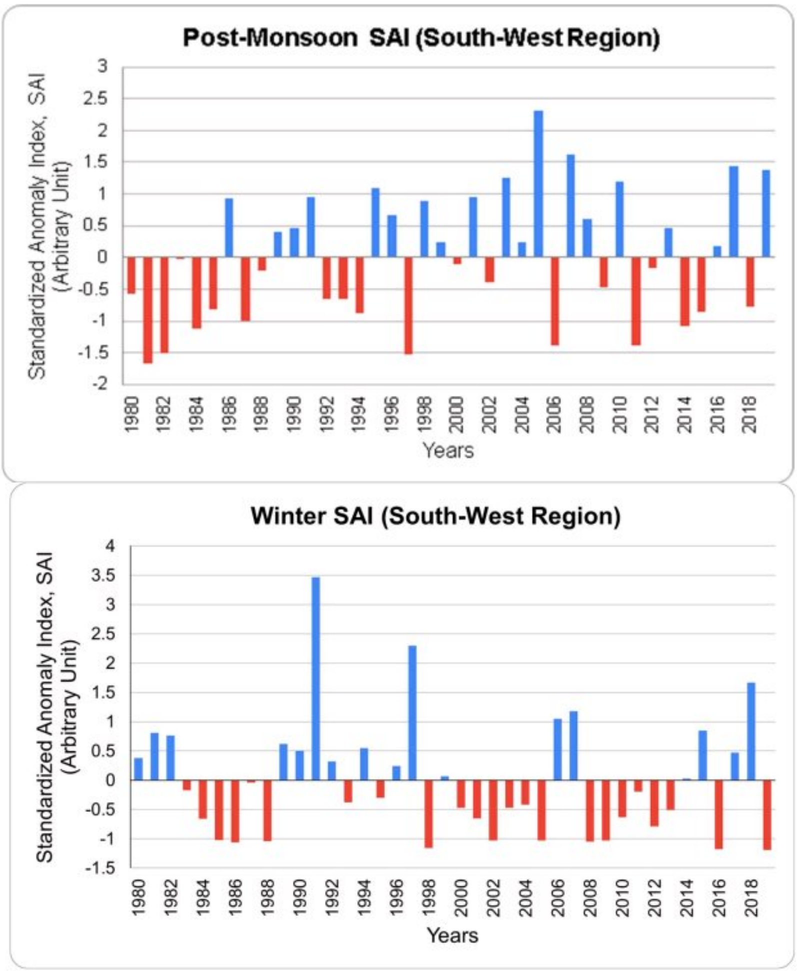


Figure 11 | Seasonal Anomaly Index for South-West region

SAI analysis of seasonal rainfall in the South-West region shows that negative anomalies exceeded positive anomalies in all season. Winter shows a predominance of negative anomalies from 1998.

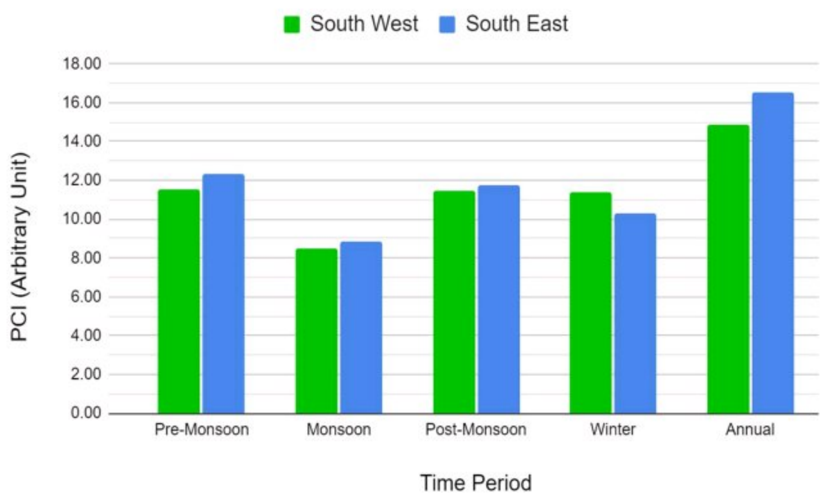


Figure 12 | Annual and seasonal PCI for coastal regions

The seasonal rainfall shows only Monsoon shows perfect uniformity of rainfall distribution indicates the same or highly similar amounts of rainfall in each month of that season. But the other seasons have moderate rainfall distribution which indicates rainfall is occurring on half of the period during these seasons.

