STUDY OF RAINFALL & TEMPERATURE

TREND IN BANGLADESH

M.Sc. Thesis

By

KARNO KUMAR MONDAL
ROLL NO: 1655502
SESSION: JAN-2016

A THESIS SUBMITTED TO THE DEPARTMENT OF PHYSICS, KHULNA UNIVERSITY OF ENGINEERING & TECHONOLOGY, KHULNA-9203 IN PARTIAL FULFILLMENT OF THE REQUIERMENT FOR THE DEGREE OF MASTER OF SCIENCE.

DEPARTMENT OF PHYSICS

KHULNA UNIVERSITY OF ENGINEERING & TECHONOLOGY
KHULNA- 9203, BANGLADESH

AUGUST-2017

Declaration

This to certify that the thesis work entitled as "**Study of Rainfall & Temperature Trend in Bangladesh**" has been carried out in fulfillment of the requirement for M.Sc. degree in the Department of Physics, Khulna University of Engineering & Technology, Khulna-9203, Bangladesh. The above research work or any part of this work has not been submitted to anywhere for the award of any degree or diploma. No other person's work has been used without due acknowledgement.

Supervisor	Candidate
…………………….	………………………
Prof.Dr.Abdullah Elias Akther	Karno Kumar Mondal

Approval

This is to certify that the thesis submitted by **Karno Kumar Mondal**entitled "**Study of Rainfall & Temperature Trend in Bangladesh**" has been accepted by the Board of Examiners for the partial fulfillment of the requirements for the degree of M.Sc. in the Department of Physics, Khulna University of Engineering & Technology, Khulna-9203, Bangladesh on September 2017.

Board of Examiners

SI. No. Name, Designation & Address

1. Prof. Dr. Md. Abdullah Elias Akhter
Department of Physics ...….. …………………
Khulna University of Engineering & TechnologyChairman &Supervisor

2. Head
Department of Physics ....
Khulna University of Engineering & Technology Member

3. Prof. Dr. Md. Mahabub Alam
Department of Physics ....
Khulna University of Engineering & Technology Member

4. Dr. Samarendra Karmakar
Director (Retd) ....…..............
SAARC Meteorological Research Center (SMRC) Member (External)

DEDICATED

TO

MY RESPECTABLE PARENTS

Acknowledgement

With my great manner it is a pleasure for me to express my deepest sense of gratitude and indebtedness to my reverend supervisor Dr. Md. Abdullah Elias Akther, Professor, Department of Physics, Khulna University of Engineering &Technology, Khulna, for his kind guidance and supervision and for his constant encouragement throughout the research work. His inspiration and friendly cooperation has accelerated my work.

I am indebted to Professor Dr. Shibendra Shekher Sikder, Head, Department of Physics, Khulna University of Engineering & Technology for his strong support in various ways during the entire period of my study in this department. I express my heartfelt gratitude and thanks to Professor Dr. Md. Mahbub Alam and Professor Dr. Jolly Sultana, Department of Physics, Khulna University of Engineering &Technology. Many thanks for their inspiration and advices from the beginning of my study. I gratefully acknowledge Md. Kamrul Hasan Reza, Associate Professors, Department of Physics, KhulnaUniversity of Engineering &Technology. And also gratefully acknowledge Mr. Sujit Kumar Shil, Md. Alamgir Hossain, Asisstant Professors and Mr. Sumon Kumar Halder, Mr. Sumon Debnath, Mr. Probal Kumar Roy, Md. Saiful Islam, Lecturers, Department of Physics, Khulna University of Engineering & Technology for their cooperation regarding writing the thesis.

My personal thankful greetings are to my good friends and well wishers for their help and cooperation. There are numerous people who could not be mentioned individually but their interesting discussions have prompted much thought on various aspects, I would also like to thank them .I would like to express my heart full thanks to my parents, sister, brother and nearest relatives for their inspiration, encouragement and multifaceted supports to carry out this thesis work.

I am grateful to the KUET authority for approval of the project in the43rdmeeting of CASR, agenda No. 43/23/02 and providing me the relevant facilities to complete this research work. Bangladesh Meteorological Department (BMD) is acknowledgedfor providing necessary data over Bangladesh.

Finally, I want to express my gratitude to Almighty Creator for his mercy.

Abstract

Climatic data collected from Bangladesh Meteorological Department was used for the study. The regression equation, the coefficient of determination, standard deviation and coefficient of variation were calculated for the analysis. Mann-Kendall test for trend and Sen's slope estimates were also calculated. Annual average temperature (Tavg) in all division is increasing. The Tavg in Khulna is increasing by 0.007°C/year, in Dhaka it is increasing by 0.021°C/year. The average temperature has also an increasing trend in other divisionsand the rates are 0.011^{0}C/year in Rajshahi, 0.019°C/year in Sylhet, 0.0001°C/year in Rangpur, 0.013°C/year in Chittagong, 0.012°C/year in Barisal and 0.003°C/year in Mymensingh.Annual maximum temperature (Tmax)has an increasing trend in Khulna, Dhaka, Rajshahi, Sylhet, Barisal and Chittagong divisions while it has decreasing trend in Rangpur and Mymensingh divisions. The Tmax in Khulna is increasing by 0.01 °C/year, in Dhaka it is increasing by 0.0179 °C/year. And the maximum temperaturehas also an increasing trend in Rajshahi, Sylhet, Chittagong and Barisal divisions.The rates of increase are 0.006 °C/year in Rajshahi, 0.018 °C/year in Sylhet, 0.020 °C/year in Chittagong and 0.0178 °C /year in Barisal divisions. Whereas the maximum temperature has a decreasing trendat -0.014 °C/year and -0.004 °C/year in Rangpur and Mymensingh divisions respectively. Annual minimum temperatures (Tmin) in all divisions areincreasing.The Tmin in Khulna is increasing by 0.0058 °C/year, in Dhaka it is increasing by 0.024 °C/year. The minimum temperature has also an increasing trend in other divisions and the rates are 0.016 °C/year in Rajshahi, 0.021°C/year in Sylhet, 0.015 °C/year in Rangpur, 0.007 °C/year in Chittagong, 0.006 °C/year in Barisal and 0.010 °C/year in Mymensingh. The Mann-Kendall test indicates that in Khulna division Tavg has an increasing trend in monsoon and post monsoon seasons with value of Z 6.31and 2.52 which are statistically significant. This test also indicates that in Dhaka division,it has an increasing trend in pre-monsoon, monsoon, post monsoonand winter seasons with value of Z 2.75, 6.23, 5.60 and4.62 respectively which are statistically significant. In Rajshahi division, it has an increasing trend in monsoon season with value of Z 6.25which is statistically significant.In Sylhet division, it has an increasing trend inpre-monsoon, monsoon, post monsoonand winter seasons with Z values of 2.24,6.10, 5.24 and4.60 respectively which are statistically significant.In Rangpur division, it has an increasing trend in monsoon while decreasing trend in winterseasons with valuesZ of 3.85 and -1.86 which are statistically significant. In Barisal division,it has an increasing trend in Monsoon and Post-monsoon seasons with Z values of are 4.77 and 3.48 which is statistically significant. In Chittagong division, it has an increasing trend in pre-monsoon, monsoon, post-monsoonand winter seasons with Z values of 2.25,6.44,3.94and 1.79respectively which are statistically significant.In Mymensingh division,it has an increasing trend inmonsoon season with Z value of 5.11 which is statistically significant. Annual total rainfall has an increasing trend in Khulna, Rajshahi, Sylhet, Chittagong, Rangpur and Mymensingh divisionswhile decreasing trend in Dhaka and Barisaldivisions. The total rainfall has an increasing trend in Khulna by 3.392 mm/year, in Rajshahi it is increasing by 2.3279 mm/year. The total rainfall has also an increasing

trend in Sylhet, Rangpur, Chittagong and Mymensingh divisions. The rates are 2.6605 mm/year in Sylhet, 5.5885 mm/year in Rangpur, 1.889 mm/year in Chittagong and 2.283 mm/year in Mymensingh division. Whereas the total rainfall has a decreasing trends (-2.0292 mm/year) in Dhaka and (-1.985 mm/year) in Barisal division. The results suggest that temperature and rainfall are increasing in most of the stations and divisions.

Contents

List of Tables

List of Figures

Abbreviations

ADBT	:	Average Dry Bulb Temperature
BBS	:	Bangladesh Bureau of Statistics
BMD	:	Bangladesh Meteorological Department
GHG	:	Greenhouse Gases
IPCC	:	Intergovernmental Panel on Climate Change
MAKESENS	:	Mann-Kendall test for trend and Sen's slope
MNT	:	Minimum Temperature
MXT	:	Maximum Temperature
TR	:	Total Rainfall
WG	:	Working Group
WMO	:	World Meteorological Organization

Symbols

%	:	Percentage
^0C	:	Degree Celsius
Cv.	:	Coefficient of variation
GHG	:	Greenhouse Gases
Mm	:	Millimeter
R^2	:	Coefficient of determination
Std.	:	Standard deviation
Tavg	:	Average temperature
Tmax	:	Maximum temperature
Tmin	:	Minimum temperature

Chapter 1

Introduction

1.1 Introduction

Bangladesh is a disaster prone country for its geological condition with the Himalayas in the north and Bay of Bengal in the south. The climatic change issues have become international priorities during the last few decades. It is evident that the global mean surface air temperature has increased by 0.3 $^{\circ}$C to 0.6 $^{\circ}$Cover last 100 years, with the five global average warmest years being in the 1980s (WMO, 1991, 1995). Over the same period global sea level has increased by 10-20 cm. The size of the global warming is broadly consistent with prediction models, but is also of the same magnitude as natural variability. The earth's climate is a complex system that includes the global atmosphere, world oceans, cryosphere, land surface, biosphere etc. Atmosphere is energetically the most active and most rapidly varying component of climate, while the oceans response rather slowly. It is generally agreed that the atmospheric concentrations of several greenhouse gases like CO_2, CH_4, and CFCs have increased during the last centuries. This increase is mainly due to man-made activities especially after industrial evolution. Many of these gases have long life time in the atmosphere, so that after a complete stop of man-made emissions, their concentrations would decrease only slowly, over decades to centuries, towards their pre-industrial values. Water vapor is the most important greenhouse gas. Changes in atmospheric water vapor concentration are expected to occur with a global warming; they must be considered as an internal feedback effect of the climate system, rather than an external forcing mechanism (IPCC, 1990).The current scientific consensus is that increasing atmospheric concentration of greenhouse gases should cause the world to warm. The rate of warming, however, is very uncertain. In 1990, the Intergovernmental Panel on Climate Change (IPCC) estimate that with a "Business-as-usual" scenario of greenhouse gas emissions, the world should be 3.3^{0}C warmer by the end of the next century, with a range of uncertainty of 2.2 to 4.9^{0}C. Subsequent analysis by IPCC and others suggest somewhat lower rates of warming. Nevertheless, such rates of global temperature are greater than those which have occurred over the last 10,000 years. By the second half of the current century, the global temperature could well exceed that which has occurred over the last 150,000 years, at least. The variation of mean annual temperature over Bangladesh follows closely to that of the Northern Hemisphere land temperature: a warming trend during 1910-1940, a slight cooling trend until the mid -1970s, and resumed warming thereafter (Folland *et al*., 1990; 1992). For the period 1979-1991, 12 of the 13 years were warmer than the reference period. The analysis of the annual rainfall for the Bangladesh region for the period 1870-1991 showed no discernible long –term trend in mean annual rainfall. Karmakar and Nessa (1997) studied climatic change and its impacts on natural disasters and southwest-monsoon in Bangladesh and the Bay of Bengal. They found that the decadal mean annual temperature over Bangladesh have shown increasing tendency especially after 1961-1970. Recent study on Bangladesh shows that yearly average maximum and minimum temperatures has found increasing trends (Basak *et.al*, 2013) and Bangladesh is going to region of the world to climate change impacts (McCarthy *et al*., 2001). The international community also recognizes that Bangladesh ranks high in the list of most vulnerable countries on earth. Bangladesh's high vulnerability to climate change is due to a number of hydro-geological and socio-economic factors that include: (a) its geographical location in South Asia; (b) its flat deltaic topography with very low elevation; (c) its extreme climate variability that is governed by monsoon and which results in acute water distribution over space and time; (d) its high population density and poverty incidence; and (e) its majority of population being dependent on crop agriculture which is highly influenced by climate variability and change. Despite the recent strides towards achieving sustainable development, Bangladesh's potential to sustain its development is faced with significant challenges posed by climate change (Ahmed and Haque, 2002). It is therefore of utmost importance to understand its vulnerability in terms of population and sectors at risk and its potential for adaptation to climate change. In this research, variability of rainfall and temperature in Bangladesh will be studied using observational data for the period 1961-2015. The arrogant Himalayas in the north and funnel shaped Bay of Bengal in the south have made Bangladesh a meeting place of the life- giving monsoon rains and the catastrophic devastation of floods, cyclones, storm surges, droughts etc. (Paramanik, 1991). Agriculture, irrigated or rain fed is inherently vulnerable to climatic hazards (Lenka, 1998).It is expected that climate change will bring changes in characteristics of natural hazards and gradual changes phenomenon of the physical system. Studies and assessments of impacts, vulnerabilities and adaptation to climate change and sea level rise for Bangladesh, clearly demonstrates that Bangladesh is one of the most climate vulnerable countries in the world (BCAS, 2009). It has predicted that monsoon rainfall will increase, resulting in higher flows during monsoon season in the river system, sea level rise will be between 0.18 to 0.79 meters which will lead to salinity intrusion and coastal flooding and frequency and intensity of natural disasters are likely to increase especially in the northern and western part of the country (Cruz et al., 2007). Sattar (2009, 2010) used a lot of examples and practical models where he concluded that sea level will not rise, that was the 100% theoretical concept and climate change is a universal ongoing phenomena. Rahman and Alam (1996) examined the trend pattern of annual and seasonal rainfall over the last 16 years of all of the high Barind districts in Bangladesh by using simple regression techniques. Talukder et al. (1988), Ali et al. (1994) tried to detect and measure rainfall variability within years but overlooked the possibility of the between-years variability. Ahmed and Karmakar (1993) studied the variability of the arrival and withdrawal of summer monsoon in Bangladesh.

1.2 Objectives of the research

The objectives of the present study are:

- To assess the climatic variability for last 56 years and
- To know the trends of climatic parameter variability in Bangladesh.

1.3 Social and Economic benefit of the research work.

The economic activities of the country, especially the agriculture are dependent on the rainfall and temperature. The weather activities of Bangladesh are dominated by the southwest monsoon. The production of agriculture is also depending on temperature variability. In addition to this, Bangladesh is supposed to become the worst victim of the impacts of global warming and associated climate change. The climate change induced enhancement of natural disasters will cause its people to suffer innumerable loss to resources and livelihood. Variability of rainfall causes flood and droughts. The effect of these can be minimized by proper management practices which include preparedness, rescue operation and rehabilitation.Again, agriculture plan can be made suitable using the knowledge of climatic change.

The trends of climatic parameters (temperature and rainfall) help the policy maker to develop the country especially in the agriculture sector.

1.4Structure of the Thesis

The thesis has been constructed with the following structure:

- Chapter 1 contains general introduction. It describes the climate and disaster of Bangladesh, objectives and social and economic benefit of the research work.
- Chapter 2 contains review of literature. . It describe about Climate change, Temperature ,Patterns of temperature, Maximum and minimum temperature, Rainfall, Patterns of rainfall, Availability of rainfall, Deficit and excess rainfall.
- Chapter 3 contains study area, source & description of data, variables & measurement under the study, analysis of data and trends analysis.
- Chapter 4 contains trends analysis results of average temperature, maximum temperature, minimum temperature and yearly total rainfall for of all station & division. Time series and trends statistics results of temperature for different season (Pre-monsoon, monsoon, post monsoon and winter) also describe.
- Chapter 5 contains the conclusion.

Chapter 2

Review of literatures

2.1 Climate change

Climate change is a burning question now-a-days and it has become very alarmingto us day by day. According to the Third Assessment Report of IPCC, South Asia is the most vulnerable region of the world to climate change impacts (McCarthy *et al*., 2001). Despite the recent strides towards achieving sustainable development, Bangladesh's potential to sustain its development is faced with significant challenges posed by climate change (Ahmed and Haque, 2002). Karmakar and Nessa (1997) studied climatic change and its impacts on natural disasters and southwest-monsoon in Bangladesh and the Bay of Bengal. Karmakar & Nessa (1997) and Karmakar (2003) provided assessment of the effects of climate change on natural disasters. Climate change is the biggest global health threat of the 21stcentury and is increasingly recognized as a public health priority (WHO, 2009; Lancet, 2011; Young et al., 2002; Yongyut, 2009). Climatic variables are vital environmental factors, which establish ecological niches of tree species and their patterns of distribution (Avise, 2000; IPCC, 2001; Yongyut, 2009). Bangladesh is one of the top most nations vulnerable to climate change (Harmeling, 2008).Any climatic change in Bangladesh will, of course, be a part of worldwide climatic changes. It is generally claimed that the temperature of the earth has been increasing since the beginning of the 20th century. Quadir *et al.* (2003) found that the climate change was not uniform throughout theyear, but has considerable seasonal variations. In Bangladesh, there are four prominent climatic seasons, namely, winter (December-February), pre-monsoon (March-May), monsoon (June-September) and post monsoon (October-November).The monsoon has its onset during the first week of June and withdraws in the first week of October; however the onset and withdrawal dates vary from year to year (Ahmed and Karmakar, 1993). According to IPCC WG-I Third Assessment Report (IPCC, 2001), the global average surface air temperature has increased by 0.6^{o}Cover the 20thCentury. The cause of such warming has been attributed mainly to the increase of atmospheric emission of greenhouse gases (GHG). Quadir *et al.* (2001) mentioned that Bangladesh enjoyed tropical monsoon climate with dry and moderate winter and hot and wet summer. As the result of global warming, the climate of Bangladesh and that of the south Asian monsoon region as a whole is likely to suffer change. Some studies already demonstrated that the temperature and precipitation have been rising over

Bangladesh and adjacent regions. The year to year variation of crop yield is mainly due to the fluctuation in weather. The most important component of weather is the amount of rainfall and its distribution during the life span of plant growth. Islam (1996) also found a minor change in the physical and climatic environment also carried a large change in plant life and plant communities (Murshid, 1987). Again, human health is at serious risk due to Greenhouse Gas emissions (Hasib and Chathoth, 2016).Climate change is inevitably resulting in changes in climate variability and in the frequency, intensity, spatial extent, duration, and timing of extreme weather and climate events (IPCC, 2012).

2.2**Temperature**

The temperature of the earth has increased significantly over the past few decades. Warmer climates will generally accelerate the growth and development of plants, but overly cool or hot weather will also affect productivity. Earlier flowering and maturity of several crops have been documented in recent decades, often associated with higher temperatures (Craufurd & Wheeler, 2009).

Increases in maximum temperatures (as climate or weather) can lead to severe yield reductions and reproductive failure in many crops. In maize, each degree day spent above 30 ^{o}Ccan reduce yield by 1.7% under drought conditions (Lobell *et al.*, 2011). Impacts of temperature extremes may also be felt at night, with rice yields reduced by 90% with night temperatures of 32 compared with 27 ^{o}C(Mohammed & Tarpley, 2009). Climate variability and extreme events can also be important for yield quality. Protein content of wheat grain has been shown to respond to changes in the mean and variability of temperature and rainfall (Porter & Semenov, 2005); specifically, high-temperature extremes during grain filling can affect the protein content of wheat grain (Hurkman*et al.*, 2009).It is evident that the global mean surface air temperature has increased by 0.3^{o}Cto 0.6^{o}Cover last 100 years, with the five global average warmest years being in the 1980s (WMO, 1991, 1995). Recent study on Bangladesh shows that yearly average maximum and minimum temperatures has found increasing trends (Basak *et.al*, 2013) and Bangladesh is going to be one of the worst sufferers due to its disaster prone and low elevation geography (Elahi and Khan, 2015). Choudhury *et al.* (1997, 2003), Quadir *et al.* (2006) and Karmakar (2000) have shown that the temperature of Bangladesh has substantially increased during the past 3-4 decades which is quite comparable to the global warming for the corresponding time period (0.17°C/ decade). Average maximum and minimum temperature in winter is 29°Cand 11°Crespectively and 34°Cand 21°Cin summer over Bangladesh (BBS, 2002). Bangladesh has a tropical monsoon type climate, with a hot and rainy summer and a pronounced dry season in the cooler months. January is the coolest month of the year with the temperature ranging 13.5°Cto 26.5°C, and April the warmest month with the temperature ranging 33°Cand 36°C. In rare cases the temperature goes down less than 5°Cbut never touches freezing point. About 90% precipitation generally occurs during monsoon in four months, June to September, despite of variation in distribution (Karim *et al.*, 1990).It is evident that, on this time scale, Bangladesh region has been getting warmer. Since the later part of the last century, there has been, on average, an overall increase in temperature by 0.5°Cwhich was comparable in magnitude to the observed global warming. The variation of mean annual temperature over Bangladesh follows closely to that of the Northern Hemisphere land temperature: a warming trend during 1910-1940, a slight cooling trend until the mid-1970s, and resumed warming there after (Folland*etal.*, 1992). For the period 1979-1991, 12 out of the 13 years were warmer than the reference period.

2.3 Patterns of temperature

Global average surface temperatures have increased +0.74°C±0.18°C between 1906–2005(e.g., IPCC 2007).Various forcing agents have been suggested for observed differential warming rates of Tmin and Tmax including the role of urbanization and land-use change (Bonan 2001; Kalnay and Cai 2003), and regional aerosol loading (Wild et al., 2007).Furthermore, as California's ecology and economy appear sensitive to changes in climate (Hayhoe et al., 2004), analysis and understanding of observed trends are important for refining future climate projections for climate sensitive sectors and natural resources within the state. Karmakar and Shrestha (2000) studied the trends of annual maximum and minimum temperaturesin Bangladesh during the period 1961-1990 and found an overall increase in temperature by 0.5°Cand which is comparable in magnitude to the global warming. Karmakar and Nessa (1997) reported climate change and its impacts on natural disaster and south-west monsoon in Bangladesh and the Bay of Bengal.

The mean annual temperature over Bangladesh has shown increasing tendency especially after 1961-1970. According to WMO (1999) atmosphere is energetically the most active and most rapid varying component of climate, while the ocean responses rather slowly. Global temperature in 1998 was the warmest since reliable instrument records began 139 years ago. The second warmest year was 1997, with the five global averages being in the 1980's warmest year. It is evident that the global mean surface air temperature has increased by 0.3°Cto 0.6°Cover the last 100 years (WMO, 1995). Chowdhury and Debsarma (1992) observed the increasing tendency of the lowest minimum temperature over Bangladesh.

2.4 Maximum and minimum temperature

Mahbub (2002) tried to find the correlation between winter temperature and monsoon rainfall and found significant correlation is different stations over Bangladesh. Karmakar and Shrestha (2000) mentioned that the annual mean maximum temperature over Bangladesh had significant decreasing trend up to 1975 and very significant increasing trend after 1975. The overall trend of annual mean maximum temperature for the period 1961-90 is of increasing order, which is statistically significant. Shrestha (2000) studied the climatic element of maximum and minimum temperature over Sir Lanka for the period 1961-1990 and found that the highest increasing trend 0.037°C /year at Anuradhapura district. He also expected in annual mean temperature 1.147 °Cand 2.09 °C would increases over Sir Lanka by the year 2050 and 2100 A.D. Karmakar and Shrestha (2000) found that the annual mean maximum temperature over Bangladesh has an increasing trend up to 1978 which is statistically significant and after 1978 it has a slight decreasing trend which is not significant. The overall Annual mean minimum temperature over Bangladesh for the period 1961-90 has a slight decreasing trend. The annual mean temperature over Bangladesh has a slight increasing trend during the whole period 1961-90, but the trend is not statistically significant. Karmaker and Shrestha (2000) reported that the present 5-year running average trends of climate elements continue, the annual mean maximum temperature was likely of rise by 0.48°C and 0.88°Cby 2050 year and 2100 years respectively whereas the annual mean minimum temperature was likely to decrease by 0.66°Cand 0.11°Cby 2050 and 2100 respectively. But the overall annual mean temperature over Bangladesh was likely to increase by 0.21°Cand 0.39°C by 2050 and 2100 years respectively. The annual- total rainfall over Bangladesh is likely to increase by 304.72 mm and 588.65 mm by 2050 and 2100 years respectively. In some places in Rajshahi and Kushtia districts the maximum temperature in summer season rises up to 40°C or more. After April, temperature decreases slightly during the summer months, which coincides with the rainy season. Widespread cloud cover causes dampening of temperature during the latter part of the pre-monsoon season. Average temperatures in July vary from about 27°Cin the southeast to 29°Cin the northwestern part of the country (Banglapedia, 2004).

2.5 Rainfall

Water that is condensed from the aqueous vapor in the atmosphere and falls in drops from the sky to the earth is called rain; and the total amount of rain that falls in a particular area within a certain time is called rainfall. The rainfall in Bangladesh varies seasonally and place to place. About 70.6% of the country average rainfall occurs in the monsoon season and 18.8% in per monsoon season. The winter and post – monsoon contribute to 1.6 and 9.0% of annual rainfall. The area weighted country average annual rainfall of Bangladesh is 2315.7 mm and monsoon rainfall is 1635.4 mm as obtained from the data of 57 years from 1948-2004 (Quadir, 2006). Availability of biologically and chemically safe, hygienic, fresh and clean water is a serious problem since the ground water contains high level of arsenic and the surface water contains unwanted chemicals, impurities, pathogens and waste materials (Hussain et al., 2001). Rainfall is the most viable potable drinking water for rural areas of Bangladesh. Among the climate parameters the most important one is rainfall. Rainfall varies not only with time geographical area and altitude in space and is a continuous random variable (Ali et al., 1994). Rainfall is the single most important climate parameter influencing agriculture of our country since 1975 to 80% of the cultivated land is non-irrigated. This is the free source of water directly and most uniformly available to a crop and the foliage. But it can be utilized most efficiently by reducing its harmful effect and increasing beneficial outcomes, which requires planning of agricultural activities in such a way that the beneficial effect of the rainfall in maximized and harmful effect minimized (Khan et al., 1991). Hargreaves and Prasad (1985) started that rainfall was erratic, uncertain and unevenly distributed. Although irrigation facilities in the country rapidly expanding, but it was a costly input in crop production. Out of the total cultivable areas available in the country about 85% of the cultivated areas were under rain-fed agriculture (Handa and Srenath, 1983).

2.6Patterns of rainfall

The rainfall patterns in Bangladesh are governed by seasonally varying meteorological system of south-west monsoon (Quadir et al., 2004). South-west monsoon is of maritime, moist and unstable air whereas the north-west monsoon is of continental, dry and stable air over Bangladesh. According to Quadir et al. (2004) monsoon and winter seasons are separated by two transitional seasons namely pre-monsoon and post-monsoon. Expect namely, the other three seasons contribute major share to the total rainfall of Bangladesh. However, life giving rain comes during South-west monsoon accounting for over 70%of the total annual rainfall. It is to be noted that the high land situated to the east and north of Bangladesh play their due role to this monsoon rain. A number of studies (Choudhury et al., 1997; Quadir et al., 2001) have reported that the precipitation in Bangladesh has been increasing during the recent decades. Hussain et al. (2001) found that the mean annual rainfall was 2387.20 mm from 1975 to 1995. May to September were the highest rainfall months when the rainfall was more than 300 mm in over 63.80 % of the years and always more than 50 mm while May to June could be useful for Karif (April to September) sowing, but the harvest may have to be postponed up to October. The prediction models for drought of different meteorological variables in Bangladesh. Sylhet is the heavy rainfall region in Bangladesh. In the month of April and May Sylhet receive 340 mm and 650 mm rain respectively. Lalkhan, the northwest border of Sylhet receive 560 mm and 600 mm rainfall in the month of April and May respectively. The south-east monsoon over sub-continent has a large effect on the general circulation. In fact monsoon of south and south-east Asia dominates significantly the summer circulation of the northern hemisphere. This monsoon is generally responsible for the major portion of annual rainfall over the Indian subcontinent. The social and economic conditions of millions of the people of the subcontinent are largely dependent upon this rainfall (Islam and Shafee, 1998). Karmakar and Mian (1994) the correlation between pre-monsoon rainfall and monsoon rainfall over different station of Bangladesh and observe no correlation. According to Ahmed and Karmakar (1993), the south-west monsoon makes its arrival at Bangladesh coast through the south-eastern part, the mean data of onset is 2 June ,and its takes about 13 days to reach the north-western part of the country.

The southwest monsoon being its withdrawal from 30th September and the withdrawal is completed through the south-eastern part of the country. Chowdhury and Debsarma (1992) investigated a significant upward trend of precipitation (by 18%) in the north, west south-west region since the early 70%, and a downward trend in the south-east. The occurrence of erratic rainfall intensity and distribution is specific character of the monsoon climate in south and south-east Asia. Drought in these areas may occur at any time, and does not generally follow a predictable pattern (chang et al., 1979).

2.7Availability of rainfall

Karmakar (2004) studied the monthly country average rainfall had inter annual variation and it had increasing linear trends during the pre-monsoon season. The rates of increase of country-average rainfall were 1.3359 mm/year, 1.0909 mm/year and 1.1189 mm/year in March, April and May respectively. The variation of monthly country average rainfall over Bangladesh maintained a similar pattern of variation with 11-13 year cycle .The study by Quadir et al. (2003) a showed that the crop yield is low for low monsoon rainfall. The yield increases with the increase of rainfall up to a certain optimum level and further increase of rainfall causes the decrease of the yield. South-west monsoon is predominant here but there is a large variation of rainfall over different parts of the country. There is a hilly structure on the eastern and northern parts. Climatologically there are two maximum rainfall (2500-4000 mm/year) regions due to orographic and hilly structure. They are north eastern and south eastern regions. North-western part gets the least rainfall (1600-2000 mm/year) and south-western region receives rainfall of 1600-2500 mm/year (Debsarma, 2003). Quadir et al. (2003) reported that the average annual over Bangladesh varies from 1429-4338 mm. About 75% of the annual precipitation occurred during the monsoon period, about 15% in the pre-monsoon season and the rest 10% occurred in winter and post-monsoon season. In Bangladesh monsoon, average rainfall varies from 1194 mm to 3454 mm (BBS, 2002). More than 70% of Bangladesh annual rainfall occurs in the monsoon (June-September) season (Hussain and Sultana, 1996; Matsumoto, 1998).The main rainfall during the monsoon season range from 1000 to 3000 mm in the country. The maximum rainfall occurs at Sylhet in the north-eastern part and along the coastline in the southern part and with a minimum in the west central part. Ali et al. (1994) found that the average annual rainfall in the country was 2486 mm. They also found that the average monsoon rainfall in every year was found to be 66.76. About 70 to 80 % of the rainfall occurred during the month from June to September .Leaving the most productive dry season (November to March) with extremely inadequate rainfall for crop growth. Talukder et al. (1988) studied the average annual rainfall in

Bangladesh was 2047 mm the contribution of the month of June, July, August and September were 416, 425, 342 and 269 mm, respectively. The annual rainfall in the country ranges from 1400 to 5800 mm, but its distribution is uneven.

2.8Deficit and excess rainfall

Ali *et al.* (1994) found that the rainfall of the wettest year 1991 was 136.15% of the average of 2485mm while the driest year of 1992 was 63.61% of the 19 years (1975 to 1993). The low value of 19.189% of the coefficient of variation produced an indication of the uniformity of the rainfall in the region in which Mymensingh is situated. The irrigation water requirement during different months of the crops growing period is a function of rainfall deficits in those months for planning an irrigation water supply system.

