

IMPACT OF CLIMATOLOGICAL CHANGE ON ZONAL CROP PRODCTION IN BANGLADESH

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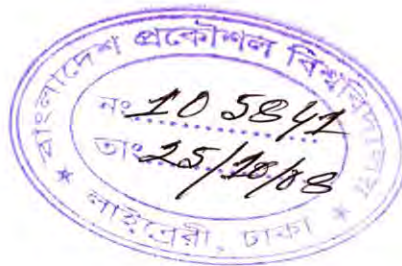
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ACRONYMS

BARC	Bangladesh Agricultural Research Council
BBS	Bangladesh Bureau of Statistics
BMD	Meteorological Department
BWDB	Bangladesh Water Development Board
CCD	Climate Change Database
DAE	Department of Agricultural Extension
DoE	Department of Environment
EPIC	Erosion Productivity Impact Calculator Change
IPCC	Intergovernment Panel on Climate
SMRC	SAARC Meteorological Research Center
SARC	SAARC Agricultural Research Center
SRDI	Soil Resource Development Institute
WMO	World Meteorological Organization



Chapter 1 INTRODUCTION

1.1 Background

Climate variability, its impacts and vulnerability are worldwide growing concern. Natural hazards like floods, droughts, cyclones and sea level rise will push poorer section of the population to the very margin of survival, making them more vulnerable (Agarwal and Mall, 2001). After industrial revolution the increase of carbon dioxide in the atmosphere is also very alarming. Climate change associated with increasing level of carbon dioxide is likely to affect developed and developing countries, with major vulnerabilities occurring in low latitude regions (Reilly et al., 2001; Darwin and Kennedy, 2000).

The Fourth Assessment Report (AR4) of the IPCC considers agriculture as one of the most vulnerable systems to be affected by climate change in the South Asian region. Most of the countries of this region generate between 20% and 40% of their GDP from the agriculture sector. The economy of Bangladesh is based on agriculture, industry and services. The agriculture sector contributes a major share in the GDP, which is about 30% and employs about 63% of the working force (BBS, 2002).

Bangladesh has been identified as one of the countries with perhaps the highest level of vulnerability to climate change (McCarthy et al., 2001). A great majority of the people of Bangladesh is dependent on agriculture for their livelihood and crop agriculture in this region is highly susceptible to variation of climate system. The climate of Bangladesh is changing and it is becoming more unpredictable every year. Annual global temperature has increased by $\sim 0.4^{\circ}\text{C}$ since 1980, with even larger changes observed in several regions (IPCC, 2001). Global warming induces changes in temperature and rainfall are already evident in many parts of the world as well as in Bangladesh. Uncertainty of rainfall and uneven temporal and spatial distribution, creating flooding and longer dry spells evoking droughty conditions. All these have profound impact on agriculture. Hazards like floods, droughts, cyclones and others, which are aggravated by climate change and CRTs variability being experienced more frequently in Bangladesh than ever before (Hussain, et al., 2005).

The potential impacts of climate change on agriculture are changing in crop yields and shifting in

relative productivity and production, which may threaten national and regional food security, with profound effects on the poor in developing countries. Low-income rural populations that depend on traditional agricultural systems or on marginal lands are particularly vulnerable.

It is anticipated that crop production would be extremely vulnerable under climate change scenarios, and as a result, food security of the country will be at risk. Despite being highly vulnerable, very little efforts have so far been made to understand potential of agricultural adaptation in Bangladesh (Karim et al., 1999).

About one-quarter of the country's GDP comes from agriculture, which makes the country's economy relatively sensitive to climate variability and change. Development activities in agricultural sector could clearly be affected by current climate variability and weather extremes, and consequently by changing climatic conditions (World Bank, 2000).

Present development efforts aim to increase food production through the expansion of irrigation, flood protection embankments, with the support of modern agricultural Technology especially HYV seeds and fertilizers to achieve national self-sufficiency in food grains. Threats from undefined climate change can terribly hinder this national target, for what reason it is of utmost significance to investigate about the trend of climate change together with model predictions and the probable impacts on the agricultural production.

Considering the circumstance stated above, the necessity of investigating the impacts of climatological change on agriculture was realized. In this study new methodology for local estimation of crop productivity is proposed. This methodology uses Erosion Productivity Impact Calculator (EPIC) model. With the climate change data provided by the Bangladesh Meteorological Department (BMD) and Intergovernment Panel on Climate Change (IPCC) EPIC is run for scenarios of present and future climate (for the next fifty years) to predict the effects of global warming on main crop yields of Bangladesh like rice (Local Transplant Aman), wheat, pulse (Mungbean) and potato in the district of Comilla, Dinajpur, Jessore and Bogra respectively. The study has been carried out with the local varieties of the respective crops.

1.2 Objectives of the Research Work

Considering the importance of agricultural sector for the economy and food requirements of Bangladesh, there is a need for reliable estimation of major crop production under varied climate change provision and circumstances. There fore present study was undertaken with the following

objectives:

- To analyze the past trend of climate change, particularly considering those climatic parameters, which are intimately related with the agricultural production (maximum temperature, minimum temperature, rainfall etc.).
- To assess impacts of climate change on rice (Local T. Aman), wheat, pulse (mungbean) and potato production based on the historic data.
- To predict the yields of the agricultural products like rice, wheat, pulses and potato for the next fifty years on model based simulation.

1.3 Selection of the Study Area

The district of Comilla, Dinajpur, Jessore and Bogura have been selected as the study areas for rice, wheat, pulse and potato respectively. The reasons of selection of the specified areas are-

- These crops grow well in the respective districts of Bangladesh.
- Climate data over last 50 years and various other data set for these zones are sequentially available which are needed to run the EPIC model.

1.4 Organization of the Study

The present study is organized as follows.

Chapter 1 provides an introduction with background and objectives of the study, selection of study areas and organization of the study.

Chapter 2 describes the literature review on climate change, its impact on agriculture and Model description.

Chapter 3 provides description of the study sites.

Chapter 4 contains data collection and methodology.

Chapter 5 contains analysis, result and discussion on climate change and its impact on agriculture. Predicted crop yields from Model based simulation result have also been included in this chapter.

Chapter 6 provides the conclusion on the present study and recommendations.

2.1 Introduction

The climate system is changing across the globe. The global climate change is impacting all spheres of the earth including physical, natural, social and economic domains and life and livelihoods of people. Many natural ecosystems are likely to change as a consequence of climate change. This change is attributed to the net effect of individual and interactive effects of changes in atmospheric composition, land use, biological diversity, and climate (Parry and Jiachen, 1991). Analysis of long-term changes in daily temperature extremes has revealed that, especially since the 1950s, cold days, cold nights, and frost evident have become less frequent. Hot days, hot nights, and heat waves have become more frequent. Global warming in the last 100 years has caused about a 0.74°C increase in global average temperature and this will result in a likely increase in global mean temperature of about 1°C above the present value by 2025 and 3°C before the end of the next century (IPCC AR4, 2007).

The main drivers of agricultural responses to climate change are biophysical effects and socio-economic factors. Crop production is affected biophysically by meteorological variables, including rising temperatures, changing precipitation regimes, and increased atmospheric carbon dioxide levels. Biophysical effects of climate change on agricultural production will be positive in some agricultural systems and regions, and negative in others, and these effects will vary through time. Since climate factors strongly interact to affect crop yields, it is likely that climate change will affect crop production (Parry and Jiachen, 1991). A large number of research groups have focused on estimation of all damages of global warming (Adams et al., 1993; Easterling et al., 1992; Dixon et al., 1994). From their exhaustive literature analysis, globally about one-fifth of all damages will occur in agriculture (Pearce et al., 1996).

In the following sections the theoretical basics regarding climate, its components, variability and change, etc. are reviewed to have a conceptual background of the issue. Afterwards, impacts and vulnerabilities of climate change with special emphasis on agriculture are presented for global, regional and local perspective.

2.2 Definition of Climate

The climate system is a complex, interactive system consisting of the atmosphere, land surface, snow and ice, oceans and other bodies of water, and living things. The atmospheric component of the climate system most obviously characterizes climate; climate is often defined as 'average weather'. Climate is usually described in terms of the mean and variability of temperature, precipitation and wind over a period of time, ranging from months to millions of years (the classical period is 30 years, as defined by the World Meteorological Organization (WMO, 1994)).

Climate varies from place to place, depending on latitude, distance to the sea, vegetation, presence or absence of mountains or other geographical factors. Climate varies also in time; from season to season, year-to-year, decade to decade or much longer time-scales, such as Ice Ages.

2.3 Climate variables

The traditional knowledge of weather and climate focuses on those variables that affect daily life most directly: average, maximum and minimum temperature, wind near the surface of the Earth, precipitation in its various forms, humidity, cloud type and amount, and solar radiation. These are the variables observed hourly by a large number of weather stations around the globe.

Climate is determined by the atmospheric circulation and by its interactions with the large scale ocean currents and the land with its features such as albedo, vegetation and soil moisture. The climate of the Earth as a whole depends on factors that influence the radiative balance, as for example, the atmospheric composition, solar radiation or volcanic eruptions.

2.4 Relationship between Climate Change and Weather

Climate is generally defined as average weather, and as such, climate change and weather are intertwined. There have been changes in weather, and the statistics of changes in weather over time identify climate change. Climate can be viewed as concerning the status of the entire Earth system, including the atmosphere, land, oceans, snow, ice and living things (Figure 2.1) that serve as the global background conditions that determine weather patterns.

activities, primarily the burning of fossil fuels and clearing of forests, have greatly intensified the natural greenhouse effect, causing global warming.

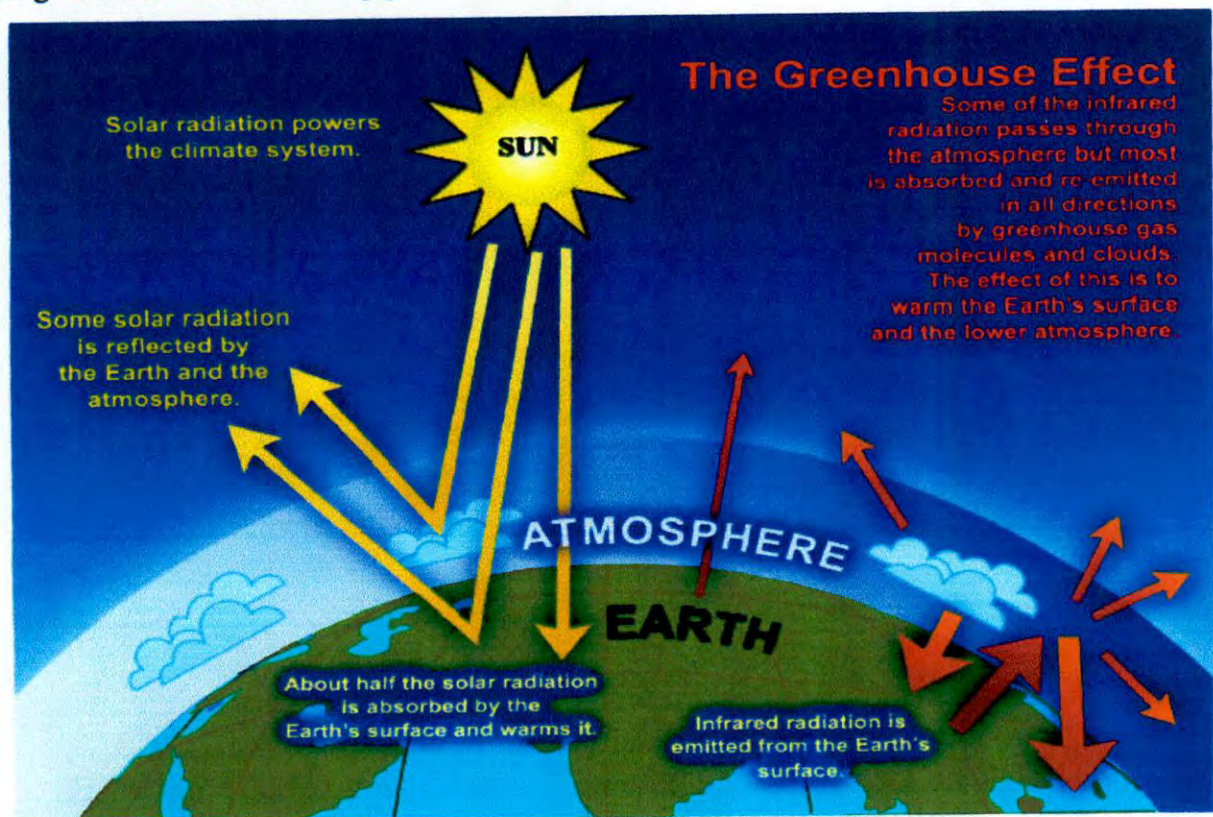


Figure 2.2 An idealized model of the natural greenhouse effect (Le Treut et al., 2007).

The amount of heat energy added to the atmosphere by the greenhouse effect is controlled by the concentration of greenhouse gases in the Earth's atmosphere. Water vapor is the most important greenhouse gas, and carbon dioxide (CO_2) is the second-most important one. Methane, nitrous oxide, ozone and several other gases present in the atmosphere in small amounts also contribute to the greenhouse effect.

All of the major greenhouse gases especially CO_2 have increased in concentration since the beginning of the Industrial Revolution (about 1700 AD) (Figure 2.3). As a result of these higher concentrations, scientists predict that the greenhouse effect will be enhanced and the Earth's climate will become warmer. Predicting the amount of warming is accomplished by computer modeling. Computer models suggest that a doubling of the concentration of the main greenhouse gas, carbon dioxide, may raise the average global temperature between 1 and 3° Celsius (Figure 2.4).

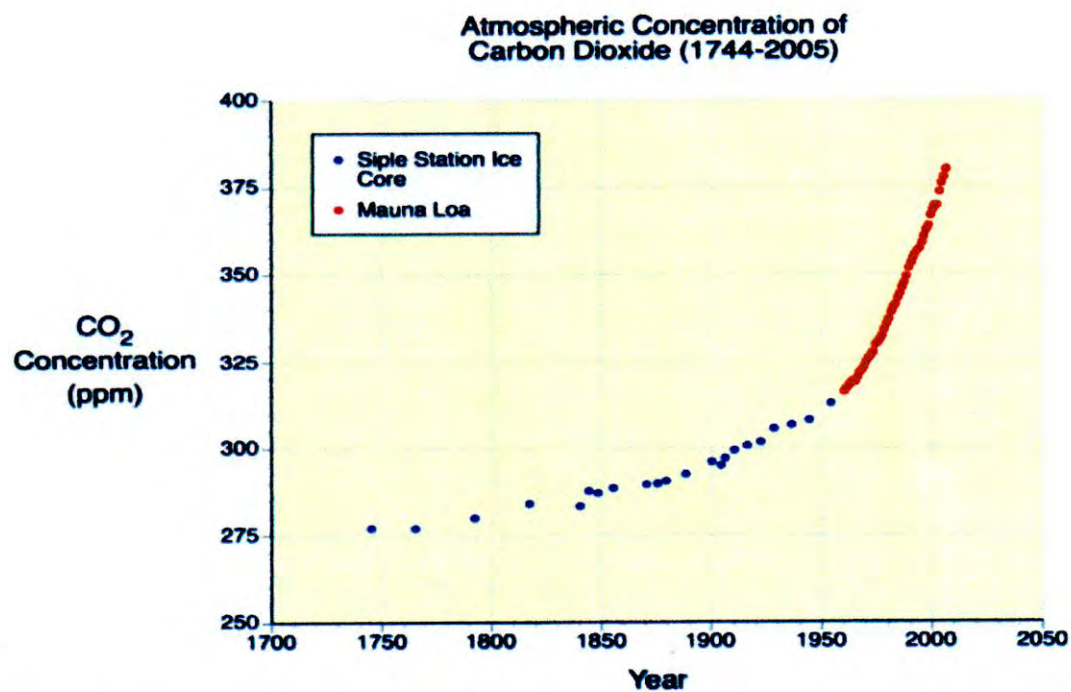


Figure 2.3 The rise in atmospheric carbon dioxide from 1744 to 2005.