Chapter Five : Conclusion

5.1 General

This study was conducted to observe the rainfall variability and change in trends in the coastal regions of Bangladesh for the period 1980 to 2019. Rainfall data from a total of 19 states along the coastal region were used for the study.

5.2 Major findings

The mean annual rainfall for the South-West coast was 1674 mm, which rises up to 4191 mm in the South-East coast. The seasonal rainfall analysis reveals that, the major share of annual rainfall, over 70%, is received in Monsoon and the least share is contributed by Winter (< 5%). The Pre-Monsoon and Post-Monsoon together contributes to the remaining 20~25% of the annual rainfall. The PCI analysis shows that, Monsoon has a perfect uniformity of precipitation distribution for both coastal regions. Whereas the rest of the seasons show moderate precipitation distribution. For annual rainfall, maximum PCI values are observed in the South-East part and majority of the study area is characterized by irregular rainfall distribution. The annual rainfall variability is low as compared to the inter-seasonal variability. It may be because monsoon rainfall contributes up to 74% of annual rainfall. Monsoon is characterized by low rainfall variability and the rest of the three seasons show high rainfall variability. Though the overall coastal area reveals an increasing trend in annual and monsoon rainfall, we found significant increasing trends only in the South-East region. This may be due to the increase of atmospheric moisture in coastal regions. Winter is getting drier in both regions with very high variability (CV > 80%). Which implies, agricultural activities in this season are highly dependent on groundwater. Increasing extreme rainfall events in the South-East region may cause increase in river water levels, flash flood and water logging. Significant increasing trend in rainfall seasonality in coastal areas indicates longer dry periods meaning potential droughts in near future.

5.3 Recommendation for further study

For further study, different aspects of the climate other than rainfall can be considered. Such aspects could include, temperature, wind speed, humidity etc. Furthermore, establishing the inter relationship among these aspects can help us better understand the ever-changing weather pattern. The variability and trend analysis can be done for the entire country. Satellite derived rainfall data can be used to create a more detailed observation of the changes in rainfall patterns.

References

1. Abu M, Kamal U, Rob K. *Delineation of the coastal zone* Dhaka, PDO-ICZMP, Bangladesh (2003)
2. Ahmad H (2019) *Bangladesh Coastal Zone Management Status and Future*. J Coast Zone Manag 22:1
3. Parvin, G. A., Takahashi, F., & Shaw, R. (2008). Coastal hazards and community-coping methods in Bangladesh. *Journal of Coastal Conservation*, *12*(4), 181–193. https://doi.org/10.1007/s11852-009-0044-0
4. Oliver, J. E. *Monthly precipitation distribution: a comparative index*. The Professional Geographer 32 (3), 300–309. https:// doi.org/10.1111/j.0033-0124.1980.00300.x.
5. Kanellopoulou, E. A. *Spatial distribution of rainfall seasonality in Greece*. Weather 57 (6), 215–219. https://doi.org/10.1256/004316502760053576.
6. R. Kabir, H. T. A. Khan, E. Ball, and C. Kaldwell, (2014) *Climate Change and public health situations in coastal areas of Bangladesh.* International Journal of Social Science Studies, vol. 2, no. 3, pp. 109–116
7. Minar, Maruf Hossain & Hossain, M. Belal & Shamsuddin, Md. (2013). *Climate Change and Coastal Zone of Bangladesh: Vulnerability, Resilience and Adaptability*. Middle-East Journal of Scientific Research. 13. 114-120.
8. Hasan, Z., Akhter, S., & Kabir, A. (2014). *Analysis of rainfall trends in the South-east Bangladesh*. Journal of Environment, 3(4), 51-56.
9. Hossain, M., Roy, K., & Datta, D. (2014). *Spatial and Temporal Variability of Rainfall over the South-West Coast of Bangladesh*. Climate, 2(2), 28–46. https://doi.org/10.3390/cli2020028
10. Mondol, M. A. H., Al-Mamun, Iqbal, M., & Jang, D.-H. (2018). *Precipitation Concentration in Bangladesh over Different Temporal Periods*. Advances in Meteorology, 2018, 1–18. https://doi.org/10.1155/2018/1849050
11. Shahid, Shamsuddin. (2012). *Rainfall variability and changes in Bangladesh during the last fifty years*. Rainfall: Behavior, Forecasting and Distribution. 23-44.
12. Khan, Md Hafijur Rahaman & Rahman, Ananna & Luo, Chuanxiu & Kumar, Sazal & Islam, G M & Hossain, Akram. (2019). *Detection of changes and trends in climatic variables in Bangladesh during 1988–2017*. Heliyon. 5. e01268. DOI: 10.1016/j.heliyon.2019.e01268.
13. Towfiqul Islam, A.R.M., Rahman, M.S., Khatun, R. et al. *Spatiotemporal trends in the frequency of daily rainfall in Bangladesh during 1975–2017*. Theor Appl Climatol 141, 869–887 (2020). https://doi.org/10.1007/s00704-020-03244-x