Thus, rainfall deficit information for different areas and periods can greatly help determine optimal water release from a reservoir in accordance with demand, when rainfall exceeds evaporation, soil moistures reserves are recharged till filed capacity is reached and any further rainfall is termed as surplus. When rainfall is less than evaporation, soil moisture is utilized and rainfall deficit conditions occurred. Rupa Kumar et al. (1992) have found significant increasing trend in monsoon rainfall along the West Coast, north Andhra Pradesh and northwest India while significant decreasing trends over Madhya Pradesh and adjoining area, northeast India and parts of Gujarat and Kerala. Amin *et al.* (2004) analyzed the period between May to October was surplus period (rainfall>PET) and generally no problem with agricultural and other water-based activities in Bangladesh. The months from November to March, and in some instant up to April was deficit period (rainfall<PET).Quadir *et al.* (2003) reported that annually, there was no aridity in Bangladesh. Also for individual months of May-October there is no aridity in Bangladesh. Only for individual months of November, December, January and February Bangladesh falls in aridity condition. In March, except Sylhet, Rangamati, Chittagong, Cox’s Bazar whole country falls in arid zone .In April, Only Rajshahi, Bogra, Dinajpur, Rangpur, Jessore, Satkhira, Cox’s Bazar fall in and zone. According to Quadir *et al.* (2003) the annual profiles that most of the maps precipitation occurs during July and August. Sylhet shows very high monsoon precipitation and Rajshahi shows a relatively low monsoon precipitation compared to the other stations. It is clear that the northeastern and southeastern part of Bangladesh gets high precipitation and the western and southwestern part is relatively. Islam *et al.* (2002) described ascent and descent of

severity of droughts mostly depended on fluctuation in rainfall distribution. Higher fluctuation was responsible for higher drought; while less varied distribution causes somewhat lower drought. Rainfall at 50% and 80% probability with respect to crop demand was almost scarce throughout the crop season. Specially, at the beginning of ripening stage availability of rainfall was nearly zero. In the year 1957,1958,1972 and 1979 longer dry season than the normal is recorded in Bangladesh (up to 190 days).In 1966 and 1967, however, the duration of dry season is less than the normal (60 days). During the drought years (1957, 1958, 1966, 1967, 1972 and 1979) the highest values of duration of dry season are observed in the northern and western parts of the country. Only in 1967 the highest value of duration of duration of dry season is found to be in Chittagong. In 1979 the deficit of rainfall is observed almost throughout the country (Mobassher *et al.*, 1995).The rainfall deficits are functions of time (Talukder *et al.*, 1994).Talukder*et al.* (1988) studied that highest rainfall in July (387.8 mm) and lowest in January (3.6 mm) for various locations in Bangladesh for a period of 18 years (1965to 1980). The mean annual rainfall was 2485.95 mm.

CHAPTER 3

Data and Methodology

3.1 Study area

The study was conducted in all divisions of Bangladesh. The names of the stations considered for study are shown in Fig.1. But stations; Feni, Chandpur, Monga, Ishurdi, Rajshahi, Khepupara Kutubdia, Teknaf and Patuakhali are not considered because data of those stations were recorded after 1960.Bangladesh with an area of 1, 47,570sq. km, located in between 20°34´ and 26°38´ north latitudes and in between 88°01´ and 92°41´ east longitudes. It is bounded by West Bengal state of India and Meghalaya (India) on the north, Bay of Bengal on the south, Myanmar and India on the east, West Bengal state of India on the west (Banglapedia, 2006). There are many lofty hills in Rangamati, Khagrachhari, and Bandarban and in the eastern part of Chittagong districts (Banglapedia, 2006). Also some hills with low altitude are in Sylhet division.On the other hand other divisions are generally plane.

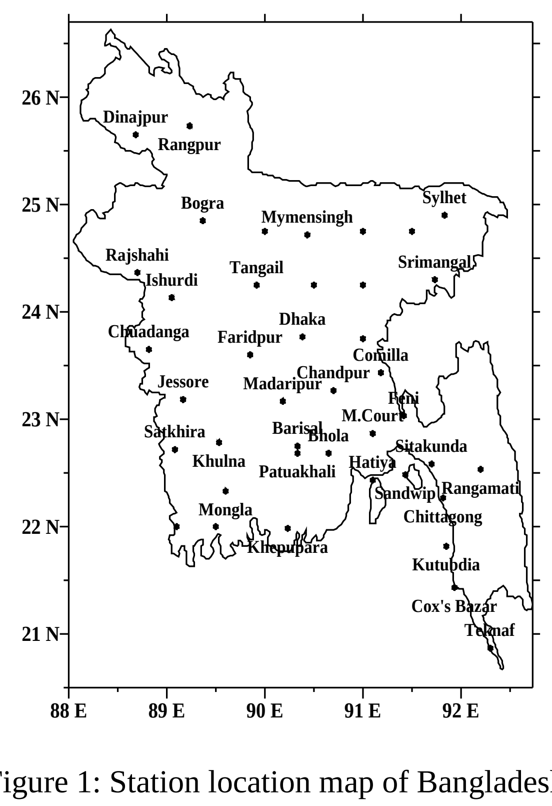


Figure 1: Station location map of Bangladesh.

3.2 Source and description of data

Monthly mean data of different climate elements such as maximum temperature (^{o}C), minimum temperature (^{o}C) and rainfall (mm) of Bangladesh for the period of January 1960 to December 2015 (i.e. 56 years) were used in this study. Data were collected from Bangladesh Meteorological Department (BMD). It is also essential to mention that there were some missing data in some months. Data were considered to be missing when the data were not recorded. To maintain the continuity, the gaps were filled up by the time mean values of the existing years. The daily and monthly data on climaticdata of Bangladesh were collected from Bangladesh Meteorological Department, Agargaon, and Dhaka, Bangladesh .Annual mean temperature, maximum temperature in ^{o}C (Tmax), minimum temperature in^{o}C (Tmin) and total rainfall in millimeter (TR).

3.3 Methodology

Different tools were applied to evaluate and assess the trends of changes of climatic variables in Bangladesh. The prime focus is on the assessment of the trend on changes of temperature. Different instruments, formula, tools and techniques were applied to accomplish the study.

3.3.1Temperature

Average seasonal temperature was calculated from average monthly minimum and maximum temperature based on different seasons. Average annual temperature data were plotted to analyze the variation and trend of temperature over Bangladesh.

3.3.2 Rainfall

For greater precision accumulated monthly rainfall (in mm) data were considered for the research. Average annual rainfall data were plotted to analysis the variation and trend of rainfall over Bangladesh.

3.3.4Analysis of data

After completion of data collection, data were compiled, tabulated and analyzed according to the objectives of the study. Data were put in MS Excel for statistical analysis. Annual averages of climatic parameters (temperature and rainfall) of different stations of Bangladesh were calculated to analyze the variation and trend line of climatic parameters during 1960-2015. Regional averages of 56 years climatic data were calculated to find out the distribution of climatic parameters.

The regression equation and the coefficient of determination (R^2) obtained through scattered diagrams by taking two indices at a time. The significance test of the coefficient of determination (R^2) carried out by using t-test (Alder and Roessler, 1964).Annual average of climatic parameters, maximum temperature in ^{o}C (Tmax), minimum temperature in ^{o}C(Tmin) and total rainfall in millimeter (TR) of Bangladesh werecalculated to analyze the variation and trend line of climatic parameters. District wise average of long terms climatic data were calculated to find out the distribution of climatic parameters. The regression equations and the coefficient of determination (R^2) were calculated.

Coefficient of variation

The coefficient of variation is a measure of spread that describes the amount of variability relative to the mean. Because the coefficient of variation is unit less, you can use it instead of the standard deviation to compare the spread of data sets that have different units or different means.

Coefficient of variation = $\frac{\sigma}{\mu} \times 100\%$
Here μ is the mean value of a set of data; σ is population standard deviation.

3.5 Trend Analysis

Mann-Kendall test for trend and Sen's slope estimates used for detecting and estimates trends in the time series of the annual values of yearly temperature for season (pre-monsoon, monsoon, post monsoon and winter). A number of Excel template developed for Mann-Kendall test for trend and Sen's slope estimation. Of them Mann-Kendall test for trend and Sen's slope estimates (MAKESENS) used for detecting and estimating trend. There are two phases in trend analysis; first the presence of a monotonic increasing or decreasing trend and secondly the slope of a linear trend is estimated. Both of the cases nonparametric tests were applied. For monotonic trend analysis the nonparametric Mann-Kendall test and for slope of linear trend estimation the non-parametric Sen's slope estimator used. Correlation coefficient of the meteorological variables and time were also computed to determine the better strength and understanding of the linear relationship between variables.

3.5.1Mann-Kendall Analysis

The Mann-Kendall test generally was applied where the data do not uniform to a normal distribution. This test evaluates a nonparametric form of monotonic trend regression analysis of y values tend to increase or decrease over time. The nonparametric Mann-Kendall test is commonly used for hydrologic data analysis; can be used to detect that are monotonic but not necessarily linear (Olofintoye, 2010). The Man-Kendall test assumed that a value can always be declared less than, greater than, or equal to another value; that are independent; and that the distribution of data remain constant in either the original units or transformed units (Helsel and Hirsch, 1988). The null hypothesis in the Mann-Kendall is that the data are independent and randomly ordered. The Mann-Kendall test does not require the assumption of normality, and not only indicates the direction but not the magnitude of significant trends (McBean and Motiee, 2008). The Mann-Kendall test compute the difference between the later measured value and all early measured values,($x_j - x_k$) , where j>k, and test statistics S is calculated using the formula;

$$S = \sum_{k-1}^{n-1} \sum_{j-k+1}^{n} s \quad (x_j - x_k) \quad (1)$$

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

$$s \quad (x_j - x_k) = \begin{cases} 1 & i \; x_j - x_k > 0 \\ 0 & i \; x_j - x_k = 0 \\ -1 & i \; x_j - x_k < 0 \end{cases} \qquad (2)$$

A large positive number of S reveals the later-measured values tend to be larger than earlier values and an upward trend is indicated. When S is a large negative number, later values tend to be smaller than earlier values and a downward trend is indicated. When the absolute value of S is small, no trend is indicated. The test statistics τ can be computed as;

$$\tau = \frac{S}{n-(n-1)/2} \qquad (3)$$

It is necessary to compute the probability associated with S and the sample size, n, to statistically quantify the significance of the trend. The variance of S is computed as;

$$VAR\,(S) = \frac{1}{1}[(n-1)\,(2n+5)\sum_{p=1}^{q} t_p\,(t_p - 1)\,(2t_p + 5)]\ (4)$$

Here q is the number of tied groups and t_p is the number of data values in the p^{th} group. The values of S and VAR(S)are used to compute the test statistics Z as follows;

$$Z=\begin{cases}\frac{S-1}{\sqrt{VAR(S)}} & \text{if } S>0\\ 0 & \text{if } S=0\\ \frac{S+1}{\sqrt{VAR(S)}} & \text{if } S<0\end{cases} \quad (5)$$

Z score follows a normal distribution. At a choice of α=0.05 (95% level of significance) and two sided alternative, the critical values of z are equal to -1.96 to 1.96 (Z0.025 = 1.96). The trend is said to be decreasing if Z is negative and the absolute value is greater than the level of significance, while it is increasing if Z is positive and greater than the level of significance.

If the absolute value of Z is less than the level of significance, there is no trend (Khambhammettu, 2005).

When n is 9 or less, the absolute value of S is compared directly to the theoretical distribution of S derived by Mann-Kendall. In MAKESENS the two-tailed test is used for four significance level α: 0.1, 0.05, 0.01 and 0.001. If n is at least 10 the normal approximation test is used and a statistically significance trend is evaluated using the Z score. MAKESENS tested the Z score significance level at α: 0.001, 0.01, 0.05 and 0.1.

3.5.2Sen's Slope Estimator

Many hydrologic variables exhibit a marked right skewness partly due to the influence of natural phenomena, and do not follow a normal distribution. Similarly the climatic data also fluctuate and deviated from a normal distribution. Hence the Sen's slope estimator, which is a nonparametric method, was used to develop the linear models in this study. Sen's slope estimator is a nonparametric method for slope estimation. Sen's nonparametric method generally used to estimate the true slope of an existing lineartrend (as change over time). If a linear trend present in a time series, then the true slope (change per unit time) can be estimated by using a simple nonparametric procedure. This means that linear model f (t) can be describe as

$$f\,(t) = Qt + B \qquad (6)$$

where Q is the slope, B is a constant and t is time. To derive an estimate of the slope Q, the slopes of all data pairs are calculated using the equation;

$$Q_i = \frac{x_j - x_k}{j-k}\ ,\ \ i = 1,2,3, \ldots \ldots .. N, j > k \qquad (7)$$

If there are n values xj in the time series there will be as many as N = n(n-1)/2 slope estimates Q_i. To obtain estimates of B in equation the n values of differences $x_i – Qt_I$ are calculated. The median of these values gives an estimate of B (Sirois, 1998). The estimates for the constant B of lines of the 99% and 95% confidence intervals are calculated by a similar procedure. Data were processed using an Excel macro names MAKESENS created by Salmi et al. (2002).

Chapter 4

Results and Discussion

4.1.1Average Temperature in Khulna Division

The annual average temperature (Tavg) showed increasing trends in Khulna, Jessore and Satkhira over the study period 1960-2015 (Figure2). In Khulna, annual Tavg was increasing by 0.005°C/yearwith its average 26.37°C.In Khulna, the increasing trend of Tavghas coefficient of determination R^2 = 0.042was not significant (Table1).The warmest year in Khulna was 1969 where Tavg was 27.3°Cand coldest year was 1981 where Tavg was 25.56°C (Figure2). Before 2015, Tavg was found to fluctuate abnormally where standard deviation and coefficient of variation of Tavg in Khulna were ± 0.406and1.53 %respectively (Table 2).

Annual Tavg in Jessore was increasing by 0.013 °C/year with its average 25.82 °C. In Jessore, the increasing trend of Tavg has coefficient of determination R^2 = 0.391wassignificant at 99% level of significance (Table1). The warmest year in Jessore was 2010 where Tavg was 27.0°C and coldest year was 1967 where Tavg was25.6°C (Figure 2). Before 2015, Tavg in Jessore was found to fluctuate abnormally where standard deviation and coefficient of variation of Tavg in Jessore were ± 0.339and 1.29 % respectively (Table 2).

Annual Tavg in Satkhira was increasing by 0.006 °C/year with its annual average 26.24 °C.In Satkhira, the increasing trend of Tavg has coefficient of determination R^2 =0.099was not significant. (Table1). The warmest year in Satkhira was 1979 where Tavg was 27.4 °C and coldest year was 1981 where Tavg was 25.56 °C (Figure 2). Before 2015, Tavg in Satkhirawas found to fluctuate abnormally where standard deviation and coefficient of variation of Tavg in Satkhira were ±0.339 and 1.28% respectively (Table 2).

Increasing trends of Tavg in Khulna, Satkhira were not significant while increasing trend in Jessore was significant in Khulna division.

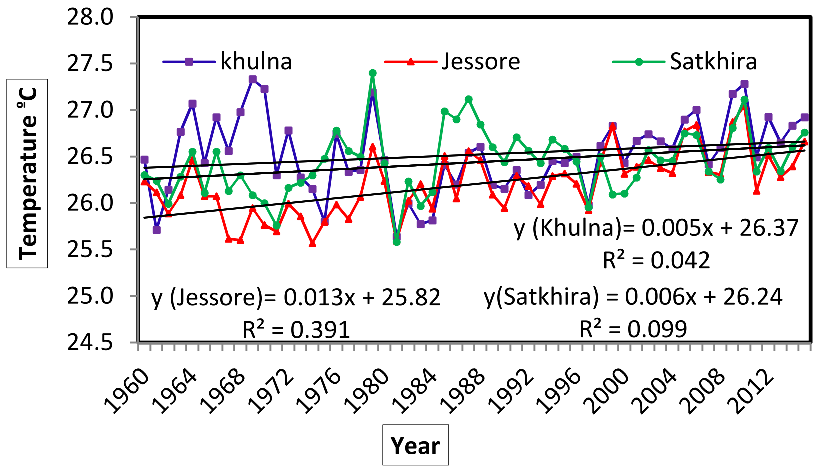


Figure 2: Temporal variation of annual average temperature in Khulna division.

4.1.2 Average Temperature in Dhaka Division

The annual Tavg showed increasing trend in Dhaka and Faridpur over the study period 1960-2015 (Figure3). In Dhaka, annual Tavg was increasing by 0.021°C/yearwith its average 25.48°C.In Dhakathe increasing trend of Tavghas coefficient of determination R^2 = 0.512was significant at 99% level of significance(Table1).The warmest year in Dhaka was 2009 where Tavg was 27.1°Cand coldest year was 1971 where Tavg was 25.0°C(Figure 3). Before 2015, Tavg was found to fluctuate abnormally where standard deviation and coefficient of variation of Tavg in Dhaka were ±0.476 and 1.82 % respectively (Table 2).

Annual Tavg in Faridpur was increasing by 0.021°C/year with its annual average 25.19°C. In Faridpur, the increasing trend of Tavghas coefficient of determination R^2 =0.557was significant at 99% level of significance (Table1). The warmest year in Faridpur was 2006 where Tavg was 26.8°C and coldest year was 1974 where Tavg was 24.7°C(Figure 3). Before 2015, Tavg in Faridpur was found to fluctuate abnormallyand after that its annual variation was normal. Standard deviation and coefficient of variation of Tavg in Faridpur were ±0.455and 1.76%respectively (Table 2).

Increasing trends of Tavg in Dhaka andFaridpurweresignificantin Dhaka division.

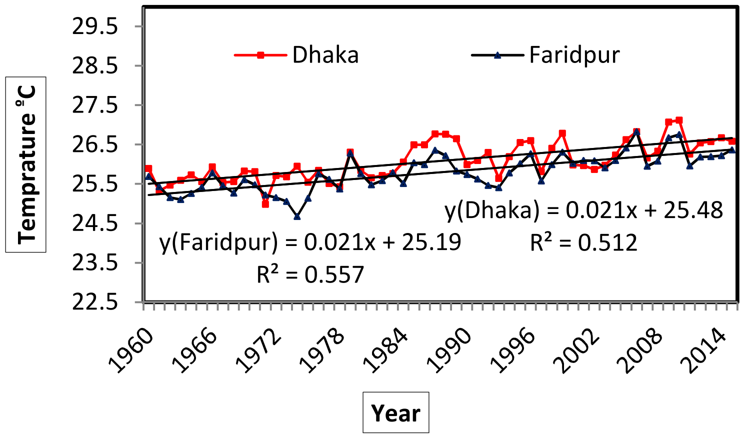


Figure 3: Temporal variation of annual average temperature in Dhaka division

4.1.3 Average Temperature in Rajshahi Division

The annual Tavg showed increasing trend in Bogra over the study period 1960-2015 (Figure 4). In Bogra, annual Tavg was increasing by 0.011°C/year with its average 25.4°C.In Bogra the increasing trend of Tavg has coefficient of determination R^2 =0.277 was significant at 99% level of significance(Table1). The warmest year in Bogra was 1979 where Tavg was 26.5°C and coldest year was 1971 where Tavg was 24.8°C (Figure 4). Before 2015, Tavg was found to fluctuate abnormally where standard deviation and coefficient of variation of Tavg in Bograwere ±0.352and 1.36% respectively (Table2).

Increasing trend of Tavg in Bogra was significant in Rajshahi division.

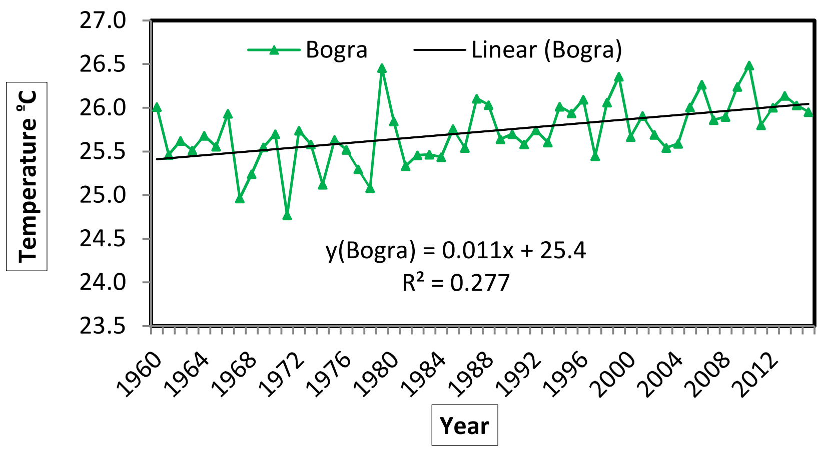


Figure 4: Temporal variation of annual average temperature in Rajshahi division

4.1.4 Average Temperature in Mymensingh Division

The annual average temperature (Tavg) showed increasing trend in Mymensinghover the study period 1960-2015 (Figure 5). In Mymensingh, annual Tavgwas increasing by 0.003°C/year with its average 25.26°C.In Mymensingh the increasing trend of Tavg coefficient of determination equal to R^2 =0.025, which was not significant(Table1). The warmest year in Mymensingh was 1999 where Tavg was 26.0°Cand coldest year was 1991 where Tavg was 24.3°C(Figure 5). Before 2015, Tavg was found to fluctuate abnormally where standard deviation and coefficient of variation of Tavg in Mymensingh were± 0.307and 1.21% respectively (Table 2).

Increasing trend of Tavg in Mymensingh was not significant in Mymensingh division.

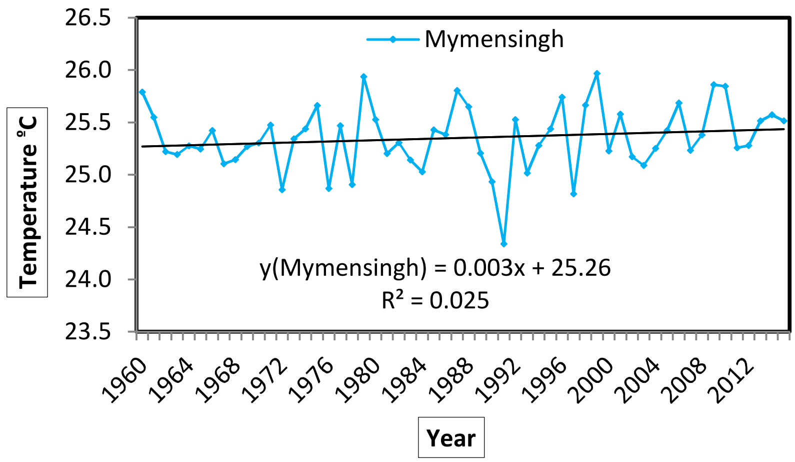


Figure 5: Temporal variation of annual average temperature in Mymensingh division

4.1.5Average Temperature in Sylhet Division

The annual average temperature (Tavg) showed increasing trend in Sylhet and Srimongal over the studyperiod, 1960-2015 (Figure 6). In Sylhet, annual Tavg wasincreasing by 0.027°C/year with its average 24.33°C.In Sylhet, the increasing trend of Tavg has coefficient of determination R^2 = 0.622, which wassignificant at 99% level of significance(Table1). The warmest year in Sylhetwas 2009 where Tavg was 26.3°C and coldest year was 1977 where Tavg was 24.3°C (Figure 6). Before 2015, Tavg fluctuate was found to abnormally where standard deviation and coefficient of variation of Tavg in Sylhet were ± 0.556and 2.21% respectively (Table 2).

Annual Tavg in Srimongalwas increasing by 0.12°C/year with its annual average 24.54°C.In Srimongal, the increasing trend of Tavghas coefficient of determination $R^2 = 0.313$, which was significant at 99% level of significance(Table1).The warmest year in Srimongalwas 1979 where Tavg was 26.8°Cand coldest year was 1971 where Tavg was 24.0°C (Figure 6). Before 2015, Tavg in Srimongal had fluctuations abnormally and after that its annual variation was normal. Standarddeviation and coefficient of variation of Tavg in Srimongalwere ±0.365and 1.46% respectively (Table 2).

Increasing trends of Tavg in Sylhet and Srimongalwere significant in Sylhet division.

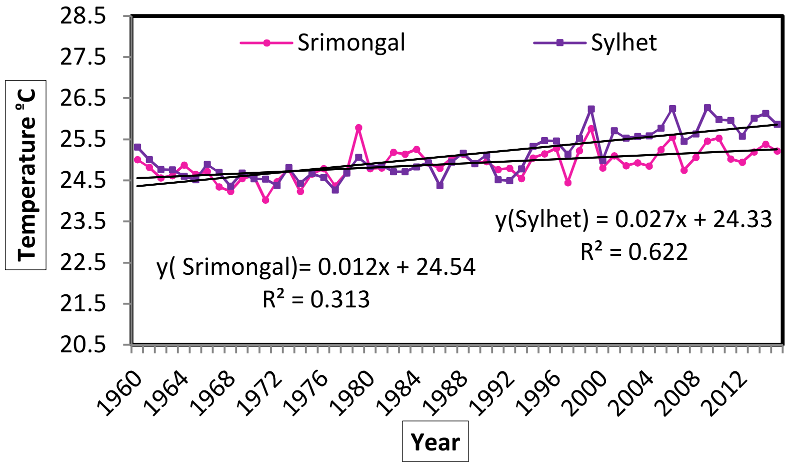


Figure 6: Temporal variation of annual average temperature in Sylhet division

4.1.6Average Temperature in Rangpur Division

The annual Tavg showed increasing trend in Rangpur and Dinajpur over the studyperiod 1960-2015 (Figure 7). In Rangpur, annual Tavg wasincreasing by 0.005°C/year with its average 24.66°C.In Rangpur, the increasing trend of Tavg has coefficient of determination$R^2 = 0.088$, which wasnot significant. (Table1). The warmest year in Rangpurwas 1999 where Tavg was 25.5°C and coldest year was 1979 where Tavg was 23.8°C(Figure 7). Before 2015, Tavg was found to fluctuate abnormally where standard deviation and coefficient of variation of Tavg in Rangpur were 0.319and 1.28%, respectively (Table 2).

Annual Tavg in Dinajpurwasdecreasing by -0.002°C/year with its annual average 25.20°C/year and. In Dinajpur, the increasing trend of Tavg has coefficient of determination$R^2 = 0.017$, which was not significant. (Table1). The warmest year in Dinajpur was 1972 where Tavg was 26.0 °C and coldest year was 1981 where Tavg was 24.1 °C (Figure 7). Before 2015, Tavg in Dinajpur was found to fluctuate abnormally where standard deviation and coefficient of variation of Tavg in Dinajpur were ±0.358and 1.42%respectively (Table 2).

Increasing trends of Tavg in Rangpur and Dinajpurwere not significant in Rangpurdivision.

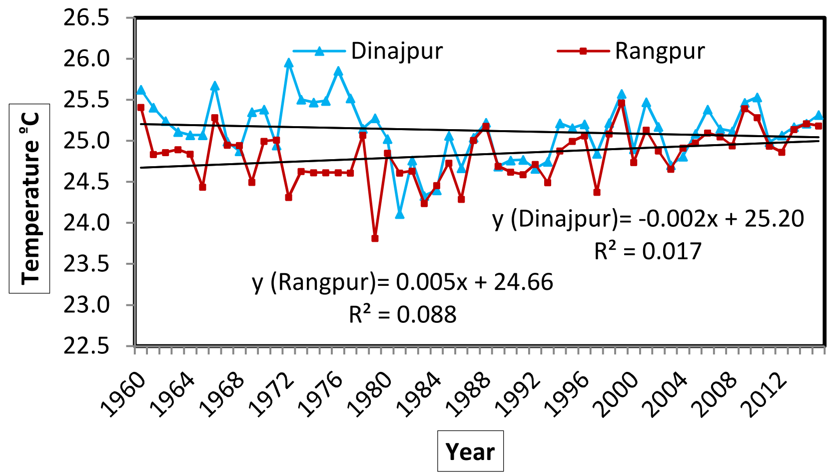


Figure 7: Temporal variation of annual average temperature inRangpur division

4.1.7Average Temperature in Barisal Division

The annual Tavg showed increasing trend in Barisal over the study period, 1960 to 2015 (Figure8). In Barisal, annual Tavg wasincreasing by 0.0012°C/year with its average 25.54°C.In Barisal the increasing trend of Tavghas coefficient of determinationR^2 =0.280, which was significant at 99% level of significance(Table1).The warmest year in Barisal was 2010 where Tavg was 26.8°Cand coldest year was 1975 where Tavg was 25.0°C(Figure 8). Before 2015, Tavg was found to fluctuate abnormally where standard deviation and coefficient of variation of Tavg in Barisal were ± 0.367and 1.41% respectively (Table 2).

Increasing trend of Tavg in Barisal was significant in Barisal division.

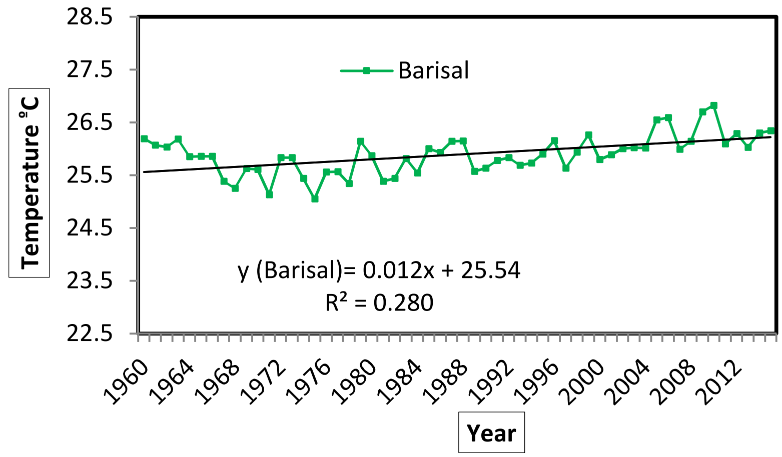


Figure 8: Temporal variation of annual average temperature in Barisal division

4.1.8 Average Temperature in Chittagong Division

The annual Tavg showed increasing trends in Chittagong, Comilla, Cox's Bazar, M. Court while only decreasing trendwas in Rangamati over the study period, 1960 to 2015 (Figure 9). In Chittagong, annual Tavg wasincreasing by 0.017 °C/year with its average 25.45 °C.In Chittagong the increasing trend of Tavghas coefficient of determination R^2 =0.426,which was significant at 99% level of significance(Table1).The warmest year in Chittagongwas 2006 where Tavg was 27.00 °Cand coldest year was 1971 where Tavg was 25.22 °C(Figure 9). Before 2015, Tavg was found to fluctuate abnormally where standard deviation and coefficient of variation of Tavg in Chittagongwere±0.427 and 1.64% respectively (Table 2).

In Comilla, annual Tavg wasincreasing by 0.006°C/yearwith its average 25.44°C. In Comilla the increasing trend of Tavghas coefficient of determination R^2 =0.104,which wasnot significant (Table1).The warmest year in Comillawas 2010 where Tavg was 26.31°Cand coldest year was 1981 where Tavg was 24.85°C(Figure 9). Before 2015, Tavg was found to fluctuate abnormally where standard deviation and coefficient of variation of Tavg in Comillawere ±0.325 and 1.26% respectively (Table 2).

In Rangamati, annual Tavg wasdecreasing by -0.010 °C/year with its average26.35 °C.In Rangamati, the decreasing trend of Tavg has coefficient of determination R^2 =0.124, which was significant at 99% level of significance(Table1).The warmest year in Rangamatiwas 1966 where

Tavg was 27.10 °C and coldest year was 1993where Tavg was 24.86°C(Figure 9). Before 2015, Tavg was found to fluctuate abnormally where standard deviation and coefficient of variation of Tavg in Rangamati were ±0.483 and 1.85%respectively (Table 2).

In Cox's Bazar, annual Tavg wasincreasing by 0.033 °C with its average 25.19 °C.InCox's Bazar the increasing trend of Tavghas coefficient of determination $R^2 = 0.779$,which was significant at 99% level of significance(Table1).The warmest year in Cox's Bazar was 2010 where Tavg was 27.30 °C and coldest year was 1971 where Tavg was 25.13 °C (Figure 9). Before 2015, Tavg was found to fluctuate abnormally where standard deviation and coefficient of variation of Tavg in Cox's Bazar were ± 0.609and 2.33%respectively (Table 2).