[Siple Station Ice Core Data. Source: Neftel et al, 1994]

[Mauna Loa Data. Source: Keeling and Whorf, 2006]

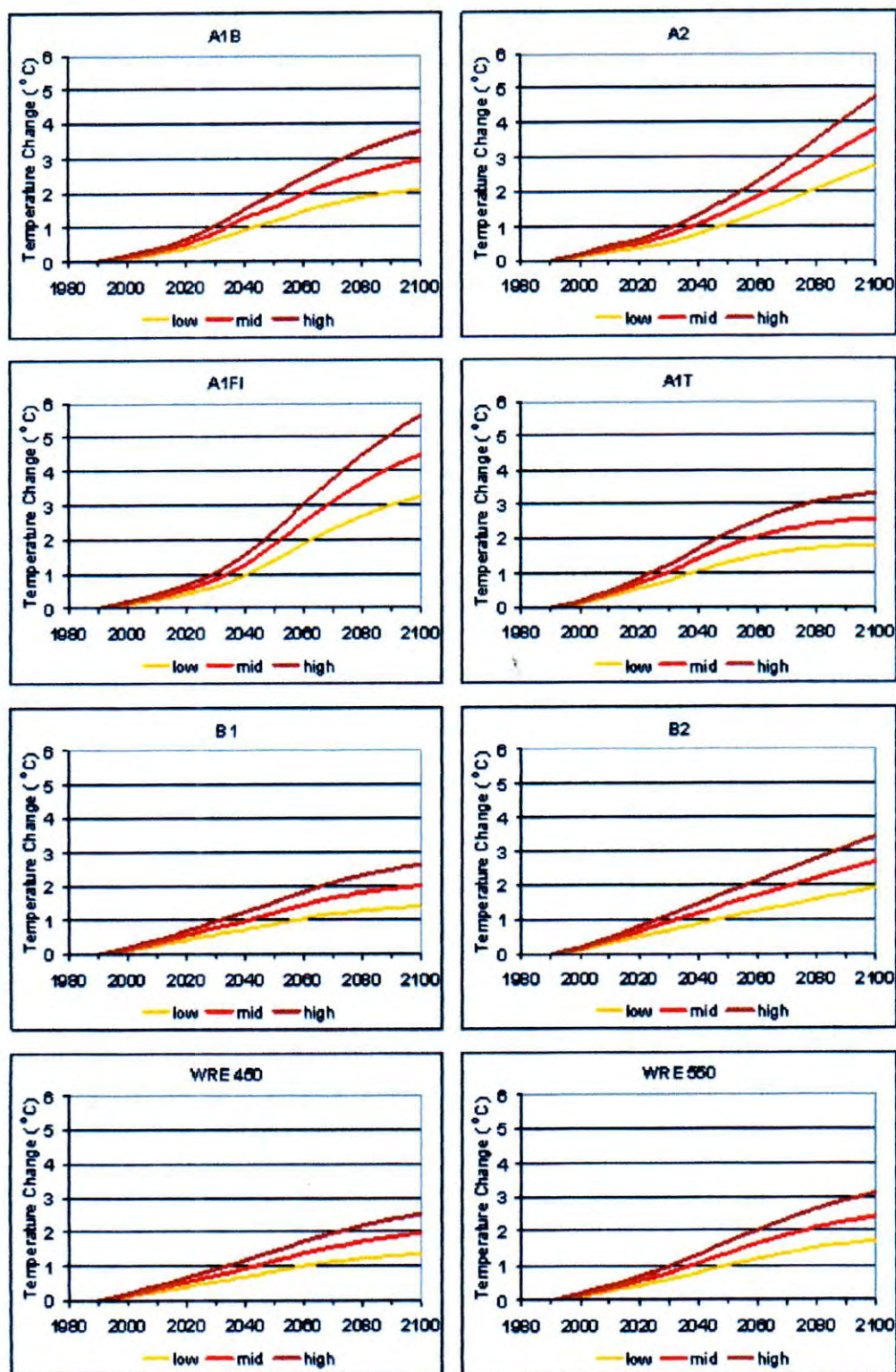


Figure 2.4 Global-average temperature change scenarios. (Source: Special Report on Emission Scenarios (SRES), 2000)

2.6 The Concern of Climate Change

A statistically significant variation of the mean state of the climate or of its variability of properties, which persists for an extended period, typically decades or longer, is referred to as "climate change".

The Framework Convention on Climate Change (UNFCCC), in its Article 1, defines climate change as: 'a change of climate which is attributed directly or indirectly to human activity that alters the composition of the global atmosphere and which is in addition to natural climate variability observed over comparable time periods'. The UNFCCC thus makes a distinction between climate change attributable to human activities altering the atmospheric composition, and climate variability attributable to natural causes.

The balance of scientific evidence now suggests that over the last century humans have begun to have a discernible influence on the earth's climate, causing it to warm (IPCC, 1996, 1998). Since the beginning of the industrial age, the concentration of CO₂ in the atmosphere has increased from 280 to 350 parts per million (Bazzaz and Fajer, 1992). The increase of CO₂ in the atmosphere has been more rapid in recent years.

The major reason for this increase may be attributable to the extensive use of fossil fuels, such as oil, coal and gas. The destruction of carbon sink by excessive land use and deforestation might be another important cause for the atmospheric CO₂ increase over the last 100 years (Houghton et al., 1990). It has been projected from the historical data and simulation models that the CO₂ level in the atmosphere will reach 600 ppm in the last half of this century (Drake and Leadley, 1991) (Figure 2.5).

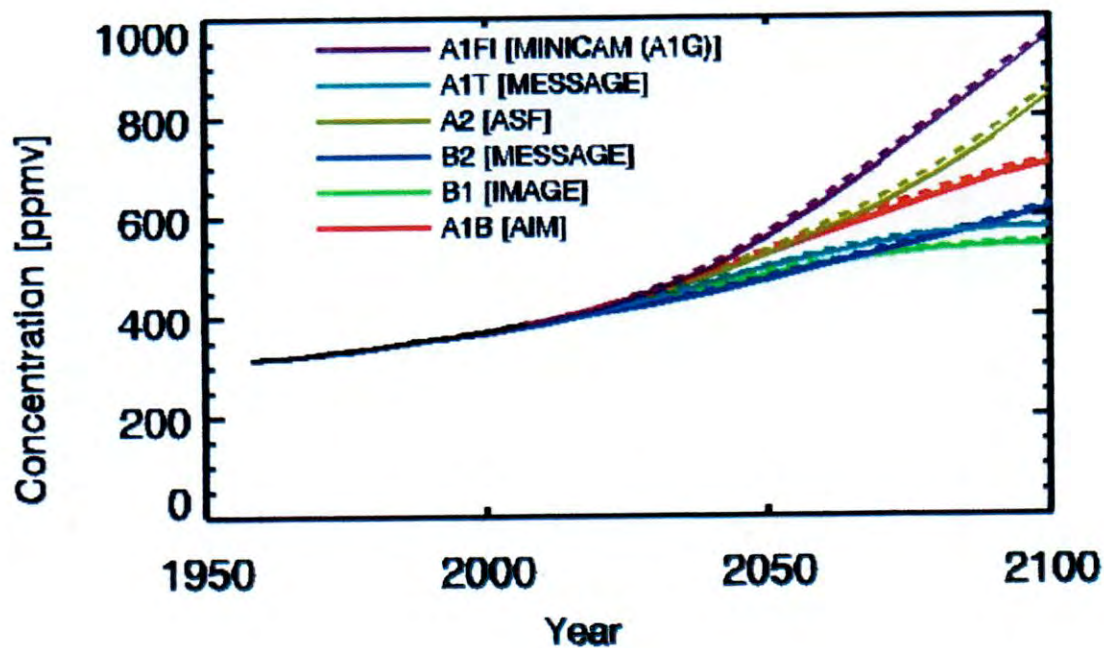


Figure 2.5 Atmospheric CO₂ concentrations as observed at Mauna Loa (black line) and projected under the 6 SRES marker and illustrative scenarios. (Source: IPCC, 2001).

Warming during this time has been strongest over the continental interiors of Asia and northern North America. However, as these are areas with large year-to-year variability, the most evident warming signal has occurred in parts of the middle and lower latitudes, particularly the tropical oceans.

2.7 Patterns of Climate Change by 2030

Knowledge of the global mean warming and change in precipitation is of limited use in determining the impacts of climates change, for instance on agriculture. For this it is needed to know changes regionally and seasonally.

ESTIMATES FOR CHANGES BY 2030

(IPCC Business-as-Usual scenario; changes from pre-industrial)

The numbers given below are based on high resolution models, scaled to be consistent with our best estimate of global mean warming of 1.8°C by 2030. For values consistent with other estimates of global temperature rise, the numbers below should be reduced by 30% for the low estimate or increased by 50% for the high estimate. Precipitation estimates are also scaled in a similar way.

Confidence in these regional estimates is low

Central North America (35°-50°N 85°-105°W)

The warming varies from 2 to 4°C in winter and 2 to 3°C in summer. Precipitation increases range from 0 to 15% in winter whereas there are decreases of 5 to 10% in summer. Soil moisture decreases in summer by 15 to 20%.

Southern Asia (5°-30°N 70°-105°E)

The warming varies from 1 to 2°C throughout the year. Precipitation changes little in winter and generally increases throughout the region by 5 to 15% in summer. Summer soil moisture increases by 5 to 10%.

Sahel (10°-20°N 20°W-40°E)

The warming ranges from 1 to 3°C. Area mean precipitation increases and area mean soil moisture decreases marginally in summer. However, throughout the region, there are areas of both increase and decrease in both parameters throughout the region.

Southern Europe (35°-50°N 10°W- 45°E)

The warming is about 2°C in winter and varies from 2 to 3°C in summer. There is some indication of increased precipitation in winter, but summer precipitation decreases by 5 to 15% and summer soil moisture by 15 to 25%.

Australia (12°-45°S 110°-115°E)

The warming ranges from 1 to 2°C in summer and is about 2°C in winter. Summer precipitation increases by around 10%, but the models do not produce consistent estimates of the changes in soil moisture. The area averages hide large variations at the sub-continental level.

2.8 Global Impacts of Climate Change

Since climate factors strongly interact to affect crop yields, it is likely that climate change will affect crop production. The tropical and subtropical countries would be more vulnerable to the potential impacts of global warming through effects on crops, soils, insects, weeds and diseases (Parry and Jiachen, 1991). The impact of climate change on agriculture of different continents is shown in Table 2.1.

Table 2.1 Impacts of climate change on global agricultural sector.

	A2 climate change	Accelerated climate change
Europe	Decline in crop productivity in south; increase for some crops in north. Decline in forest productivity in south, and potential for increase in north.	Major decline in crop productivity in south; substantial increases in north. Decline in productivity in south, and potential for increase in north
North America	Decline in crop productivity in parts of mid-west due to increased drought; higher productivity in north.	Reduction in crop productivity in mid-west, and increase in north
South America	Decline in crop productivity due to temperatures, with major decline in north east Brazil.	Large decline in crop productivity Due to higher temperatures, with widespread reduction in crop production in north east Brazil.
Asia	Widespread reduction in crop Productivity, with major decreases in central Asia; potential for increase in east Asia	Widespread reduction in crop productivity, with major decreases in central Asia; potential for increase in east Asia
Africa	General reduction in crop productivity, with major reductions in south; increase in numbers of people at risk of hunger	General large reduction in crop productivity, with very major reductions in south; large increase in numbers of people at risk of hunger
Australia	Decrease in crop productivity in parts of Australia.	Decrease in crop productivity in parts of Australia.

Note: A2 is one of the Emission Scenarios of the IPCC Special Report on Emission Scenarios (SRES). Approximate CO₂ equivalent concentration corresponding to the computed radiative forcing due to the anthropogenic gases and aerosol in 2100 for the SERS, A2 is about 1250ppm.

United States and Canada, and for Asia (including China) and the Pacific Rim, where many more studies have been conducted, the results generally range from severe negative effects (-60, -70%, or complete crop failure) to equally large potential yield increases (Figure 2.6).

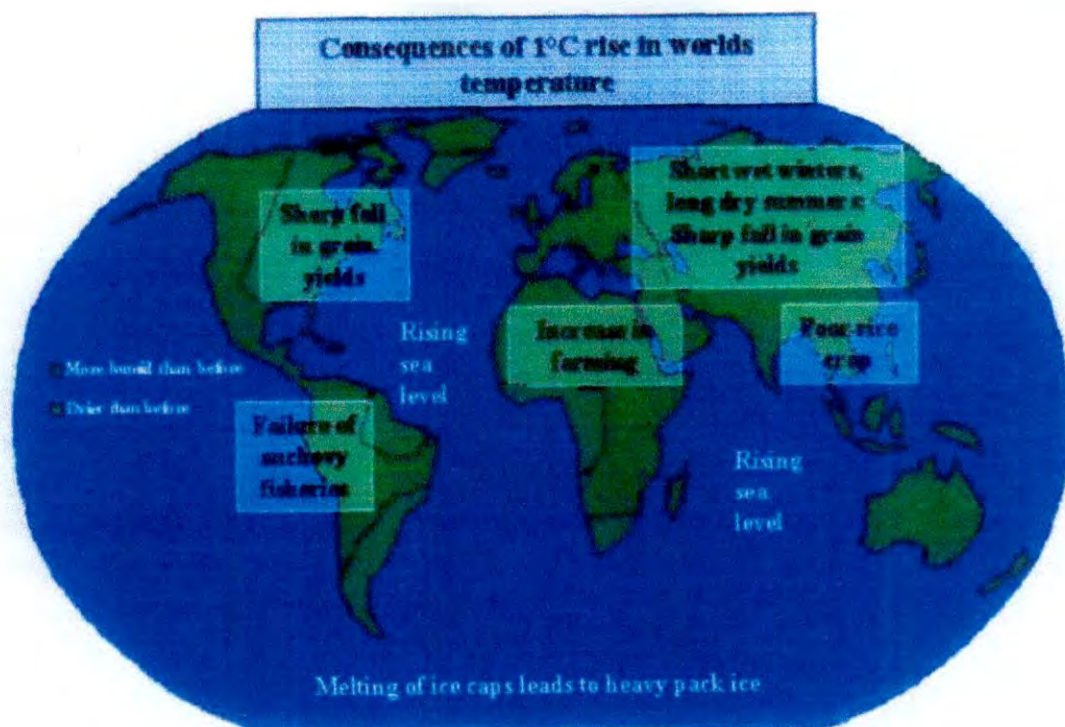


Figure 2.6 Global impacts of climate change on agricultural yields. (Source: University of Southampton, 2000)

Studies for the United States and Canada demonstrate the wide range of impacts across sites with total or near-total crop failure every year projected for wheat and soybeans at one site in the United States (Rozenzweig et al., 1993) but wheat yield increases of 180 to 230% for other sites in the United States and Canada (Rozenzweig et al., 1993; Shibles et al., 1975). Investigations on potential agronomic effects of several climate change scenarios on grain (corn, wheat, and soybean) farming in US indicated that a mild climate change scenario had a minimal negative effect on all crop yields. Corn and soybean yields were negatively affected by the more severe (hotter) climate change scenario. Under all climate change scenarios, corn and wheat area and production decline over the 100-year analysis, and soybean area and production increased over the years (Shibles et al., 1975).

Studies conducted of wheat response in Australia found impacts ranging from -34% to +65% for the same climate scenario and site depending on which known and currently grown wheat cultivar were specified in the crop model (Pearce et al., 1996).

In Brazil the impact of climate change on agriculture was estimated using agricultural yields, and land values (a Ricardian Approach). Although there were varying regional consequences, the net impact was negative. The Center-West region was most negatively impacted and the South region benefits mildly from warming (Cure and Acock, 1986).

In Africa due to accelerated climate change impacts there might be a general large reduction in crop productivity, with very major reductions in south region; causing large increase in numbers of people at risk of hunger.

Thus, an impact analysis that narrowly specifies a crop variety is likely to generate a much different estimated impact than an analysis that specifies responses on the basis of the genetic variation across existing cultivars.

2.9 Regional Impacts of Climate Change

It is apparent that climate change would have considerably varying impacts on crop agriculture in regional scale. This is because; the climate patterns, agricultural systems, management processes and adaptation scopes are not the same at different regions of the world. Bangladesh is an Asian country, so the discussion on regional climate change impacts on agriculture was centered on this region.

In South and Southeast Asia, strengthening of the monsoon circulation and an increase in wet-season rainfall under enhanced greenhouse conditions - that is, an increase in summer rainfall in the southwest monsoon region and an increase in winter rainfall in the northeast monsoon region would be observed (Shin and Lee, 1995). Changes in dry-season rainfall are less consistent and are estimated only as broad-scale regional rainfall changes; local-scale changes could be much greater (Whetton, 1994).

A study of the potential impact on rice yields conducted for most of the countries of South and Southeast Asia and for China, Japan, and Korea using the same crop model found yield changes for India to range from -3% to +28%, for Malaysia from +2% to +27%, for the Philippines from -14%

to +14%, and for mainland China from -18% to -4% (Matthews et al., 1995) depending on whether the GISS, GFDL or UKMO climate scenario was used.

It was concluded that the severe yield losses in South, Southeast and East Asia for rice in many scenarios was due to a threshold temperature effect that caused spikelet sterility but that genetic variation with regard to the threshold likely provided significant opportunity to switch varieties as temperatures rose (Matthews et al., 1995).

Increased atmospheric CO₂ can raise plant productivity through CO₂ fertilization, and can cause changes in the temperature, rainfall, solar radiation, and wind patterns that can impact either positively or negatively on plant and animal productivity (Anderson and Domsch, 1986).

While climate change will alter the way agricultural enterprises are managed, one should not conclude that climate change will have only negative impacts on agriculture and cause a decreasing level of productivity. However, the importance of examining climate change from a long term perspective is the uncertainty it introduces (Decker et al, 1990).

2.9.1 Climate of Bangladesh

Geographical location and physical settings govern the climate of any country. Bangladesh extends from 20°34'N to 26°38'N latitude and from 88°01'E to 92°41'E longitude. Except the hilly southeast, most of the country is a low-lying plain land. To its south lies the Bay of Bengal and to the west lie the plain land of West Bengal and the vast tract of the Gangetic Plain. Bangladesh is located in the tropical monsoon region and its climate is characterized by high temperature, heavy rainfall, often-excessive humidity, and fairly marked seasonal variations.

From the climatic point of view, three distinct seasons can be recognized in Bangladesh - the cool dry season from November through February, the pre-monsoon hot season from March through May, and the rainy monsoon season which lasts from June through October. The month of March may also be considered as the spring season, and the period from mid-October through mid-November may be called the autumn season.

2.9.2 Temperature

From Figure 2.7 it can be seen that January is the coldest month in Bangladesh. Average temperatures in January vary from about 17°C in the northwestern and northeastern parts to 20°-21°C in the coastal areas. In late December and early January, minimum temperature in the extreme northwestern and northeastern parts of the country reaches within 4 to 7 degrees of freezing point (Banglapedia, 2008). As the winter season progresses into the pre-monsoon hot season, temperature rises, reaching the maximum in April, which is the middle of the pre-monsoon hot season.

Average temperatures in April vary from about 27°C in the northeast to 30°C in the extreme west central part of the country. In some places in 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 covers causes dampening of temperature during the later part of the pre-monsoon season. Average temperatures in July vary from about 27°C in the southeast to 29°C in the northwestern part of the country.