14. Mannan, Md & Karmakar, Samarendra. (2008). *Climatic feature of heavy rainfall activities in monsoon season and its socio-economic impact in Bangladesh*. In Proceedings of SAARC Seminar on Application ofWeather and Climate Forecasts in the Socio-EconomicDevelopment and Disaster Mitigation, 5–7

15. Bari, S. H., Hussain, M. M., & Husna, N.-E.-A. (2016). *Rainfall variability and seasonality in northern Bangladesh*. Theoretical and Applied Climatology, 129(3–4), 995–1001. https://doi.org/10.1007/s00704-016-1823-9

16. Shahid, Shamsuddin. (2011). *Trends in extreme rainfall events of Bangladesh. Theoretical and Applied Climatology*. 104. 489-499. 10.1007/s00704-010-0363-y.

17. Karim, Md. R., Mahabub, A. F., & Prosun, S. S. (2018). *Statistical Analysis of Rainfall Trend and Variability Due to Climate Change in Bangladesh.* (Doctoral dissertation, Department of Civil and Environmental Engineering, Islamic University of Technology, Board Bazar, Gazipur, Bangladesh).

18. Alemu, M. M., & Bawoke, G. T. (2019). *Analysis of spatial variability and temporal trends of rainfall in Amhara region, Ethiopia*. Journal of Water and Climate Change, 11(4), 1505–1520. https://doi.org/10.2166/wcc.2019.084

19. Islam, M., Rahman, M., & Bräuning, A. (2019). *Impact of extreme drought on tree-ring width and vessel anatomical features of Chukrasia tabularis.* Dendrochronologia, 53, 63–72. https://doi.org/10.1016/j.dendro.2018.11.007

20. Shamsuddoha, M., & Chowdhury, R. K. (2007). *Climate change impact and disaster vulnerabilities in the coastal areas of Bangladesh*. COAST Trust and Equity and Justice Working Group (EJWG).

21. Pandit, D. V. (2016). Seasonal rainfall trend analysis. International Journal of Engineering Research and Application, 6(7), 69-73.

22. Mondal, A., Kundu, S., & Mukhopadhyay, A. (2012). Rainfall trend analysis by Mann-Kendall test: A case study of north-eastern part of Cuttack district, Orissa. International Journal of Geology, Earth and Environmental Sciences, 2(1), 70-78.

23. Koudahe, Komlan & Adewumi, Johnson & Awokola, Olufiropo & Adekunle, Adebola & Djaman, Koffi. (2017). Trend in Standardized precipitation Index and Standardized anomaly index in context of climate change in southern Togo. Atmospheric and Climate Sciences. 7. 20. 10.4236/acs.2017.74030.

24. Nandargi, S. S., Mahto, S. S., & Ram, S. (2017). Changes in Seasonality Index over sub-divisions of India during 1951-2015. The Open Atmospheric Science Journal, 11(1).