In M. Court, annual Tavg wasincreasing by 0.026 °C with its average 25.10 °C.In M. Court the increasing trend of Tavghas coefficient of determination $R^2 =0.688$, which was significant at 99% level of significance(Table1).The warmest year in M. Court was 2010 where Tavg was 26.93^{0}C and coldest year was 1990 where Tavg was 24.89°C (Figure 9). Before 2015, Tavg was found to fluctuate abnormally where standard deviation and coefficient of variation of Tavg in M. Court were±0.523and 2.02% respectively (Table 2).

Increasing trends of Tavg in Chittagong, Cox's Bazar, and M. Court were significant while increasing trend of Tavg in Comillawas not significant.And decreasing trend inRangamatiwas significant in Chittagongdivision.

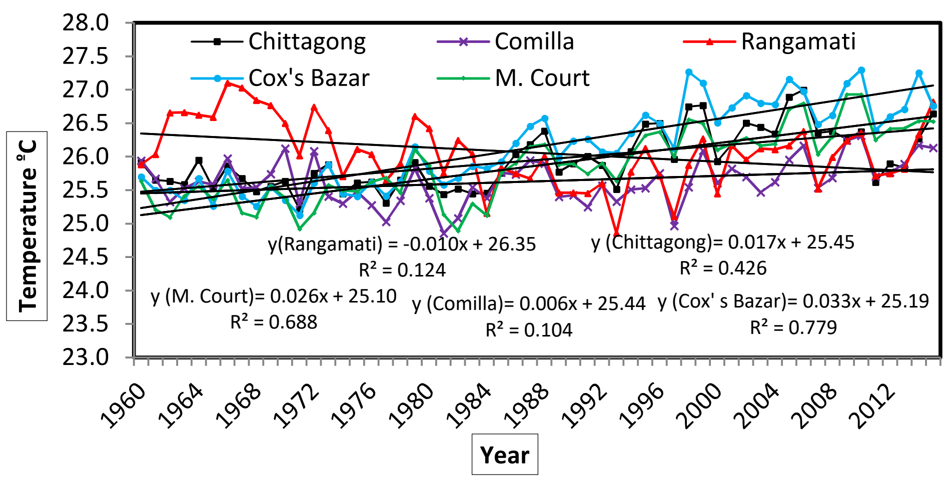


Figure 9: Temporal variation of annual average temperature in Chittagong division

4.1.9 Comparison of Tavg among all divisions

The temperature Tavg showed increasing trends in Khulna, Dhaka, Rajshahi, Sylhet, Rangpur, Chittagong and Barisal divisions over the study period 1960-2015 (Figure 10). In Khulna, annual Tavg wasincreasing by 0.007 °C with its average 26.15°C. In Khulna division, the increasing trend of Tavghas coefficient of determinationR^2 =0.1752, which was not significant(Table1). The warmest year in Khulna was 2010 where Tavg was 27.15°Cand coldest year was1981 where Tavg was 25.61°C(Figure 10). Before 2015, Tavg fluctuate abnormally and its cause is an unknown where standard deviation and coefficient of variation of Tavg in Khulna was ± 0.296and 1.12% respectively (Table 2).

In Dhaka, annual Tavg wasincreasing trend by 0.021 °C/yearwith its average 25.33 °C. In Dhaka the increasing trend of Tavghas coefficient of determination R^2=0.5603, which was significantat 99% level of significance (Table1). The warmest year in Dhaka was 2010 where Tavg was 26.94 °C and coldest year was 1971 where Tavg was 25.10 °C (Figure 10). Before 2015, Tavg was found to fluctuate abnormally where standard deviation and coefficient of variation of Tavg in Dhaka were ±0.446 and 1.71% respectively (Table 2).

In Rajshahi, annual Tavg was increasing by 0.011 °C/year with its average 25.40 °C.In Rajshahi the increasing trend of Tavg has coefficient of determination R^2=0.277 which wassignificant at 99% level of significance (Table1).Thewarmest year in Rajshahi was 2010 where Tavg was 26.49 °C and coldest year was 1971 where Tavg was 24.77 °C (Figure 10). Before 2015, Tavg was found to fluctuate abnormally where standard deviation and coefficient of variation of Tavg in Rajshahi were ± 0.352 and 1.36% respectively (Table 2).

In Sylhet, annual Tavg was increasing by 0.019 °C/year with its average 24.44 °C. In Sylhet the increasing trend of Tavghas coefficient of determination R^2=0.525, which was significantat 99% level of significance(Table1).The warmest year in Sylhet was 1999 where Tavg was 26.00 °C and coldest year was 1971 where Tavg was 24.28 °C (Figure 10). Before 2015, Tavg was found to fluctuate abnormally where standard deviation and coefficient of variation of Tavg in Sylhet were ±0.429and 1.71 % respectively (Table 2).

In Rangpur, annual Tavg was increasing by 0.0006 °C/year with its average 24.95 °C. In Rangpur the increasing trend of Tavg has coefficient of determination R^2=0.001, which was not significant (Table1).The warmest year in Rangpur was 1960 where Tavg was 25.52 °C and coldest year was 1983 where Tavg was 24.28 °C (Figure 10). Before 2015, Tavg was found to fluctuate abnormally where standard deviation and coefficient of variation of Tavg in Rangpur were ±0.280and 1.12% respectively (Table 2).

In Chittagong, annual Tavg was increasing by 0.0138 °C/year with its average 25.53 °C. In Chittagong the increasing trend of Tavg has coefficient of determination R^2=0.4005, which was significantat 99% level of significance (Table1).Thewarmest year in Chittagong was 2006 where Tavg was 26.66 °C and coldest year was 1971 where Tavg was 25.32 °C (Figure 10). Before 2015, Tavg was found to fluctuate abnormally where standard deviation and coefficient of variation of Tavg in Chittagong were ±0.352and 1.36% respectively (Table 2).

In Barisal, annual Tavg was increasing by 0.012 °C/year with its average 25.54 °C.In Barisal the increasing trend of Tavg has coefficient of determinationR^2=0.280 which was significantat 99% level of significance (Table1).Thewarmest year in Barisal was 2010 where Tavg was 26.82 °C and coldest year was 1975 where Tavg was 25.05 °C (Figure 10). Before 2015, Tavg was found to fluctuate abnormally wherestandard deviation and coefficient of variation of Tavg in Barisal were ±0.367and 1.41% respectively (Table 2).

In Mymensingh, annual Tavg was increasing by 0.0026 °C/year with its average 25.26 °C. In Mymensingh the increasing trend of Tavg has coefficient of determination R^2=0.025, which was not significant (Table1). The warmest year in Mymensingh was 1999 where Tavg was 25.97 °C and coldest year was1991 where Tavg was 24.34 °C (Figure 10). Before 2015, Tavg was found to fluctuate abnormally where standard deviation and coefficient of variation of Tavg in Mymensingh were ±0.307 and 1.21%respectively (Table 2).

Increasing trends of Tavg in Mymensingh and Rangpur were not significant while Khulna, Dhaka, Chittagong, Rajshahi, Barisaland Sylhet divisions were significant in Bangladesh.

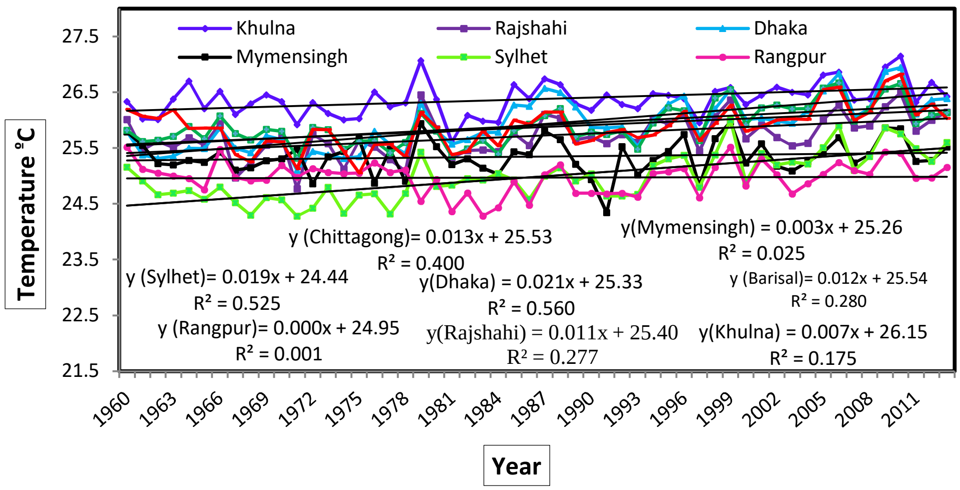


Figure 10: Temporal variation of annual average temperature in all divisions

Table1: Regression equation of trend lines for Average Temperature

Station/ division	Regression equation with R^2	Correlation of coefficient r
Khulna	y = 0.005x + 26.37, R^2 = 0.042	0.204939
Jessore	y= 0.013x + 25.82 , R^2 = 0.391	0.6253**
Satkhira	y=0.006x+26.24 , R^2 = 0.099	0.314643
Bogra	y = 0.011x + 25.40, R^2 = 0.277	0.526308**
Dhaka	y= 0.021x + 25.48, R^2 = 0.512	0.715542**
Faridpur	y= 0.021x + 25.19, R^2 = 0.557	0.746324**
Mymensingh	y= 0.003x + 25.26, R^2 = 0.025	0.158114
Srimongal	y= 0.012x + 24.54 , R^2 = 0.313	0.559464**
Sylhet	y= 0.027x + 24.33 , R^2 = 0.622	0.78867**
Dinajpur	y = -0.002x + 25.20 , R^2 = 0.017	0.130384
Rangpur	y= 0.005x + 24.66 , R^2 = 0.088	0.296648
Chittagong	y= 0.017x + 25.45 , R^2 = 0.426	0.652687**
Comilla	y= 0.006x + 25.44 , R^2 = 0.104	0.32249
Rangamati	y= -0.010x + 26.35 , R^2 = 0.124	0.352136**
Cox's Bazar	y= 0.033x + 25.19 , R^2 = 0.779	0.88261**
M. Court	y= 0.026x + 25.10 , R^2 = 0.688	0.829458**
Barisal	y= 0.012x + 25.54 , R^2 = 0.280	0.52915**
Khulna division	y=0.007x+26.15 , R^2 = 0.175	0.41833*
Dhaka division	y=0.021x+25.33, R^2=0.560	0.748331**
Rajshahi division	y = 0.011x + 25.40, R^2 = 0.277	0.526308**
Mymensingh division	y= 0.003x + 25.26, R^2 = 0.025	0.158114
Sylhet division	y=0.019x+24.44, R^2=0.525	0.724569**
Rangpur division	y=0.000x+24.95 , R^2=0.001	0.031623
Chittagong division	y=0.013x+25.53, R^2=0.400	0.632456**
Barisal division	y= 0.012x + 25.54 , R^2 = 0.280	0.52915**

** Significant at 0.01 level of significance

Table 2: Variability of Annual Average Temperature

Station/District	Standard Deviation	Coefficient of Variation%
Khulna	± 0.406	1.53
Jessore	± 0.339	1.29
Satkhira	± 0.339	1.28
Bogra	± 0.352	1.36
Dhaka	± 0.476	1.82
Faridpur	± 0.455	1.76
Mymensingh	± 0.307	1.21
Srimongal	± 0.365	1.46
Sylhet	± 0.556	2.21
Dinajpur	± 0.358	1.42
Rangpur	± 0.319	1.28
Chittagong	± 0.427	1.64
Comilla	± 0.325	1.26
Rangamati	± 0.483	1.85
Cox's Bazar	± 0.609	2.33
M.Court	± 0.523	2.02
Barisal	± 0.367	1.41
Khulna Division	± 0.296	1.12
Dhaka Division	± 0.446	1.71
Rajshahi Division	± 0.352	1.36
Mymensingh Division	± 0.307	1.21
Sylhet Division	± 0.429	1.71
Rangpur Division	± 0.280	1.12
Chittagong Division	± 0.352	1.36
Barisal Division	± 0.367	1.41

4.1.10Distribution of coefficient of variation for annual average temperature

Distribution of coefficient of variation for annual average temperature of the country is shown in (Figure 11) using the data from the (Table 2). It's indicates the amount of variability relative to the mean value of annual average temperature of the station of the country. So, it is easy way to understand the change of average temperature of specific region/station of the country. From the figure, it is seen thatthe northeastern and southeastern region of the country has maximum coefficient of variation and the maximum value was 2.33% at Cox's bazar region. The middle eastern and middle western of the country has minimum coefficient of variation and the minimum value was 1.26% at Comilla region. The coefficient of variation has been found to decrease from Cox's bazar towards southwesternregionand center of the country. The coefficient of variation has been found to increase from center of the country towards northeastern hilly and southeastern region.

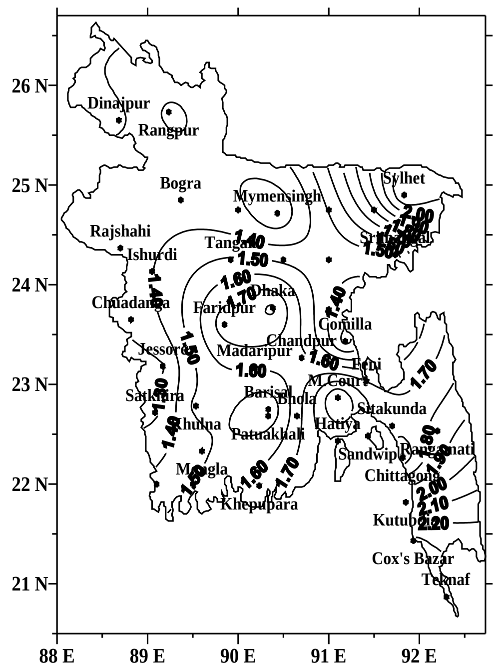


Figure 11: Distribution of coefficient of variation for annual average temperature

4.2.1Maximum Temperature in Khulna Division

The annual Tmax showed increasing trends in Khulna, Jessore and Satkhira over the study period1960-2015 (Figure 12). In Khulna, annual Tmax wasincreasing by 0.008 ^{o}C/year with averagemaximum temperature of 30.99 ^{o}C. In Khulna, the increasing trend of Tmax has coefficient of determination equal to 0.080which was significant (Table3).There is inter-annual variation of Tmax; the standard deviation and coefficient of variation of Tmax in Khulna were±0.471 and 1.50 % respectively (Table 4).

In Jessore, Tmax wasincreasing by 0.020 ^{o}C/year with average maximum temperature of 30.97 ^{o}C. In Jessore, the increasing trend of Tmaxhas coefficient of determination equal to 0.468which was significant at 99% level of significance (Table3).The warmest year in Jessore was 2009 where Tmax was32.92 °Cand coldest year was 1981 where Tmax was 30.62 °C (Figure 12). There is inter-annual variation of Tmax; standard deviation and coefficient of variation of Tmax in Jessore were ±0.490and1.55% respectively (Table 4).

In Satkhira, annual Tmax wasincreasing by 0.001 °C/year with average maximum temperature of 31.32 °C. In Satkhira, the increasing trend of Tmax has coefficient of determination equal to0.003 which wasnot significant (Table3). The warmest year in Satkhira was1987 where Tmax was 32.51 °C and coldest year was 1981 where Tmax was 30.08 °C (Figure 12). There is inter-annual variation of Tmax;standard deviation and coefficient of variation of Tmax in Satkhira were ±0.446and1.42 % respectively (Table 4).

Increasing trends ofTmax in Satkhira wasnot significant while increasing trend in Jessoreand Khulnawere significant in Khulna division.

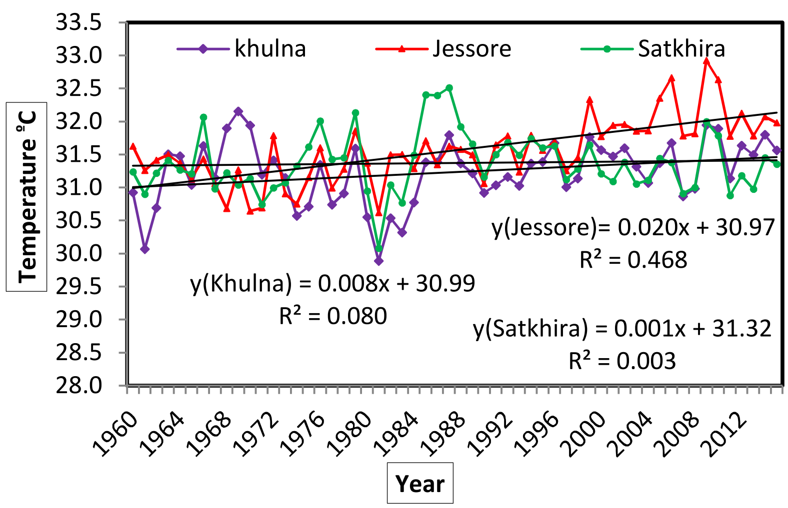


Figure 12: Temporal variation of annual maximum temperature in Khulna division

4.2.2Maximum Temperature in Dhaka Division

The annual maximum temperature (Tmax) showed increasing trends in Dhaka and Faridpur over the study period 1960-2015 (Figure 13). In Dhaka, annualTmaxwasincreasing by 0.016 °C/year with average maximum temperature of 30.12 °C. In Dhaka, the increasing trend of Tmaxhas coefficient of determinationequal to 0.232 which wassignificant at 99% level of significance(Table3).The warmest year in Dhaka was 1996 where Tmax was 31.7 °C and coldest year was 1971 where Tmax was 29.0 °C (Figure 13).There is inter-annual variation of Tmax; where standard deviation and coefficient of variation of Tmax in Dhaka were ±0.544 and 1.78 % respectively (Table 4).

In Faridpur, annual Tmax wasincreasing by 0.020 °C/year with average maximum temperature of 29.89 °C. In Faridpur, the increasing trend of Tmax has coefficient of determination equal to 0.493 which was significant at 99% level of significance (Table 3). The warmer year in Faridpur was 2009 where Tmax was 31.66°Cand coldest year was 1962 where Tmax was 29.58 °C (Figure 13).There is inter-annual variation of Tmax; where standard deviation and coefficient of variation of Tmax in Faridpur were ±0.471and 1.54%respectively (Table 4).

Increasing trends of Tmax in Faridpur and Dhaka were significant inDhaka division.

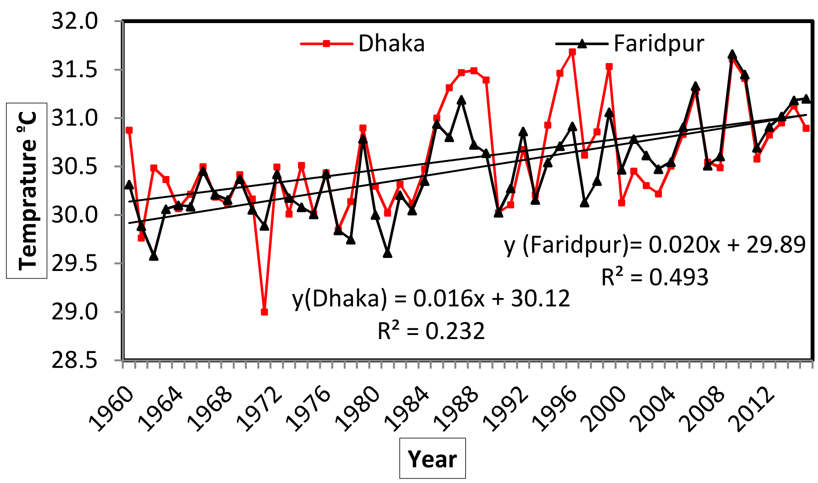


Figure 13: Temporal variation of annual maximum temperature in Dhaka division.

4.2.3Maximum Temperature in Rajshahi Division

The annual maximum temperature (Tmax) showed increasing trend in Bogra over the study period, 1960 to 2015 (Figure 14). In Bogra annual Tmax wasincreasing by 0.006 °C/year with average maximum temperature of 30.47 °C. In Bogra the increasing trend of Tmax has coefficient of determination equal to 0.051 which was not significant (Table 3). The warmest year in Bogra was 1979 where Tmax was 31.7 °C and coldest year was 1971 where Tmax was 29.7(Figure 14).There is inter-annual variation of Tmax; where standard deviation and coefficient of variation of Tmax in Bogra were ±0.411 and 1.34% respectively (Table 4).

Increasing trend ofTmax in Bogra was not significant in Rajshahi division.

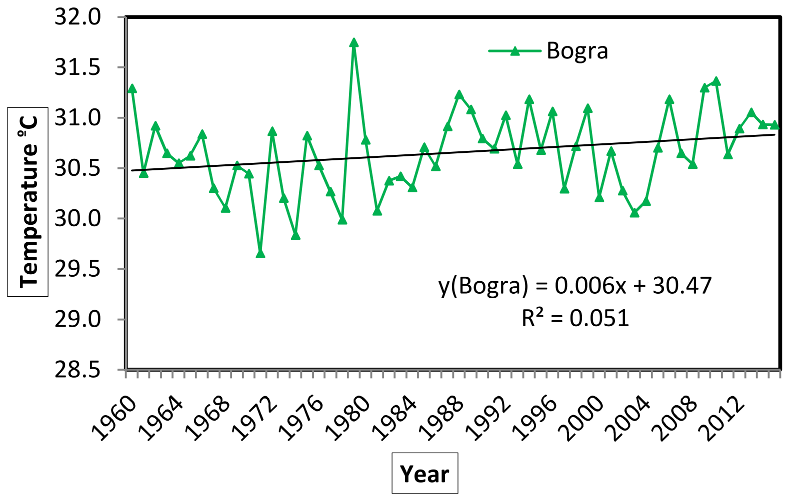


Figure 14: Temporal variation of annual maximum temperature in Rajshahi division

4.2.4Maximum Temperature in Mymensingh Division

The annual maximum temperature (Tmax) showed decreasing trend in Mymensingh over the study period, 1960 to 2015 (Figure 15). In Mymensingh annual Tmax wasdecreasing by -0.004 °C/year with average maximum temperatureof 30.07 °C .In Mymensingh the decreasing trend of Tmaxhas coefficient of determinationequal to 0.033 which was not significant (Table3).The warmest year in Mymensingh was 1979 where Tmax was 30.93 °C and coldest year was 2003 where Tmax was 29.28 °C (Figure 15). There is inter-annual variation of Tmax; where standard deviation and coefficient of variation of Tmax in Mymensingh were ±0.373 and1.24% respectively (Table 4).

Decreasing trend of Tmax in Mymensingh was not significant in Mymensingh division.

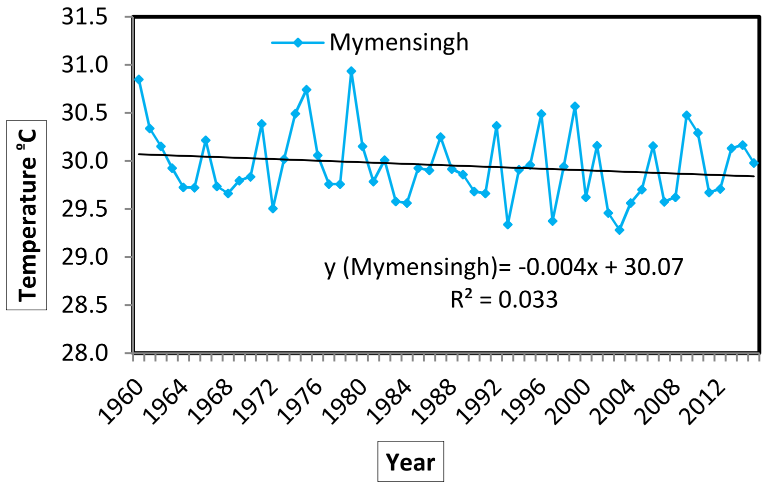


Figure 15: Temporal variation of annual maximum temperature in Mymensingh division

4.2.5 Maximum Temperature in Sylhet Division

The annual maximum temperature (Tmax) showed increasing trends in Sylhet and Srimongal over the study period, 1960 to 2015 (Figure 16). In Sylhet annual Tmax wasincreasing by 0.032 °C/year with average maximum temperature of 28.94 °C .In Sylhet the increasing trend of Tmaxhas coefficient of determination equal to 0.583 which wassignificant at 99% level of significance (Table3).The warmest year in Sylhet was 2014 where Tmax was 31.5 °C and coldest year was 1977 where Tmax was 28.5 °C (Figure 16).There is inter-annual variation of Tmax; where standard deviation and coefficient of variation of Tmax in Sylhet were ±0.681 and 2.28% respectively (Table 4).

In Srimongal annual maximum temperature Tmax wasincreasing by 0.007°C/year with average maximum temperature of 30.31°C.In Srimongal the increasing trend of Tmax withcoefficient of determinationequal to 0.071 which was not significant. (Table3). The warmest year in Srimongal was 1999 where Tmax was 31.64°Cand coldest year was 1977 where Tmax was 29.66°C (Figure 16).There is inter-annual variation of Tmax; where standard deviation and coefficient of variation of Tmax in Srimongal were ±0.480 and 1.56% respectively (Table 4).

Increasing trend of Tmax inSrimongalwas not significant while increasing trend of Sylhet was significant in Sylhetdivision.

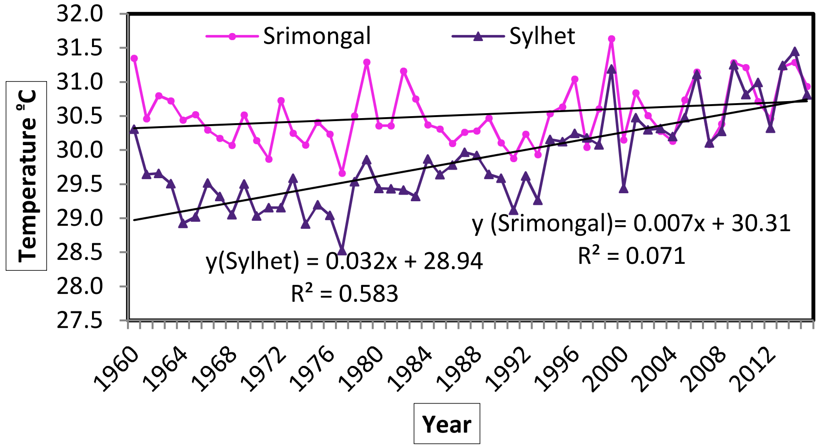


Figure 16: Temporal variation of annual maximum temperature in Sylhet division

4.2.6Maximum Temperature in Rangpur Division

The annual maximum temperature (Tmax) showed decreasing trend in Rangpur and Dinajpur over the study period, 1960 to 2015 (Figure 17). In Rangpur annual Tmax wasdecreasing by -0.014°C/ year withaverage maximum temperatureof 30.18°C.In Rangpur the decreasing trend of Tmax has coefficient of determinationequal to 0.130 which was significant at 99% level of significance (Table).The warmest year in Rangpur was 1972 where Tmax was 32.1°Cand coldest year was 1979 where Tmax was 27.5°C (Figure 17).There is inter-annual variation of Tmax; where standard deviation and coefficient of variation of Tmax in Rangpur were ±0.627and 2.10 % respectively (Table 4).

In Dinajpur annual maximum temperature Tmax wasdecreasing by- 0.011 °C/year with average maximum temperature of 30.51 °C .In Dinajpur the decreasing trend of Tmax has coefficient of determination equal to 0.116 which was not significant. (Table3). The warmest year in Dinajpurwas 1972 where Tmax was 32.2 °C and coldest year was 1981where Tmax was 28.9 °C (Figure 17).There is inter-annual variation of Tmax; where standard deviation and coefficient of variation of Tmax in Dinajpurwere ±0.549and1.82% respectively (Table 4).

Decreasing trend of Tmax in Dinajpur was not significant while Rangpurwas significant in Rangpur division.

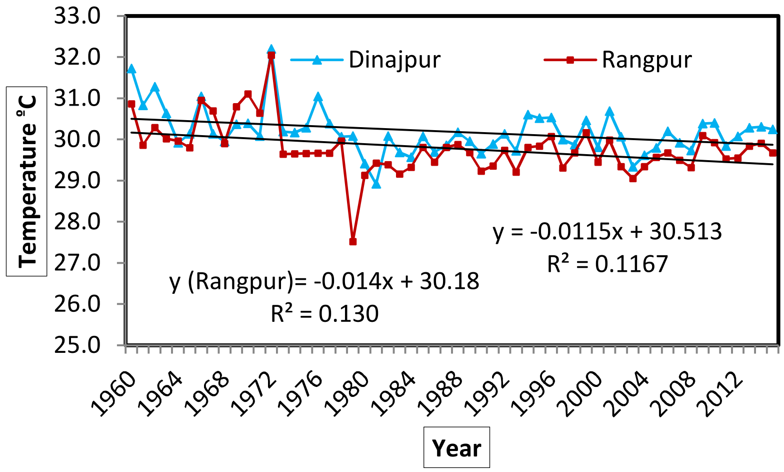


Figure 17: Temporal variation of annual maximum temperature in Rangpur division.

4.2.7 Maximum Temperature in Barisal Division

The annual (Tmax) showed increasing trend in Barisal over the study period, 1960 to 2015 (Figure 18). In Barisalannual Tmax wasincreasing by 0.017°C/year withaverage maximum temperatureof 29.98°C. In Barisal the increasing trend of Tmax has coefficient of determination equal to 0.399 which wassignificant at 99% level of significance (Table3).The warmest year in Barisalwas 2009 where Tmax was 31.5°Cand coldest year was 1971where Tmax was 29.4°C (Figure 18).There is inter-annual variation of Tmax; where standard deviation and coefficient of variation of Tmax in Barisalwere ±0.441and 1.44% respectively (Table 4).

Increasingtrend of Tmax in Barisalwas significant in Barisaldivision.

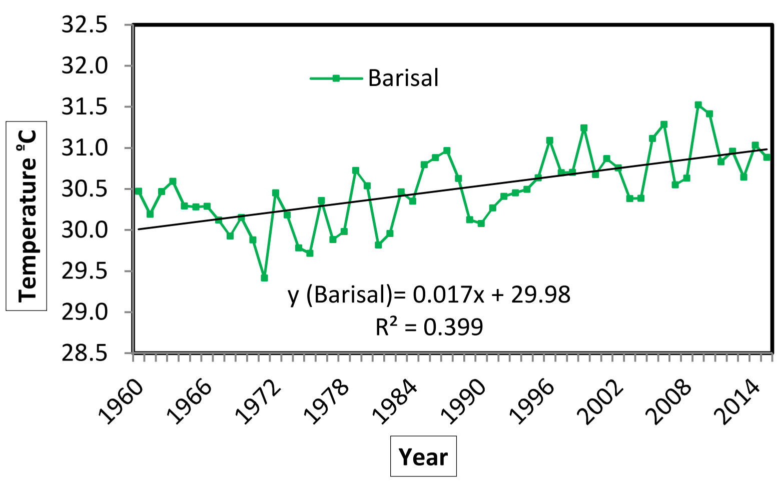


Figure 18: Temporal variation of annual maximum temperature inBarisal division

4.2.8Maximum Temperature in Chittagong Division

The annual maximum temperature (Tmax) showed increasing trend in Chittagong, Comilla,Rangamati, Cox's Bazar and M. Court over the study period, 1960 to 2015 (Figure 19). In Chittagong annual Tmax wasincreasing by 0.018 °C/year with average maximum temperature of 29.69 °C.In Chittagong the increasing trend of Tmaxhas coefficient of determination equal to 0.332 which was significant at 99% level of significance(Table3). The warmest year in Chittagong was 2006 where Tmax was 31.64 °C and coldest year was 1971 where Tmax was 29.36°C (Figure 19). There is inter-annual variation of Tmax; where standard deviation and coefficients of variation of Tmax in Chittagong were ±0.527 and1.74% respectively (Table 4).