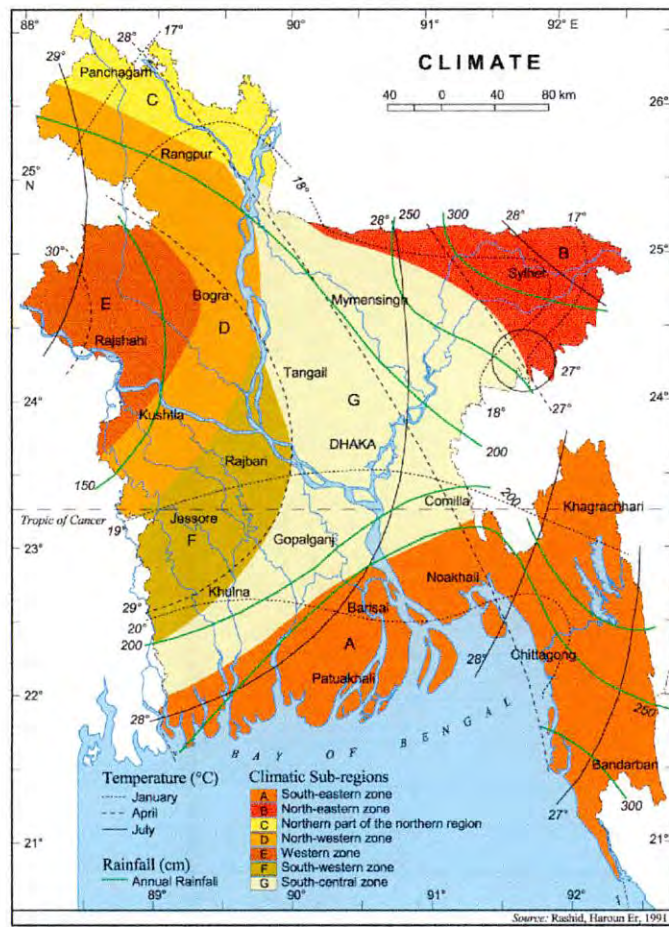


Figure 2.7 Different climatic parameters of Bangladesh (Source - Banglapedia, 2008)

2.9.3 Rainfall

The single most dominant element of the climate of Bangladesh is the rainfall. Because of the country's location in the tropical monsoon region, the amount of rainfall is very high. However, there is a distinct seasonal pattern in the annual cycle of rainfall, which is much more pronounced than the annual cycle of temperature.

The winter season is very dry, and accounts for only 2%-4% of the total annual rainfall. Rainfall during this season varies from less than 2 cm in the west and south to slightly over 4 cm in the northeast. As the winter season progresses into the pre-monsoon hot season, rainfall increases due to intense surface heat and the influx of moisture from the Bay of Bengal. Rainfall during this season accounts for 10%-25% of the total annual rainfall which is caused by the thunderstorms or nor' waster. The amount of rainfall in this season varies from about 20 cm in the west central part to slightly over 80 cm in the northeast. Rainfall during the rainy season account for

70% of the annual total in the eastern part, 80% in the southwest, and slightly over 85% in the northwestern part of Bangladesh. The amount of rainfall in this season varies from 100 cm in the west central part to over 200 cm in the south and northeast.

2.9.4 Humidity

March and April are the least humid months over most of the western part of the country. The least humid months in the eastern areas are January to March. The relative humidity is everywhere over 80% during June through September. The average relative humidity for the whole year ranges from 78.1% at Cox's Bazar to 70.5% at Pabna.

2.9.5 Cloud cover

During the winter season, the cloud cover is at a minimum. On an average, the cloud cover in this season is about 10% almost all over the country. With the progression of the season, the cloud cover increases, reaching 50-60% by the end of the pre-monsoon hot season.

During the summer monsoon season, which is also the rainy season, the cloud cover is very widespread. In the months of July and August, which is the middle of the rainy season, the cloud cover varies from 75 to 90% all over the country. However, it is more extensive in the southern and eastern parts (90%) than in the northwestern part (75%). After the withdrawal of the summer monsoon, the cloud cover decreases rapidly, dropping to 25% in the northern and western parts, and 40-50% in the southern and eastern parts.

2.9.6 Atmospheric pressure and wind

During the winter season, winds generally have a northerly component (flowing from north or northwest). While, during the summer season, the prevailing wind direction in Bangladesh has generally a southerly component (flowing from the south, southwest or southeast).

However, wind directions during the transition seasons (in spring and autumn) are variable. Generally, winds are stronger in summer (8-16 km/hr) than in winter (3-6 km/hr). The mean pressure is 1,020 millibars in January and 1,005 millibars during March through September.

2.10 Overview of Climate Variability and Change

The pattern and behavior of climate and weather play a significant role in freshwater availability, agriculture, economic growth and performance, and livelihoods. Recent studies and the regional stakeholder consultation workshops have revealed that the erratic nature of rainfall and temperature has indeed increased (NAPA Regional Workshop reports 2005). Adverse effects of erratic nature of rainfall and temperature on agricultural productivity and availability of freshwater is already quite evident in many areas of Bangladesh.

2.10.1 Observed Changes

Observed data indicates that the temperature is generally increasing in the monsoon season (June, July and August). Average monsoon time maximum and minimum temperatures show an increasing trend annually at the rate of 0.05°C and 0.03°C, respectively. While, average winter time (December, January and February) maximum and minimum temperatures show respectively a decreasing and an increasing trend annually at the rate of 0.001 °C and 0.016°C (Ahmed, 2000).

It was revealed in a study carried out by SAARC Meteorological Research Centre, that there is an increasing trend of mean maximum and minimum temperature in some seasons and decreasing trend in some others has been seen. Overall the trend of the annual mean maximum temperature has shown a significant increase over the period of 1961-90.

In a research study SAARC Metrological Research Centre described that there has been a significant increasing trend in the cyclone frequency over the Bay of Bengal during November and May, which are main months for cyclone in the Bay of Bengal. The SMRC carried out a study on recent relative

sea level rise in the Bangladesh coast. The study showed that the rate of sea level rise during the last 22 years is many times higher than the mean rate of global sea level rise over 100 years. It must be pointed out however that the rise in sea level includes that due to regional tectonic subsidence. Variation among the stations was also found.

Due to other factors behind the salinity intrusion, such as withdrawal of water at Farakka (by India), the trend towards salinization in the coastal zone is very clear. Thirteen southwestern districts are adversely affected due to Farakka, facing reduced dry season river flow, lowering of groundwater table, depletion of soil moisture and increasing soil salinity. As a consequence of these adverse effects agriculture at the southwestern coastal region is seriously constrained.

2.10.2 Future Scenarios

Generally, future changes of temperature and rainfall for Bangladesh are estimated taking 1990 as the base year and using two general approaches i.e. (a) projection based on observed data, and (b) using available climate model. The present changes in the observed climatic elements have been projected up to 2050 and 2100 years (Table 2.2).

Table 2.2 Climate change scenarios for Bangladesh NAPA. (Source: IPCC TAR Report, 2001)

Year	Temperature change (C°) Mean			Precipitation change (%) Mean			Sea Level Rise (cm)
	Annual	Dec-Jan- Feb	Jun-Jul- Aug	Annual	Dec-Jan- Feb	Jun-Jul- Aug	NAPA
2030	1.0	1.1	0.8	5	-2	6	14
2050	1.4	1.6	1.1	6	-5	8	32
2100	2.4	2.7	1.9	10	-10	12	88

Based on the present trend of 5-year running average of the climatic elements, the annual mean maximum temperature is likely to rise by 0.48°C and 0.88°C in 2050 and 2100 years respectively. The 5-year running average of annual mean minimum temperature is likely to decrease by 0.06°C and 0.11°C by 2050 and 2100 respectively (Karmakar and Shrestha, 2000).

Ahmed and Alam (1999) developed climate change scenarios with General Circulation Models (GCMs) and assessed the vulnerability to climate change for different sectors based on climate scenarios for two projection years 2030 and 2070. The results revealed that the average increase in temperature would be 1.3°C and 2.6°C for the years 2030 and 2070 respectively.

2.10.3 Impacts of Climate change in Bangladesh

Bangladesh is particularly vulnerable to the impacts of climate change. However, the extent, intensity and magnitude of impacts are not known exactly. Bangladesh is a deltaic country; some 70% of the country is at risk of flooding and over 20% of the country experiences 'normal' floods during the monsoon period every year.

Bangladesh is already experiencing climate related hazards like floods, droughts, cyclones and others which are aggravating because of climate change (and variability). Climatic changes in Bangladesh will include changes in temperature and precipitation patterns.

Related risks include the likely increase in periods of drought, increase in frequency of severe flooding and increasing duration of the floods due to drainage congestion following sea level rise. Climate change will also affect agricultural production (Table 2.3). Increased precipitation and fluxes combined with sea-level rise will mean that coastal waters become more saline and ground water aquifers may face saline intrusion.

Table 2.3 Intensity of impacts on different sectors due to Climate Change. (Source: NAPA Team, 2005)

Physical Vulnerability Context								Sectoral Vulnerability Context
Extreme Temperature	Sea Level Rise		Drought	Flood		Cyclone & storm Surges	Erosion & Accretion	
	Coastal inundation	Salinity intrusion		River Flood	Flash Flood			
+++	++	+++	+++	+	++	+++	-	Crop Agriculture
++	+	+	++	++	+	+	-	Fisheries
++	++	+++	-	-	+	+++	-	Livestock
+	++	-	-	++	+	+	+++	Infrastructure
++	+++	++	-	++	+	+	-	Industry
++	+++	+++	-	++	-	+	-	Biodiversity
+++	+	+++	-	++	-	++	-	Health
-	-	-	-	-	-	+++	+++	Human settlement
++	+	-	-	+	-	-	-	Energy

Climate change therefore threatens both previous achievements and future efforts to reduce poverty in Bangladesh, particularly by threatening water and food security and damage to essential infrastructure during more frequent disaster events.

2.11 Distinctive Agriculture of Bangladesh

Bangladesh's climate, with a warm wet summer and a cool dry winter, provides conditions suitable for growing a wide range of annual and perennial crops: tropical (e.g., rice, jute) in summer; temperate (e.g., wheat, potato, mungbean) in winter; and subtropical (e.g., sugarcane, banana) throughout the year. The high rainfall and seasonal flooding make conditions particularly suitable for paddy cultivation, and rice is the staple cereal. None-the-less, cropping is highly diversified. Bangladeshi farmers have more than 100 different crops in their collective

repertoire. Additionally, it is estimated that there are over 10,000 rice varieties, adapted to specific micro-environments. The great majority of these varieties belong to the Aman group.

2.12 Rice in Bangladesh

A large number of cropping patterns are generally practiced in Bangladesh, depending on the crop production environment which is greatly influenced by land type, soil texture, flooding regimes, rainfall (amount and distribution) and resource base of the farmers.

Total cropped area is about 13.4 million ha, with more than 170% cropping intensities. Areas under single, double, and triple cropping are 3.5, 3.7 and 0.99 million ha, respectively. Rice alone covers about 80% of the total cropped area, of which HYVs share is about 50% (BBS, 2002). China, India, Indonesia, Bangladesh, Thailand, and Vietnam produce about 80 percent of the world rice production. Among the leading rice growing countries of the world, Bangladesh ranked fourth in both rice area and production (table 2.4).

Table 2.4 Rice area, production, and yield for 12 leading countries in order of production (IRRI, Annual Report, 1993)

Country	Rice Area (Ha*10 ³)	Rough Rice Production (T*10 ³)	Yield (T/Ha)
China	33,100	187,450	5.7
India	42,200	110,954	2.6
Indonesia	10,108	44,321	4.4
Bangladesh	10,140	28, 575	2.6
Thailand	10,000	20,340	2.0
Vietnam	6,295	19,428	3.1
Myanmar	4,830	13,201	2.7
Japan	2,049	12,005	5.9
Philippines	3,423	9,670	2.8
Brazil	4,143	9,503	2.3
Korea Rep.	1,209	7,478	6.1
USA	1,113	7,600	6.3

In Bangladesh, rice accounts for 95 percent of the food grain production. Rice production in Bangladesh was less than 10 million tons in 1970 and then exceeded 25 million tons in 2005 (BRRI, Annual Report, 2005). Rice occupies over 75 percent of the total cropped area of the country.

Rice shows more genetic and morphological diversity than almost any other cultivated crop. During later part of the 20th century, high yielding rice varieties replaced many traditional cultivars. Consequently, genetic erosion in rice proceeded more rapidly.

In general, rice is less tolerant to drought stress than other cereals while it is the only food crop (cereal) that can tolerate water logging. Usually the climate of Bangladesh is characterized by high rainfall and temperature and marked by seasonal variation of solar radiation and day-length.

The depth and duration of inundation of land in the monsoon season, water holding capacity and moisture status of the soil in dry season largely govern rice varieties adaptation and cropping pattern both under rain fed and irrigated conditions.

2.12.1 Local Transplant Aman rice

The seedlings of the Local Transplanted Aman (T. Aman) rice are raised during mid-June to mid-July. Transplanting starts from mid July and continues up to early October. Harvesting is done during mid-October to mid December. The major characteristics of the T. Aman rice variety are photoperiod sensitivity, seed dormancy and adaptation to cold temperature at the reproductive phase of the crop.

It was observed that the grain yield of modern T. Aman varieties decreases gradually with the delay of planting dates beyond August. It is known that the low temperature causes sterility when the variety is planted late. If photoperiod sensitive variety is planted late, it will get short period for its vegetative growth and thus yield will decrease. Therefore, time of planting is important for the T. Aman rice varieties.

2.12.2 Climatic Effect on Rice Production

Usually the climate of Bangladesh is characterized by high rainfall and temperature and marked by seasonal variation of solar radiation and day length (table 2.5).

(a) Rainfall

The monsoon starts in June and ends in October. Monthly rainfall fluctuates over the seasons and years causing drought at the beginning and end of the monsoon. Annual rainfall is about 2311 mm but not uniformly distributed throughout the year.

In some years the period between November and May is rainless particularly in the western part of the country. Rainfall is much in the eastern part of the country than the western part (Table 2.5).

Variability of rainfall affects rice at different times. If the variability is associated with the onset of the rain, stand establishment and growth duration of rice are affected. If viability is associated with untimely cessation of rain at the reproductive stage of the rice crop, yield reduction is severe. Rainfall variability is more critical for upland rice than lowland rice.

Table 2.5 Mean rainfall, temperature, bright shine hours and day length in Bangladesh. (Source: Agro-Climatic Survey of Bangladesh-Manalo).

Months	Rainfall (mm)	Temp Max (C°)	Temp Min (C°)	Bright Sun- Shine (hr)	Day Length (hr)
January	13.0	25.5	12.0	8.9	10.8
February	19.4	27.9	14.2	9.1	11.4
March	45.5	32.2	18.8	8.6	12.0
April	113.4	34.0	22.8	8.5	12.7
May	255.1	33.2	24.4	8.2	13.3
June	426.3	31.6	25.2	4.2	13.6
July	434.4	30.9	25.6	4.6	13.5
August	399.1	31.2	25.6	4.7	13.0
September	290.0	31.4	25.4	5.8	12.3
October	161.0	30.9	23.3	7.3	11.6
November	33.1	28.8	17.7	9.1	11.0
December	14.6	26.3	13.4	8.8	10.7

In general, rice is less tolerant to drought stress than other cereals and when stressed it suffers more rapidly than other cereals. On the other hand, it is the only food crop (cereal) that can tolerate water logging. Thus rice may be considered as semi-aquatic plant.

(b) Temperature

Highest temperature prevails during March to September and the lowest between last week of December and first week of January. In summer, the temperature may rise up to 40.5°C. Both low and high temperature affects rice at different stages of its life cycle. Critical temperatures at different growth stages are given below in Table 2.6.

Table 2.6 Critical temperatures at different growth stages of paddy. (Source: IRRI, 1995).

Growth stage	Low critical Temp (C°)	High critical Temp(C°)	Optimum critical Temp (C°)
Germination	16-19	45	18-40
Seedling emergence & establishment	12-35	35	25-30
Rooting	16	35	25-28
Tillering	9-16	33	25-31
Panicle differentiation	15-20	30	-
Anthesis	22	35-36	30-33
Ripening	12-18	>30	20-29

(c) Low Temperature Effects

Critical low temperature for sterility is about 15-20°C. This sterility is due to cold injuries occurring in anthesis. The low temperature causes: poor germination, slow growth and discoloration of seedlings, stunted vegetative growth characterized by reduced plant, height and less tiller, delayed heading and incomplete panicle exertion, degeneration of spikelets, and spikelet sterility. The cold injury to the rice crop is ultimately reflected in increase in growth duration and reduction in grain yield.

(d) High Temperature Effects

High temperature increases plant height but decreases growth duration of a photo-insensitive rice plant. According to Satake and Yoshida (1978) spikelet sterility from high temperature (35-40°C) is induced largely on the day of flowering. Within the flowering day, high temperature during anthesis was the most detrimental. Fertility of spikelets was 75% at 35°C for hours, about 55% at 38°C for 4 hours and about 15% at 41 °C for 2 hours when the rice plants were at the anthesis stage.

(e) Solar Radiation

Solar radiation is necessary for photosynthesis of plants. The bright sunshine hour varies from 4.2 hours day in June to 9.1 in February and November. Rice plant's most critical period of solar energy requirement is from panicle initiation until about 10 days before maturity for accumulating dry matter content. Higher solar radiation results in higher yield. Effective sunshine during the summer season is drastically reduced due to frequent cloudy skies.

(f) Day Length

The interval between sunrise and sunset is the day length or photoperiod. Day length in Bangladesh varies from 10.7 to 13.7 hours. In lowland rainfed rice culture, delay in transplanting photoperiod-sensitive Aman varieties because of delayed rains does not usually affect the grain yields.

It is because of the flexibility at the seedling stage that photoperiod-sensitive traditional T. Aman varieties are grown during Aman season. In some areas, the need to delay harvesting until monsoon-season floodwater has receded makes it essential to grow photoperiod-sensitive varieties.

2.13 Wheat in Bangladesh

Wheat is one of the main crops of Bangladesh. It is cereal plant of the genus *Triticum*, especially, *T. aestivum*, of the family Graminae. The grain constitutes a major food item and an important commodity on the world grain market. The civilization of West Asia and of the European peoples has been largely based on wheat, while rice has been more important in the East Asia. Since agriculture began, wheat has been the chief source of bread for Europe and the Middle East. It was introduced into Mexico by the Spaniards in the early part of 16th century

and into Virginia, USA by English colonists early in the 17th century. Although it is one of the oldest of the cereal crops, it was introduced in Bengal in 1930-31. Its importance as a food crop was recognized around 1942-43. In Bangladesh the time of transplanting of wheat is November to December and time of harvest is March to Mid April (Table 2.8).

The total area under wheat crop has been estimated at 13,79,900 acres in year 2005 compared to 15,86,110 acres in the 2003-04 i.e. 13.0% lower. The wheat area in Bangladesh is gradually declining over the last several years. This has been happening due to increase of parallel crops like Boro, Potato, Maize etc. the comparative estimates of 2004-2005 and the last two years are shown in Table 2.7. The yield rate has also decreased mainly due to relatively higher temperature and shortened of cold season.

Table 2.7 Wheat area and estimated yield rates (Source: Yearbook of Agricultural Statistics of Bangladesh, 2005)

years	Area (in hectare)	% change over previous year	Yield per hectare (M.ton)	% change over previous year
2004-2005	5,58,413	(-) 13.0	1.748	(-) 10.50
2003-2004	6,41,875	(-) 9.14	1.953	(-) 8.44
2002-2003	7,06,475	(-) 4.77	2.133	(-) 1.49

2.13.1 Weather Condition for Wheat Cultivation

Wheat production is highly dependent on weather condition. Wheat needs 12 to 15 inches (31 to 38 centimeters) of water to produce a good crop. It grows best when temperatures are warm, from 70° to 75° F (21° to 24° C), but not too hot. Wheat also needs a lot of sunshine, especially when the

grains are filling. Areas with low humidity are better since many wheat diseases thrive in damp weather.

Table 2.8 Time of sowing/ transplanting, time of harvest and per acre seed requirement of different crops. (Source: Yearbook of Agricultural Statistics of Bangladesh, 2005).

Crop	Time of Sowing/ Transplanting	Time of Harvest	Per Acre seed Requirement
Local Transplant Aman	End June to Early September	December to early January	9-11 kg
Wheat	November to December	March to Mid April	(a) 28-33 kg if sown without irrigation (b) 33-37 kg if sown with 1-2 times irrigation (c) 37-47 kg if sown with 4-5 times irrigation
Potato	Mid September to November	Mid January to March	4-6 Ql tuber
Mung bean	Mid August to Mid September	Mid November to Mid December	8-10 kg

2.14 Potato (Local) in Bangladesh

A British governor promoted potato cultivation in Bengal in the 1770s, and within a century it was a well established garden vegetable. However, large scale production was held back by the lack of suitable varieties: European cultivars were not adapted the hot Bengali plains.

Asia and Europe are the world's major potato producing regions, accounting for more than 80 percent of world production in 2007 (Table 2.9). Today, the potato has become a highly successful October-March winter crop in Bangladesh, with a production value - estimated at \$560 million in 2005 - second only to that of paddy rice. In 2007, Bangladeshi farmers harvested more than 4.3 million tonnes of potatoes (12 times more than in 1961), which placed the country at No. 14 among the world's potato producers and No. 4 in Asia. Annual consumption has been growing briskly, from around 7 kg per capita in 1990 to more than 24 kg in 2006. (Source: FAOSTAT. FAO, 2008).

Table 2.9 Potato production, by region, 2007. (Source: FAOSTAT. FAO,2008)

	Harvested area	Quantity	Yield
	hectares	tonnes	tonnes/hectare
Africa	1 503 145	16 308 530	10.84
Asia/Oceania	8 743 857	137 182 946	15.68
Europe	7 439 553	128 608 372	17.28
Latin America	962 434	15 985 825	16.61
North America	615 032	22 626 288	36.78
WORLD	19 264 021	320 711 961	16.64

2.14.1 Weather and Cultivating Condition of Potato

Well-fertilized, sunny land with sufficient moisture in soil is appropriate for potato plantation. The first fortnight of November is the right time. In certain northwestern areas, farmers even plant potato in October to harvest the crop early. Virtually all potatoes in this country are planted manually. On the basis of the soil quality and potato variety farmers determine the spacing in between the seed tubers and the adjacent rows. Row spacing is usually from 45 to 60 cm. Optimum depth of planting depends on temperature and moisture of the soil, probable weather following planting, and mode of conducting field operations later. If planting is shallow and only about 5 cm deep, the soil must be gradually ridged over the row incidental to cultivation. This ensures that the developing tubers are well covered with soil to protect them from light and pests. Mulching is frequently done over the rows with water hyacinth, straw etc to preserve the soil moisture and to prevent the growth of weeds. The optimal temperature for plant growth 18°C and the minimum temperature is 7°C.

2.15 Pulse (Mungbean) in Bangladesh

The common pulses in Bangladesh are Masur (lentil), Mung (green gram), Mashkalai (black gram), Chhola (chick pea), Kheshari (lathyrus or grass pea), and Motor (pea). Kheshari is widely cultivated, mostly as fodder, and also consumed by the villagers of the northern part of the country. Masur is popular to all classes of people, and is taken in almost all meals. Mashkalai and Chhola are taken occasionally. Pulses are cultivated as rabi crop mainly in the western and northern parts.

About 70 percent of mung bean production is concentrated in the four southern districts of Patuakhali, Barisal, Bhola, and Noakhali. Patuakhali alone accounts for 30 percent of the area in which mung bean is grown. Also a very high yield has been obtained in BARI mung-2 in the greater Jessore and Jhenidhah regions. In the year 2004-05 Mung bean was cultivated in 60180 Acres of area in Bangladesh and the production was 17935 metric tons.

2.15.1 Weather Condition for Mungbean Cultivation

Productivity of pulses in Bangladesh is low and unstable compared to that of wheat or rice. The major constraints on productivity are that pulses in general have genetically low yield potential—particularly the indigenous varieties. It is very sensitive to too much water and fertilizer and often shows negative response to these factors. It is more sensitive to climatic factors such as excess soil moisture, humidity and rainfall, terminal heat stress, and soil factors, when compared with cereals. The optimal temperature for plant growth is 25°C and the minimum temperature is 10°C. Mungbean is being cultivated as a long duration minor legume crop during the end of May to the end of October. The time of transplanting is Mid August to Mid September. The time of harvest is Mid November to Mid December (Table 2.8).

2.16 Threshold Values for Crop's Cultivation

Rice (*Oryza sativa*)

Irrigated/bunded

Growing Season:

Kharif-I

T. Aman (Local)

Land Factors	Range	Optimum
Soil Permeability (cm d ⁻¹)	Slow to moderate	Slow (<12 cm d ⁻¹)
Effective Soil Depth (m)	0.25 to 1.20 m	> 0.90 m
Available Soil Moisture (mm) ⁺	>400 mm (900-1200 mm)*	>400 mm (>1000 mm)*
Nutrient Status	Low to high	High
Soil Reaction (pH)	4.5-8.2	5.5-7.5
Soil Salinity (dS m ⁻¹ or m mhos cm ⁻¹)	0 to < 3 dS m ⁻¹ (10% yield loss)	0 to <2 dS m ⁻¹
Soil Consistency/Texture	C1-C4 / SiCL, CL, Si, SiL, SC, L, SCL, SL	C1-C2/ SiCL, CL, Si, SiL, SC
Drainage	Imperfectly to moderately-well drained	Poor to Imperfectly drained
Depth of inundation (cm)	Saturated to flooded up to 25% of plant height	Saturated to flooded up to 10-20 cm
Slope (%)	0 to <3	Flat floodplains
Irrigation	4000 kg of water/ 1 kg rice production	
Fertilizer N:K:S	200: 100: 60 kg/ Ha (recommended)	

C1 = not more than slightly firm, slightly sticky, slightly plastic, hard

C2 = fine, very firm, sticky, plastic, hard, very hard

C3 = extremely firm, very sticky, very plastic, extremely hard

C4 = organic material to at least 25 cm below the surface

SiCL = silty clay loam, CL = clay loam, Si = silt, SiL = silt loam, SC = sandy clay, L = loam, SCL = sandy clay loam, SL = sandy loam, LfS = loamy fine sand, LS = loamy sand, LcS = loamy coarse sand, fS = fine sand, S = sand, cS = coarse sand

* Maximum evapotranspiration

⁺ In case of irrigated crops water is applied as and when required

Irrigated Wheat (*Triticum aestivum*)

Irrigated

Growing Season: Rabi

Land Factors	Range	Optimum
Soil Permeability (cm d ⁻¹)	Moderate to rapid (>12 to >305 cm d ⁻¹)	Rapid
Effective Soil Depth (m)	> 0.90 to 2.00 m	> 0.90 to 1.50 m
Available Soil Moisture (mm) ⁺	200 to 350 mm (350-500 mm)*	300 to <400 mm (350 mm)*
Nutrient Status	Low to high	High
Soil Reaction (pH)	5.2-8.5	6.0-8.2
Soil Salinity (dS m ⁻¹ or m mhos cm ⁻¹)	0 to < 7.4 dS m ⁻¹ (10% yield loss)	< 6.0 dS m ⁻¹
Soil Consistency/Texture	C1-C2 / SiC, CL, Si, SiL, SC, L, SCL, SL	C1-C2/ SiL, SC, L
Drainage	Well drained to moderately well drained	Well drained
Depth of inundation (cm)	Not flooded, cannot withstand flooding	Not flooded, cannot withstand flooding
Slope (%)	0 to <3	Flat floodplains
Irrigation	1000 kg of water / 1 kg wheat production	
Fertilizer N:P:K:S	100:26:33:20 kg/ Ha (recommended)	

C1 = not more than slightly firm, slightly sticky, slightly plastic, hard

C2 = fine, very firm, sticky, plastic, hard, very hard

C3 = extremely firm, very sticky, very plastic, extremely hard

C4 = organic material to at least 25 cm below the surface

SiCL = silty clay loam, CL = clay loam, Si = silt, SiL = silt loam, SC = sandy clay, L = loam, SCL = sandy clay loam, SL = sandy loam, LfS = loamy fine sand, LS = loamy sand, LcS = loamy coarse sand, fS = fine sand, S = sand, cS = coarse sand

* Maximum evapotranspiration

⁺ In case of irrigated crops water is applied as and when required

Potato (*Solanum tuberosum*)**Irrigated****Growing Season: Rabi**

Land Factors	Range	Optimum
Soil Permeability (cm d ⁻¹)	Moderate to rapid (>12 to >305 cm d ⁻¹)	Rapid
Effective Soil Depth (m)	> 0.50 to 1.00 m	> 0.60 to 1.00 m
Available Soil Moisture (mm) ⁺	>150 to 400 mm (500-700 mm)*	300 to <400 mm (700 mm)*
Nutrient Status	Low to high	High
Soil Reaction (pH)	4.5-8.4	5.6-7.3
Soil Salinity (dS m ⁻¹ or m mhos cm ⁻¹)	0 to < 4.0 dS m ⁻¹ (10% yield loss)	< 2.0 dS m ⁻¹
Soil Consistency/Texture	C1-C2 / SiL, SC, L, SCL, SL	C1-C2/ L, SCL,
Drainage	Well drained to imperfectly drained	Well drained
Depth of inundation (cm)	Not flooded, cannot withstand flooding	Not flooded, cannot withstand flooding
Slope (%)	0 to <3	Flat floodplains
Irrigation	1000 kg of water / 1 kg potato production	
Fertilizer N:K:S	300: 150: 100 kg/ Ha (recommended)	

C1 = not more than slightly firm, slightly sticky, slightly plastic, hard

C2 = fine, very firm, sticky, plastic, hard, very hard

C3 = extremely firm, very sticky, very plastic, extremely hard

C4 = organic material to at least 25 cm below the surface

SiCL = silty clay loam, CL= clay loam, Si = silt, SiL =silt loam, SC = sandy clay, L = loam, SCL = sandy clay loam, SL = sandy loam, LfS = loamy fine sand, LS = loamy sand, LcS = loamy coarse sand, fS = fine sand, S = sand, cS = coarse sand

Pulses-Mungbean

Irrigated

Growing Season: Rabi

Land Factors	Range	Optimum
Soil Permeability (cm d ⁻¹)	Moderate to rapid (>12 to >305 cm d ⁻¹)	Rapid
Effective Soil Depth (m)	> 0.60 to 1.5 m	1.00 to 1.50 m
Available Soil Moisture (mm) ⁺	>150 to 400 mm (250-500 mm)*	300 to <400 mm (300-350 mm)*
Nutrient Status	Low to high	High
Soil Reaction (pH)	5.0-8.2	6.0-7.5
Soil Salinity (dS m ⁻¹ or m mhos cm ⁻¹)	0 to < 2.0 dS m ⁻¹ (10% yield loss)	0.0 - < 0.5 dS m ⁻¹
Soil Consistency/Texture	C1-C2 / SiC, CL, Si, SiL, SC, L, SCL, SL	C1-C2/ SiL, L, SC, SCL
Drainage	Well drained to moderately well drained	Well drained
Depth of inundation (cm)	Not flooded, cannot withstand flooding	Not flooded, cannot withstand flooding
Slope (%)	0 to <3	Flat floodplains
Irrigation	40 kg of water/ 1 kg mungbean production (almost negligible)	
Fertilizer	Almost not needed	

C1 = not more than slightly firm, slightly sticky, slightly plastic, hard

C2 = fine, very firm, sticky, plastic, hard, very hard

C3 = extremely firm, very sticky, very plastic, extremely hard

C4 = organic material to at least 25 cm below the surface

SiCL = silty clay loam, CL= clay loam, Si = silt, SiL =silt loam, SC = sandy clay, L = loam, SCL = sandy clay loam, SL = sandy loam, LfS = loamy fine sand, LS = loamy sand, LcS = loamy coarse sand, fS = fine sand, S = sand, cS = coarse sand

* Maximum evapotranspiration

⁺ In case of irrigated crops water is applied as and when required

Source: BARC

2.17 Climate Change Induced Vulnerability to Crop Production

Since climate factors strongly interact to affect crop yields, it is likely that climate change will affect crop production. The tropical and subtropical countries would be more vulnerable to the potential impacts of global warming through effects on crops, soils, insects, weeds and diseases (Parry and Jiachen, 1991).

On the other hand, elevated carbon dioxide (CO₂) concentrations will have beneficial effects on crop production. Karim et al. (1999) reported significant decrease in food grain production, especially for wheat (68% decrease) by a rise in temperature; and doubling of atmospheric concentration of CO₂ in combinations with a similar rise in temperature would result in an overall 20 percent rise in rice production and 31 percent decline in wheat production.

There have been many studies to assess the impact of climate change on crop production on sub-regional, regional and global levels. Models have provided an important means for integrating many different factors that affect crop yield over a cropping season (Rosenzweig et al, 1999).

Bangladesh is highly susceptible to climatic events; flood and droughts are frequent and damaging (Karim et al., 1996). Quantification of climatic risk to evaluate management decisions objectively is an important area for model applications.

Agricultural activities are already highly susceptible to the elements of nature or biophysical systems of the country. A favorable weather helps the farmers to have a good harvest while a bad patch of local weather spoils the expected harvest. Soil, the most important natural resource for agricultural activities, is highly responsive to physical systems. A rise in surface temperature may cause higher rates of decomposition of soil organic matter, the latter having significant effect on crop yield.

2.18 Crop Agriculture and Food Security

Various studies indicate that a rise of 1°C to 2°C in combination with lower solar radiation causes sterility in rice spikelets. High temperature was found to reduce yields of HYVs of Aus, Aman and Boro rice in all study locations and in all seasons. The effect was particularly evident at a rise of temperature by 4°C (Ahmed, 2000).

The production of crop in Bangladesh is constrained by too much water during the wet season and too little during the dry season. Presently total irrigated area is 4.4 million ha which is more than 50 % of the potentially irrigable area of 7.12 million ha cultivated area. This area is being irrigated through surface and ground water resource (BARC, 1998).

A simulation study conducted under the climate change country study assessed the vulnerability of foodgrain production due to climate change in Bangladesh. The GFDL model predicted about 17% decline in overall rice production and as high as 61% decline in wheat production compared to the baseline situation. The highest impact would be on wheat followed by rice (Aus variety). This translates to a reduction of 4.5 million tons of rice at the present level (2002) of production. Of the three varieties of rice grown in Bangladesh, the Aus rice (grown during the summer, monsoon period under rain-fed conditions) seems to be the most vulnerable. The other model, Canadian Climate Change Model (CCCM) predicted a significant fall in food grain production.

It was noticed that temperature increase of 4°C would have severe impact on food-grain production, especially for wheat production. On the other hand, carbon-dioxide fertilization would facilitate food-grain production. A rise in temperature would cause significant decrease in production, 28% and 68% for rice and wheat, respectively.

Moreover, doubling of atmospheric concentration of CO₂ in combination with a similar rise in temperature would result into an overall 20% rise in rice production and 31% decline in wheat production. It was found that Boro rice would enjoy good harvest under severe climate change scenario with doubling of atmospheric concentration of CO₂ (Karim et al., 1999).

The apparent increase in yield of Boro (dry season rice crop generally grown under irrigated conditions and includes high yielding varieties) and other crops might be constrained by moisture stress. A 60% moisture stress on top of other effects might cause as high as 32% decline in Boro yield, instead of having an overall 20% net increase (Ahmed, 2000).

It is feared that moisture stress would be more intense during the dry season, which might force the Bangladeshi farmers to reduce the area for Boro cultivation. Shortfall in foodgrain production would severely threaten food security of the poverty-ridden country.

Under a severe (4°C temperature rise) climate change scenario the potential shortfall in rice production could exceed 30% from the trend, while that for wheat and potato could be as high as 50% and 70%, respectively (Karim et al, 1996).

Under a moderate climate change scenario the crop loss due to salinity intrusion could be about 0.2MT (Habibullah et al., 1999). The loss of production due to such effects may be relatively higher compared to that under floods. However, the loss incurred in other sectors could be much higher in case of floods than the direct climatic changes. The effect of low-flow on agricultural vulnerability is considered to be much less intense compared to other effects. The ultimate impacts of loss of food grain production would increase import of food, which will require spending hard currency.