In Comilla annual Tmax wasincreasing by 0.005°C/year with average maximum temperature of 30.14 °C.In Comilla the increasing trend of Tmaxhas coefficient of determination equal to 0.046 which was not significant (Table3). The warmest year in Comillawas 2009 where Tmax was 31.14°Cand coldest year was 1981 where Tmax was 29.23°C (Figure 19). There is inter-annual variation of Tmax; where standard deviation and coefficient of variation of Tmax in Comilla were ±0.401and 1.32%respectively (Table 4).

In Rangamati annual Tmax wasincreasing by 0.008 °C/year with average maximum temperature of 30.89 °C .In Rangamati the increasing trend of Tmax has coefficient of determination equal to 0.040 which was not significant (Table3). The warmest year in Rangamati was 1998 where Tmax was 32.21 °C and coldest year was 1977 where Tmax was 29.57 °C (Figure 19). There is inter-annual variation of Tmax; where standard deviation and coefficient of variation of Tmax in Rangamatiwere ±0.642 and 2.06%respectively (Table 4).

InCox's Bazarannual Tmax wasincreasing by 0.045°C/year with average maximum temperature of 28.92°C. In Cox's Bazarthe increasing trend of Tmaxhas coefficient of determination equal to 0.802 which was significant at 99% level of significance (Table3).The warmest year inCox's Bazarwas 2014 where Tmax was 31.66°Cand coldest year was 1968 where Tmax was

28.90°C(Figure 19). There is inter-annual variation of Tmax; where standard deviation and coefficient of variation of Tmax in Cox's Bazar were ±0.824 and2.72% respectively (Table 4).

In M.Court annual maximum temperature Tmax wasincreasing by 0.025°C/year withaverage maximum temperatureof 29.34°C. In M. Court the increasing trend of Tmaxhas coefficient of determination equal to 0.583was significant at 99% level of significance (Table3). The warmest year in M. Court was 2009 where Tmax was 31.36°Cand coldest year was 1981 where Tmax was 29.03°C (Figure 19).There is inter-annual variation of Tmax; where standard deviation and coefficient of variation of Tmax in M. Court were ±0.537 and 1.78% respectively (Table 4).

Increasing trends of Tmax Comilla, and Rangamati werenot significant while increasing trends in Cox's Bazar, M. Court, and Chittagongwere significant in Chittagong division.

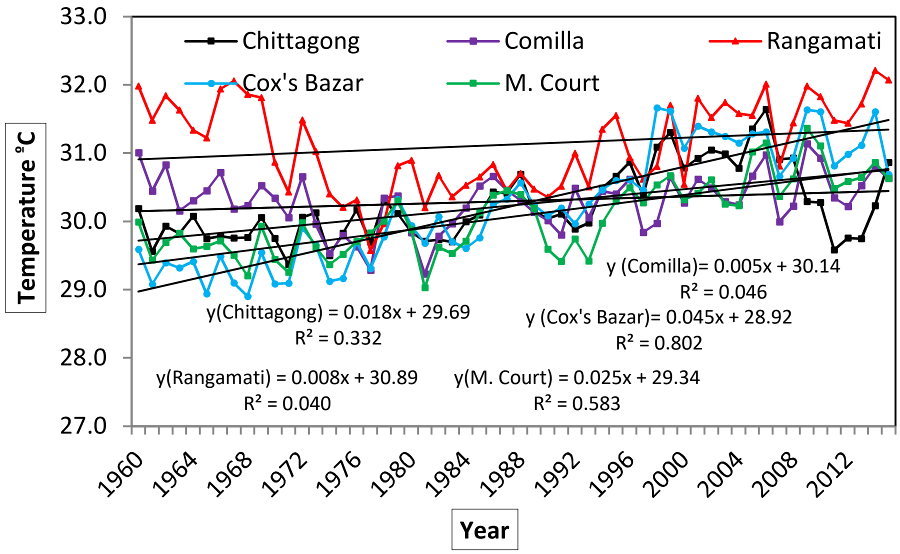


Figure 19: Temporal variation of annual maximum temperature in Chittagong division

4.2.9Comparison of Tmax among all Divisions

The temperature Tmax showed increasing trends in Khulna, Dhaka, Rajshahi, Sylhet, Rangpur, Chittagong and Barisal divisions over the study period, 1960 to 2015 (Figure 20). In Khulna, annual Tmax was increasing by 0.010 °C/year with average maximum temperature of 31.10 °C .In

Khulna The increasing trend of Tmaxhas coefficient of determination equal to0.1796 which wassignificant(Table3). The warmest year in Khulna was2009 where Tmax was 32.29 °C and coldest year was 1981 where Tmaxwas 30.19 °C(Figure 20). There is inter-annual variation of Tmax; where standard deviation and coefficient of variation of Tmax Tavg in Khulna were ±0.367 and 0.108% respectively (Table 4).

In Dhaka, annual Tmax was increasing by 0.0179 °C/year with average maximum temperature of 31.01 °C.In Dhaka the increasing trend of Tmaxhas coefficient of determination equal to 0.3468 which was significantat 99% level of significance(Table3). The warmest year in Dhaka was 2009 where Tmax was 31.64 °C and coldest year was 1971 where Tmax was 29.44 °C (Figure 20). There is inter-annual variation of Tmax; where standard deviation and coefficient of variation of Tmax in Dhaka were ±0.479 and 1.56% respectively (Table 4).

In Rajshahi, annual Tmax was increasing by 0.006 °C/year with average maximum temperature of 30.47 °C .In Rajshahi the increasing trend of Tmax has coefficient of determination equal to 0.0511which was not significant. (Table3). The warmest year in Rajshahi was 1979 where Tmax was 31.75 °C and coldest year was 1971 where Tavg was 29.66 °C (Figure 20). There is inter-annual variation of Tmax; where standard deviation and coefficient of variation of Tavg in Rajshahi were ±0.411and 1.34% respectively (Table 4).

In Sylhet, annual (Tmax) was increasing by 0.018 °C/year with average maximum temperature of 29.65 °C .In Sylhet the increasing trend of Tmax has coefficient of determination equal to 0.3302 which was significant at 99% level of significance (Table3). The warmest year in Sylhet was 1999 where Tmax was 31.41 °C coldest year was 1977 where Tmax was 29.10 °C (Figure 20). There is inter-annual variation of Tmax; where standard deviation and coefficient of variation of Tmax in Sylhet were ±0.513and 1.70% respectively (Table 4).

In Rangpur, annual Tmax was decreasing by -0.0144 °C/year with average maximum temperature of 30.38 °C.In Rangpur the decreasing trend of Tmaxhas coefficient of determination equal 0.1702which was significant (Table3). The warmest year in Rangpur was 1972 where Tmax was 32.12 °C and coldest year was 1979 where Tavg was 28.80 °C (Figure 20). There is inter-annual variation of Tmax; where standard deviation and coefficient of variation of Tmax in Rangpur were ±0.535and 1.78% respectively (Table 4).

In Chittagong, annual Tmax Tavg was increasing by 0.020 °C/year with average maximum temperature of 29.81 °C.The increasing trend of Tmax has coefficient of determination equal to 0.4696 which was significantat 99% level of significance (Table3).The warmest year in Chittagong was 2006 where Tmax was 31.42 °C and coldest year was 1977 where Tmax was 29.54 °C (Figure 20). There is inter-annual variation of Tmax; where standard deviation and coefficient of variation of Tmax in Chittagong were ±0.469 and 1.54 % respectively (Table 4).

In Barisal, annual Tmax was increasing by 0.017 °C /year with average maximum temperature of 29.99 °C. In Barisal the increasing trend of Tmax has coefficient of determination equal to 0.3991which was significant at 99% level of significance (Table3). The warmest year in Barisal was 2009 where Tmax was 31.52 °C and coldest year was 1971 where Tavg was 29.42 °C (Figure 20). There is inter-annual variation of Tmax; where standard deviation and coefficient of variation of Tmax in Barisal were ±0.441 and 1.44% respectively (Table 4).

In Mymensingh, annual Tmax was decreasing by -0.004 °C/year with average maximum temperature of 30.07 °C. In Mymensingh the decreasing trend of Tmax has coefficient of determination equal to 0.033 whichwas not significant. (Table3). The warmest year in Mymensingh was 1979 where Tmax was 30.93 °C and coldest year was 2003 where Tmax was 29.28 °C (Figure 20). There is inter-annual variation of Tmax; where standard deviation and coefficient of variation of Tmax in Mymensingh were ±0.373and1.24% respectively (Table 4).

Increasing trends of Tmax in Rajshahiwas not significant while Chittagong, Barisal, Dhaka, Rangpur, Khulna andSylhet divisions were significant. And decreasing trendsof Tmax in Mymensingh division was not significant in Bangladesh.

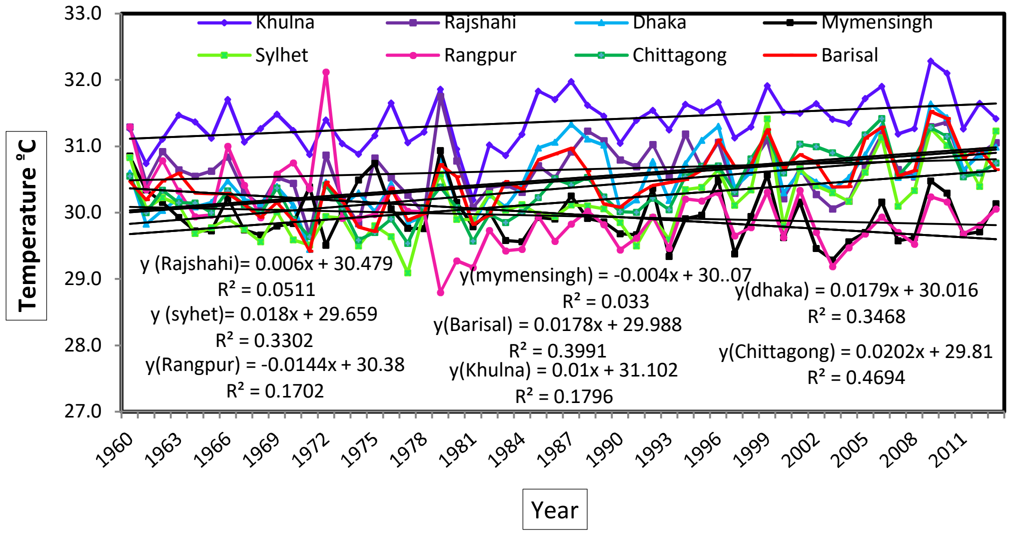


Figure 20: Comparison of annual maximum temperature in all divisions

** Significant at 0.01 level of significance

Table3: Regression equation with R^2 and correlation of coefficient for Maximum Temperature

Station/ division	Regression equation with R^2	Correlation ofcoefficient r
Khulna	y = 0.008x + 30.99, R^2 = 0.080	0.282843**
Jessore	y= 0.020x + 30.97 , R^2 = 0.468	0.684105**
Satkhira	y = 0.001x + 31.32, R^2 = 0.003	0.054772
Bogra	y = 0.006x + 30.47, R^2 = 0.051	0.2529322
Dhaka	y = 0.016x + 30.1,R^2 = 0.232	0.481664**
Faridpur	y = 0.020x + 29.89 , R^2 = 0.493	0.70214**
Mymensingh	y = -0.004x + 30.07 , R^2 = 0.033	0.181659
Srimongal	y = 0.007x + 30.31, R^2 = 0.071	0.266458
Sylhet	y = 0.032x + 28.94 , R^2 = 0.583	0.763544**
Dinajpur	y = -0.0115x + 30.51, R^2 = 0.116	0.341614**
Rangpur	y = -0.014x + 30.18, R^2 = 0.130	0.360555**
Chittagong	y= 0.018x + 29.69 , R^2 = 0.332	0.576194**
Comilla	y = 0.005x + 30.14 , R^2 = 0.046	0.214476
Rangamati	y= 0.008x + 30.89 , R^2 = 0.040	0.2
Cox's Bazar	y = 0.045x + 28.92 , R^2 = 0.802	0.895545**
M. Court	y = 0.025x + 29.34 , R^2 = 0.583	0.763544**
Barisal	y= 0.0178x + 29.98, R^2 = 0.399	0.631744**
Khulna division	y= 0.01x + 31.102, R^2 = 0.1796	0.423792**

Dhaka division	y= 0.0179x + 30.016 , R^2 = 0.3468	0.588897**
Rajshahi division	y = 0.006x + 30.47, R^2 = 0.051	0.2529322
Mymensingh division	y = -0.004x + 30.07 , R^2 = 0.033	0.181659
Sylhet division	y = 0.018x + 29.65 , R^2 = 0.3302	0.57463**
Rangpur division	y = -0.0144x + 30.38 , R^2 = 0.1702	0.412553**
Chittagong division	y = 0.0202x + 29.81, R^2 = 0.4694	0.685128**
Barisal division	y= 0.0178x + 29.98, R^2 = 0.399	0.631744**

Table 4: Variability of Annual Maximum Temperature

Station/District	Standard Deviation	Coefficient of Variation%
Khulna	±0.471	1.50
Jessore	±0.490	1.55
Satkhira	±0.446	1.42
Bogra	±0.411	1.34
Dhaka	±0.544	1.78
Faridpur	±0.471	1.54
Mymensingh	±0.373	1.24
Srimongal	±0.480	1.56
Sylhet	±0.681	2.28
Dinajpur	±0.549	1.82
Rangpur	±0.627	2.10
Chittagong	±0.527	1.74
Comilla	±0.401	1.32
Rangamati	±0.642	2.06
Cox's Bazar	±0.824	2.72
M.Court	±0.537	1.78
Barisal	±0.441	1.44
Khulna Division	±0.367	0.108
Dhaka Division	±0.479	1.56
Rajshahi Division	±0.411	1.34

Mymensingh Division	±0.373	1.24
Sylhet Division	±0.513	1.70
Rangpur Division	±0.535	1.78
Chittagong Division	±0.469	1.54
Barisal Division	±0.441	1.44

4.2.10 Distribution of coefficient of variation for annual average maximum temperature

Distribution of coefficient of variation for annual average temperature of the country is shown in (Figure 21) using the data from the (Table 4). It's indicates the amount of variability relative to the mean value of annual average maximum temperature of the station of the country. So, it is easy way to understand the change of average temperature of specific region/station of the country. From the figure, it is seen that the northeastern -southeastern and a portion of northwesternregion (Figure 21) of the country has maximum coefficient of variation and the maximum value was 2.72% at Cox's bazar region. The western , middle of eastern , middle of northern and center of the country has minimum coefficient variation and the minimum value was 1.24 % at Mymensingh region .The coefficient of variation has been found to decrease from Cox's bazar towards western,southwestern region and center of the country. The coefficient of variation has been found to increase from center of the country towards northeastern hilly and southeastern - some portion ofnorthwestern region.

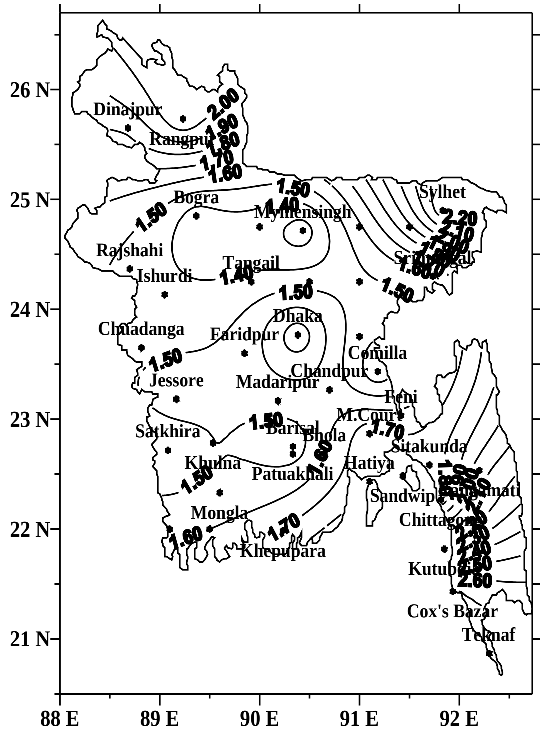


Figure 21: Distribution of coefficient of variation for annual average maximum temperature

4.3.1Minimum Temperature in Khulna Division

The annual Tmin showed increasing trends in Jessore, Khulna and Satkhira over the study period, 1960 to 2015 (Figure 22). In Khulna, annual Tmin was increasing by 0.002°C/year with its average minimum temperature 21.19°C.In Khulna the increasing trend of Tminhas coefficient of determinationR^2=0.004which was not significant. (Table5). The highest Tmin in Khulna was in 1979 where Tmin was 22.8°Cand lowest Tmin was in 1997 where Tmin was 20.9°C (Figure 22). Before 2015, Tmin was found to fluctuate abnormally where standard deviation and coefficient of variation of Tmin in Khulna were ±0.481and 2.20% respectively (Table 6).

In Jessore, annual Tmin was increasing by 0.005°C/year with its average minimum temperature21.74°C. In Jessore the increasing trend of Tmin has coefficient of determination R^2=0.076which was not significant (Table5). The highest Tmin in Jessore was in 1964 where Tmin was 21.56°Cand lowest Tmin was in 1967 where Tmin was 20.17°C(Figure 22).Before 2015, Tminwas found to fluctuateabnormallywhere standard deviation and coefficient of variation of Tmin in Jessore were ±0.319and 1.53% respectively (Table 6).

In Satkhira, annual Tmin was increasing by 0.011°C/year with its average minimum temperature21.17°C.In Satkhira the increasing trend of Tmin has coefficient of determinationR^2=0.202which was significant at 99% level of significance (Table5). The highest Tmin in Satkhira was 1979 where Tmin was 22.67°Cand lowest Tmin was in 1999 where Tmin was 20.54°C (Figure 22). Before 2015, Tmin was found to fluctuateabnormallywhere standard deviation and coefficients of variation of Tmin in Satkhira were±0.420 and 1.95% respectively (Table 6).

Increasing trends of Tmin in Khulna and Jessorewere not significant while Satkhira was significantin Khulna division.

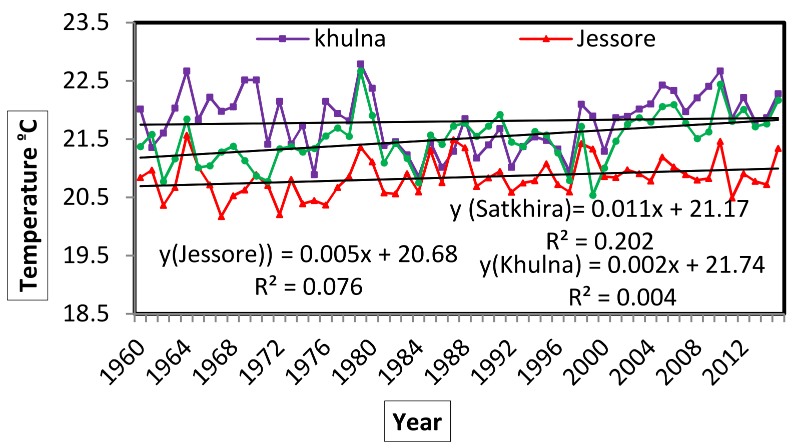


Figure 22: Temporal variation of annual minimum temperature in Khulna division

4.3.2Minimum Temperature in Dhaka Division

The annual Tmin showed increasing trend in Dhaka and Faridpur over the study period, 1960 to 2015 (Figure 23). In Dhaka, annual Tmin was increasing by 0.025°C/year with its average minimum temperature 20.84°C .In Dhaka the increasing trend of Tmin has coefficient of determinationR^2= 0.640 which was significant at 99% level of significance (Table5). The highest Tmin in Dhaka was in 2010 where Tmin was 22.83°Cand lowest Tmin was in 1962 where Tmin was 20.46°C(Figure 21).Before 2015, Tmin was found to fluctuate abnormally where standard deviation and coefficient of variation of Tmin in Dhaka were ±0.523 and 2.42% respectively (Table 6).

In Faridpur, annual Tmin was increasing by 0.021°C/year with its average minimum temperature20.49°C. In Faridpur the increasing trend of Tmin has coefficient of determination R^2= 0.369which was significant at 99% level of significance (Table5). The highest Tmin in Faridpur was in 1964 where Tmin was 22.33°Cand lowest Tmin was in 1974 where Tmin was 19.26°C (Figure 23). Before 2015, Tmin was found to fluctuate abnormally where standard deviation and coefficient of variation of Tmin in Faridpur were ±0.578 and 2.73% respectively (Table 6).

Increasing trends of Tmin in Dhaka and Faridpur were significant in Dhaka division.

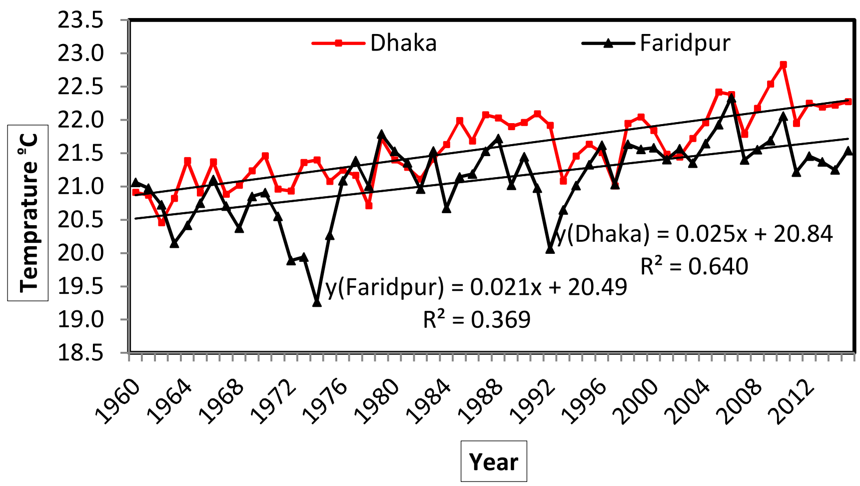


Figure 23: Temporal variation of annual minimum temperature in Dhaka division

4.3.3Minimum Temperature in Rajshahi Division

The annual Tmin showed increasing trend in Bogra over the study period, 1960 to 2015 (Figure 24). In Bogra, annual Tmin was increasing by 0.016 °C/year with its average minimum temperature 20.32 °C.In Bogra the increasing trend of Tminhas coefficient of determination R^2=0.422which was significant at 99% level of significance(Table5). The highest Tmin in Bogra was in 2010 where Tmin was 21.6 °C and lowest Tmin was in 1967 where Tmin was 19.6 °C

(Figure 22). Before 2015, Tmin was found to fluctuate abnormally where standard deviation and coefficient of variation of Tmin in Bogra were ±0.409 and 1.96% respectively (Table 6).

Increasing trend of Tmin in Bogra was significant in Rajshahi division.

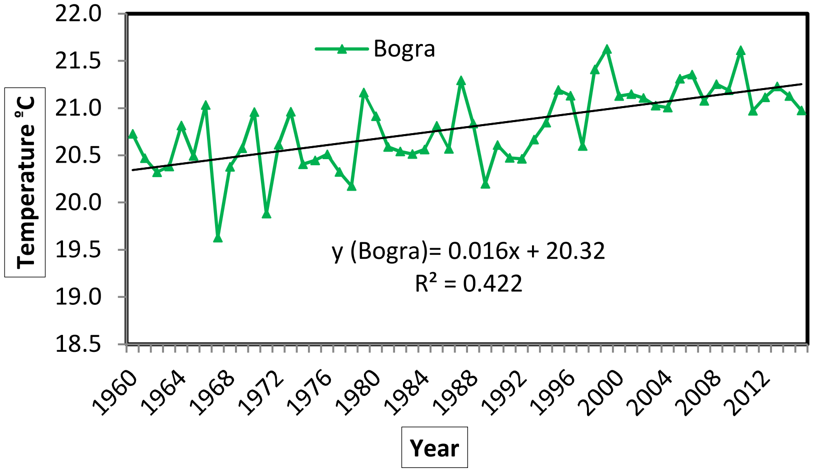


Figure 24: Temporal variation of annual minimum temperature in Rajshahi division

4.3.4Minimum Temperature in Mymensingh Division

The annual Tmin showed increasing trend in Mymensingh over the study period, 1960 to 2015 (Figure 25). In Mymensingh, annual Tmin was increasing by 0.010 °C/year withits average minimum temperature 20.45 °C. In Mymensingh the increasing trend of Tmin has coefficient of determination R^2= 0.158which was significant at 99% level of significance (Table5).The highest Tmin in Mymensingh was in 2010 where Tmin was 21.40 °C and lowest Tmin was in 1991 where Tmin was 19.01 °C (Figure 25). Before 2015, Tmin was found to fluctuate abnormally where standard deviation and coefficient of variation of Tmin in Mymensingh were ±0.417and 2.01% respectively (Table 6).

Increasing trend of Tmin in Mymensingh was significant in Mymensingh division.

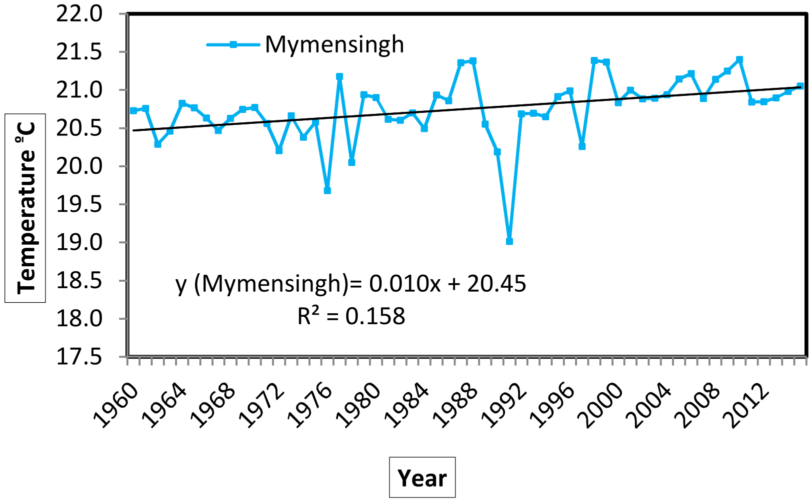


Figure 25: Temporal variation of annual minimum temperature in Mymensingh division

4.3.5 Minimum Temperature in Sylhet Division

The annual Tmin showed increasing trends in Sylhet and Srimongal over the study period, 1960 to 2015 (Figure 26). In Sylhet, annual Tmin wasincreasing by 0.022°C/year with its average minimum temperature 19.72°C.In Sylhet the increasing trend of Tminhas coefficient of determinationR^2=0.491which wassignificant at 99% level of significance (Table5). Thehighest Tmin in Sylhetwas in 2006 where Tmin was 21.38°Cand lowest Tmin was 1986 where Tmin was 18.96°C(Figure 26). Before 2015, Tmin was found to fluctuate abnormally where standard deviation and coefficient of variation of Tmin in Sylhet were ±0.514and 2.52% respectively (Table 6).

In Srimongal, annual Tmin wasincreasing by 0.018 $^{\circ}$C/year withits average minimum temperature 18.77 $^{\circ}$C.In Srimongal the increasing trend of Tmin has coefficient of determinationR^2=0.354which wassignificant at 99% level of significance (Table5). The highest Tmin in Srimongal was in 1979 where Tmin was 20.28 $^{\circ}$C and lowest Tmin was in 1971 where Tmin was 18.18 $^{\circ}$C (Figure 26). Before 2015, Tmin was found to fluctuate abnormally where standard deviation and coefficient of variation of Tmin in Srimongal were ±0.492 and 2.55% respectively (Table 6).

Increasing trends of Tmin in Sylhet and Srimongalwere significant in Sylhet division.

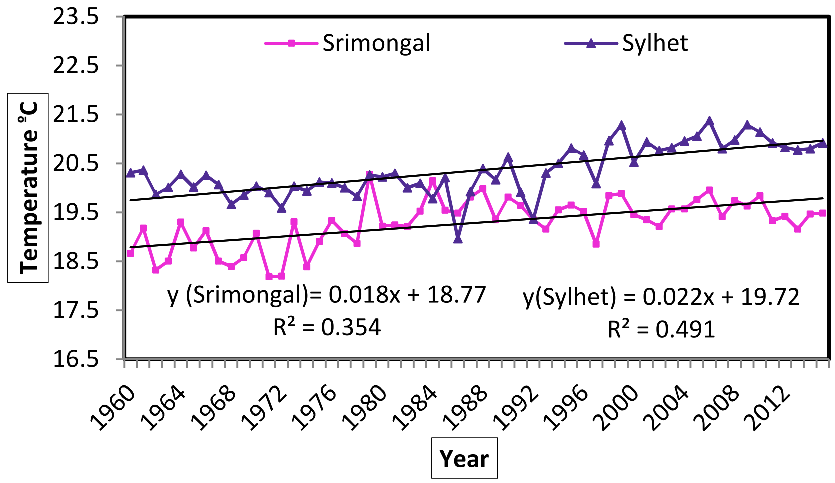


Figure 26: Temporal variation of annual minimum temperature in Sylhet division

4.3.6Minimum Temperature in Rangpur Division

The annual Tmin showed increasing trends in Rangpur and Dinajpur over the study period, 1960 to 2015 (Figure 27). In Rangpur, annual Tmin wasincreasing by 0.025 °C/year withits average minimum temperature 19.14 °C. In Rangpur the increasing trend of Tmin has coefficient of determinationR^2= 0.372which was significant at 99% level of significance (Table5).The highest Tmin in Rangpur was in 1999 where Tmin was 20.76 °Cand lowest Tmin was in 1972 where Tmin was 16.57 °C(Figure 27). Before 2015, Tmin was found to fluctuate abnormally where standard deviation and coefficient of variation of Tmin in Rangpur were ±0.683 and 3.43% respectively (Table 6).

In Dinajpur, annual Tminwasincreasing by 0.005 °C/year with its average minimum temperature 19.90 °C. In Dinajpur the increasing trend of Tmin has coefficient of determinationR^2=0.040 which wasnot significant. (Table5). The highest Tmin in Dinajpur was in 1973 where Tmin was 20.82 °C and lowest Tmin was in 1983 where Tmin was 18.97 °C (Figure 27). Before 2015, Tminwas found to fluctuate abnormally where standard deviation and coefficient of variation of Tmin in Dinajpur were ±0.452 and2.25% respectively (Table 6).

Increasing trend of Tmin in Rangpur was significant while Dinajpurwas not significant in Rangpur division.

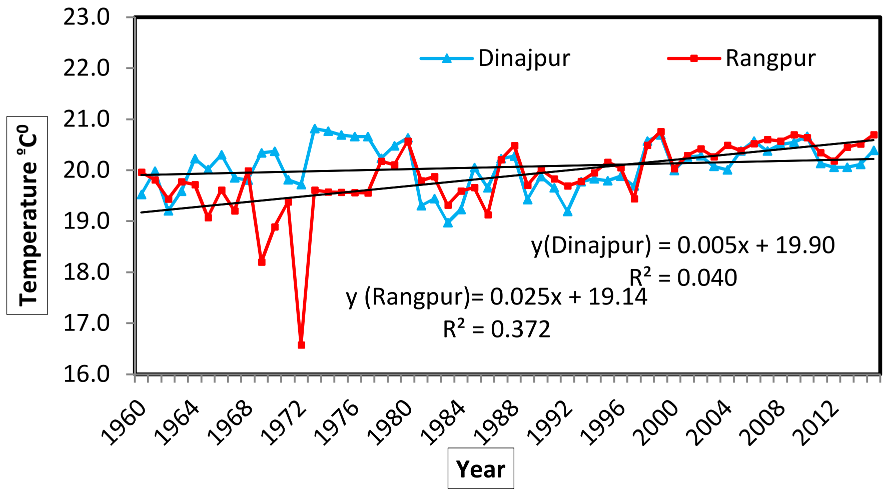


Figure 27: Temporal variation of annual minimum temperature in Rangpur division

4.3.7Minimum Temperature in Barisal Division

The annual Tmin showed increasing trend in Barisal over the study period, 1960 to 2015 (Figure 28). In Barisal, annual Tmin wasincreasing by 0.006°C/year withits average minimum temperature 21.09°C. In Barisal the increasing trend of Tminhas coefficient of determinationR^2= 0.065was not significant. (Table5). The highest Tmin in Barisal was in 2010 where Tmin was 22.22°Cand lowest Tmin was in 1975 where Tmin was 20.38°C Figure 28). Before 2015, Tmin was found to fluctuate abnormally and its cause is an unknown where standard deviation and coefficient of variation of Tmin in Barisal were ±0.398 and1.87% respectively (Table 6).