2.19 EPIC Model (Erosion Productivity Impact Calculator)

The EPIC (Erosion Productivity Impact Calculator) model is a comprehensive agricultural management model, which uses a daily time step to simulate weather, hydrology, soil temperature, erosion-sedimentation, nutrient cycling, tillage, crop management and growth, pesticide and nutrient movement with water and sediment, and field-scale costs and returns. Led by Dr. Jimmy Williams, scientists of the USDA Agricultural Research Service (ARS) developed the EPIC8120 model on May 29th, 1998. This Appendix describes user guide for execution of the EPIC model (version 8120).

EPIC is designed to be:

- Capable of simulating the relevant biophysical processes simultaneously, as well as realistically, using readily available inputs and, where possible, accepted methodologies;
- Capable of simulating cropping systems for hundreds of years because erosion can be a relatively slow process;
- Applicable to a wide range of soils, climates and crops;
- Efficient, convenient to use, and capable of simulating the particular effects of management on soil erosion and productivity in specific environments.

Model Components

In EPIC, the major biophysical processes simulated are called components. EPIC consists of the following ten major components:

Weather: Daily rain, snow, maximum and minimum temperatures, solar radiation, wind and relative humidity can be based on measured data and/or generated stochastically.

Hydrology: Runoff, percolation, lateral subsurface flow, and snow melt are simulated. Any one of four methods can be used to estimate potential evapotranspiration.

Erosion: EPIC simulates soil erosion caused by wind and water. Sheet and rill erosion/sedimentation result from runoff from rainfall, snow melt, and irrigation.

Nutrient Cycling: The model simulates nitrogen and phosphorus fertilization, transformations, crop uptake and nutrient movement. Nutrients can be applied as mineral fertilizers, in irrigation water, or as animal manures.

Pesticide Fate: The model simulates pesticide movement with water and sediment as well as degradation on foliage and in soil.

Soil Temperature: Soil temperature responds to weather, soil water content, and bulk density. It is computed daily in each soil layer.

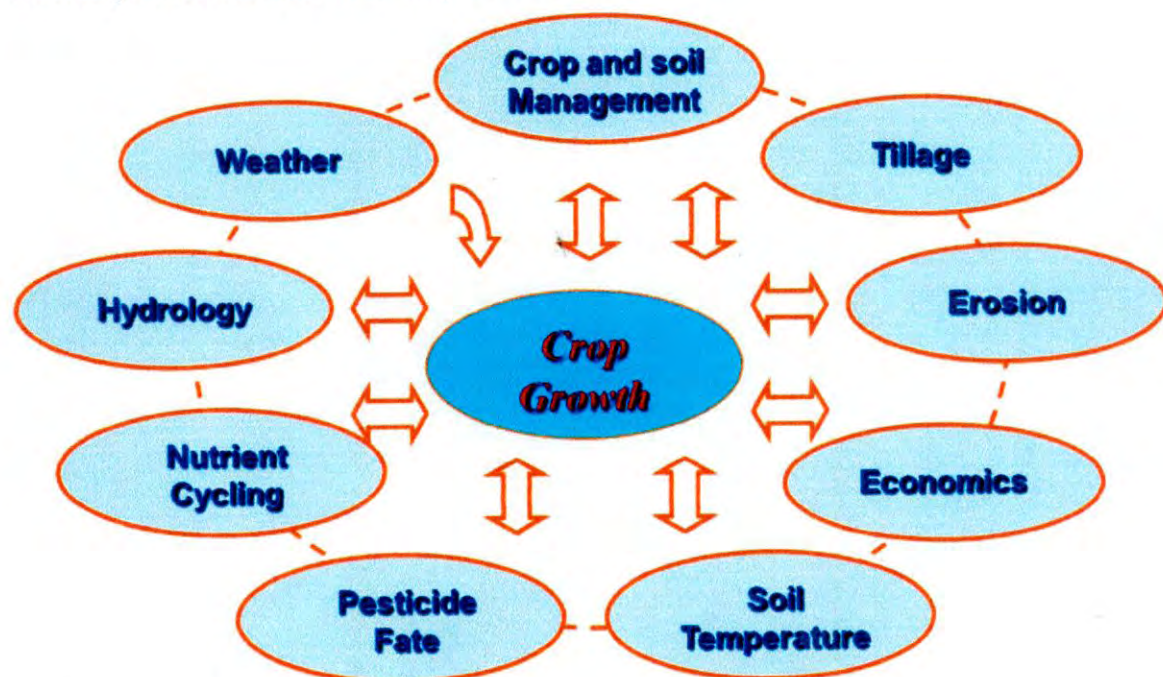
Tillage: Tillage equipment affects soil hydrology and nutrient cycling. The user may change the characteristics of simulated tillage equipment, if needed.

Crop Growth: A single crop model capable of simulating major agronomic crops, pastures, and trees is used. Crop-specific parameters are available for most crops. The user may adjust or create new sets of parameters as needed. The model can also simulate crops grown in complex rotations and, in certain cases, in mixtures.

Crop and Soil Management: The EPIC model is capable of simulating a variety of cropping variables, management practices and naturally occurring processes. These include different crop characteristics, plant populations, dates of planting and harvest, fertilization, irrigation, artificial drainage systems, tillage, runoff control with furrow dikes and other methods, liming, and pest control. The model can also gauge the effects of such varied management practices, as whether the crop is harvested for grain or fodder or if it is grazed or burned.

Economics: A simple accounting package is included to calculate the costs of inputs and compute returns.

Basically EPIC can deal with the problems like



In this study we are interested here about the Crop Growth Model part in this study.

BACKGROUND OF THE STUDY AREA

3.1 Introduction

In the following sections the basic information about the study areas, Dinajpur, Comilla, Jessore and Bogra districts regarding their location and geography, administration, population, land tenure system, climate, soil types, land classes, agrological zones etc are briefly presented.

3.2 Dinajpur District

3.2.1 Location and Geography of Dinajpur District

Dinajpur district (Figure 3.1) is under Rajshahi division. Its coordinate is 25.63° N 88.65° E and altitude is 37 m. The total area of the district is 3,437.98km² and it is bounded by THAKURGAON and PANCHAGARH districts on the north, GAIBANDHA and JOYPURHAT districts on the south, NILPHAMARI and RANGPUR districts on the east, the Indian state of West Bengal on the south west.. It consists of six municipalities, 57 wards, 200 mahallas, 13 upazilas, 101 union parishads and 2142 villages.

3.2.2 Population Statistics

- Total Population is 2,617,942(According to the census of 2001 and Bangladesh Statistical Beauró) Among them male 51.12%, female 48.88%.
- Muslim 76.65%, Hindu 20.58%, Christian 0.80%, Buddhist 0.11% and other 1.86%.
- Ethnic nationals: the Santal and Oraon.
- Average literacy 60%; male 34.7% female 19.5%.
- Main occupations Agriculture 42.85%, agricultural labourer 29.19%, wage labourer 2.48%, commerce 10.2%, transport 1.67%, service 5.58%, others 8.03%.
- Land control Landless 40%, small farmers 30%, medium farmers 25%, large farmers 5%; per capita cultivable land 500m².

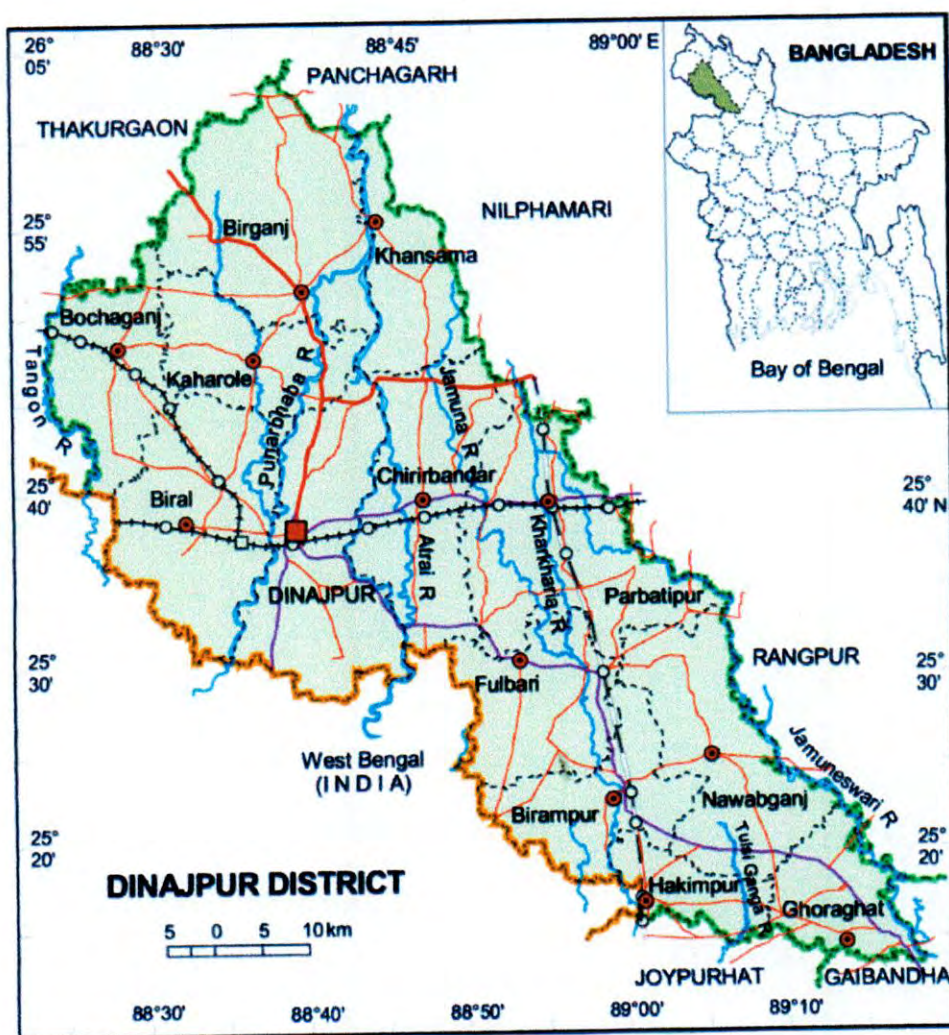


Figure 3.1 Dinajpur District Map with administrative units (Source: Banglapedia, 2008)

3.2.3 Climate

The district has hot summer and cold winter. The summer begins from end of March and continues till the end of the June. Winter starts from November and continues till February.

(a) Maximum and Minimum Temperature

In Dinajpur district the annual average highest temperature is 33.0°C and lowest is 10.5°C (for year 1991-2005). Figure 3.2 shows the 15 years' average maximum, minimum temperature and rainfall on monthly basis. The maximum and minimum temperatures were observed in April and January respectively.

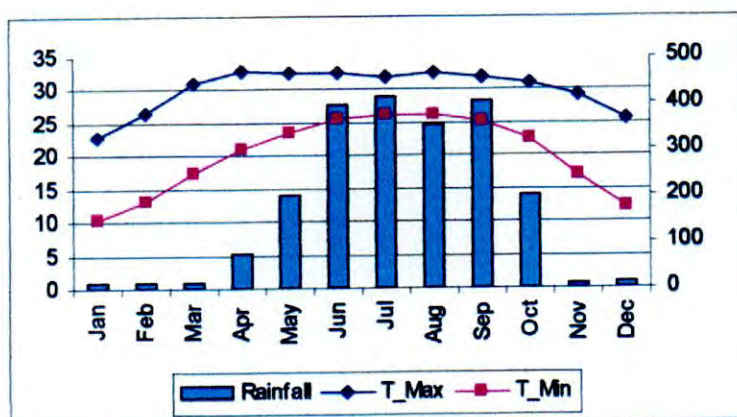


Figure 3.2 Graphical presentation of climatic parameters (1991-2005) of Dinajpur.

(b) Rainfall

In Dinajpur the average annual rainfall of year 1991-2005 was 2101 mm. The average humidity was recorded 81% in January and around 85% in July, August and September. During dry season, the area experiences average 55mm rainfall. Long term statistical analysis of rainfall data suggest that about 3 or 4 months of the dry season the area remains almost completely without rain.

(c) Solar Radiation

The yearly average solar radiation in Dinajpur district is about $18 \text{ MJ m}^{-2} \text{ day}^{-1}$. The maximum solar radiation of $24.3 \text{ MJ m}^{-2} \text{ day}^{-1}$ is reached during April and a minimum value of $11.2 \text{ MJ m}^{-2} \text{ day}^{-1}$ in the month of December and January.

(d) Wind Speed

The average monthly wind speed varies from 0.62 m/s to 1.18 m/s (for the year 1991-2005). The wind speed is generally higher during the monsoon as compared to that of winter months. However, storms generally occur in Bangladesh in the month of April-May and again in October and November.

3.2.4 Agroecological Zones (AEZ) and Soil Type

Dinajpur district consists of two agroecological zones namely, Level Barind Track (AEZ-25) and North-Eastern Barind Track (AEZ-27), where the Level Barind Track (AEZ-25) is predominant (Figure 3.3).

i. Level Barind Tract (AEZ-25)

This region is developed over MADHUPUR CLAY. The landscape is almost level. The predominant soils have grey, silty, puddled topsoil with ploughpan. Shallow grey terrace soil and deep grey terrace soils are the major components of general soil types of the area. The soils are low in available moisture holding capacity and slightly acidic to acidic in reaction. Organic matter status is very low and most of the available nutrients are limiting.

ii. North Eastern Barind Tract (AEZ-27)

This region occupies several discontinuous areas on the north-eastern margins of the Barind Tract. It has silty or loamy topsoil and clay loams to clay subsoil. The soils are strongly acidic in reaction. Organic matter in the soils is low. General fertility is poor.

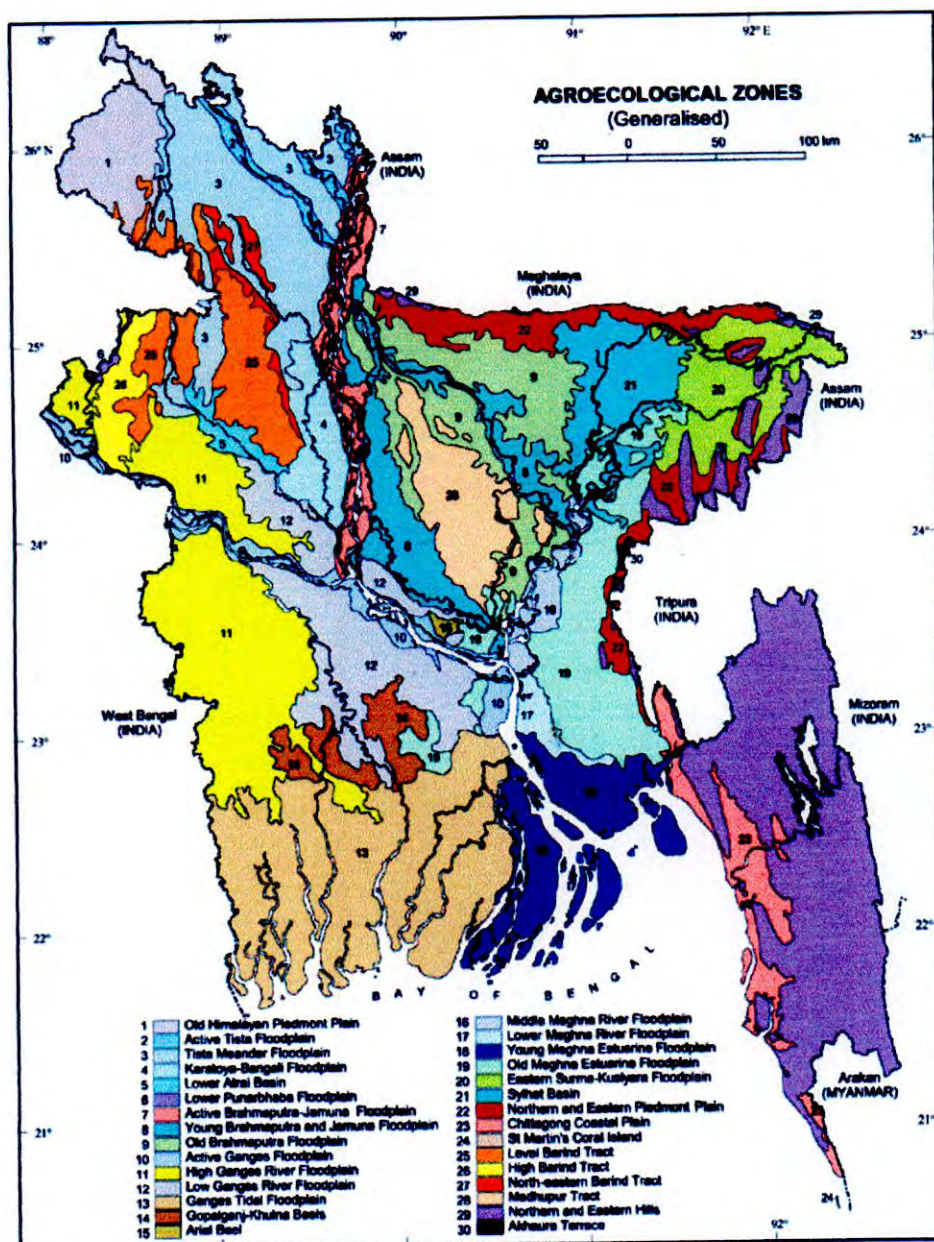


Figure 3.3 Agroecological zones of Bangladesh (Source: Banglapedia, 2008)

3.2.5 Land Type and Soil Condition

According to the land resource information database of BARC on Dinajpur district, Table 3.1, 3.2 and 3.3 show the different land information.

Table 3.1 Available Soil Moisture Holding Capacity by Land type under AEZ of Dinajpur district (Based on LRI database of BARC)

Agro-ecological Zone (AEZ)	Available Soil Moisture	Area (Ha)					Table Total
		Inundation Land Type					
		Highland	Medium Highland	Medium Lowland	Lowland	Very Lowland	
Level Barind Tract	100-200 MM	146311	274109	21507	10179	.	452106
	200-300 MM	2984	2055	237	.	.	5276
	300-400 MM	295	75	.	.	.	370
	Group Total	149590	276239	21744	10179	.	457752
North-Eastern Barind Tract	100-200 MM	36623	60766	719	.	.	98108
	200-300 MM	2299	.	.	.	.	2299
	Group Total	38922	60766	719	.	.	100407

Table 3.2 Slope by Land type under AEZ of Dinajpur district (Based on LRI database of BARC)

Agro-echological Zone (AEZ)	Slope	Area (Ha)					Table Total
		Inundation Land Type					
		Highland	Medium Highland	Medium Lowland	Lowland	Very Lowland	
Level Barind Tract	S1 (<3%)	149590	276239	21744	10179	.	457752
	Group Total	149590	276239	21744	10179	.	457752
North-Eastern Barind Tract	S1 (<3%)	38922	60766	719	.	.	100407
	Group Total	38922	60766	719	.	.	100407

Table 3.3 Drainage by Land type under AEZ of Dinajpur district (Based on LRI database of BARC)

Agro- ecological Zone (AEZ)	Drainage	Area (Ha)					Table Total
		Highland	Inundation Land Type			Very Lowland	
			Medium Highland	Medium Lowland	Low land		
Level Barind Tract	Well Drained	15	.	.	.	.	15
	Moderately Well Drained	4588	.	.	.	.	4588
	Imperfectly Drained	144987	.	.	.	.	144987
	Poorly Drained but Surface Drains Early	.	276239	12674	7925	.	296838
	Poorly Drained but Surface Drains Late	.	.	9070	2254	.	11324
	Group Total	149590	276239	21744	10179	.	457752
	Well Drained	8660	.	.	.	.	8660
North- Eastern Barind Tract	Moderately Well Drained	24352	.	.	.	.	24352
	Imperfectly Drained	5910	.	.	.	.	5910
	Poorly Drained but Surface Drains Early	.	60766	20	.	.	60786
	Poorly Drained but Surface Drains Late	.	.	699	.	.	699
	Group Total	38922	60766	719	.	.	100407

3.3 Comilla District

3.3.1 Location and Geography of Comilla District

Comilla district (Figure 3.4) is under Chittagong division. Its coordinate is 23.4583° N 91.1833° E and altitude is 10 m. The total area of the district is 3085.17 sq km and it is bounded by BRAHMANBARIA and NARAYANGANJ districts on the north, NOAKHALI and FENI districts on the south, Tripura (state of India) on the east, MUNSHIGANJ and CHANDPUR districts on the west. Main rivers are MEGHNA, GUMTI and DAKATIA. Comilla district has 5 municipalities, 54 wards, 148 mahallas, 12 upazilas, 1 thana, 180 union parishads, 2704 mouzas and 3624 villages. The upazilas are COMILLA SADAR, BARURA, CHANDINA, DAUDKANDI, LAKSHAM, BRAHMANPARA, BURICHANG, CHAUDDAGRAM, DEBIDWAR, HOMNA, MURADNAGAR and NANGALKOT; the municipalities are Comilla Sadar, Barura, Chandina, Daudkandi and Laksham.

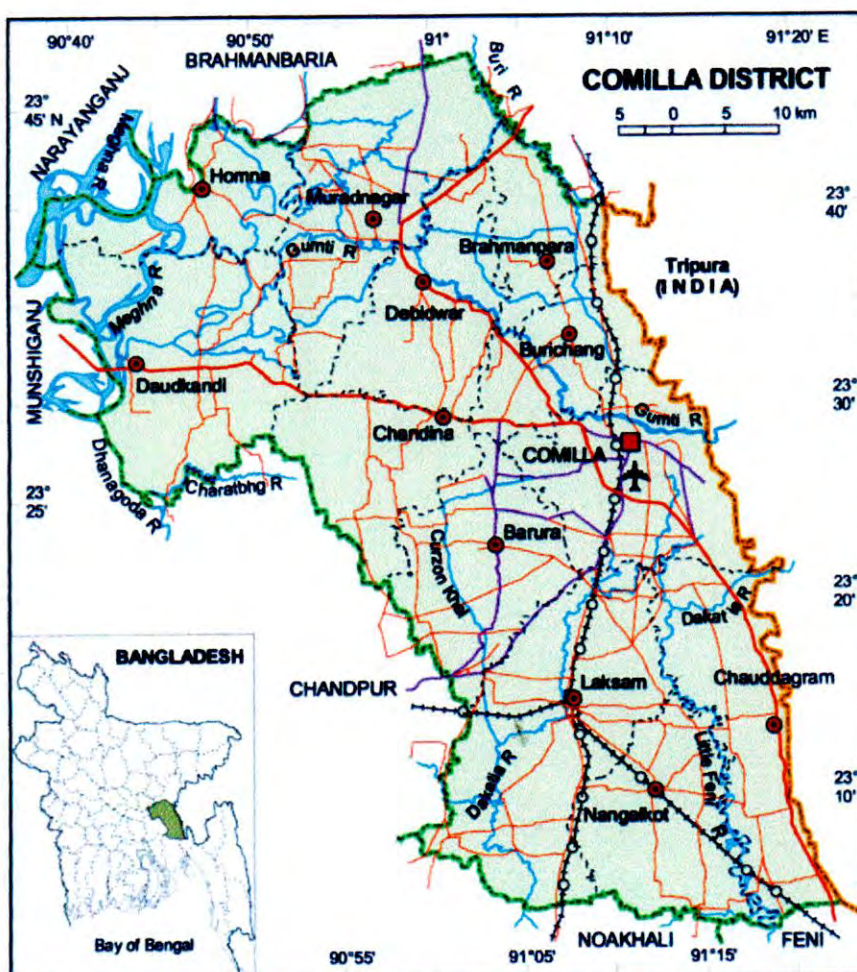


Figure 3.4 Comilla District Map with administrative units (Source: Banglapedia, 2008)

3.3.2 Population Statistics

- Total Population is 4586879 (According to the census of 2001 and Bangladesh Statistical Bureau). Among them male 49.33%, female 50.61%.
- Muslim 93.85%, Hindu 5.9%, Buddhist 0.13%, Christian 0.03% and others 0.09%.
- Ethnic nationals: Tipra and Rishi (characteristically Mongalite), on the border of Tripura State.
- Average literacy 33.1%; male 40.2% and female 26%.
- Main occupations Agriculture 43.28%, commerce 11.6%, service 10.78%, transport 3.36%, agricultural labourer 15.89%, wage labourer 2.46%, construction 1.03%, and others 11.6%.

- Land control Among the peasants 30% are landless, 46% small, 20% intermediate and 4% rich.

3.3.3 Climate

The climate is almost tropical with predominant monsoon influence. The district has hot summer and mild winter. The summer begins from beginning of April and continues till the end of the July. Winter starts from November and continues till February.

(a) Maximum and Minimum Temperature

In Comilla district the annual average highest temperature is 32.6°C and lowest is 11.9°C of year 1991-2005. Figure 3.4 shows the 15 years' average maximum, minimum temperature and rainfall on monthly basis. The maximum and minimum temperatures were observed in April-May and January respectively.

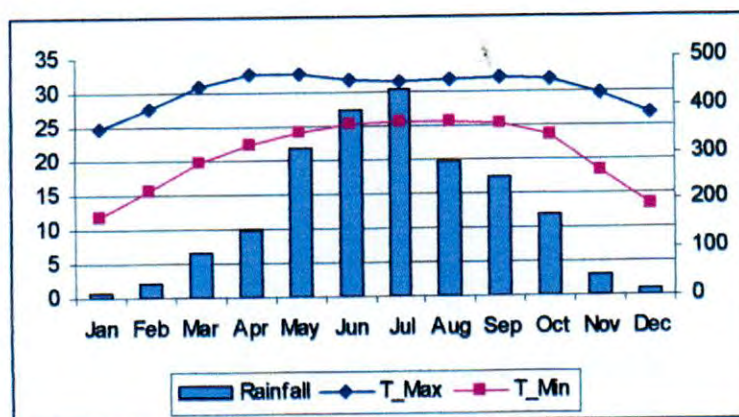


Figure 3.5 Graphical presentation of climatic parameters (1991-2005) of Comilla.

(b) Rainfall

In Comilla the average annual rainfall of year 1991-2005 was 2155 mm. The average humidity was recorded 78% in January and around 87% in July. During dry season, the area experiences average 105mm rainfall. Long term statistical analysis of rainfall data shows that the winter rainfall is limited and the season remains dry and cold. March and April are pre-monsoon season having high temperature and low water vapor in air.

(c) Solar Radiation

The yearly average solar radiation in Comilla district is about $16.9 \text{ MJ m}^{-2} \text{ day}^{-1}$. The maximum solar radiation of $23.3 \text{ MJ m}^{-2} \text{ day}^{-1}$ is reached during April and May and a minimum value of $10.2 \text{ MJ m}^{-2} \text{ day}^{-1}$ in the month of December and January.

(d) Wind Speed

The average monthly wind speed varies from 0.87 m/s to 2.8 m/s (for the year 1991-2005). The wind speed is generally higher during the monsoon as compared to that of winter months. However, storms generally occur in Bangladesh in the month of April-May and again in October and November.

3.3.4 Agroecological Zones (AEZ) and Soil Type

Comilla district consists of three agroecological zones namely, Old Meghna Estuarine Floodplain (AEZ-19), Northern and Eastern Piedmont Plain (AEZ-22) and Northern and Eastern Hills (AEZ-29), where the Old Meghna Estuarine Floodplain (AEZ-19) is predominant (Figure 3.3).

i. Old Meghna Estuarine Floodplain (AEZ-19)

This region occupies a large area, mainly low-lying land between the south of the Surma-Kushiyara floodplain and the northern edge of the young Meghna estuarine floodplain. Silt loam soils predominate on highlands and silty clay to clay on lowlands. Organic matter content of the soils are moderate. Topsoils are moderately acidic, but subsoils neutral in reaction. General fertility level is medium.

ii. Northern and Eastern Piedmont Plains (AEZ-22)

This is a discontinuous region occurring as a narrow strip of land at the foot of the northern and eastern hills. The region comprises merging alluvial fans which slope gently outward from the foot of the northern and eastern hills into smooth, low-lying basins. Grey piedmont soils and non-calcareous grey floodplain soils are the major general soil types of the area. Soils of the area are loams to clays, slightly acidic to strongly acidic in reaction. General fertility level is low to medium.

iii. Northern and Eastern Hills (AEZ-29)

This region includes the country's hill areas. Relief is complex. Hills have been dissected to different degrees over different rocks. In general, slopes are very steep and few low hills have flat summits. BROWN HILL SOILS is the predominant general soil type of the area. Organic matter content and general fertility level are low.

3.3.5 Land Type and Soil Condition

According to the land resource information database of BARC on Comilla district, Table 3.4, 3.5 and 3.6 show the different land information.

Table 3.4 Available Soil Moisture Holding Capacity by Landtype under AEZ of Comilla district (Based on LRI database of BARC)

Agro-ecological Zone (AEZ)	Available Soil Moisture	Area (Ha)					Table Total
		Inundation Land Type					
		Highland	Medium Highland	Medium Lowland	Lowland	Very Lowland	
Old Meghna Estuarine Floodplain	< 100 MM		81				81
	100-200 MM	740	5627	9139	9228	663	25397
	200-300 MM	10069	51578	100740	67104	16109	245600
	300-400 MM	3123	126659	143066	89112	6791	368751
	> 400 MM			746	645		1391
	Group Total	13932	183945	253691	166089	23563	641220
Northern and Eastern Piedmont Plain	< 100 MM	9686	2986				12672
	100-200 MM	75554	97097	61505	36233	2741	273130
	200-300 MM	46972	25555	2829	489	606	76451
	300-400 MM	267	1050	289			1606
	> 400 MM			5		152	157
	Group Total	132479	126688	64628	36722	3499	364016
Northern and Eastern Hills	< 100 MM	241579	1496	1325			244400
	100-200 MM	1036404	7116	3066	826		104741
	200-300 MM	97082	30563	1501			2
	300-400 MM	35	79	57			129146
	> 400 MM		142	1306	79	140	171
	Group Total	1375100	39396	7255	905	140	1667
							142279
	Group Total	1375100	39396	7255	905	140	6

Table 3.5 Slope by Land type under AEZ of Comilla district (Based on LRI database of BARC)

Agro-ecological Zone (AEZ)	Slope	Area (Ha)					Table Total
		Inundation Land Type					
		Highland	Medium Highland	Medium Lowland	Lowland	Very Lowland	
Old Meghna Estuarine Floodplain	S1 (<3%)	9665	182208	253691	166089	23563	635216
	S2 (3-8%)	4267	1737	.	.	.	6004
	Group Total	13932	183945	253691	166089	23563	641220
Northern and Eastern Piedmont Plain	S1 (<3%)	128122	126688	64628	36722	3499	359659
	S3 (8-16%)	262	.	.	.	.	262
	S4 (16-30%)	45	.	.	.	.	45
	S5 (30-45%)	4050	.	.	.	.	4050
	Group Total	132479	126688	64628	36722	3499	364016
	S1 (<3%)	133653	39396	7255	905	140	181349
Northern and Eastern Hills	S2 (3-8%)	894	.	.	.	.	894
	S3 (8-16%)	98273	.	.	.	.	98273
	S4 (16-30%)	4740	.	.	.	.	4740
	S5 (30-45%)	235076	.	.	.	.	235076
	S6 (>45%)	902464	.	.	.	.	902464
	Group Total	1375100	39396	7255	905	140	1422796

Table 3.6 Drainage by Landtype under AEZ of Comilla district (Based on LRI database of BARC)

Agro- ecological Zone (AEZ)	Drainage	Area (Ha)					Table Total
		Inundation Land Type					
		Highland	Medium Highland	Medium Lowland	Lowland	Very Lowland	
Old Meghna Estuarine Floodplain	Moderately Well Drained	5772	.	.	.	.	5772
	Imperfectly Drained	8160	.	.	.	.	8160
	Poorly Drained but Surface Drains	.	179946	208666	55684	244	444540
	Early	.	.	.	.	.	.
	Poorly Drained but Surface Drains	.	3999	44279	102644	18491	169413
	Late	.	.	.	.	.	.
	Very Poorly Drained	.	.	746	7761	4828	13335
	Group Total	13932	183945	253691	166089	23563	641220
Northern and Eastern Piedmont Plain	Well Drained	4098	.	.	.	.	4098
	Moderately Well Drained	9125	.	.	.	.	9125
	Imperfectly Drained	119256	.	.	.	.	119256
	Poorly Drained but Surface Drains	.	122816	22292	8809	.	153917
	Early	.	.	.	.	.	.
	Poorly Drained but Surface Drains	.	3872	41239	18135	1398	64644
	Late	.	.	.	.	.	.
	Very Poorly Drained	.	.	1097	9778	2101	12976

Northern and Eastern Hills	Group Total	132479	126688	64628	36722	3499	364016
	Well Drained	1166533	.	.	.	.	1166533
	Moderately Well Drained	117787	.	.	.	.	117787
	Imperfectly Drained	90780	.	.	.	.	90780
	Poorly Drained but Surface Drains Early	.	37679	3871	114	.	41664
	Poorly Drained but Surface Drains Late	.	1575	1441	769	140	3925
	Very Poorly Drained	.	142	1943	22	.	2107
	Group Total	1375100	39396	7255	905	140	1422796

3.4 Jessore District

3.4.1 Location and Geography of Jessore District

Jessore district (Figure 3.6) is under Khulna division. Its coordinate is 23.17° N 89.20° E and altitude is 7 m. The total area of the district is 2,578.20 km² and it is bounded by JHENAI DAH and MAGURA districts on the north, SATKHIRA and KHULNA districts on the south, NARAIL and Khulna districts on the east, West Bengal of India on the west. It consists of 4 municipalities, 36 wards, 8 upazilas, 92 unions, 1329 mouzas, 1434 villages and 120 mahallas. The upazilas are ABHAYNAGAR, BAGHERPARA, CHAUGACHHA, JHIKARGACHHA, KESHABPUR, JESSORE SADAR, MANIRAMPUR and SHARSHA.

3.4.2 Population Statistics

- Total Population is 2440693 (According to the census of 2001 and Bangladesh Statistical Bureau) Among them male 51.22%, female 48.78%.
- Muslim 86.5%; Hindu 13.21% and others 0.29%.
- Average literacy 33.4%; male 41% and female 25.1%.
- *Main occupations* Agriculture 39.84%, agricultural labourer 24.13%, wage labourer 2.68%, commerce 11.99%, service 8.66%, industry 1.41%, transport 3.11% and others 8.18%.



Figure 3.6 Jessore District Map with administrative units (Source: Banglapedia, 2008)

3.4.3 Climate

The climate is almost tropical with predominant monsoon influence. The district has hot summer and mild winter. The summer begins from beginning of April and continues till the end of the July. Winter starts from November and continues till February.

(a) Maximum and Minimum Temperature

In Jessore district the annual average highest temperature is 35.7°C and lowest is 10.9°C of year 1991-2005. Figure 3.7 shows the 15 years' average maximum, minimum temperature and rainfall on monthly basis. The maximum and minimum temperatures were observed in April-May and January respectively.

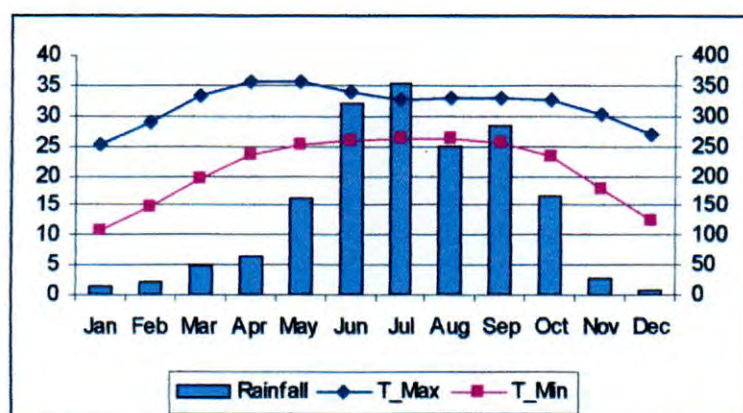


Figure 3.7 Graphical presentation of climatic parameters (1991-2005) of Jessore.