Increasing trend of Tmin in Barisal was not significant in Barisal division.

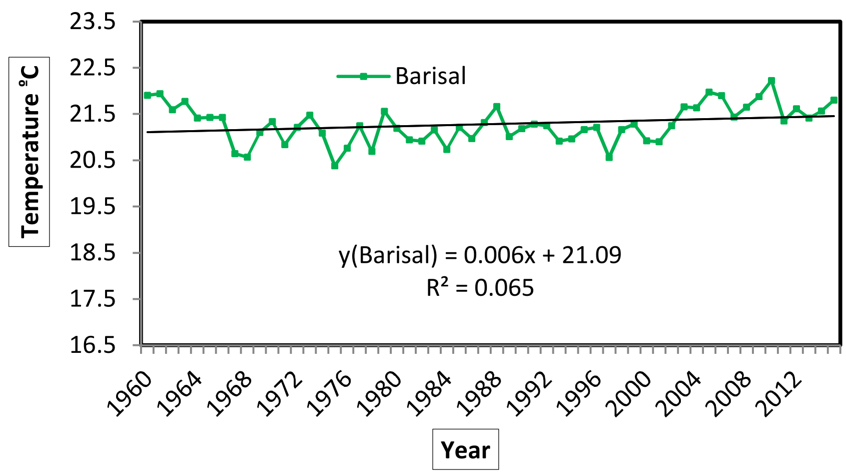


Figure 28: Temporal variation of annual minimum temperaturein Barisal division

4.3.8 Minimum Temperature in Chittagong Division

The annual Tmin showed increasing trendsin Chittagong, Comilla,Cox's bazar and M. Court while decreasing trend in Rangamati over the study period, 1960 to 2015 (Figure 29).In Chittagong, annual Tmin wasincreasing by 0.015°C/year with its average minimum temperature 21.21°C. In Chittagong the increasing trend of Tminhas coefficient of determinationR^2=0.342which was significant at 99% level of significance (Table5). The highest Tmin in Chittagong was in 2010 where Tmin was 22.48°Cand lowest Tmin was in 1977 where Tmin was 20.92°C (Figure 29). Before 2015, Tmin fluctuate was found to abnormally where standard deviation and coefficient of variation of Tmin in Chittagong were ±0.433and 2.00% respectively (Table 6).

In Comilla, annual Tmin was increasing by 0.007 °C/year with its average minimum temperature 20.74 °C. In Comilla the increasing trend of Tminhas coefficient of determinationR^2= 0.099which was not significant (Table5). Thehighest Tmin in Comillawas in 1970 where Tmin was 21.90 °C and lowest Tmin was in 1962 where Tmin was 19.81 °C (Figure 29). Before 2015, Tmin was found to fluctuate abnormally where standard deviation and coefficient of variation of Tmin in Comilla were ±0.391and 1.86% respectively (Table 6).

In Rangamati, annual Tmin wasdecreasing by -0.028 °C/year with its average minimum temperature 22.18 °C.In Rangamati the decreasing trend of Tminhas coefficient of determinationR^2= 0.351which was significant at 99% level of significance (Table5).The highest Tmin in Rangamatiwas in 1979 where Tmin was 22.80 °C and lowest Tmin was in 1993 where Tmin was 19.49 °C (Figure 29).Before 2015, Tmin was found to fluctuate abnormally where standard deviation and coefficient of variation of Tmin in Rangamati were ±0.611 and 3.66% respectively (Table 6).

In Cox's Bazar, annual Tmin wasincreasing by 0.020 °C/year with its average minimum temperature 21.47 °C .In Cox's Bazarthe increasing trend of Tminhas coefficient of determinationR^2= 0.527which was significant at 99% level of significance (Table5).Thehighest Tmin was in 2005 where Tmin was 23.04 °Cand lowest Tmin was 1971 where Tmin was 21.16 °C (Figure 29). Before 2015, Tmin was found to fluctuate abnormally where standard deviation and coefficient of variation of Tmin in Cox's Bazar were ±0.465and 2.10% respectively (Table 6).

In M. Court, annual Tmin wasincreasing by 0.028 °C/year withits average minimum temperature 20.85 °C. In M. Court the increasing trend of Tmin has coefficient of determinationR^2= 0.575which was significant at 99% level of significance (Table5). The highest Tmin in M. Court was in 2010 where Tmin was 22.76 °C and lowest Tmin was in 1982 where Tmin was 20.16 °C (Figure 29). Before 2015, Tmin was found to fluctuate abnormally where standard deviation and coefficient of variation of Tmin in M. Court were ±0.604 and 2.79% respectively (Table 6).

Increasing trend of Tmin in Comilla was not significant while Cox's Bazar, M. Court, Chittagong and Rangamati were significantin Chittagong division.

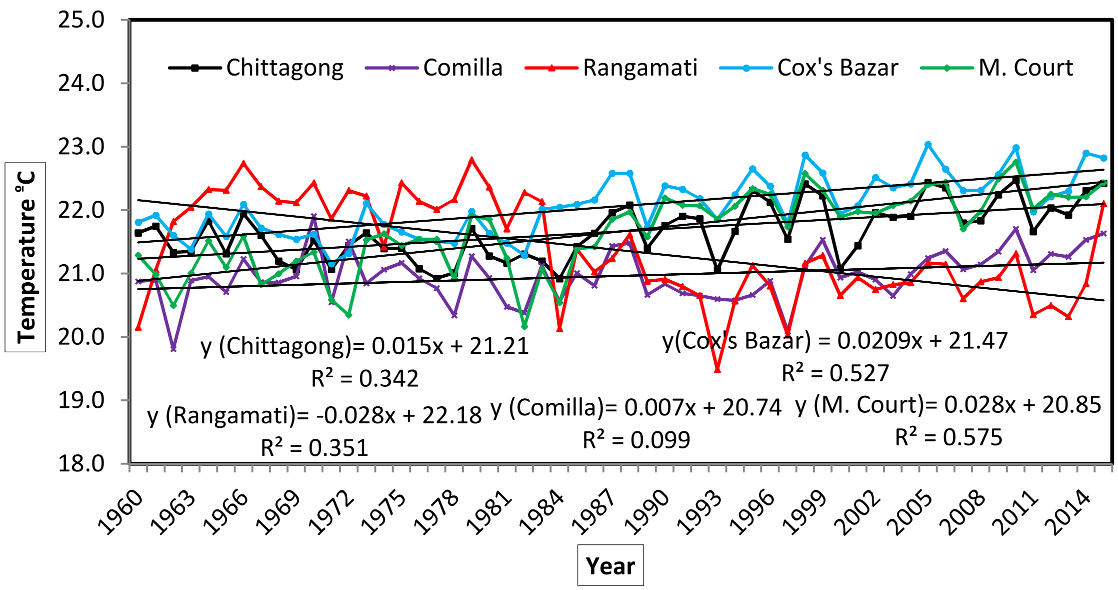


Figure 29: Temporal variation of annual minimum temperature in Chittagong division

4.3.9Comparison of Tmin among in all divisions

The Figure 28 shows the temporal variation of minimum temperature (Tmin), which has increasing trend in Khulna, Dhaka, Rajshahi, Sylhet, Rangpur, Chittagong and Barisaldivision over the study period 1960-2015 (Figure 30). In Khulna, annual Tmin was increasing by 0.0058°C/year with average Tmin of 21.21°C. In Khulna the increasing trend of Tmin hascoefficient of determination R^2= 0.0813 which was significant (Table5). The highest Tmin in Khulna was in 1979 where Tmax was 22.27°Cand lowest Tmin was in 1984 where Tmin was 20.73°C (Figure 30). There was inter-annual fluctuation in Tmin; standard deviation and coefficient of variation of annual Tmin in Khulnawere ±0.321and 1.50%, respectively (Table 6).

In Dhaka, annualTmin was increasing by 0.0246 °C/year with its average minimum temperature 20.65 °C.In Dhaka the increasing trend of Tminhas coefficient of determination R^2= 0.6025 which was significantat 99% level of significance (Table 5).The highest Tmin in Dhaka was in 2010 where Tmin was 22.45 °Cand lowest Tmin was in 1974 where Tmin was 20.33 °C (Figure 30). There was inter-annual fluctuation in Tmin; standard deviation and coefficient of variation of Tmin in Dhaka were ±0.493 and 2.31% respectively (Table 6).

In Rajshahi, annual Tmin was increasing by 0.016 °C/year with its average minimum temperature 20.32 °C .In Rajshahi the increasing trend of Tmin has coefficient of determination R^2= 0.422 which was significant at 99% level of significance (Table5). The highest Tmin in Rajshahi was in 1999 whereTmin was 21.63 °Cand lowest Tmin was in 1967 where Tmin was 19.63 °C (Figure 30). There was inter-annual fluctuation in Tmin; standard deviation and coefficient of variation of Tmin in Rajshahi were ±0.409 and 1.96% respectively (Table 6).

In Sylhet, annual Tmin was increasing by 0.021 °C /year with its average minimum temperature 19.23 °C.In Sylhet the increasing trend of Tmin has coefficient of determination R^2= 0.5593 which was significantat 99% level of significance (Table5).The highest Tmin in Sylhet was in 2006 where Tmin was 20.67 °C and lowest Tmin was in 1972 where Tmin was 18.90 °C(Figure 30). There was inter-annual fluctuation in Tmin; standard deviation and coefficient of variation of Tmin in Sylhet were ±0.434and 2.19% respectively (Table 6).

In Rangpur, annual Tmin was increasing by 0.0156 °C/year with its average minimum temperature 19.52 °C.In Rangpur the increasing trend of Tminhas coefficient of determination R^2= 0.2729 which was significant at 99% level of significance (Table5). The highest Tmin in Rangpur was in 1999 where Tmin was 20.72 °C and lowest Tmin was in 1972 where Tmin was 18.15 °C (Figure 30). There was inter-annual fluctuation in Tmin; standard deviation and coefficient of variation of Tmin in Rangpur were ±0.465and 2.33% respectively (Table 6).

In Chittagong, annual Tmin wasincreasing by 0.0073 °C/year with its average minimum temperature 21.29 °C.In Chittagong the increasing trend of Tmin has coefficient of determination R^2= 0.1414 which was significantat 99% level of significance (Table5).The highest Tmin in Chittagong was in 2015 where Tminwas 22.28 °C and lowest Tmin was in 1984 where Tmin was 20.84 °C(Figure 30).). There was inter-annual fluctuation in Tmin; standard deviation and coefficient of variation of Tmin in Chittagong were ±0.319and 1.48% respectively (Table 6).

In Barisal, annual Tmin is increasing by 0.006 °C/year with its average minimum temperature 21.09 °C.In Barisal the increasing trend of Tmin has coefficient of determination R^2= 0.065which was not significant (Table5). The highest Tmin in Barisal was in 2010 where Tmin was 22.22 °C and lowest Tmin was in 1975 whereTmin was 20.38 °C (Figure 30). There was inter-annual fluctuation in Tmin; standard deviation and coefficient of variation of Tmin in Barisal were ±0.398and 1.87% respectively (Table 6).

In Mymensingh, annual Tmin was increasing by 0.010 °C/year with its average minimum temperature 20.45 °C.In Mymensingh the increasing trendof Tmin has coefficient of determination R^2=0.158 which was significantat 99% level of significance (Table5).The highest Tmin in Mymensingh was in 2010 where Tmin was 21.40 °C and lowest Tmin was in 1991 where Tmin was 19.01 °C (Figure 30). There was inter-annual fluctuation in Tmin; standard deviation and coefficient of variation of Tmin in Mymensingh were ±0.417and 2.01% respectively (Table 6).

Increasing trend of Tmin in Barisal was not significant while the trends of Tmin in Dhaka, Rangpur, Sylhet, Rajshahi, Chittagong,Khulna and Mymensingh divisions were significant.

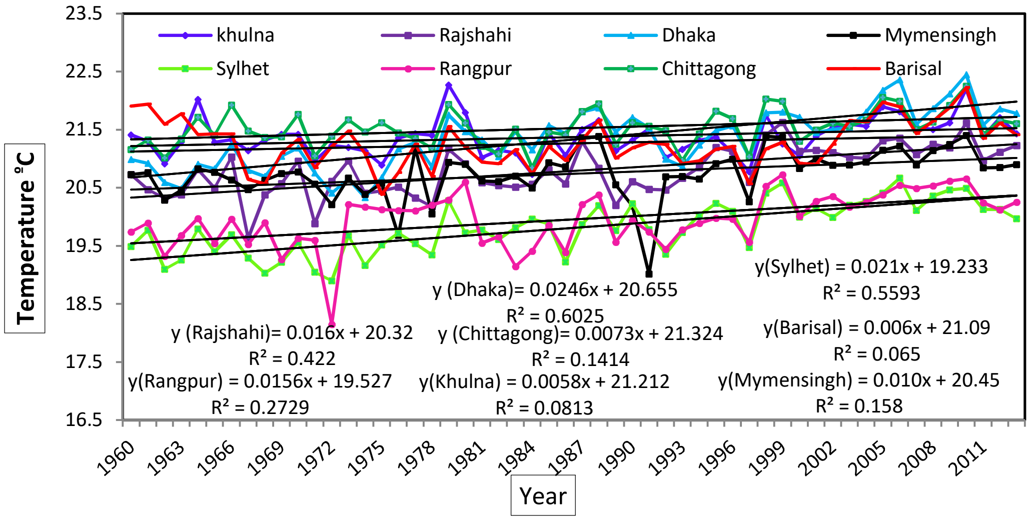


Figure 30: Comparison of average minimum temperature in all divisions

** Significant at 0.01 level of significance

Table5: Regression equation of trend lines for minimum temperature

Station/ division	Regression equation with R^2	Correlation of coefficient r
Khulna	y= 0.002x + 21.74, $R^2 = 0.004$	0.063246
Jessore	y= 0.005x + 20.68, $R^2 = 0.076$	0.275681
Satkhira	y = 0.011x + 21.17, $R^2 = 0.202$	0.449444**
Bogra	y = 0.016x + 20.32, $R^2 = 0.422$	0.649615**
Dhaka	y = 0.025x + 20.84, $R^2 = 0.640$	0.8**
Faridpur	y = 0.021x + 20.49, $R^2 = 0.369$	0.607454**
Mymensingh	y = 0.010x + 20.45, $R^2 = 0.158$	0.397492**
Srimongal	y = 0.018x + 18.77, $R^2 = 0.354$	0.594979**
Sylhet	y = 0.022x + 19.72, $R^2 = 0.491$	0.700714**
Dinajpur	y= 0.005x + 19.90 , $R^2 = 0.040$	0.2

Rangpur	y = 0.025x + 19.14 , R^2 = 0.372	0.609918**
Chittagong	y= 0.015x + 21.21 , R^2 = 0.342	0.584808**
Comilla	y = 0.007x + 20.74, R^2 = 0.099	0.314643
Rangamati	y = -0.028x + 22.18, R^2 = 0.351	0.592453**
Cox's Bazar	y = 0.020x + 21.47, R^2 = 0.527	0.725948**
M. Court	y= 0.028x + 20.85, R^2 = 0.575	0.758288**
Barisal	y= 0.006x + 21.09 , R^2 = 0.065	0.207846
Khulna division	y=0.0058x+21.212, R^2 = 0.081	0.285132**
Dhaka division	y=0.0246x+20.655, R^2=0.6025	0.776209**
Rajshahi division	y = 0.016x + 20.32, R^2 = 0.422	0.649615**
Mymensingh division	y = 0.010x + 20.45, R^2 = 0.158	0.397492**
Sylhet division	y=0.021x+19.233, R^2=0.5593	0.747864**
Rangpur division	y=0.0156x+19.527, R^2=0.2729	0.522398**
Chittagong division	y=0.0073x+21.324, R^2=0.1414	0.376032**
Barisal division	y= 0.006x + 21.09 , R^2 = 0.065	0.207846

Table 6: Variability of Annual Minimum Temperature

Station/District	Standard Deviation	Coefficient 0f Variation%
Khulna	± 0.481	2.20
Jessore	± 0.319	1.53
Satkhira	± 0.420	1.95
Bogra	± 0.409	1.96
Dhaka	± 0.523	2.42
Faridpur	± 0.578	2.73
Mymensingh	± 0.417	2.01
Srimongal	± 0.492	2.55
Sylhet	± 0.514	2.52
Dinajpur	± 0.452	2.25
Rangpur	± 0.683	3.43
Chittagong	± 0.433	2.00
Comilla	± 0.391	1.86
Rangamati	± 0.611	3.66
Cox's bazar	± 0.465	2.10
M.Court	± 0.604	2.79

Barisal	± 0.398	1.87
Khulna Division	± 0.321	1.50
Dhaka Division	± 0.493	2.31
Rajshahi Division	± 0.409	1.96
Mymensingh Division	± 0.417	2.01
Sylhet Division	± 0.434	2.19
Rangpur Division	± 0.465	2.33
Chittagong Division	± 0.319	1.48
Barisal Division	± 0.398	1.87

4.3.10 Distribution of coefficient of variation for annual average minimum temperature

Distribution of coefficient of variation for annual average temperature of the country is shown in (Figure 31) using the data from the (Table 6). It's indicates the amount of variability relative to the mean value of annual average maximum temperature of the station of the country. So, it is easy way to understand the change of average temperature of specific region/station of the country. From the figure, it is seen that the eastern and some portion of northwestern region of the country has maximum coefficient of variation and the maximum value was 2.72% at Cox's bazar region .The western,middle of the south, some portion middle of the northand center of the country has minimum coefficient variation and the minimum value was 1.24 % at Mymensingh region .The coefficient of variation has been found to decrease from Cox's bazar towardswestern, northeasternand center of the country. The coefficient of variation has been found to increase from center of the country towards some portion of northwestern, southeastern and northeastern region of the country.

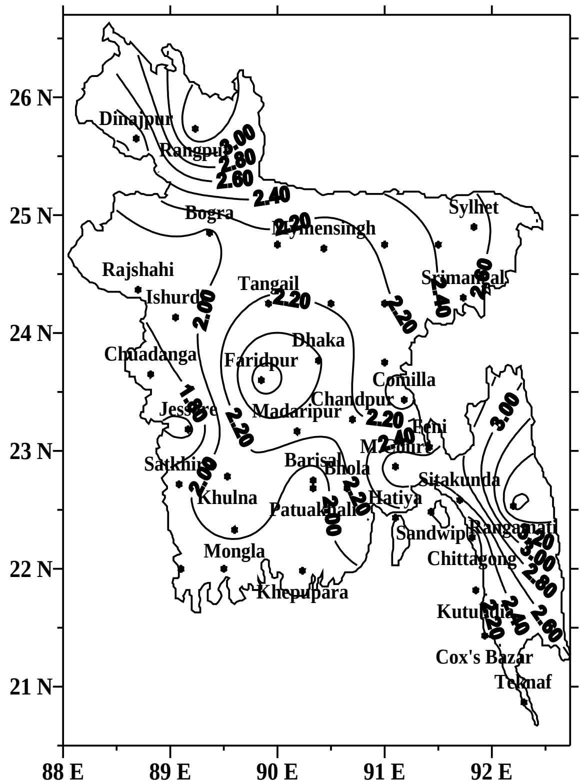
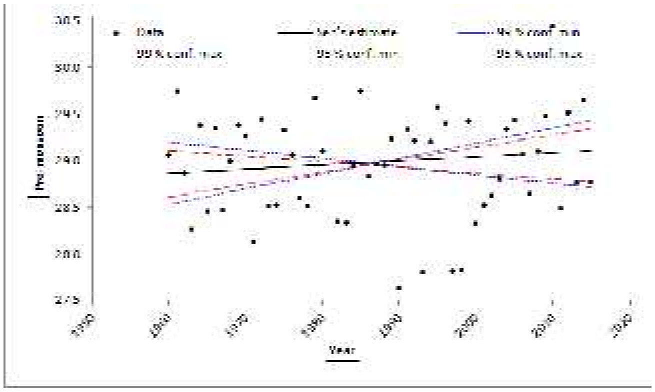


Figure 31: Distribution of coefficient of variation for annual average minimum temperature

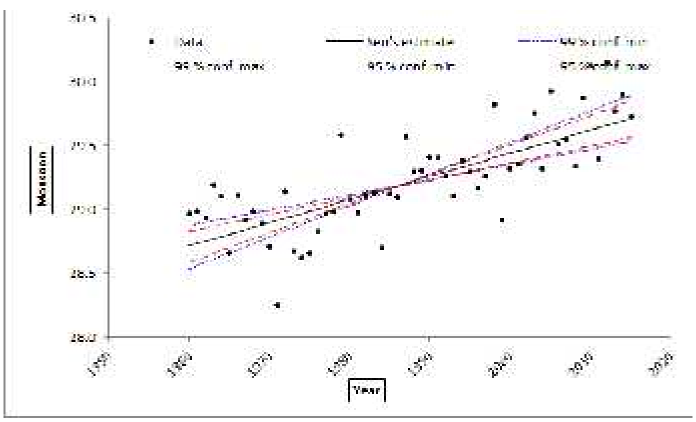
3.4.1 Seasonal trends and variation of annual average temperature in Khulna division

Seasonal trends and variationofannual average temperature (Tavg) in Khulna division for pre-monsoon, monsoon, post-monsoon and winter seasonsfor the period,1960-2015 using Man-Kendall test .This test indicates that Tavg has increasing trends in pre-monsoon, post- monsoon and monsoon seasons while decreasing trend in winter season .In pre-monsoon season, the value of Zequal to 0.86 wasnotstatistically significant (Figure 32).In monsoon season, the value of Z equal to 6.31 wasstatistically significant (Figure 33). In post-monsoonseason, the value of Zequal to 2.52 was statistically significant (Figure 34).In winter season, the value of Zequal to -1.36 was not statistically significant (Figure 35).The significance level of the Mann-Kendall test for monsoon andpost- monsoon seasonsare given below (Table 7).



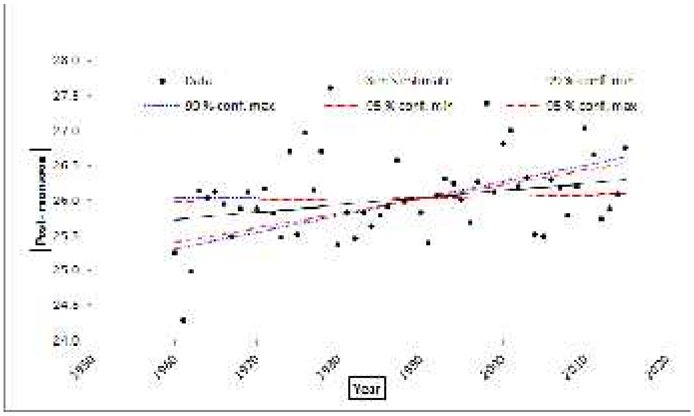
TeNumber	1
Name	Pre-monsoon
Years	1960 - 2016
n	56
Test S	
Test Z	0.86
Signific.	
Q	4.36E-03
Qmin99	-8.00E-03
Qmax99	1.83E 02
Qmin95	-6.00E-03
Qmax95	1.33E-02
B	2.89E+01
Bmin99	2.92E+01
Bmax99	2.85E+01
Bmin95	2.91E+01
Bmax95	2.86E+01

Figure 32: Time series and trends statistics of annual Tavg in Khulna division for pre-monsoon



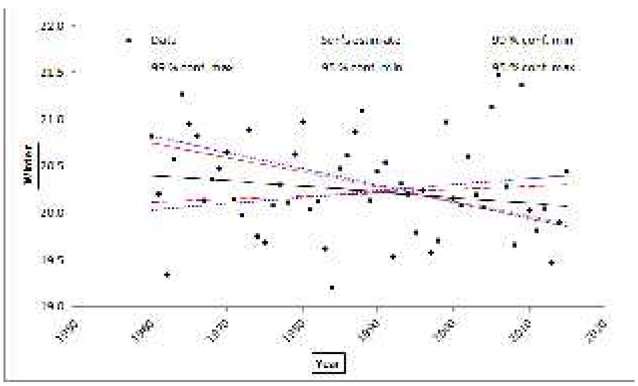
TeNumber	1
Name	Monsoon
Years	1960 - 2016
n	56
Test S	
Test Z	6.31
Signific.	***
Q	1.81E-02
Qmin99	1.19E-02
Qmax99	2.47E-02
Qmin95	1.34E-02
Qmax95	2.29E-02
B	2.87E+01
Bmin99	2.89E+01
Bmax99	2.85E+01
Bmin95	2.88E+01
Bmax95	2.86E+01

Figure 33: Time series and trends statistics ofannual Tavg in Khulna division for monsoonseason



TsNumber	1
Name	Post monsoon
Years	1960 - 2015
n	56
Test S	
Test Z	2.52
Signific.	*
Q	1.02E-02
Qmin99	-2.58E-04
Qmax99	2.37E-02
Qmin95	1.93E-03
Qmax95	2.08E-02
B	2.57E+01
Bmin99	2.60E+01
Bmax99	2.53E+01
Bmin95	2.60E+01
Bmax95	2.54E+01

Figure 34: Time series and trends statistics of annual Tavg in Khulna division for post-monsoon season



TsNumber	1
Name	Winter
Years	1960 - 2015
n	53
Test S	
Test Z	-1.36
Signific.	
Q	6.79E 03
Qmin99	-1.74E-02
Qmax99	6.63E-03
Qmin95	-1.54E-02
Qmax95	3.21E-03
B	2.04E+01
Bmin99	2.08E+01
Bmax99	2.00E+01
Bmin95	2.07E+01
Bmax95	2.01E+01

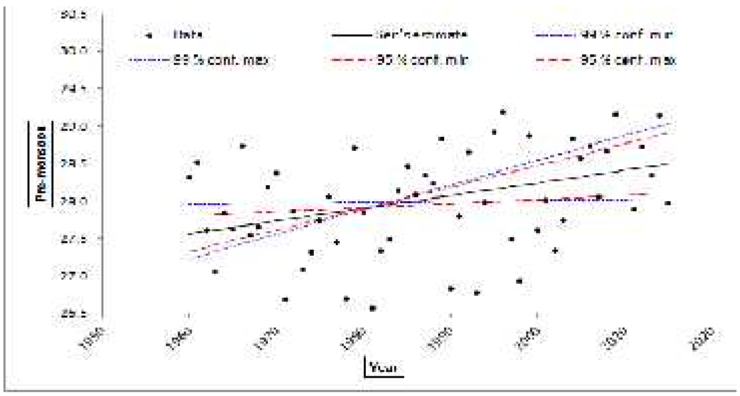
Figure 35: Time series and trends statistics of annual Tavg in Khulna division for winter season

Table 7: The significance level of the Mann-Kendall test for post- monsoon and monsoon seasons inKhulna division.

Season	Test Z value	Significant symbol	Level of significance
Post-monsoon	2.52	*	0.05
Monsoon	6.31	***	0.001

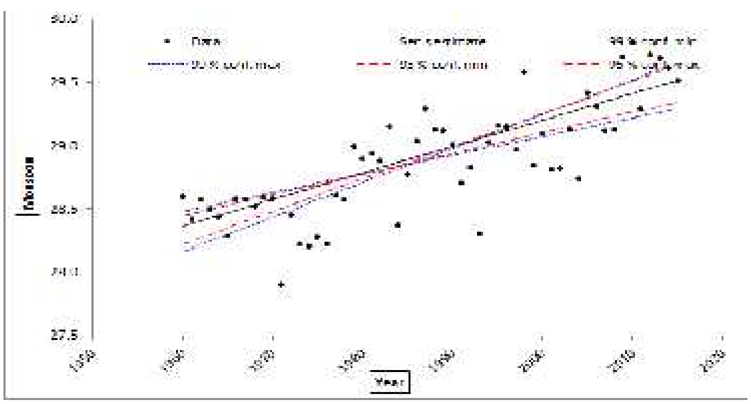
4.4.2Seasonal trends and variation of annual average temperature in Dhaka division

Seasonal trends and variation of annual average temperature (Tavg)in Dhaka division for pre-monsoon, monsoon, post-monsoon and winter seasonsfor the period,1960-2015 using Man-Kendall test .This test indicates that Tavg has increasing trends in pre-monsoon, post-monsoon, monsoon and winter seasons .In pre-monsoon season, the value of Z equal to 2.75 was statistically significant (Figure 36). In monsoon season, the value of Z equal to 6.23was statistically significant (Figure 37). In post-monsoon season, the value of Z equal to 5.60 was statistically significant Figure 38). In winter season the value of Z equal to 4.62 was statistically significant (Figure 39).The significance level of the Mann-Kendall test for the monsoon and post-monsoonseasons are given(Table 8).