(b) Rainfall

In Jessore the average annual rainfall of year 1991-2005 was 1712 mm. The average humidity was recorded 78% in January and around 87% in July. During dry season, the area experiences average 40mm rainfall. Long term statistical analysis of rainfall data suggest that about 3 or 4 months of the dry season the area remains almost completely without rain. The winter season remains dry and cold. March and April are pre-monsoon season having high temperature and low water vapor in air.

(c) Solar Radiation

The yearly average solar radiation in Jessore district is about $17.31 \text{ MJ m}^{-2} \text{ day}^{-1}$. The maximum solar radiation of $23.28 \text{ MJ m}^{-2} \text{ day}^{-1}$ is reached during April to June and a minimum value of $12.67 \text{ MJ m}^{-2} \text{ day}^{-1}$ in the month of December and January.

(d) Wind Speed

The average monthly wind speed varies from 1.2 m/s to 4.1 m/s (for the year 1991-2005). The wind speed is generally higher during the monsoon as compared to that of winter months. However, storms generally occur in Bangladesh in the month of April-May and again in October and November.

3.4.4 Agroecological Zones (AEZ) and Soil Type

Jessore district consists of mainly one agroecological zone namely, High Ganges River Flood plain (AEZ-11) (Figure 3.3).

i. High Ganges River Floodplain (AEZ-11)

This region includes the western part of the Ganges river floodplain which is predominantly highland and medium highland. Most areas have a complex relief of broad and narrow ridges and inter-ridge depressions. The upper parts of high ridges stand above normal flood level. Lower parts of ridges and basin margins are seasonally shallowly flooded. General soil types predominantly include calcareous dark grey floodplain soils and calcareous brown floodplain soils. Organic matter content in the brown ridge soils is low but higher in the dark grey soils. Soils are slightly alkaline in reaction. General fertility level is low.

3.4.5 Land Type and Soil Condition

According to the land resource information database of BARC on Jessore district, Table 3.7, 3.8 and 3.9 show the different land information.

Table 3.7 Available Soil Moisture Holding Capacity by Land type under AEZ of Jessore district (Based on LRI database of BARC)

Agro-ecological Zone (AEZ)	Available Soil Moisture	Area (Ha)					Table Total
		Inundation Land Type				Very Lowland	
		Highland	Medium Highland	Medium Lowland	Lowland		
High Ganges River Floodplain	< 100 MM	137	159	101	150	.	547
	100-200 MM	55194	240725	158060	27475	.	481454
	200-300 MM	497059	175804	2181	1037	.	676081
	300-400 MM	10252	.	.	.	.	10252
	> 400 MM	.	.	804	1911	.	2715
	Group Total	562642	416688	161146	30573	.	1171049

Table 3.8 Slope by Landtype under AEZ of Jessore district (Based on LRI database of BARC)

Agro-ecological Zone (AEZ)	Slope	Area (Ha)					Table Total
		Inundation Land Type				Very Lowland	
		Highland	Medium Highland	Medium Lowland	Lowland		
High Ganges River Floodplain	S1 (<3%)	562622	416688	161146	30573	.	1171029
	S5 (30-45%)	20	.	.	.	.	20
	Group Total	562642	416688	161146	30573	.	1171049

Table 3.9 Drainage by Landtype under AEZ of Jessore district (Based on LRI database of BARC)

Agro- ecological Zone (AEZ)	Drainage	Area (Ha)					Table Total
		Highland	Inundation Land Type			Very Lowland	
			Medium Highland	Medium Lowland	Lowland		
High Ganges River Floodplain	Well Drained	1479	722	.	.	.	2201
	Moderately Well Drained	109088	.	.	.	.	109088
	Imperfectly Drained	452075	.	.	.	.	452075
	Poorly Drained but Surface Drains Early	.	415239	68929	3400	.	487568
	Poorly Drained but Surface Drains Late	.	727	87220	17636	.	105583
	Very Poorly Drained	.	.	4997	9537	.	14534
	Group Total	562642	416688	161146	30573	.	1171049

3.5 Bogra District

3.5.1 Location and Geography of Bogra District

Bogra district (Figure 3.8) is under Rajshahi division. Its coordinate is 24.78° N 89.35° E and altitude is 20 m. The total area of the district is 2,919.9 km², bounded by JOYPURHAT and GAIBANDHA districts on the north, the CHALAN BEEL, NATORE and SIRAJGANJ districts on the south, JAMUNA river and JAMALPUR district on the east, Part of Chalan Beel, NAOGAON and Natore districts on the west. Main rivers are KARATOYA, NAGAR, Bangali, ICHAMATI. Notable Beels are Betgari, Kaigari, Subeel, Nuruler Beel, Poradaha Beel, Keshpathar, Kalidaha, Padma, Sattarail, Garai, Arulia Demradaha, Sara, Gobarchapa, Mahichbaran, Ziadaha, Ramchandrapur, Kokira, Bahuar Beel, Kachiar Beel. Adamdighi, Sangshar, Badla, Sil Kawrer Dighi, Shahar Dighi, Kuldighi, Khadash Dighi are also notable water bodies. Bogra district consists of 5 municipalities, 48 wards, 166 mahallas, 11 upazilas, 109 union parishads, 1782 mouzas and 2706 villages. The upazilas are ADAMDIGHI, BOGRA SADAR, DHUNAT, DUPCHANCHIA, GABTALI, KAHALOO, NANDIGRAM, SARIAKANDI, SHERPUR, SHIBGANJ, SONATOLA.

3.5.2 Population Statistics

- Total Population is 2988567 (According to the census of 2001 and Bangladesh Statistical Bureau). Among them male 50.84%, female 49.16%.
- Muslim 91%, Hindu and others 9%.

- Average literacy 28.4%; male 35.4%, female 21%.
- *Main occupations* Agriculture 45.8%, agricultural labour 21.09%, wage labour 1.92%, commerce 12.21%, service 6.29%, transport 2.72%, others 9.97%.
- *Land control* Among the peasants 19.82% are landless, 15.1% marginal, 16.8% small peasants, 43.64% intermediate, and 4.64% rich.

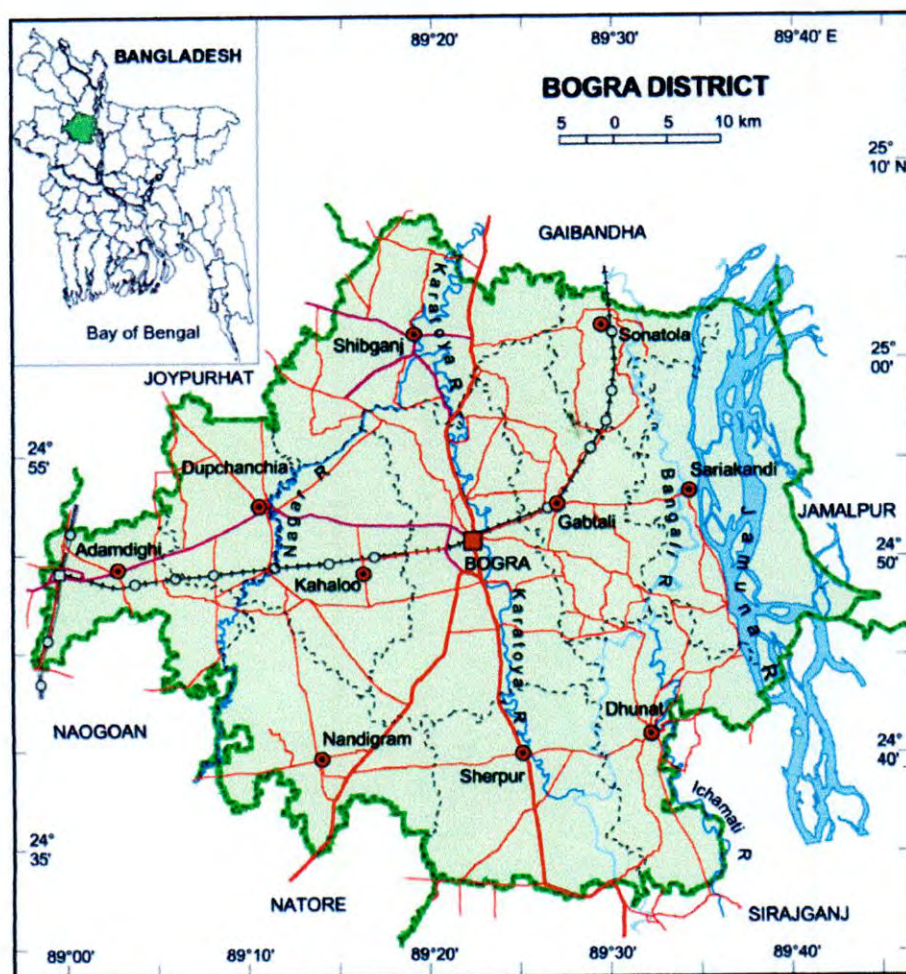


Figure 3.8 Bogra District Map with administrative units (Source: Banglapedia, 2008)

3.5.3 Climate

The district has hot summer and mild winter. The summer begins from end of March and continues till the end of the August. Winter starts from November and continues till February.

(a) Maximum and Minimum Temperature

In Bogra district the annual average highest temperature is 33.4°C and lowest is 11.4°C. Figure 3.9 shows the 15 years' average maximum, minimum temperature and rainfall on monthly basis. The maximum and minimum temperatures were observed in April and January respectively.

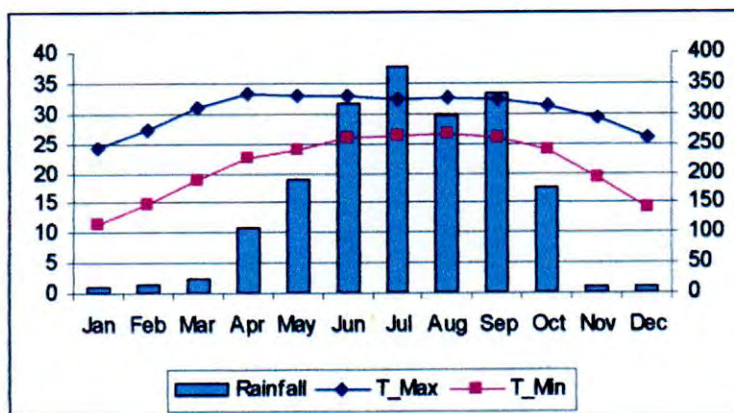


Figure 3.9 Graphical presentation of climatic parameters (1991-2005) of Bogra.

(b) Rainfall

In Bogra the average annual rainfall of year 1991-2005 was 1854 mm. The average humidity was recorded 77% in January and around 85% in September. During dry season, the area experiences average around 55mm rainfall. Long term statistical analysis of rainfall data suggest that about 3 or 4 months of the dry season the area remains almost completely without rain.

(c) Solar Radiation

The yearly average solar radiation in Bogra district is about 17.8 MJ m⁻² day⁻¹. The maximum solar radiation of 23.7 MJ m⁻² day⁻¹ is reached during April and May and a minimum value of 12.1 MJ m⁻² day⁻¹ in the month of December and January.

(d) Wind Speed

The average monthly wind speed varies from 0.96 m/s to 2.5 m/s (for the year 1991-2005). The wind speed is generally higher during the monsoon as compared to that of winter months. However, storms generally occur in Bangladesh in the month of April-May and again in October and November.

3.5.4 Agroecological Zones (AEZ) and Soil Type

Bogra district consists of three agroecological zones namely, Karatoya-Bangali Floodplain (AEZ-4), Level Barind Tract (AEZ-25) and North-Eastern Barind Tract (AEZ-27), where the Level Barind Tract (AEZ-25) is predominant (Figure 3.3).

i. Karatoya-Bangali Floodplain (AEZ-4)

This region is very similar to the Tista Meander Floodplain in physiography and soil, and comprises a mixture of Tista and BRAHMAPUTRA sediments. Most areas have smooth, broad, floodplain ridges and almost level basins. The soils are grey silt loams and silty clay loams on ridges and grey or dark grey clays in basins. Five general soil types occur in the region, of which non-calcareous grey floodplain and non-calcareous dark grey floodplain soils predominate. The soil is moderately acidic throughout. Organic matter contents are generally low in the cultivated layer of ridge soils and moderate in basins. General fertility is medium. The eastern half of BOGRA and most of SIRAJGANJ districts are included in this zone.

ii. Level Barind Tract (AEZ-25)

This region is developed over MADHUPUR CLAY. The landscape is almost level. The predominant soils have grey, silty, puddled topsoil with ploughpan. Shallow grey terrace soil and deep grey terrace soils are the major components of general soil types of the area. The soils are low in available moisture holding capacity and slightly acidic to acidic in reaction. Organic matter status is very low and most of the available nutrients are limiting.

iii. North Eastern Barind Tract (AEZ-27)

This region occupies several discontinuous areas on the north-eastern margins of the Barind Tract. It has silty or loamy topsoil and clay loams to clay subsoil. The soils are strongly acidic in reaction. Organic matter in the soils is low. General fertility is poor.

3.5.5 Land Type and Soil Condition

According to the land resource information database of BARC on Bogra district, Table 3.10, 3.11 and 3.12 show the different land information.

Table 3.10 Available Soil Moisture Holding Capacity by Land type under AEZ of Bogra district (Based on LRI database of BARC)

Agro-ecological Zone (AEZ)	Available Soil Moisture	Area (Ha)					Table Total
		Inundation Land Type					
		Highland	Medium Highland	Medium Lowland	Lowland	Very Lowland	
Karatoya-Bangali Floodplain	< 100 MM	365		222			587
	100-200 MM	4314	5427	2715	10298	1447	24201
	200-300 MM	17087	28810	28987	1211		76095
	300-400 MM	38174	79145	2979			120298
	Group Total	59940	113382	34903	11509	1447	221181
Level Barind Tract	100-200 MM	146311	274109	21507	10179		452106
	200-300 MM	2984	2055	237			5276
	300-400 MM	295	75				370
	Group Total	149590	276239	21744	10179		457752
North-Eastern Barind Tract	100-200 MM	36623	60766	719			98108
	200-300 MM	2299					2299
	Group Total	38922	60766	719			100407

Table 3.11 Slope by Landtype under AEZ of Bogra district (Based on LRI database of BARC)

Agro-ecological Zone (AEZ)	Slope	Area (Ha)					Table Total
		Inundation Land Type					
		Highland	Medium Highland	Medium Lowland	Lowland	Very Lowland	
Karatoya-Bangali Floodplain	S1 (<3%)	59940	113382	34903	11509	1447	221181
	Group Total	59940	113382	34903	11509	1447	221181
Level Barind Tract	S1 (<3%)	149590	276239	21744	10179	.	457752
	Group Total	149590	276239	21744	10179	.	457752
North-Eastern Barind Tract	S1 (<3%)	38922	60766	719	.	.	100407
	Group Total	38922	60766	719	.	.	100407

Table 3.12 Drainage by Landtype under AEZ of Bogra district (Based on LRI database of BARC)

Agro-ecological Zone (AEZ)	Drainage	Area (Ha)					Table Total
		Inundation Land Type					
		Highland	Medium Highland	Medium Lowland	Lowland	Very Lowland	
Karatoya-Bangali Floodplain	Moderately Well Drained	55	.	.	.	.	55
	Imperfectly Drained	59885	.	.	.	.	59885
	Poorly Drained but Surface Drains Early	.	113382	25743	6689	.	145814

Level Barind Tract	Poorly Drained but Surface Drains Late	.	.	9160	4820	1447	15427
	Group Total	59940	113382	34903	11509	1447	221181
	Well Drained	15	.	.	.	.	15
	Moderately Well Drained	4588	.	.	.	.	4588
	Imperfectly Drained	144987	.	.	.	.	144987
	Poorly Drained but Surface Drains Early	.	276239	12674	7925	.	296838
	Poorly Drained but Surface Drains Late	.	.	9070	2254	.	11324
	Group Total	149590	276239	21744	10179	.	457752
	Well Drained	8660	.	.	.	.	8660
	Moderately Well Drained	24352	.	.	.	.	24352
North- Eastern Barind Tract	Imperfectly Drained	5910	.	.	.	.	5910
	Poorly Drained but Surface Drains Early	.	60766	20	.	.	60786
	Poorly Drained but Surface Drains Late	.	.	699	.	.	699
	Group Total	38922	60766	719	.	.	100407

Source: BARC.

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METHODOLOGY AND DATA COLLECTION**4.1 Introduction**

The research work is divided into two analysis parts: (i) recent climate change analysis and its impact on agricultural production and (ii) prediction of the yields of the agricultural products (like rice, wheat, pulses and potato) for the next fifty years on model based simulation.

For the first part, statistical analysis of observed climatic data, which are intimately related with agricultural production, has been done. This is useful for the understanding of the recent trend of changes in the local climate and climate related extreme events, such as extreme temperatures, rainfall amount and their pattern.

Then trend of change in yield for the crops rice (Local T. Aman), wheat, pulses and potato were analyzed. And an attempt was taken to investigate about any possible correlation between the trend of local climate change and agricultural yield of the study crops.

Afterwards, during the second analysis part, after calibration of the EPIC model, future yields of the respective crops were simulated up to the year of 2050.

The flowchart (Figure 4.1) illustrated the sequential steps from data collection, organization, analysis and the various methods used all through the research work.

4.2 Collection of Climatic and Agricultural Data

Data on various aspects related to agriculture and local climate, particularly of the study areas, Dinajpur, Comilla, Jessore and Bogra, was collected from authentic organizations. In Bangladesh all sorts of climatic data are recorded and handled by Bangladesh Meteorological Department (BMD).