TsNumber	1
Name	Pre-monsoon
Years	1960 - 2015
n	56
Test S	
Test Z	2.75
Signific.	**
Q	1.70E-02
Qmin99	1.21E-03
Qmax99	3.29E-02
Qmin95	5.50E-03
Qmax95	2.88E-02
B	2.73E+01
Bmin99	2.80E+01
Bmax99	2.72E+01
Bmin95	2.73E+01
Bmax95	2.73E+01

Figure 36: Time series and trends statistics of Tavg in Dhaka division for Pre-monsoon season



TsNumber	1
Name	Monsoon
Years	1960 - 2015
n	56
Test S	
Test Z	6.23
Signific.	***
Q	2.10E-02
Qmin99	1.49E-02
Qmax99	2.71E-02
Qmin95	1.64E-02
Qmax95	2.57E-02
B	2.84E+01
Bmin99	2.85E+01
Bmax99	2.82E+01
Bmin95	2.84E+01
Bmax95	2.82E+01

Figure 37: Time series and trends statistics of annual Tavg in Dhaka division for monsoon season

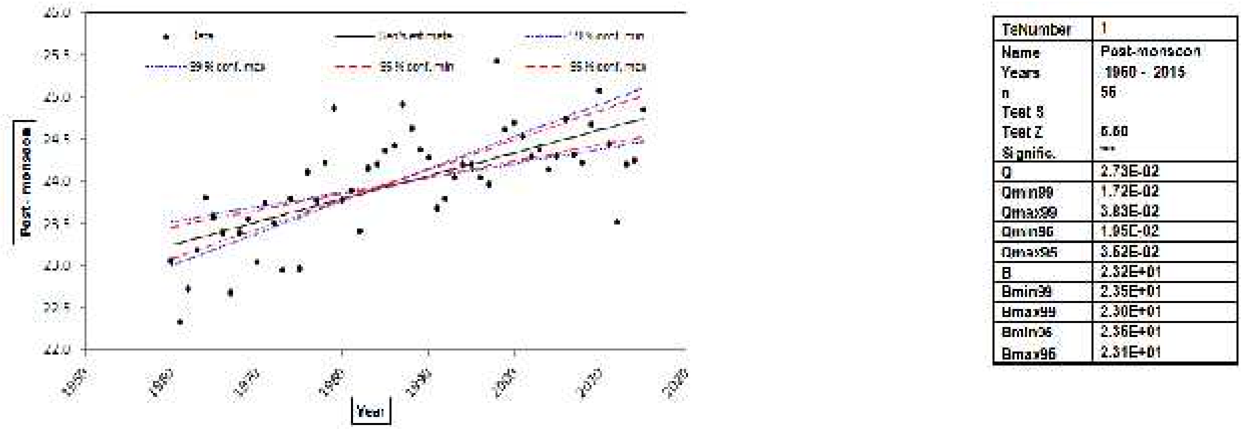


Figure 38: Time series and trends statistics annual Tavg in Dhaka division for post –monsoon season

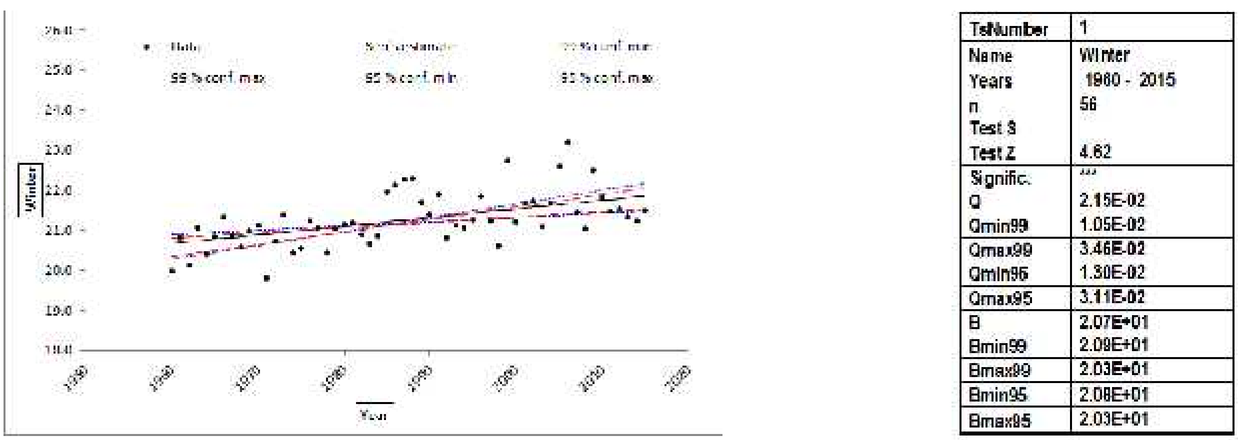


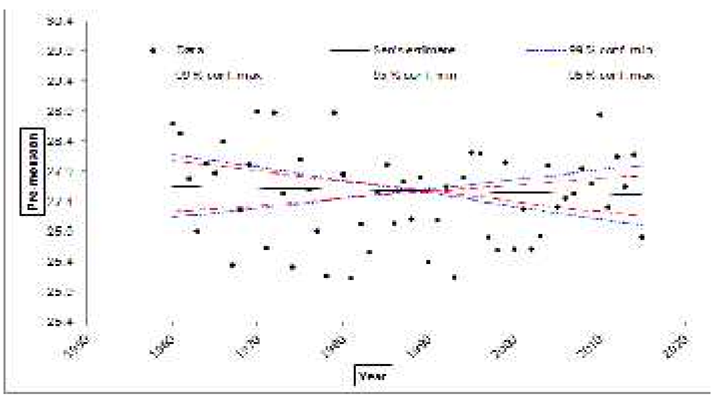
Figure 39: Time series and trends statistics of annual Tavg in Dhaka division for winter season

Table8: The significance level of the Mann-Kendall test for pre-monsoon, monsoon, post-monsoon and winter seasonsin Dhaka division.

Season	Test Z value	Significantsymbol	Level of significance
Pre-monsoon	2.75	**	0.01
Monsoon	6.23	***	0.001
Post- monsoon	5.60	***	0.001
Winter	4.62	***	0.001

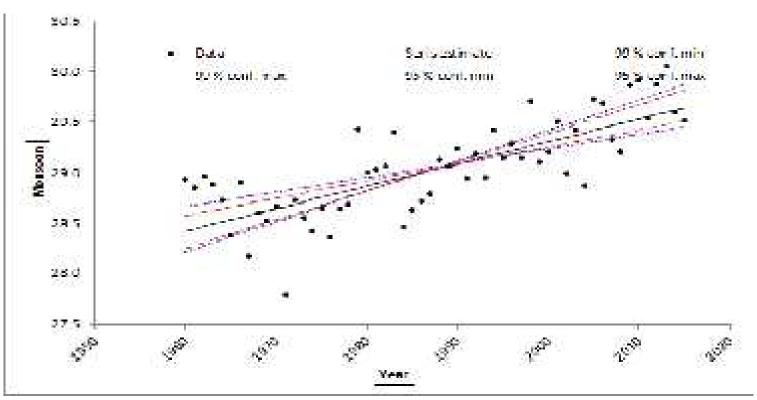
4.4.3 Seasonal trends and variation of annual average temperature in Rajshahi division

Seasonal trends and variation of annual average temperature (Tavg)in Rajshahi division for pre-monsoon, monsoon,post-monsoon and winter seasons for the period, 1960-2015 using Man-Kendalltest. Thistest indicatesthat Tavg has increasing trends in monsoon, post-monsoon, winter seasons while decreasing trend in pre-monsoon season. In pre-monsoon season the value of Z equal to -0.46 was not statistically significant (Figure 40).In monsoon season the value of Z equal to 6.25 was statistically significant(Figure 41).In P-monsoon season the value of Z equal to 5.34 was not statistically significant(Figure 42).In winter season the value of Zequal to 0.46 was not statistically significant(Figure 43).The significance level of the Mann-Kendall test for the monsoon and post- monsoon seasons are given below (Table 9).



TsNumber	1
Name	Pre-monsoon
Years	1960 - 2015
n	56
Test S	
Test Z	-0.46
Signific.	
Q	-2.52E-03
Qmin99	-2.16E-02
Qmax99	1.58E-02
Qmin95	-1.87E-02
Qmax95	1.10E-02
B	2.76E+01
Bmin99	2.82E+01
Bmax99	2.71E+01
Bmin95	2.81E+01
Bmax95	2.72E+01

Figure 40: Time series and trends statistics of annual Tavg Rajshahi division for pre-monsoon



TsNumber	1
Name	Monsoon
Years	1960 - 2015
n	56
Test S	
Test Z	6.25
Signific.	***
Q	2.21E-02
Qmin99	1.44E-02
Qmax99	3.01E-02
Qmin95	1.69E-02
Qmax95	2.85E-02
B	2.84E+01
Bmin99	2.87E+01
Bmax99	2.82E+01
Bmin95	2.86E+01
Bmax95	2.82E+01

Figure 41: Time series and trends statistics of annual Tavgin Rajshahi division for monsoon season

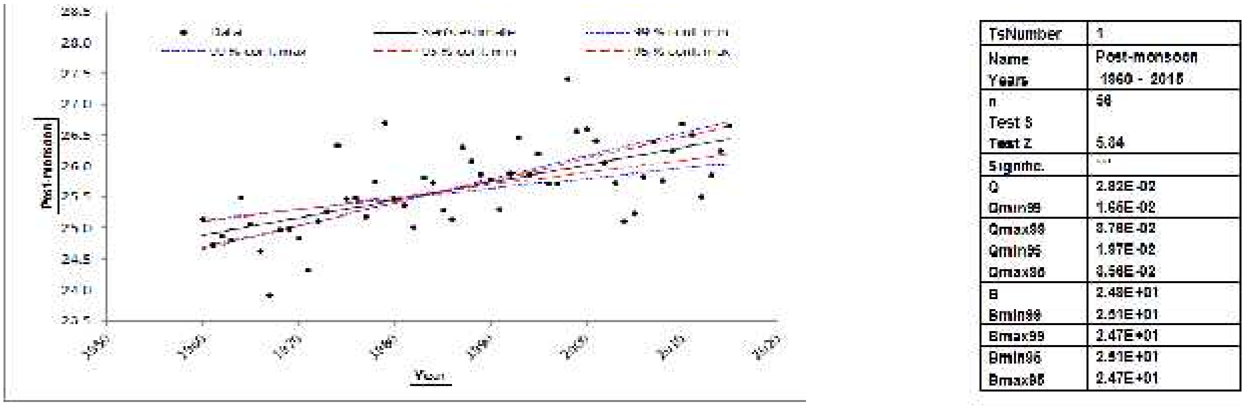


Figure 42: Time series and trends statistics of annual Tavgin Rajshahi division for post-monsoon

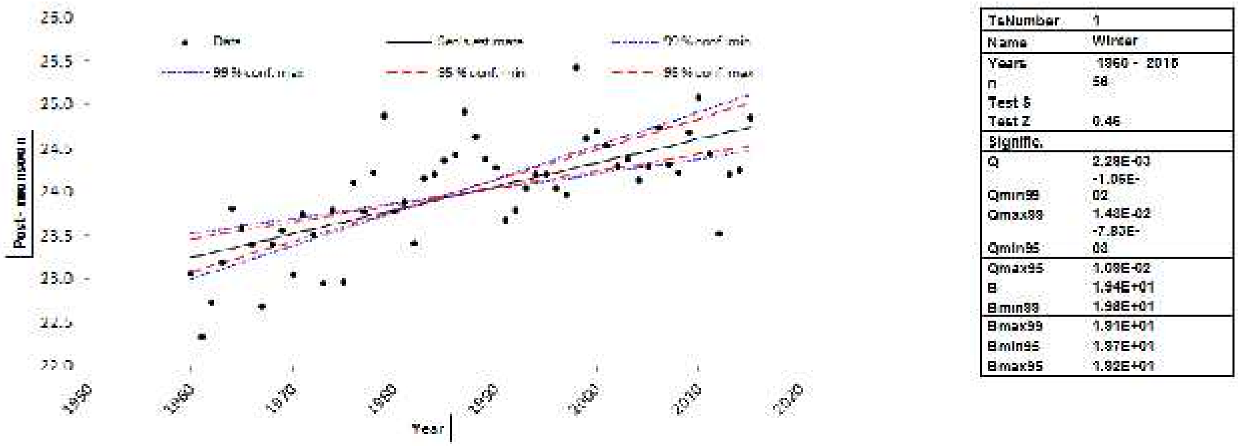


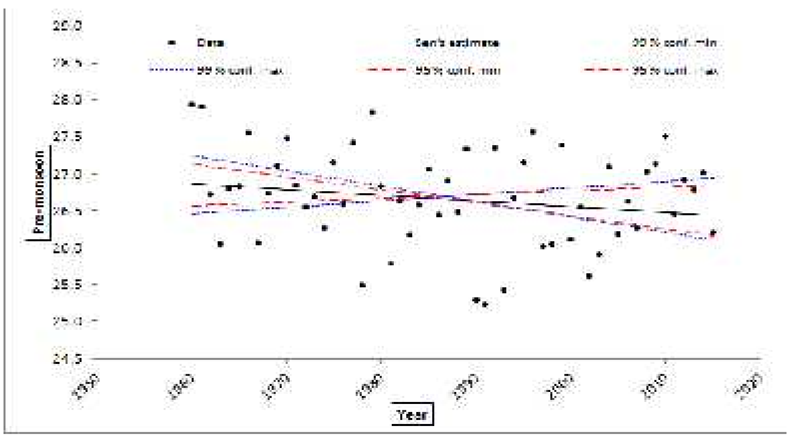
Figure 43: Time series and trends statistics of annual Tavg in Rajshahi division for winterseason

Table 9: The significance level of the Mann-Kendall test for the monsoon and post -monsoon seasons in Rajshahi division.

Season	Test Z value	Significantsymbol	Level of significance
Monsoon	6.25	***	0.001
Post- monsoon	5.34	***	0.001

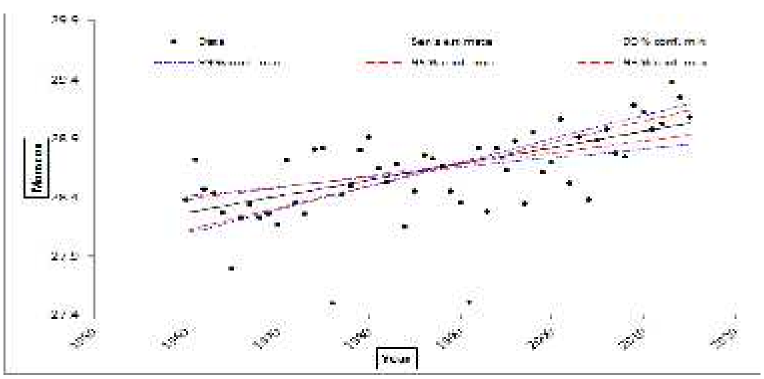
4.4.4 Seasonal trends and variation of annual average temperature in Mymensingh division

Seasonal trends and variation of annual average temperature (Tavg) in Mymensingh division for pre-monsoon, monsoon, post monsoon and winter seasons for the period, 1960-2015 using Man-Kandell test .This test indicates that Tavg has increasing trends in monsoon, post-monsoon while decreasing trends in pre-monsoon, winter .In pre-monsoon season the value of Z equal to -1.11 was not statistically significant (Figure 44).In monsoon season the value of Z equal to 5.11 was statistically significant(Figure 45).In the post-monsoon season the value of Z equal to 1.45 was not statistically significant(Figure 46).In the winter season the value of Z equal to -1.56 was not statistically significant (Figure 47).The significance level of the Mann-Kendall test for the monsoon, post-monsoon aregiven in the (Table 10)



TaNumber	1
Name	Pre-monsoon
Years	1960 - 2015
n	56
Test S	
Test Z	-1.11
Signific.	
Q	7.73E-03
Qmin99	-2.03E-02
Qmax99	8.31E-03
Qmin95	[illegible]
Qmax95	5.08E-03
B	2.69E+01
Bmin99	[illegible]
Bmax99	2.55E+01
Bmin95	2.71E+01
Bmax95	[illegible]

Figure 44: Time series and trends statistics of annual Tavg in Mymensingh division for pre-monsoon.



TaNumber	1
Name	Monsoon
Years	1960 - 2015
n	56
Test S	
Test Z	5.11
Signific.	***
Q	1.38E-02
Qmin99	8.16E-03
Qmax99	2.01E-02
Qmin95	9.04E-03
Qmax95	1.85E-02
B	2.83E+01
Bmin99	2.84E+01
Bmax99	2.81E+01
Bmin95	2.84E+01
Bmax95	2.81E+01

Figure 45: Time series and trends statistics of annual Tavg in Mymensingh division for monsoon

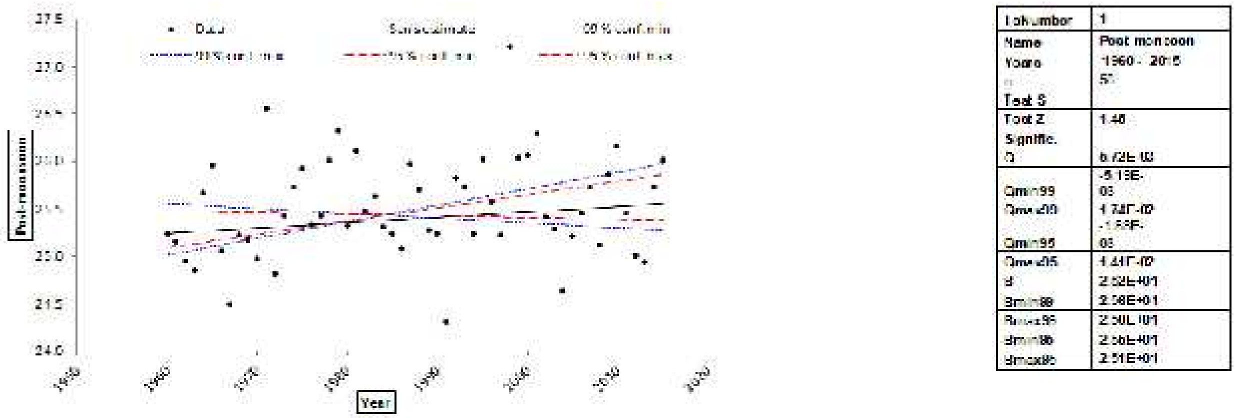


Figure 46: Time series and trends statistics of annual Tavg in Mymensingh division for post-monsoon.

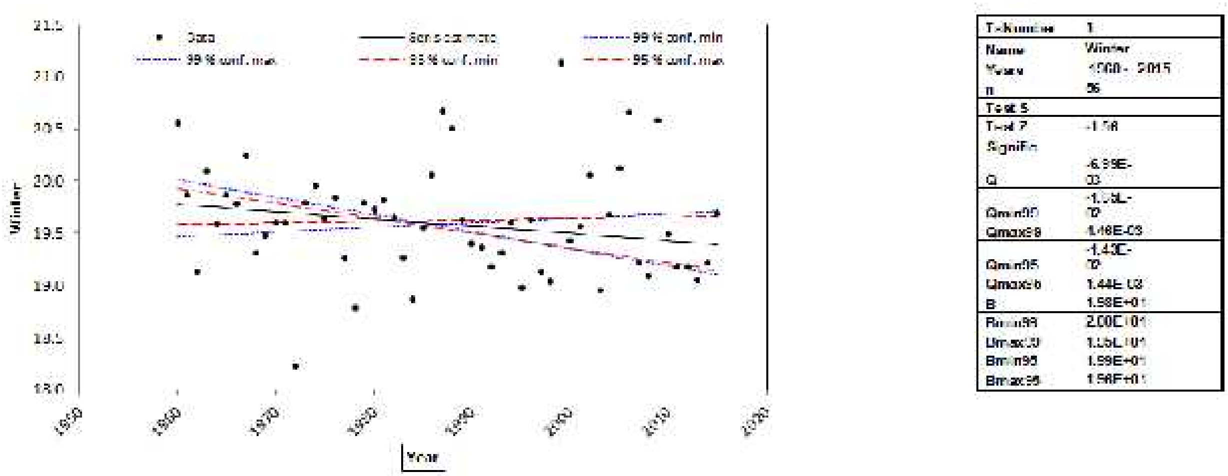


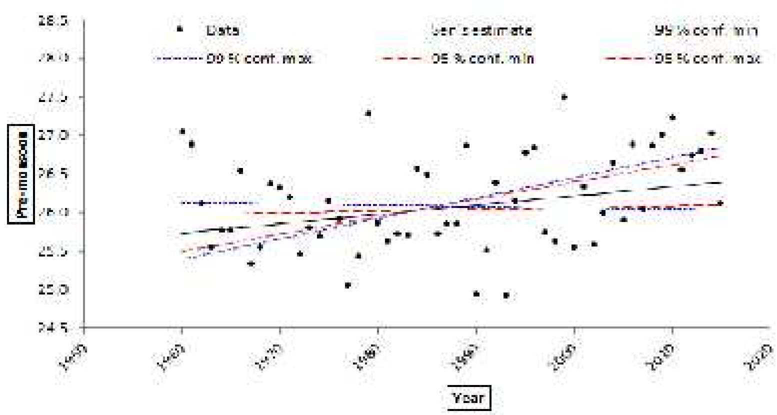
Figure 47: Time series and trends statistics of annual Tavg in Mymensingh division for winter

Table10:The significance level of the Mann-Kendall test for the monsoon inMymensingh division.

Season	Test Z value	Significant symbol	Level of significance
Monsoon	5.11	***	0.001

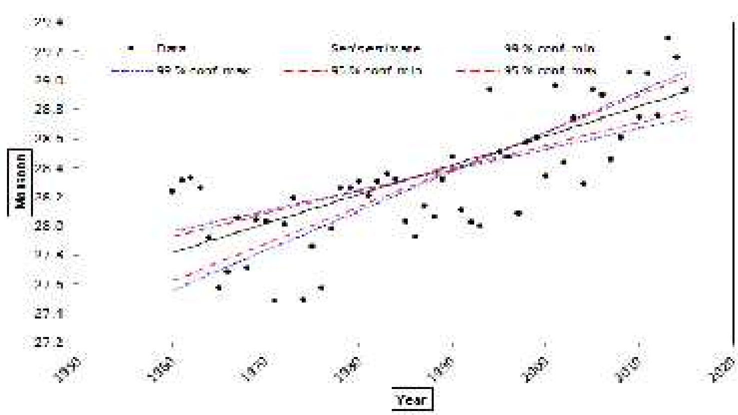
4.4.5Seasonal trends and variation of annual average temperature in Sylhet division

Seasonal trends and variation of annual average temperature (Tavg) in Sylhet division for pre-monsoon, monsoon, post monsoon and winter for the period, 1960-2015 using Man- Kandell test. This test indicatesthat Tavg has increasing trends in pre-monsoon, monsoon and post-monsoon and winter seasons. In pre-monsoon season the value of Z equal to 2.24 was statistically significant (Figure 48).In monsoon season the value of Z equal to 6.10 was statistically significant(Figure 49).In post-monsoon season the value of Z equal to 5.24 was statistically significant(Figure 50).In winter season the value of Z equal to 4.28 was statistically significant(Figure51).The significance level of the Mann-Kandell test for the pre-monsoon, monsoon, post- monsoon seasons are given in the (Table 11).



TsNumber	1
Name	Pre-monsoon
Years	1960 - 2015
n	56
Test S	
Test Z	2.24
Signific.	*
Q	1.20E-02
Qmin99	-1.73E-03
Qmax99	2.84E-02
Qmin95	2.14E-03
Qmax95	2.25E-02
B	2.57E+01
Bmin99	2.61E+01
Bmax99	2.54E+01
Bmin95	2.60E+01
Bmax95	2.56E+01

Figure 48: Time series and trends statistics of annual Tavg in Sylhet division for pre-monsoon



TsNumber	1
Name	Monsoon
Years	1960 - 2015
n	56
Test S	
Test Z	6.10
Signific.	***
Q	2.01E-02
Qmin99	1.42E-02
Qmax99	2.73E-02
Qmin95	1.57E-02
Qmax95	2.35E-02
B	2.78E+01
Bmin99	2.80E+01
Bmax99	2.76E+01
Bmin95	2.73E+01
Bmax95	2.78E+01

Figure 49: Time series and trends statistics of annual Tavg in Sylhetdivision for monsoon

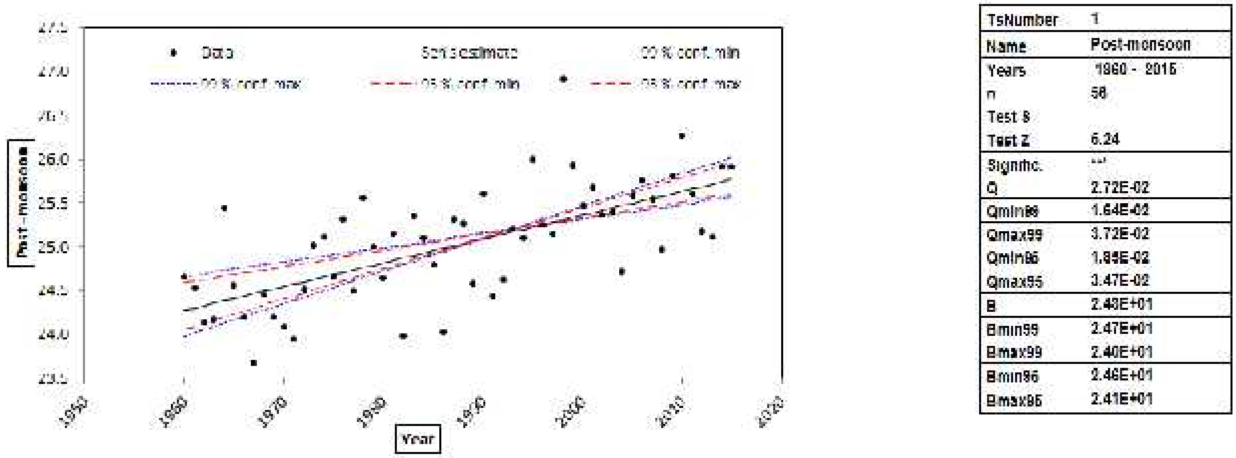


Figure 50: Time series and trends statistics of annual Tavg in Sylhet division for post-monsoon season

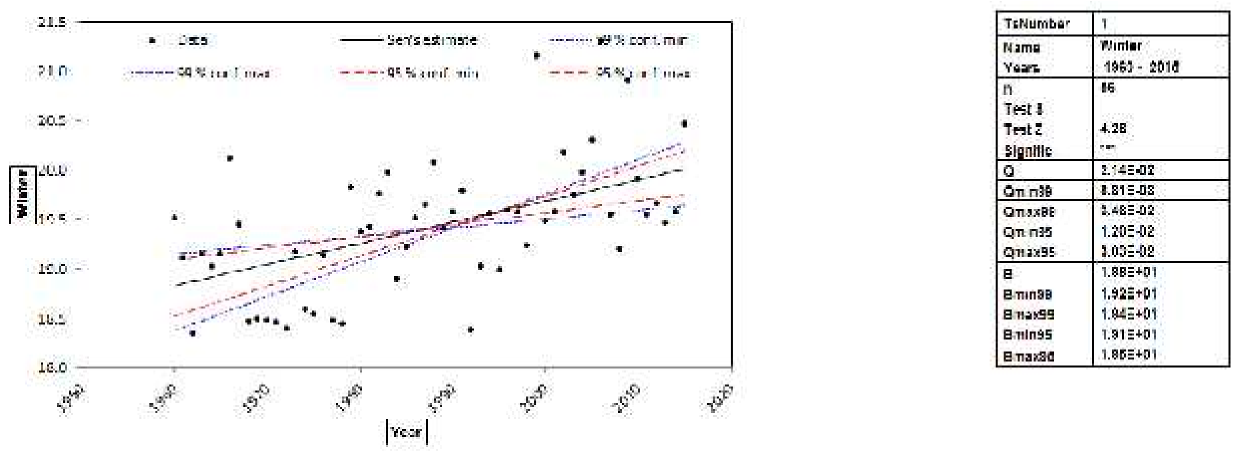


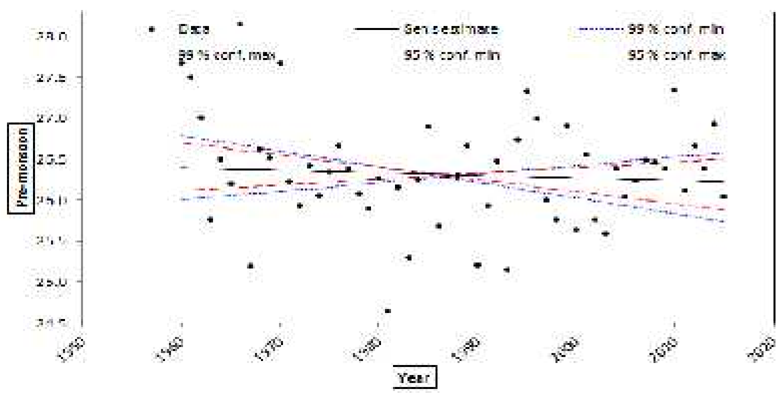
Figure 51: Time series and trends statistics of annual Tavg in Sylhet division for winter season

Table11: The significance level of the Mann-Kandell test for the pre-monsoon, monsoon, post monsoon and winter seasons in Sylhetdivision.

Season	Test Z value	Significantsymbol	Level of significance
Pre-monsoon	2.24	*	0.05
Monsoon	6.10	***	0.001
Post- monsoon	5.24	***	0.001
Winter	4.28	***	0.001

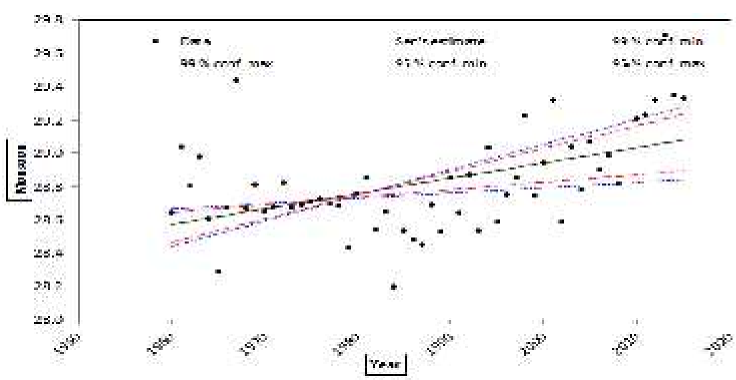
4.4.6Seasonal trends and variation of annual average temperature in Rangpur division

Seasonal trends and variation of annual average temperature (Tavg) in Rangpur divisionfor pre-monsoon, monsoon, post monsoon and winter seasons for the period,1960-2015 using Man-Kendall test. This test indicates that Tavg has increasing trends in pre-monsoon, monsoon and post-monsoon seasons, while decreasing trend in winter season. In pre-monsoon season the value of Z equal to -0.57 was not statistically significant (Figure 52).In monsoon season the value of Z equal to 3.85 was statistically significant(Figure 53).In post-monsoon season the value of equal to Z 1.75 was statistically significant(Figure 54).In winter season the value of Z equal to -1.86 was statistically not significant (Figure 55).The significance level of the Mann-Kendall test for the monsoon, post- monsoon seasons are given in the (Table12).



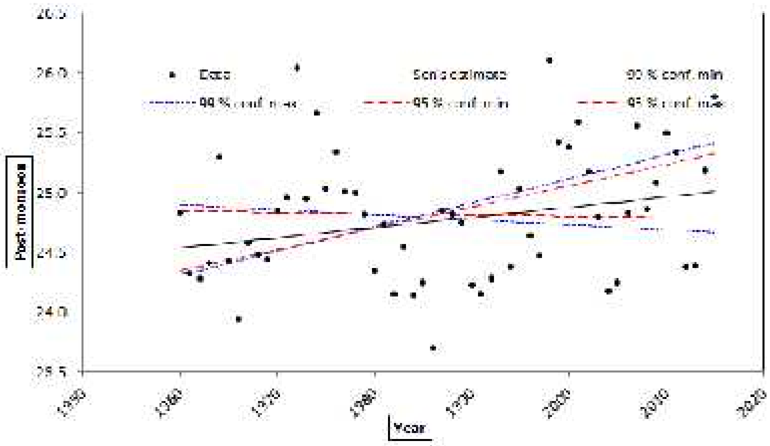
TsNumber	1
Name	Pre-monsoon
Years	1960 - 2016
n	56
Test S	
Test Z	-0.57
Signific.	
Q	-3.08E-03
Qmin99	-1.92E-02
Qmax99	1.05E-02
Qmin95	-1.50E-02
Qmax95	7.07E-03
B	2.64E+01
Bmin99	2.68E+01
Bmax99	2.60E+01
Bmin95	2.67E+01
Bmax95	2.61E+01

Figure 52: Time series and trends statistics of annual Tavg in Rangpur division for pre-monsoon (1960-2015)



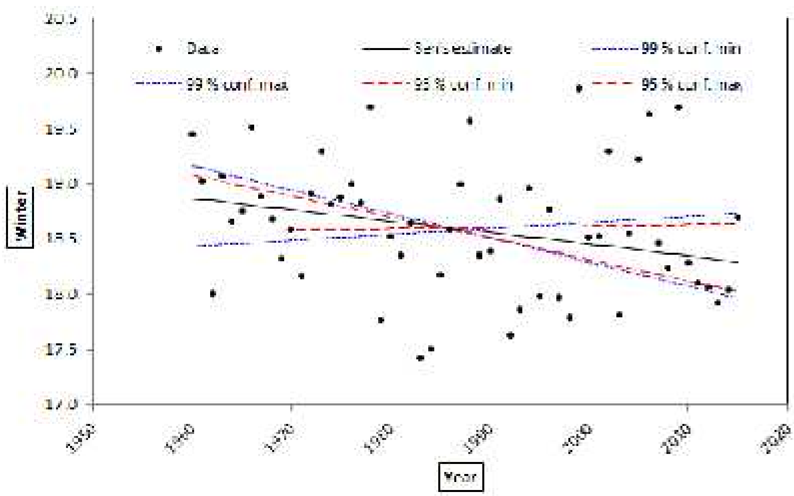
TsNumber	1
Name	Monsoon
Years	1960 - 2016
n	53
Test S	
Test Z	3.85
Signific.	***
Q	8.17E-03
Qmin99	3.18E-03
Qmax99	1.53E-02
Qmin95	4.48E-03
Qmax95	1.41E-02
B	2.88E+01
Bmin99	2.87E+01
Bmax99	2.84E+01
Bmin95	2.86E+01
Bmax95	2.80E+01

Figure 53: Time series and trends statistics of annual Tavg in Rangpur division for monsoon



TsNumber	1
Name	Post-monsoon
Years	1960 - 2016
n	58
Test S	
Test Z	1.76
Signific.	+
Q	8.66E-03
Qmin99	-4.20E-03
Qmax99	2.01E-02
Qmin95	-1.04E-03
Qmax95	1.78E-02
B	2.46E+01
Bmin99	2.49E+01
Bmax99	2.43E+01
Bmin95	2.48E+01
Bmax95	2.43E+01

Figure 54: Time series and trends statistics of annual Tavg in Rangpur division of post- monsoon



TsNumber	1
Name	Winter
Years	1960 - 2016
n	56
Test S	
Test Z	-1.86
Signific.	+
Q	-1.04E-02
Qmin99	-2.17E-02
Qmax99	5.50E-03
Qmin95	-1.81E-02
Qmax95	1.22E-03
B	1.88E+01
Bmin99	1.92E+01
Bmax99	1.84E+01
Bmin95	1.91E+01
Bmax95	1.86E+01

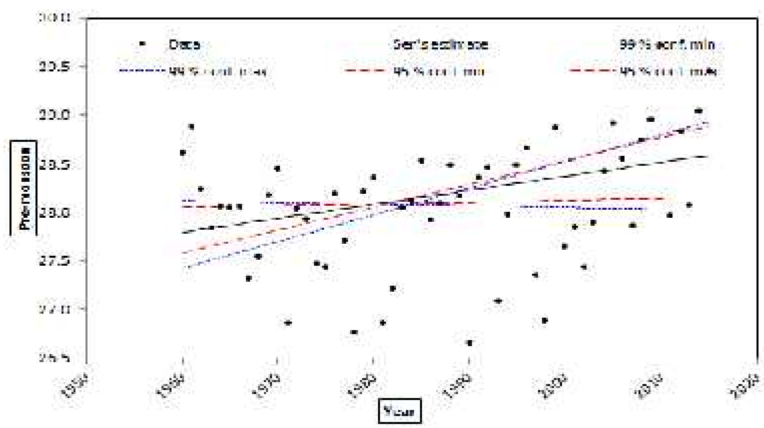
Figure 55: Time series and trends statistics of annual Tavg in Rangpur division for winter

Table12:The significance level of the Mann-Kandell test for monsoon, post-monsoon and winter seasons in Rangpur division.

Season	Test Z value	Significantsymbol	Level of significance
Monsoon	3.85	***	0.001
Post- monsoon	1.75	+	0.1
Winter	1.86	+	0.1

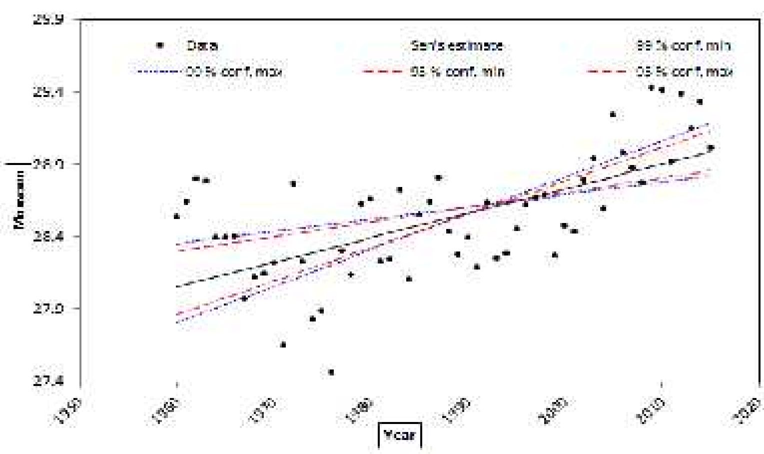
4.4.7Seasonal trends and variationof annual average temperature in Barisal division

Seasonal trends and variation of annual average temperature (Tavg) in Barisal division for pre-monsoon, monsoon, post- monsoon and winter seasons for the period,1960-2015 using Man-Kendall test.This test indicates that Tavg has increasing trends in pre-monsoon, monsoon, post-monsoon and winter seasons.In pre-monsoon season the value of Z equal to 2.31 was not statistically significant (Figure56).In monsoon season the value of Z equal to 4.77 was statistically significant(Figure57).In post-monsoon season the value of Z equal to 3.48 wasstatistically significant(Figure58).In winter season the value of Z equal to 0.81 which was statistically not significant (Figure59).The significance level of the Mann-Kendall test for the monsoon, post- monsoon seasons are given in the (Table13).



TsNumber	1
Name	Pre monsoon
Years	1960 - 2015
n	56
Test S	
Test Z	2.31
Signific.	[illegible]
Q	1.44E-02
Qmin99	-1.74E-03
Qmax99	2.75E-02
Qmin95	1.70E-03
Qmax95	2.38E-02
B	2.78E+01
Bmin99	2.81E+01
Bmax99	2.74E+01
Bmin95	2.80E+01
Bmax95	2.75E+01

Figure 56: Time series and trends statistics of annual Tavg in Barisal division for pre-monsoon



TsNumber	1
Name	Monsoon
Years	1960 - 2015
n	56
Test S	
Test Z	4.77
Signific.	**
Q	1.69E-02
Qmin99	8.57E-03
Qmax99	2.51E-02
Qmin95	1.02E-02
Qmax95	2.30E-02
B	2.81E+01
Bmin99	2.83E+01
Bmax99	2.78E+01
Bmin95	2.83E+01
Bmax95	2.79E+01

Figure 57: Time series and trends statistics of annual Tavg in Barisal division for monsoon

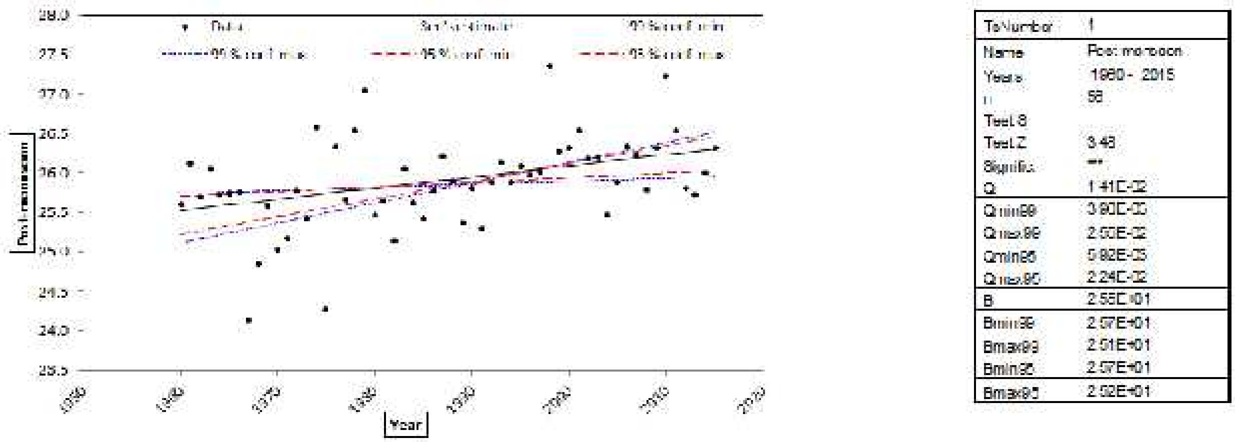


Figure 58: Time series and trends statistics of annual Tavg in Barisal division forpost-monsoon

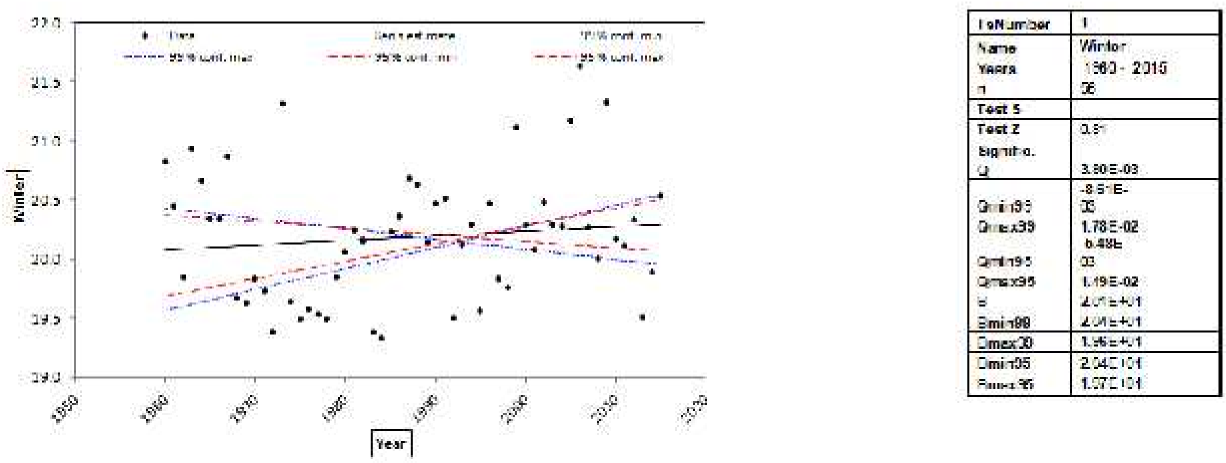


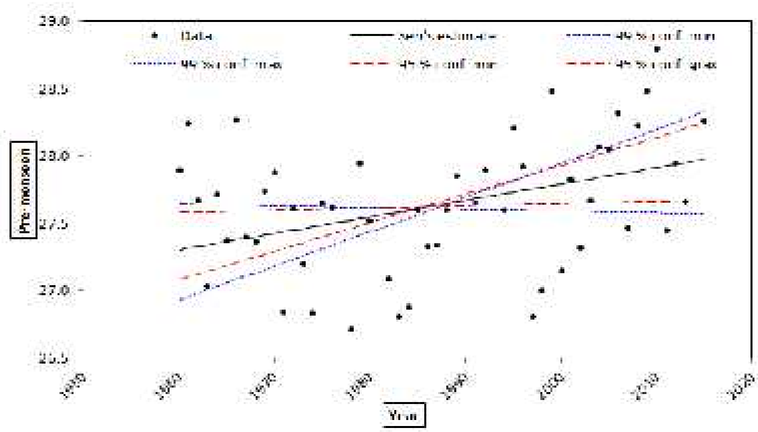
Figure 59: Time series and trends statistics of annual Tavg in Barisal division for winter

Table 13: The significance level of the Mann-Kendall test for the pre-monsoon, monsoon and post -monsoon seasons in Barisal division.

Season	Test Z value	Significantsymbol	Level of significance
Pre-monsoon	2.31	*	0.05
Monsoon	4.77	***	0.001
Post- monsoon	3.48	***	0.001

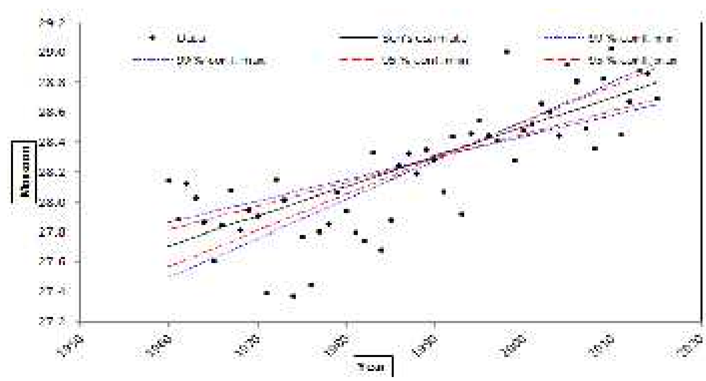
4.4.8 Seasonal trends and variation of annual average temperature in Chittagong division

Seasonal trends and variation of annual average temperature (Tavg) in Chittagong division for pre-monsoon, monsoon, post monsoon and winter seasons for the period, 1960-2015 using Man-Kandell test.This test indicates that Tavg has increasing trends in pre-monsoon, monsoon ,post-monsoon and winter seasons.In pre-monsoon season the value of Z equal to 2.25 was statistically significant (Figure 60).In monsoon season the value of Z equal to 6.44 was statistically significant(Figure 61).In post -monsoon season the value of Z equal to3.94 wasstatistically significant(Figure 62).In winter season thevalue of equal to Z 1.79 was statistically significant (Figure 63).The significance level of the Mann-Kandell test for the monsoon, post- monsoon seasons are given in (Table14).



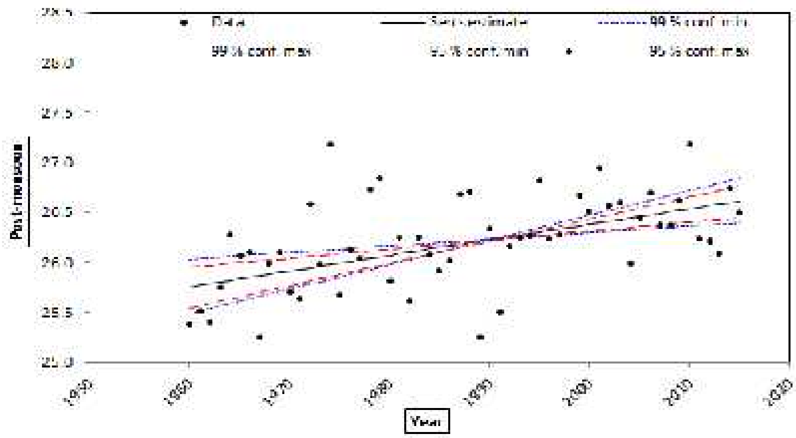
TsNumber	1
Name	Pre-monsoon
Years	1980 - 2015
n	58
Test S	
Test Z	2.25
Signific.	*
Q	1.22E-02
Qmin95	-1.26E-03
Qmax99	2.84E-02
Qmin95	1.67E-03
Qmax95	2.12E-02
B	2.73E+01
Bmin95	2.78E+01
Bmax99	2.89E+01
Bmin95	2.78E+01
Bmax95	2.71E+01

Figure 60: Time series and trends statistics of annual Tavg in Chittagong division for pre-monsoon



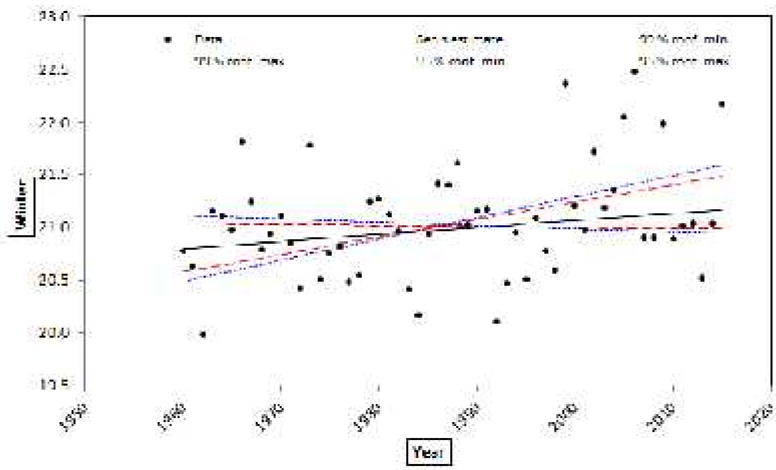
TsNumber	1
Name	Monsoon
Years	1960 - 2015
n	53
Test S	
Test Z	6.44
Signific.	***
Q	1.98E-02
Qmin99	1.43E-02
Qmax99	2.61E-02
Qmin95	1.69E-02
Qmax95	2.41E-02
B	2.77E+01
Bmin99	2.79E+01
Bmax99	2.76E+01
Bmin95	2.78E+01
Bmax95	2.76E+01

Figure 61: Time series and trends statistics of annual Tavg in Chittagong division formonsoon



TsNumber	1
Name	Post-monsoon
Years	1960 - 2015
n	56
Test S	
Test Z	3.94
Signific.	***
Q	1.06E-02
Qmin99	5.68E-03
Qmax99	2.48E-02
Qmin95	8.01E-03
Qmax95	2.22E-02
B	2.58E+01
Bmin99	2.60E+01
Bmax99	2.55E+01
Bmin95	2.60E+01
Bmax95	2.56E+01

Figure 62: Time series and trends statistics of annual Tavg in Chittagong division for post-monsoon



TsNumber	1
Name	Winter
Years	1960 - 2015
n	56
Test S	
Test Z	1.80
Signific.	+
Q	5.59E-03
Qmin99	-3.06E-03
Qmax99	2.00E-02
Qmin95	-9.84E-04
Qmax95	1.64E-02
B	2.08E+01
Bmin99	2.11E+01
Bmax99	2.06E+01
Bmin95	2.10E+01
Bmax95	2.06E+01

Figure 63: Time series and trends statistics of annual Tavg in Chittagong division for winter

Table 14: The significance level of the Mann-Kandell test for the Pre-monsoon, monsoon, post monsoon and winter seasons in Chittagong division

Season	Test Z value	Significant symbol	Level of significance
Pre-monsoon	2.25	*	0.05
Monsoon	6.44	***	0.001
Post- monsoon	3.94	***	0.001
Winter	1.79	+	0.1

4.5.1AnnualTotal Rainfall in Khulna Division

The annual total rainfall showed increasing trends in Khulna, Jessore and Satkhira over the study period, 1960 to 2015 in Khulna division. Annual total rainfall in Khulna was increasing at the rate of 4.960 mm/year with its total rainfall of 1630 mm and coefficient of determination 0.050(Figure 64). The increasing trend of total rainfall in Khulna was not significant. (Table15). There was inter-annual fluctuation in total rainfall; where standard deviation and coefficient of variation of total rainfall in Khulna were ± 355.761 and 20.081% respectively (Table16).

Annual total rainfall in Jessore was increasing at the rate of 3.682 mm/year with its total rainfall of 1531 mm and coefficient of determination 0.0386 (Figure 64). The increasing trend of total rainfall in Jessore was not significant (Table15).There was inter-annual fluctuation in total rainfall; standard deviation and coefficient of variation of total rainfall in Jessore was ± 302.845and 18.509% respectively (Table16).

Annual total rainfall in Satkhira was increasing at the rate of 1.580 mm/year with its total rainfall of 1652 mm and coefficient of determination 0.008 (Figure 64). The increasing trend of total rainfall in Satkhira was not significant. (Table15). There was inter-annual fluctuation in total rainfall; standard deviation and coefficient of variation of total rainfall in Satkhira were ± 286.309 and 16.864% respectively (Table16).

Increasing trend of annual total rainfall in Khulna, Jessore and Satkhirawere not significant in Khulna division.

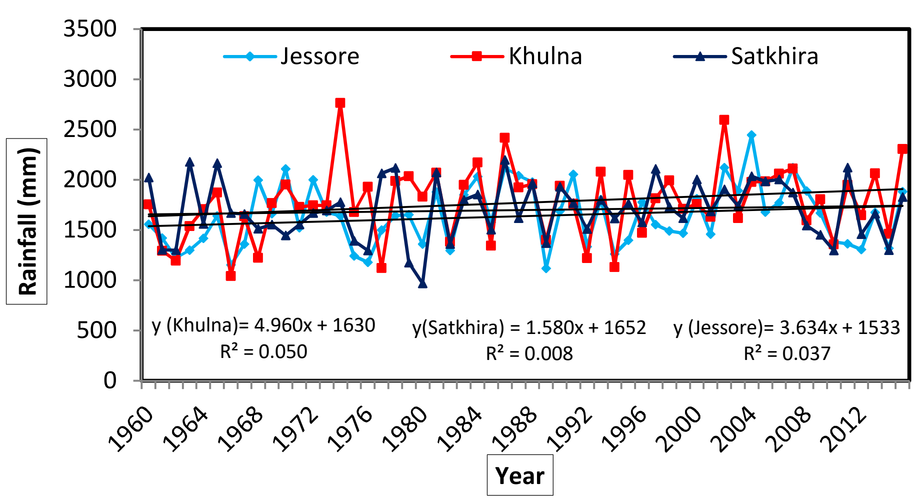


Figure 64: Temporal annual total rainfall in Khulna division.

4.5.2AnnualTotal Rainfall in Dhaka Division

The annual total rainfall showed decreasing trend in Dhaka over the study period, 1960 to 2015 in Dhaka division. Annual total rainfall in Dhaka was decreasing at the rate of -2.009 mm/year with its total rainfall of 2094 mm and coefficient of determination 0.007 (Figure65). The decreasing trend of total rainfall in Dhakawas not significant. (Table15). There was inter-annual fluctuation in total rainfall; standard deviation and coefficient of variation of total rainfall in Dhaka were ±384.610and 18.878% respectively (Table16).

Annual total rainfall in Faridpur was decreasingat the rate of -2.049 mm/year with its total rainfall of 1849 mm and coefficient of determination 0.008 (Figure 65). The decreasing trend of total rainfall in Faridpur was not significant. (Table15) .There was inter-annual fluctuation in total rainfall; standard deviation and coefficient of variation of total rainfall in Faridpur were ±359.521 and 20.069% respectively (Table16).

In Dhaka and Faridpur decreasing trends of annual total rainfall werenot significant in Dhaka division.

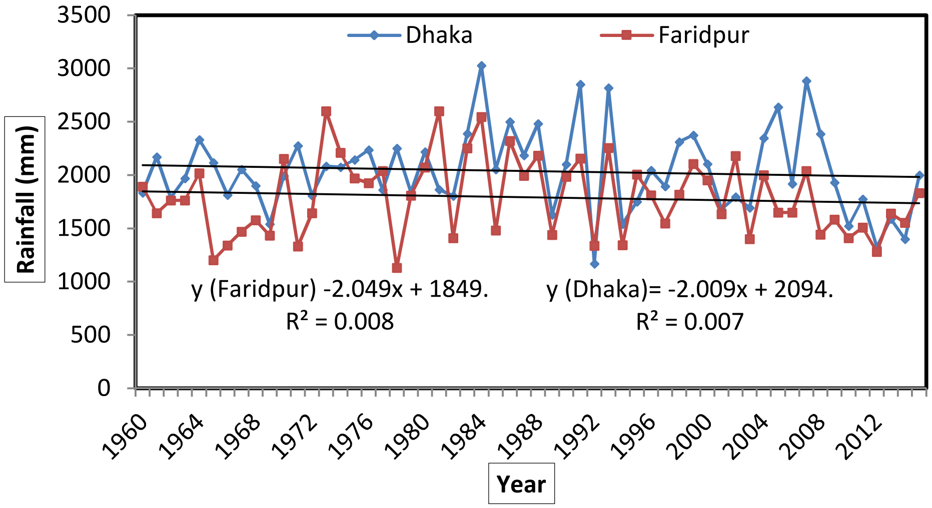


Figure 65: Temporal annual total rainfall in Dhaka division.

4.5.3AnnualTotal Rainfall in Rajshahi Division

The annual total rainfall showed increasing trends in Bogra over the study period, 1960 to 2015 in Rajshahi division.Annual total rainfall in Bogra was increasing at the rate of 2.7517 mm/year with its total rainfall of 1608 mm and coefficient of determination 0.0134 (Figure 66). The increasing trend of total rainfall in Bogra was not significant (Table15).There was inter-annual fluctuation in total rainfall; standard deviation and coefficient of variation of total rainfall in Bogra were ±391.371 and 23.206% respectively (Table16).

In Bogra increasing trend of annual total rainfall was not significant in Rajshahi division.

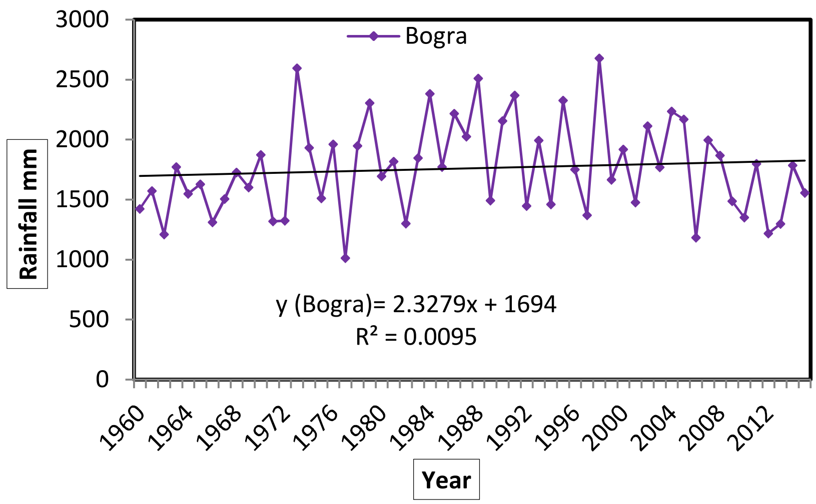


Figure 66: Temporal annual total rainfall in Rajshahi division.

4.5.4 AnnualTotal Rainfall in Mymensingh Division

The annual total rainfall showed increasing trend in Mymensingh over the study period, 1960 to 2015 in Mymensingh division .Annual total rainfall in Mymensingh was increasing at the rate of 2.2836 mm/year with its total rainfall of 2098 mm and coefficient of determination 0.006 (Figure 67). The increasing trend of total rainfall in Mymensingh was not significant (Table15). There was inter-annual fluctuation in total rainfall; standard deviation and coefficient of variation of total rainfall in Mymensingh were ±475.964and 22.006% respectively (Table16).In Mymensingh increasing trend of annual total rainfall was not significant in Mymensingh division.

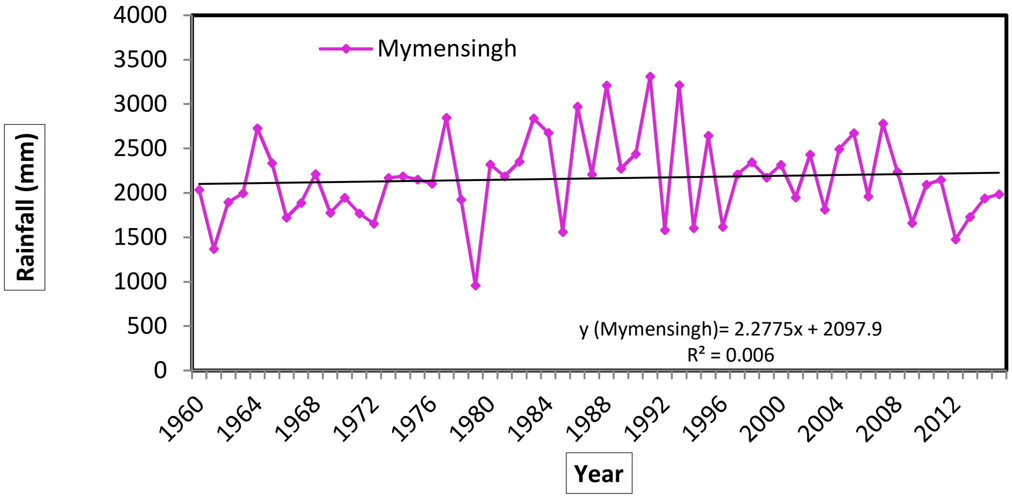


Figure 67: Temporal annual total rainfall in Mymensingh division.

4.5.5 AnnualTotal Rainfall in Sylhet Division

The annual total rainfall showed increasing trend in Sylhet and Srimongal over the study period, 1960 to 2015 in Sylhet division. Annual total rainfall in Sylhet was increasing at the rate of 3.3107 mm/year with its total rainfall of 3896 mm and coefficient of determination 0.0064 (Figure 68). The increasing trend of total rainfall in Sylhet was not significant (Table15).There was inter-annual fluctuation in total rainfall; standard deviation and coefficient of variation of total rainfall in Sylhet were ± 669.545and 16.778 % respectively (Table16).

Annual total rainfall in Srimongal was increasing at the rate of 2.0103mm/year with its total rainfall of 2239mm and coefficient of determination 0.005 (Figure 68). The increasing trend of total rainfall in Srimongalwas not significant. (Table15). There was inter-annual fluctuation in total rainfall; standard deviation and coefficient of variation of total rainfall in Srimongal were ±458.095and 19.949% respectively (Table16).

Increasing trends of annual total rainfall in Sylhet and Srimongalwere not significant in Sylhet division.

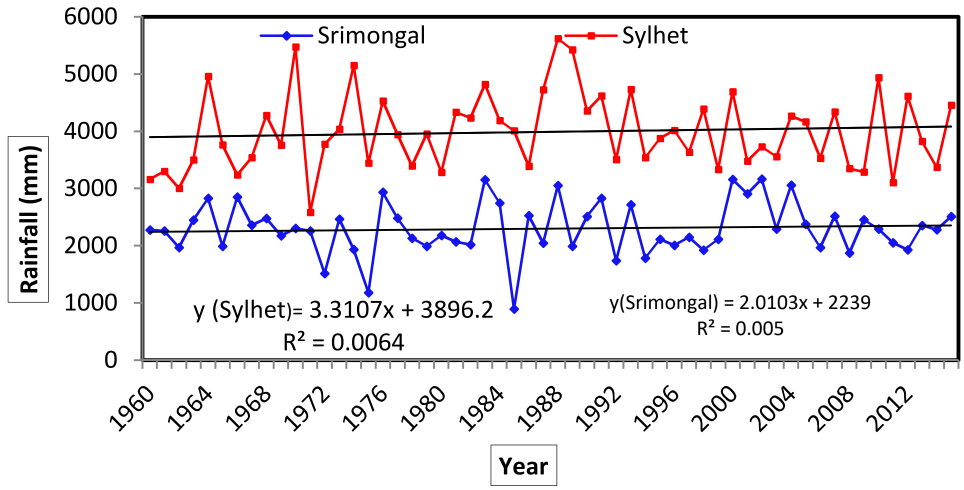


Figure 68: Temporal annual total rainfall in Sylhet division.

4.5.6 AnnualTotal Rainfall in Rangpur Division

The annual total rainfall showed increasing trend in Rangpur and Dinajpur over the study period, 1960 to 2015 in Rangpur division. Annual total rainfall in Rangpurwas increasing at the rate of 7.452mm/year with its total rainfall of 1927 mm and coefficient of determination 0.0645(Figure 69). The increasing trend of total rainfall in Rangpur was not significant (Table15). There was inter-annual fluctuation in total rainfall; standard deviation and coefficient of variation of total rainfall in Rangpur were ± 474.282 and 22.164% respectively (Table16).

Annual total rainfall in Dinajpur was increasing at the rate of 3.7258 mm/year with its total rainfall of 1803.7mm and coefficient of determination 0.0213 (Figure 69). The increasing trend of total rainfall in Dinajpur was not significant. (Table15). There was inter-annual fluctuation in total rainfall; standard deviation and coefficient of variation of total rainfall in Dinajpur were ±412.821 and 21.614% respectively (Table16).

Increasing trends of annual total rainfall in Rangpur and Dinajpur were not significant in Rangpur division.

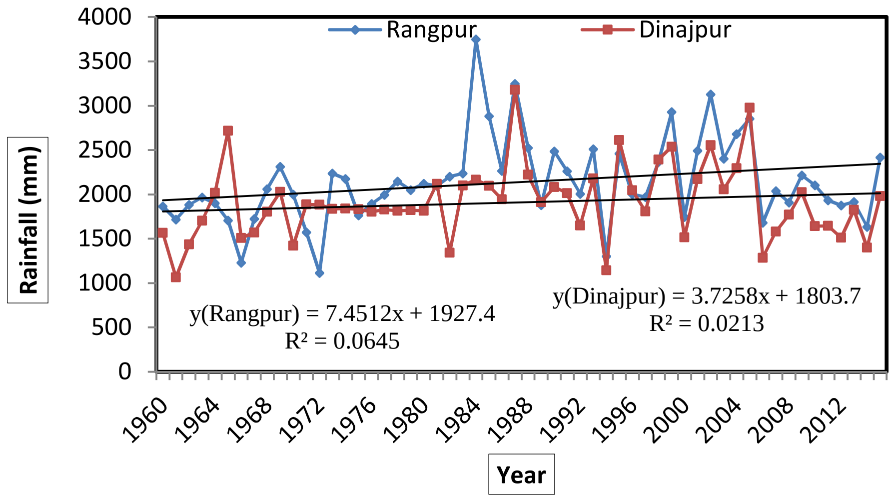


Figure 69: Temporal annual total rainfall in Rangpur division.

4.5.7 AnnualTotal Rainfall in Barisal Division

The annual total rainfall showed decreasing trend in Barisal over the study periods 1960 to 2015 in Barisal division. Annual total rainfall in Barisal was decreasing at the rate of -1.985 mm/year with its total rainfallof 2137mm and coefficient of determination 0.0062 (Figure 70). The decreasing trend of total rainfall in Barisal was not significant (Table15). There was inter-annual fluctuation in total rainfall; standard deviation and coefficient of variation of total rainfall in Barisal were ±408.747 and 19.647% respectively (Table16).

In Barisal division decreasing trend of annual total rainfall was not significant in Barisal division.

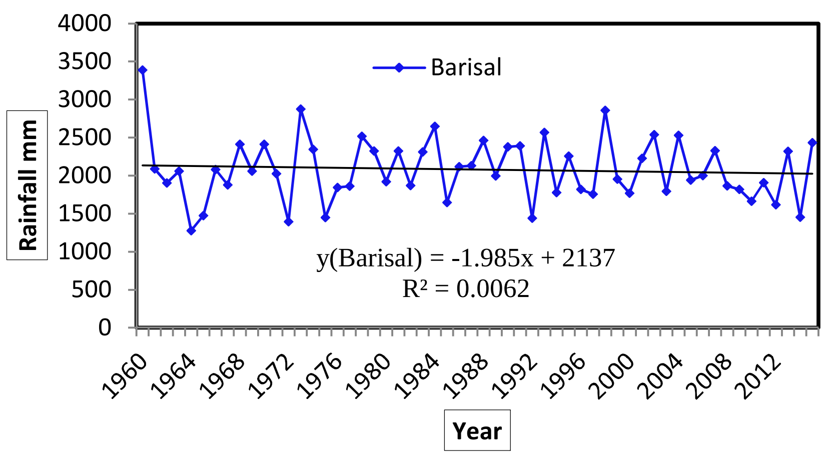


Figure 70: Temporal annual total rainfall in Barisal division.

4.5.8 AnnualTotal Rainfall in Chittagong Division

The annual total rainfall showed increasing trends in Chittagong, Rangamati,Cox's Bazarand decreasing trends in Comilla and M. Court over the study period, 1960 to 2015 in Chittagong division. Annual total rainfall in Chittagong was increasing at the rate of 10.397mm/year with its total rainfall of 2568mm(Figure 71).In Chittagong the increasing trend of total rainfallhas coefficient of determination 0.1143 which was significant at 95%significance (Table15).). There was inter-annual fluctuation in total rainfall; standard deviation and coefficient of variation of total rainfall in Chittagong were ± 497.150and 17.358% respectively (Table16).

Annual total rainfall in Rangamati was increasing at the rate of 2.5971mm/year with its total rainfall of 2442 mm and coefficient of determination 0.0067 (Figure 71). The increasing trend of total rainfall in Rangamatiwas not significant (Table15).There was inter-annual fluctuation in total rainfall; standard deviation and coefficient of variation of total rainfall in Rangamati were ± 514.354and 20.442% respectively (Table16).

Annual total rainfall in Cox's Bazar was increasing at the rate of 2.0551mm/year with its total rainfall of 3685 mm and coefficient of determination 0.0213 (Figure 71). The increasing trend of total rainfall in Cox's Bazarwas not significant (Table15).There was inter-annual fluctuation in total rainfall; standard deviation and coefficient of variation of total rainfall inCox's Bazarwere ±582.155and 15.552% respectively (Table16).

Annual total rainfall in Comilla was decreasing at the rate of -5.2992 mm/year with its total rainfall of 2244 mm and coefficient of determination 0.0402 (Figure 71). The decreasing trend of total rainfall in Comilla was not significant (Table15). There was inter-annual fluctuation in total rainfall; standard deviation and coefficient of variation of total rainfall in Comilla were ±427.070 and20.400% respectively (Table16).

Annual total rainfall in M. Court was decreasingat the rate of -0.3051mm/year with its total rainfall of 3075 mm and coefficient of determination 0.0001 (Figure 71). The decreasing trend of total rainfall in M. Court was not significant. (Table15). There was inter-annual fluctuation in total rainfall; standard deviation and coefficient of variation of total rainfall in M. Court were ±474.631 and15.479% respectively (Table16).

Increasing trends of annual total rainfall Rangamati andCox's Bazar were not significant while Chittagong was significant in Chittagongdivision. Anddecreasing trends of annual total rainfall Comilla andM. Court werenot significant in Chittagong division.

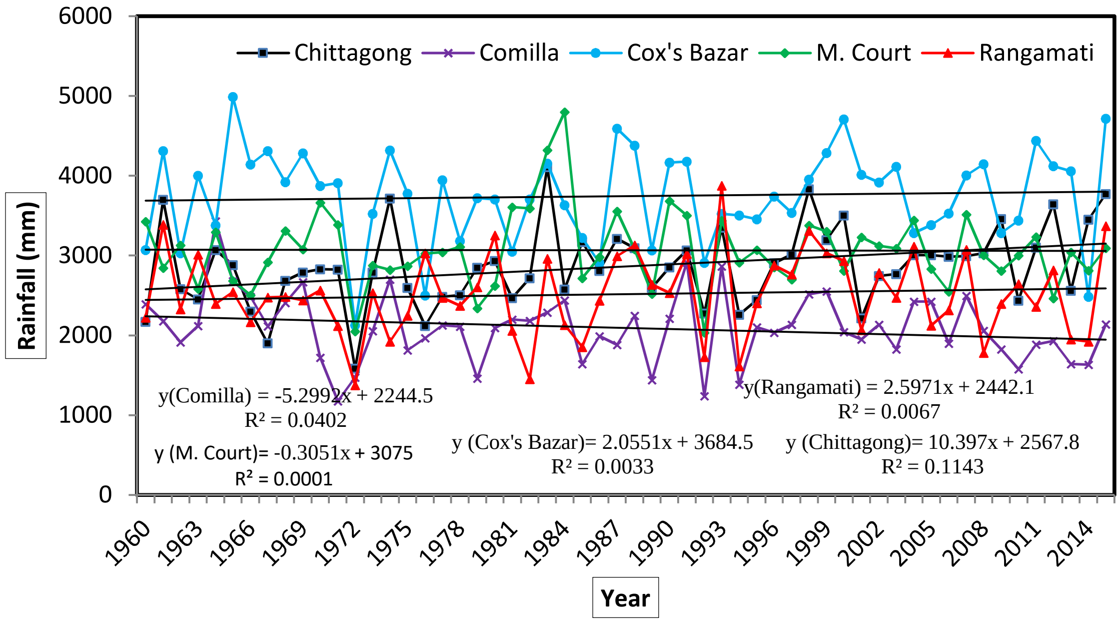


Figure 71: Temporal annual total rainfall in Chittagong division.

4.5.9. Comparison of annualtotal rainfall among all divisions

The annual total rainfall showed increasing trends in Khulna, Rajshahi, Sylhet, Rangpur and Chittagong divisions while decreasing trends in Barisal and Dhaka over the study period, 1960 to 2015 (Figure 72).Annual total rainfall in Khulna was increasing at the rate of 3.392 mm/year with its total rainfall of 1606 mm and coefficient of determination was 0.0447(Figure 72). The increasing trend of total rainfall in Khulna was not significant (Table15).There was inter-annual fluctuation in total rainfall; standard deviation and coefficient of variation of total rainfall in Khulna were ±250.936and 14.741% respectively (Table16).

Annual total rainfall in Dhaka was decreasing at the rate of -2.0292 mm/year with its total rainfall of 1972 mm and coefficient of determination was 0.0102 (Figure 72). The decreasing trend of total rainfall in Dhaka was not significant (Table15).There was inter-annual fluctuation in total rainfall; standard deviation and coefficient of variation of total rainfall in Dhaka were ±324.758and16.964% respectively (Table16).

Annual total rainfall in Rajshahi was increasing at the rate of 2.3279 mm/year with its total rainfall of 1694 mm and coefficient of determination was 0.0095 (Figure 72). The increasing trend of total rainfall in Rajshahi was not significant (Table15).There was inter-annual fluctuation in total rainfall; standard deviation and coefficient of variation of total rainfall in Rajshahi were ±386.266% and 21.942% respectively (Table16).

Annual total rainfall in Mymensingh was increasing at the rate of 2.283 mm/year with its total rainfall of 2097 mm and coefficient of determination was 0.006 (Figure 72). The increasing trend of total rainfall in Mymensingh was not significant (Table15).There was inter-annual fluctuation in total rainfall; standard deviation and coefficient of variation of total rainfall in Mymensingh were ±475.129 and 21.968% respectively (Table16).

Annual total rainfall in Rangpur was increasing at the rate of 5.5885 mm/year with its total rainfall of 1866 mm and coefficient of determination was 0.0495 (Figure 72). The increasing trend of total rainfall in Rangpur was not significant (Table15).There was inter-annual fluctuation in total rainfall; standard deviation and coefficient of variation of total rainfall in Rangpur were ±406.097and20.055% respectively (Table16).

Annual total rainfall in Chittagong was increasing at the rate of 1.889 mm/year with its total rainfall of 2803 mm and coefficient of determination was 0.0081 (Figure72). The increasing trend of total rainfall in Chittagong was significant at 95% level of significance (Table15). There was inter-annual fluctuation in total rainfall; standard deviation and coefficient of variation of total rainfall in Chittagong were ± 338.472and 11.848% respectively (Table16).

Annual total rainfall in Sylhet was increasing at the rate of 2.6605 mm/year with its total rainfall of 3038 mm and coefficient of determination was 0.009 (Figure72). The increasing trend of total rainfall in Sylhet was not significant (Table15). There was inter-annual fluctuation in total rainfall; standard deviation and coefficient of variation of total rainfall in Sylhet were±453.336and 14.42%respectively (Table16).

Annual total rainfall in Barisal was decreasing at the rate of -1.985 mm/year with its total rainfall of 2137 mm and coefficient of determination was 0.0062 (Figure 72). The decreasing trend of total rainfall in Barisal was not significant. (Table15). There was inter-annual fluctuation in total rainfall; standard deviation and coefficient of variation of total rainfall in Barisal were ±408.747and19.647% respectively (Table16).

Increasing trends of Total rainfall in Mymensingh, Rangpur, Khulna, Chittagong, Rajshahi and Sylhet divisions were not significant and decreasing trends of Total rainfall Barisal and Dhaka were not significant in Bangladesh.

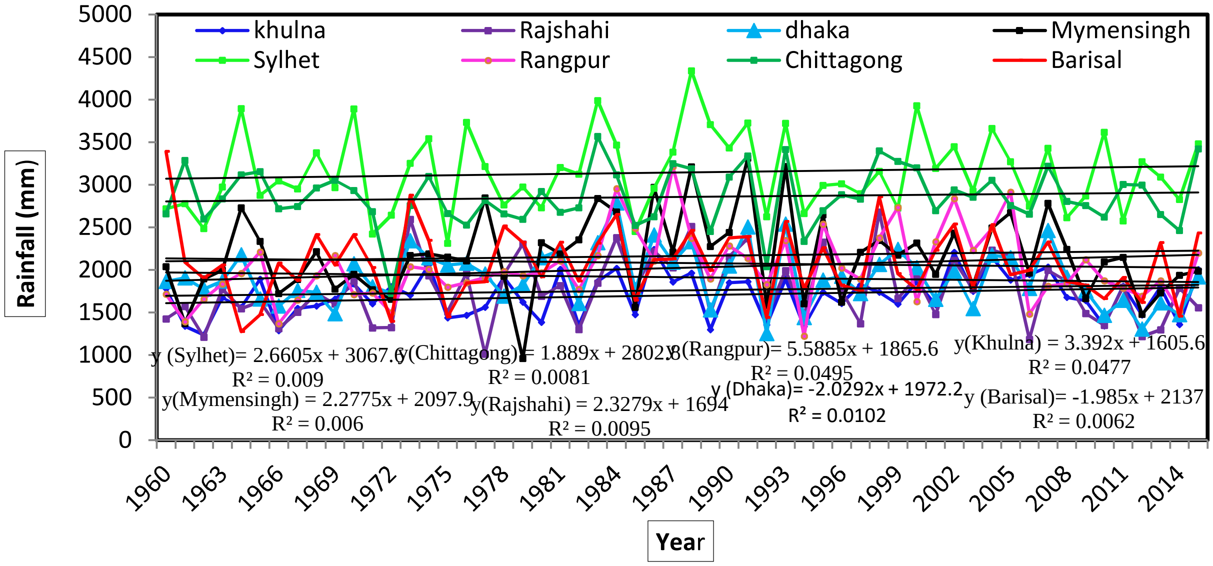


Figure 72: Comparison of temporal annual total rainfall in all divisions.

*Significant at 0.05 level of significance

Table15: Regression equation of trend lines for Total Rainfall

Station/ division	Regression equation with R^2	Correlation of coefficient r
Khulna	y =3.634x + 1533 , $R^2 = 0.037$	0.192354
Jessore	y= 1.580x + 1652, $R^2 = 0.008$	0.089443
Satkhira	y = 2.751x + 1608 , $R^2 = 0.013$	0.097468
Bogra	y= 2.3279x + 1694,$R^2 = 0.0095$	0.0974680
Dhaka	y = -2.009x + 2094 , $R^2 = 0.007$	0.083666
Faridpur	y =-2.049x + 1849 , $R^2 = 0.008$	0.089443
Mymensingh	y = 2.283x + 2097 , $R^2 = 0.006$	0.07746
Srimongal	y = 2.0103x + 2239 , $R^2 = 0.005$	0.070711
Sylhet	y = 3.3107x + 3896.2 , $R^2 = 0.0064$	0.08
Dinajpur	y= 3.7258x + 1803.7 , $R^2 = 0.0213$	0.145945
Rangpur	y = 7.4512x + 1927.4 , $R^2 = 0.0645$	0.253969
Chittagong	y =10.397x + 2567.8 , $R^2 = 0.1143$	0.338083*
Comilla	y = -5.2992x + 2244.5, $R^2 = 0.0402$	0.200499
Rangamati	y = 2.5971x + 2442.1, $R^2 = 0.0067$	0.081854
Cox's bazar	y = 2.0551x + 3684.5 , $R^2 = 0.0033$	0.057446
M. Court	y = -0.3051x + 3075 , $R^2 = 0.0001$	0.01
Barisal	y = -1.985x + 2137 , $R^2 = 0.0062$	0.07874
Khulna division	y= 3.392x + 1605.6 , $R^2 = 0.0477$	0.218403
Dhaka division	y =-2.0292x + 1972.2, $R^2 = 0.0102$	0.100995
Rajshahi division	y= 2.3279x + 1694,$R^2 = 0.0095$	0.0974680
Mymensingh division	y = 2.283x + 2097 , $R^2 = 0.006$	0.07746
Sylhet division	y =2.6605x + 3067.6, $R^2 = 0.009$	0.094868
Rangpur division	y = 5.5885x + 1865.6, $R^2 = 0.0495$	0.222486
Chittagong division	y= 1.889x + 2802.8, $R^2 = 0.0081$	0.09
Barisal division	y= -1.985x + 2137, $R^2 = 0.0062$	0.07874

Table 16: Variability of Annual Total Rainfall

Station/District	Standard Deviation	Coefficient of Variation%
Khulna	± 355.761	20.081
Jessore	± 302.845	18.509
Satkhira	± 286.309	16.864
Bogra	±391.371	23.206
Dhaka	±384.610	18.878
Faridpur	±359.521	20.069
Mymensingh	±475.784	22.006
Srimongal	±458.095	19.949
Sylhet	± 669.545	16.778
Dinajpur	±412.821	21.614
Rangpur	± 474.282	22.164
Chittagong	± 497.150	17.358
Comilla	±427.070	20.400
Rangamati	± 514.354	20.442
Cox’s bazar	±582.155	15.552
M.Court	±474.631	15.479
Barisal	±408.747	19.647
Khulna Division	±250.936	14.741
Dhaka Division	±324.758	16.964
Rajshahi Division	±386.266	21.942
Mymensingh Division	±475.7849	22.006
Sylhet Division	±453.336	14.421
Rangpur Division	±406.097	20.055
Chittagong Division	±338.472	11.848
Barisal Division	±408.747	19.647

4.5.10 Distribution of coefficient of variation for annual total rainfall

Distribution of coefficient of variation for annual average temperature of the country is shown in (Figure 73) using the data from the (Table 16). It's indicates the amount of variability relative to the mean value of annual average maximum temperature of the station of the country. So, it is easy way to understand the change of average temperature of specific region/station of the country. From the figure, it is seen that the some portion of northeastern, some portion of northwesternand center of the country has maximum coefficient of variation and the maximum value was 23.21% atBogra region .The some portion of northeastern, southeastern and has minimum coefficient variation and the minimum value was 15.48 % at M.Courtregion .The coefficient of variation has been found to decrease from center towards northeastern hilly region, southeastern andsouthwest of the country. The coefficient of variation has been found to increase from center towards some portion of northern region of the country.

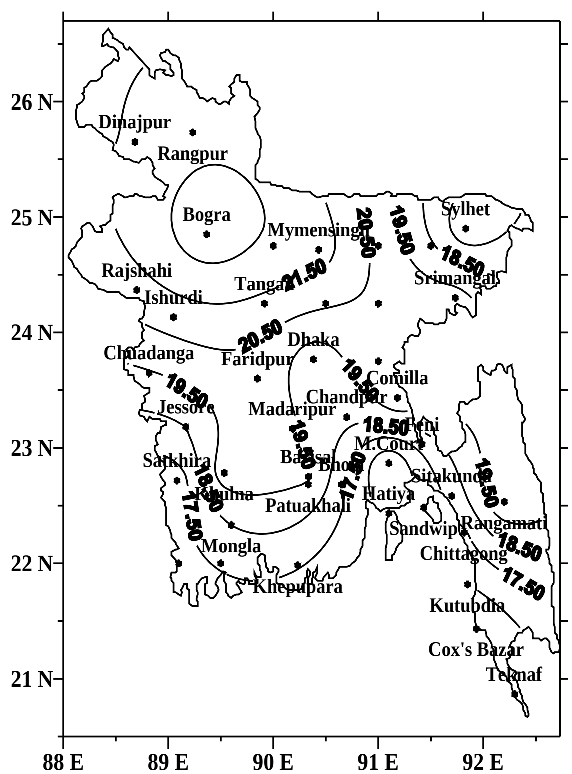


Figure 73: Distribution of coefficient of variation for annual total rainfall

Chapter 5

Conclusions

Climatic data collected from Bangladesh Meteorological Department was used for the study. The regression equations, the coefficient of determination, standard deviation and coefficient of variation were calculated for the analysis. Mann-Kendall test for trend and Sen's slope estimates were also calculated.

- Annual average temperature (Tavg) in all division is increasing. The Tavg in Khulna is increasing by 0.007 °C/year, in Dhaka it is increasing by 0.021 °C/year. The average temperature has also an increasing trend in other divisionsand the rates are 0.011^{0}C/year in Rajshahi, 0.019 °C/year in Sylhet, 0.0001 °C/year in Rangpur, 0.013 °C/year in Chittagong, 0.012 °C/year in Barisal and 0.003 °C/year in Mymensingh.
- Annual maximum temperature (Tmax) has an increasing trend in Khulna, Dhaka, Rajshahi, Sylhet, Barisal and Chittagong divisions while it has decreasing trend in Rangpur and Mymensingh divisions. The Tmax in Khulna is increasing by 0.01 °C/year, in Dhaka it is increasing by 0.0179 °C/year. And the maximum temperature has also an increasing trend in Rajshahi, Sylhet, Chittagong and Barisal divisions. The rates of increase are 0.006 °C/year in Rajshahi, 0.018 °C/year in Sylhet, 0.020 °C/year in Chittagong and 0.0178 °C /year in Barisal divisions. Whereas the maximum temperature has a decreasing trend at -0.014 °C/year and -0.004 °C/year in Rangpur and Mymensingh divisions respectively.
- Annual minimum temperatures (Tmin) in all divisions are increasing. The Tmin in Khulna is increasing by 0.0058 °C/year, in Dhaka it is increasing by 0.024 °C/year. The minimum temperature has also an increasing trend in other divisions and the rates are 0.016 °C/year in Rajshahi, 0.021 °C/year in Sylhet, 0.015 °C/year in Rangpur, 0.007 °C/year in Chittagong, 0.006 °C/year in Barisal and 0.010 °C/year in Mymensingh.
- The Mann-Kendall test indicates that in Khulna division Tavg has an increasing trend in monsoon and post monsoon seasons with value of Z 6.31and 2.52 which are statistically significant. This test also indicates that in Dhaka division, it has an increasing trend in pre-monsoon, monsoon, post monsoon and winter seasons with value of Z 2.75, 6.23, 5.60 and 4.62 respectively which are statistically significant. In Rajshahi division, it has an increasing trend in monsoon season with value of Z 6.25 which is statistically significant. In Sylhet division, it has an increasing trend in pre-monsoon, monsoon, post monsoon and winter seasons with Z values of 2.24, 6.10, 5.24 and 4.60 respectively which are statistically significant. In Rangpur division, it has an increasing trend in monsoon while decreasing trend in winter seasons with values Z of 3.85 and -1.86 which are statistically significant. In Barisal division, it has an increasing trend in Monsoon and Post- monsoon seasons with Z values of are 4.77 and 3.48 which is statistically significant. In Chittagong division, it has an increasing trend in pre-monsoon, monsoon,

post-monsoon and winter seasons with Z values of 2.25, 6.44, 3.94 and 1.79 respectively which are statistically significant. In Mymensingh division, it has an increasing trend in monsoon season with Z value of 5.11 which is statistically significant. Annual total rainfall has an increasing trend in Khulna, Rajshahi, Sylhet, Chittagong, Rangpur and Mymensingh divisionswhile decreasing trend in Dhaka and Barisal divisions. The total rainfall has an increasing trend in Khulna by 3.392 mm/year, in Rajshahi it is increasing by 2.3279 mm/year.

- The total rainfall has also an increasing trend in Sylhet, Rangpur, Chittagong and Mymensingh divisions. The rates are 2.6605 mm/year in Sylhet, 5.5885 mm/year in Rangpur, 1.889 mm/year in Chittagong and 2.283 mm/year in Mymensingh division. Whereas the total rainfall has a decreasing trends (-2.0292 mm/year) in Dhaka and (-1.985 mm/year) in Barisal division. The results suggest that temperature and rainfall are increasing in most of the stations and divisions.

References:

Ahmed, A.U. and Haque, N., 2002: Climate Change and Sustainable Development. Paper presented at the Dhaka Meet on Sustainable Development, March 14-18, 2002.Incorporated in Q.K. Ahmad and A.U. Ahmed (eds.), Citizens' Perspectives on Sustainable Development, Bangladesh Unnayan Parishad (BUP).

Ali MM, Ahmed M, Talukder MSU and Hye M A 1994: Rainfall distribution and agricultural droughts influencing cropping pattern at Mymensingh region. Progressive Agriculture, 5: 197-204.

Basak, J. K, Titumi, R. A. M. and Dev, N. C., 2013: Climate Change in Bangladesh: A Historical Analysis of Temperature and Rainfall Data, Journal of Environment (2013), Vol. 02, Issue 02, pp. 41-46

BCAS 2009: Policy Study on The Probable Impacts of Climate Change on Poverty and Economic Growth and the Options of Coping with Adverse Effect of Climate Change in Bangladesh, Support to Monitoring PRS and MDGs in Bangladesh, General Economics Division, Planning Commission, Government of the People's Republic of Bangladesh and UNDP Bangladesh.

Banglapedia 2004: National Encyclopedia of Bangladesh .Asiatic Society of Bangladesh. 5 Old Secretariat Road Nimtali, Dhaka-1000.

Banglapedia 2006: National Encyclopedia of Bangladesh. Dhaka: Asiatic Society of Bangladesh.

BBS (Bangladesh Bureau of Statistics) 2002: Year Book of Agricultural Statistics of Bangladesh. Stat. Div. Minis. Planning Govt.People's Repub. Bangladesh.

Choudhury AM, Haque MA and Quadir DA 1997: Consequences of global warming and sea level rise in Bangladesh, Marine Geodesy.20: 13-31.

Cruz RV, Harasawa H, Lal M, Wu S, Anokhin Y, Punsalmaa B, Honda Y, Jafari M, Li C and Huu Ninh N 2007: Asia. Climate Change 2007: Impacts, Adaptation and Vulnerability. Contribution of Working Group II to the Fourth Assessment Report of the Intergovernmental Panel on Climate Change, M.L. Parry, O.F. Canziani, J.P. Palutikof, P.J. van der Linden and C.E. Hanson, Eds., Cambridge University Press, Cambridge, UK, pp. 469 506.

Elahi, F. and Khan, N. I., 2015: A Study on the Effects of Global Warming in Bangladesh: 2015, International Journal of Environmental Monitoring and Analysis 2015; 3(3): 118-121, Published online April 17, 2015 (http://www.science publishinggroup.com/j/ijema) doi10.11648/j.ijema.20150303.12 ISSN: 2328-7659 (Print);

Folland, C.K., Kari, T.R. and Vinnikov, E.Ya.1990: "climate change: The IPCC Scientific Assesment", Cambrige University Press, Cambridge.

Folland, C.K., Kari, T.R. Nicholls, N., Nyenzi, B.S., Parker, D.E. and VinnikovKYa., 1992: "climate change: The Supplement Report to the IPCC Scientific Assesment", Cambrige University Press, Cambridge.

Hussain MA and Sultana N 1996: Rainfall distribution over Bangladesh stations during the monsoon months in the absence of depression and cyclonic stoilils. Mausam. 47: 339-348.

IPCC, 1990: "Policymaker's summary: Climate change: the IPCC Assesment", Cambrige University Press, Cambridge.

IPCC WG-I 2001: Summary for the policy markers climate change 2001: Scientific Basis .Intergovernmental Panel on Climate Change, WMO, Geneva Switzerland p. 20.

Islam MN and Shafee S 1998: Predication models for drought and different meteorological variables in Bangladesh. Dhaka Univ. J. Sci. 46(2): 327-334.

Islam MT 1996: The need of agro-forestry for protecting soil degradation and enriching dry and farming in Bangladesh. Bangladesh J.Train.and Dev. 9(2): 98-101.

Karmakar S 2004: Regression forecasting pre-monsoon rainfall in Bangladesh. Proc. of SAARC Seminar on Agricultural Applications of Meteorology during 23-24 December 2003 held in Dhaka, Bangladesh.p.101.

Karmakar S and Main ER 1994: Regression forecasting of monsoon rainfall in Bangladesh, paper presented in the seminar on monsoon dynamics held at the German Cultural Center Dhaka, Bangladesh, November 1, 1994.

Karmakar S and Nessa J 1997: Climate change and its impacts on natural disasters and SW-monsoon in Bangladesh and the Bay of Bengal. J. Bangladesh Aca. Sci. 21(2): 127-136.

Karmakar S and Shrestha MM 2000: Resent climate change in Bangladesh. Report No. 4, SAARC Meteorological Research Centre (SMRC), Dhaka, Bangladesh.

Khambhammettu P 2005: Mann-Kendall Analysis, Annual Groundwater Monitoring Report of HydroGeologic Inc, Fort Ord, California. Delta of Nigeria.USEP: Journalof Research InformationinCivil Engineering, Vol.7, No.2,

Karim Z, Ibrahim M, Iqbal AM and Ahmed M 1990: Drought in Bangladesh Agricultural and irrigation schedules for major crops; Bangladesh Agric. Res.Council.p.1.

Lenka D 1998: Climate Weather and Crops in India, 23 Daryagang, New Delhi110002. 5 p.

McCarthy, J.J., Canziani, O. F., Leary, N. A., Dokken, D. J. and White, K.S., 2001: Climate Change 2001: Impacts, Adaptation. and Vulnerability, Inter-Governmental Panel on Climate Change (IPCC), Work Group II Input to the Third Assessment Report, Cambridge University Press, Cambridge.

Mahbub A 2002: Correlation between winter temperature and monsoon rainfall all over Bangladesh. Paper presented in 2nd Biennial Conference on Physical and Modern Development, held in Dhaka, Bangladesh, March 30-31, 2002.

McBean E and Motiee H 2008: Assessment of Impact of Climate Change on Water Resources: A Long Term Analysis of the Great Lakes of North America, Hydrology and Earth System Sciences, Vol. 12, pp. 239–255.

Murshid KAS 1987: Weather, new technology instability in grain production in Bangladesh. Bangladesh Dev. Study. 15: 31-56.

Peel MC, Finlayson BL and McMahon TA, 2007: "Updated world map of the Koppen–Geiger climate classification". Hydrology Earth Syst. Sci. 11 (5): 1633– 1644. Doi: 10.5194/hess-11-1633-2007.

Paramanik MAH 1991: Natural Disaster, Article prepared for Bangladesh Space Research and Remote Sensing Organization (SPARRSO), Dhaka, Bangladesh

Quadir DA 2006: Climate variability of Bangladesh. Contribution to Monsoon Asia Integrated Regional Study (MAIRS), SMRC, Dhaka.

Quadir DA, Hussain MA, Mannan MA, Ferdous N, Ahasan MN and Afroz R 2003: Aridity Condition over Bangladesh. In Proc. SAARC Seminar on Climate Variability in the South Asian Region and its Impacts held during 10-12 December 2002. pp. 146-149.

Quadir DA, Shrestha ML, Khan TMA, Ferdousi N, Rahman M and Mannan AM 2004: Variation of surface air temperature over the land areas in and around the Bay of Bengal, Natural Hazards, 32, 561-584.

Quadir DA, Shrestha ML, Khan TMA, Nazlee F, Rahman M and Mannan AM 2001: The dynamic change of climate in Bangladesh and the adjacent Regions in Association with Global Warming.Presented in the International Conference of Mechanical Engineering, BUET, 26-28 December, 2001, Dhaka, Bangladesh.

Rahman MS and Alam MS 1996: Patterns of rainfall variability and trend in the high Barind region, Rajshahi University Studies Part-B, Journal of Science, 24.

Sattar MA 2010: Bangladesh Land Not Going to the Sea: The Universal Statement, Bangladesh J. Environ. Sci., 18, 1-16

Sattar MA 2009: Scientific Study and Universal Statements on No Rising of Sea (Level) Waters in the Globe, Bangladesh J. Environ. Sci., 17, 1-17

Shrestha ML 2000: Recent climate change in Sri Lanka. SAARC Meteorological Research Centre, SMRC, No.5.

Smith L 2000: Trends in Russian Arctic river-ice formation and breakup. Physical Geography, 20 (1): 46-56.

Talukder MSU, Ali MA, Hye MA and Hossain MG 1994: Prediction of cumulative rainfall deficits using growth models .Bangladesh J. Agril. Sci. 21(2): 377383.

Talukder MSU, Ali SMA, Haque MM and Hossain MA 1988: A study on rainfall pattern of Bangladesh .BangladeshJ. Agril. Sci. 15(2): 59-64.

Talukder MSU, Ali MA, Huq MM and Hossain MA 1988: “A study on rainfall pattern in Bangladesh”, Bangladesh Journal of Agricultural Sciences, 15: 217224 .Warick RA, BhuiyaAH and MirzaMQ 1994: Briefing Doc. No. 1. BUP. pp. 17-20.

WMO, 1991: “Proceeding of the Second World Climate Conference”, pp. 24

WMO, 1995: “climate Change 1995: The Science of Climate Change”, Published for the Intergovernmental Panel on Climate Change, Cambridge University Press, Cambridge.