Some relevant data are also recorded by Bangladesh Water Development Board (BWDB), e.g., rainfall data. Department of Agricultural Extension (DAE) collects and maintains the agricultural data from field level. District level agricultural area, production and yield data are available from DAE and Bangladesh Agricultural Research Council (BARC). Irrigation, fertilizer requirement data are available in BARC. The Soil Resource Development Institute (SRDI) is the source for land and soil resource information.

SAARC Meteorological Research Center (SMRC) and SAARC Agricultural Research Center (SARC) are sources of pertinent information for climate and agriculture of Bangladesh. Recently

developed Climate Change Database (CCD) authorized by the Climate Change Cell (CCC) of Department of Environment (DoE) is a reliable source of hydro-meteorological and district-wise crop agricultural data.

Although Bangladesh Bureau of Statistics (BBS) records and compiles both agricultural and climatic data in a regular basis, for particular details those data were collected principally from BMD and BARC and DAE. CO₂ concentration in air data was collected from Intergovernment Panel on Climate Change (IPCC). In this study the concentration of CO₂ was assumed same for the whole country. Other required supporting data and information were collected from previously stated different relevant government research organizations.

4.3 Recent Trend Analysis of Climate Change

During the first phase, analyses of recent experiences in climate variation and extreme events were conducted. These analyses focused on climate variability and change assessments.

In order to understand the climate variability and change throughout the period 1948-2005; the analysis work devoted to recognize the recent trend of variation of each climatic parameter. In addition to this trend analysis, an effort was taken to investigate the probable linkage between the climate variability and change and trend of agricultural production, so that the impact on production can be revealed.

4.4 Investigation of Impacts on Agricultural Production

For this part of analysis, the agricultural production data for the crops, rice (Local T. Aman), wheat, potato and pulse (mungbean) of Comilla, Dinajpur, Bpgra and Jessore were collected from DAE and BARC. The data was used to recognize the trend of production of these crops in response to highest maximum and lowest minimum temperature and the amount of seasonal total rainfall, for the period of 1991-2005.

Then, the trend of agricultural production data together with the trends of change in climatic data were investigated in such a manner, so as to enable, to realize any types of probable impacts of climate change on agriculture during the specified period.

4.5 Prediction of Future Yield

The model calibration was carried out for the four individual crops. After successful calibration of the EPIC model, crop yield simulation studies for next fifty years were conducted from the output of the model to obtain the future trend of yield for those four individual crops. In order to assess the effects of global warming on main crop yields EPIC will be used.

4.6 Crop Simulation Studies Using EPIC Model

The EPIC (Erosion Productivity Impact Calculator) model is a comprehensive agricultural management model, which uses a daily time step to simulate weather, hydrology, soil temperature, erosion-sedimentation, nutrient cycling, tillage, crop management and growth, pesticide and nutrient movement with water and sediment, and field-scale costs and returns.

Compared with many other process-based crop growth models, EPIC model seems to be more suitable to simulate crop yields for relative comparisons of soils, crops, and management scenarios and has a good accuracy to estimate field yields.

The EPIC model (version 8120) integrates the major processes that occur in the atmosphere – soil–crop–management system, including 10 sub-models: weather, hydrology, erosion, nutrient, pesticide fate, soil temperature, tillage, crop growth, crop and soil management, and economics.

4.6.1 Input dataset

- **Site description-** The coordinate and altitude data of the four study districts (Dinajpur, Comilla, Bogra and Jessore) were given individually for each individual model run.
- **Climate data-** For this study, the historical climate data of 15 years (1991-2005) of the four study district were inputted which include daily values of minimum / maximum temperature, precipitation, average wind speed, solar radiation and average relative humidity. In fact, EPIC also provides options for simulating various combinations of the

above daily weather variables with a stochastic weather generator. EPIC estimates the missing values of the above parameters.

The basic data set needed for each site was the historical climate data of 15 years (1991-2005) of a record of monthly maximum and minimum temperatures, precipitation, S.D. of maximum daily air temperature, S.D. of minimum daily air temperature, S.D. of daily precipitation, skew coefficient for daily precipitation, probability of wet day after dry day, and probability of wet day after wet day were inputted.

Heat Unit was needed to calculate for the model run for each site. Daily Heat Unit is computed by using the following equation

$$HU_k = \left(\frac{T_{mxk} + T_{mnk}}{2} \right) - T_{bj} \quad HU_k \geq 0$$

Where HU, T_{mxk} , T_{mnk} are the variables of heat units, maximum temperature and minimum temperature in °C on day k and T_{bj} is the crop-specific base temperature in °C (no growth occurs at or below T_b) of crop j. Average heat unit for the specific period was calculated from the daily heat unit.

The Heat Unit Index (HUI) ranging from 0 at planting to 1 at physiological maturity is computed by the following equation

$$HUI_i = \frac{\sum_{k=1}^i HU_k}{PHU_j}$$

Where HUI is the heat unit index for day i, and PHU is the potential heat units required for the maturation of crop j.

- **Soil data-** EPIC requires numerous inputs to describe the soil and its behavior. Two types of information must be furnished. First, up to sixteen variables provide general information about the soil to be used in the simulation. Second, up to twenty variables are used to describe the physical and chemical characteristics of each identifiable layer (up to ten) in the profile. But many variables can be left blank or zero if they are unavailable. EPIC model can estimate the missing variables automatically.

In this study, the necessary soil data including sand content, silt content, soil PH, organic carbon, content of calcium carbonate, etc., were derived from the Soil Resource Development Institute (SRDI) for all sites.

- **Management data and yield data-** EPIC needs detailed descriptions of management practices. These descriptions must specify the timing of individual operations either by date or month. There are two options for irrigation and fertilizer scheduled application in the EPIC program: manually and automatically. In this study, only the manual mode is adopted for the calibration of EPIC model. The detailed management operation schedules in each field site were collected from were applied in EPIC model on crop basis.

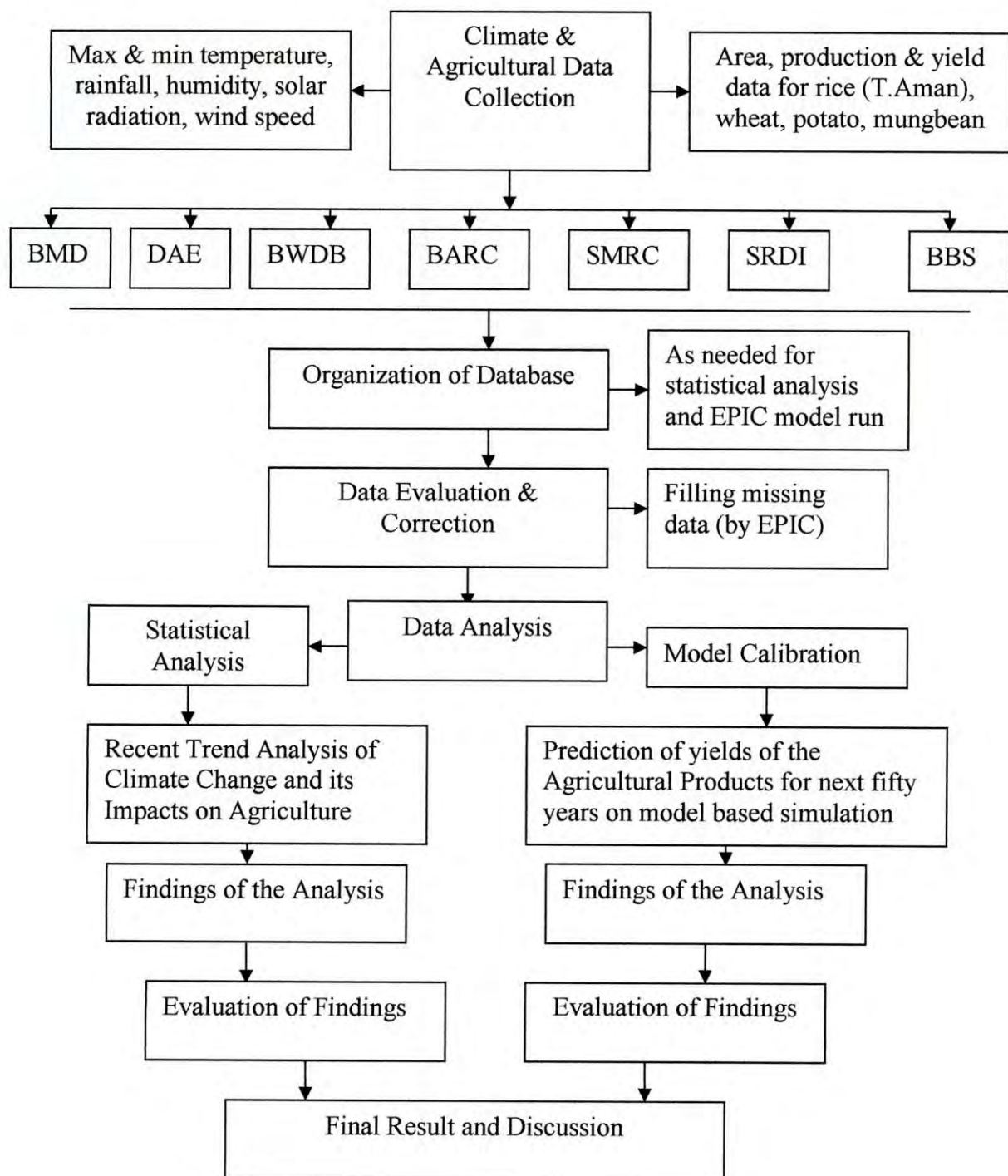


Figure 4.1 Flowchart of the methods used throughout the study work.

ANALYSIS, RESULT AND DISCUSSION**5.1. Introduction**

The total analytical part of the study can be divided into two parts. At first, the past trend of climate change was analyzed statistically for its probable impacts on rice (T. Aman), wheat, potato and pulse (mungbean) production of Comilla, Dinajpur, Bogra and Jessore district respectively. Later, prediction of the yields of the respective crops for the next fifty years on model based simulation was done after successful model calibration. Hence the results and their discussions were presented sequentially for those two parts.

5.2 Trend Analysis of Climate Change of Comilla District

The results from the statistical analysis using annual average maximum and minimum temperature and total precipitation for the time period of 1948 to 2005 have been presented in the following sections.

5.2.1 Temperature trends

Temperature represents the primary indicator for climate change. In Bangladesh 1999 was the warmest year during the period of 1948-2005 while, in Comilla 1988 was the warmest year during the same period.

a) Trend of Average Annual Maximum Temperature

During Climate Scenario 1(1948-1980), the average annual maximum temperature had a statistically very insignificant increasing trend with $R^2 = 0.0005$ (Figure 5.1). Climate Scenario 2 (1960-1990) showed that the average annual maximum temperature had a decreasing trend with $R^2 = 0.098$ (Figure 5.2).

In Climate Scenario 3 (1970-2000), the average annual maximum temperature had an increasing trend with $R^2 = 0.1134$ (Figure 5.3). The trend of average annual maximum temperature (Figure 5.4) for the overall Climate Scenario 4 (1948-2005) of Comilla district exhibited an increasing trend with $R^2 = 0.026$. Climate Scenario 5 (1991-2005) shows the recent trend of average annual maximum temperature which has an increasing trend with $R^2 = 0.0985$ (Figure 5.5).

During 1960-1990, the average annual maximum temperature exhibited a decreasing trend; otherwise there was a statistically insignificant increasing trend of average annual maximum temperature through the period of 1948-2005.

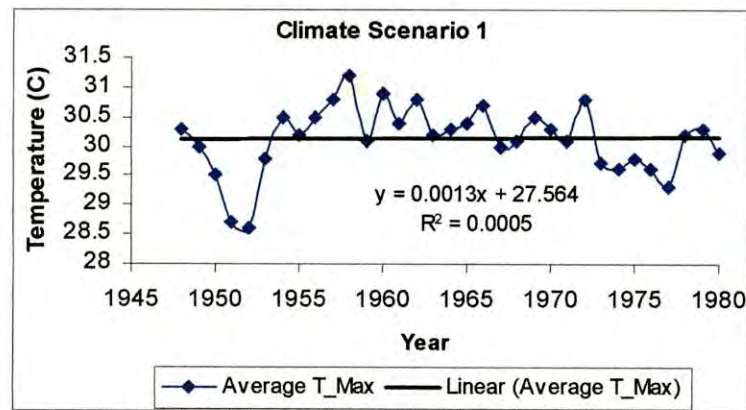


Figure 5.1 Average annual maximum temperature (1948-1980) of Comilla

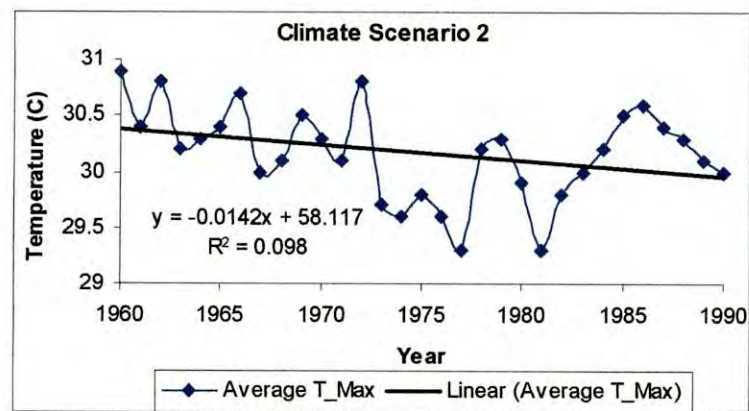


Figure 5.2 Average annual maximum temperature (1960-1990) of Comilla.

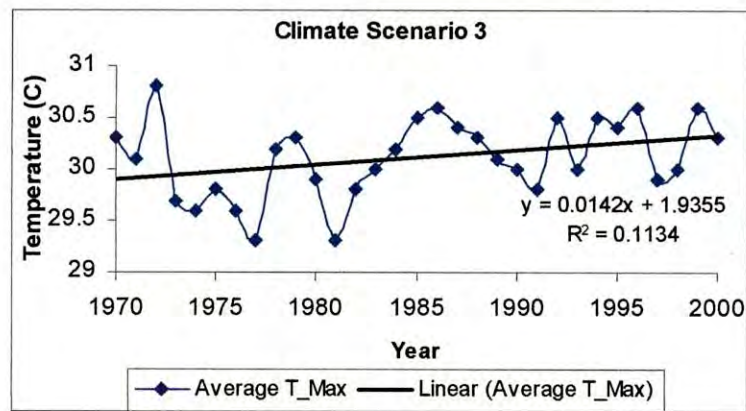


Figure 5.3 Average annual maximum temperature (1970-2000) of Comilla

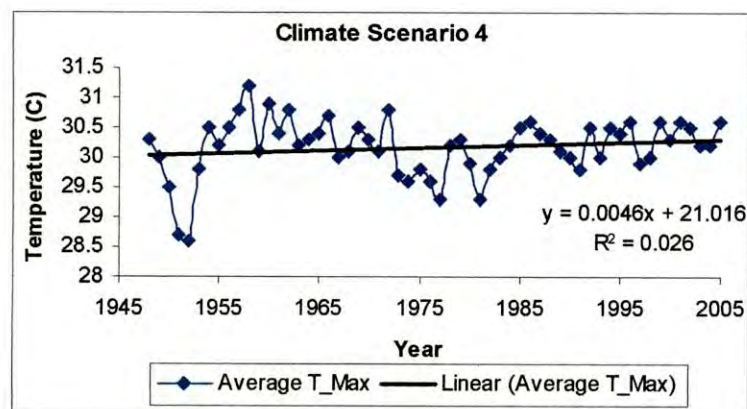


Figure 5.4 Average annual maximum temperature (1948-2005) of Comilla

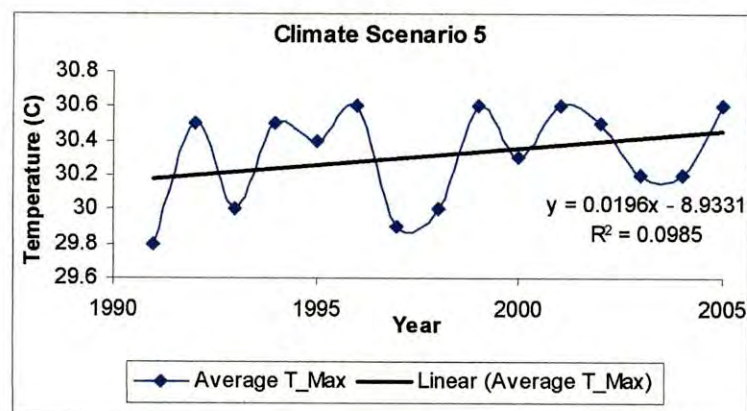


Figure 5.5 Average annual maximum temperature (1991-2005) of Comilla

b) Trend of Average Annual Minimum Temperature

The trends of the average annual minimum temperature over Comilla for the period 1948-2005 were shown in Figures 5.6 to 5.10. Figure 5.6 shows that during Climate Scenario 1 (1948-1980), the average annual minimum temperature has a statistically very insignificant increasing trend with $R^2 = 0.0091$. Climate Scenario 2 (1960-1990) exhibits an increasing trend with $R^2 = 0.0115$ which is not statistically much significant too (Figure 5.7).

During climate scenario 3 (1970-2000), the average annual minimum temperature had a decreasing trend (Figure 5.8) with $R^2 = 0.0668$. For the overall period of 1948-2005, Figure 5.9 shows that the annual minimum temperature had a statistically very insignificant decreasing trend with $R^2 = 0.0034$. Climate Scenario 5 (1991-2005) shows the recent trend of average annual minimum temperature which has an increasing trend with $R^2 = 0.2091$ (Figure 5.10).

Therefore, it could be revealed that there was a decreasing trend during 1970-2000 which has affected the overall Climate Scenario for the period 1948-2005; and the annual average minimum temperature had a decreasing trend through the period of 1948-2005; which was not statistically significant.

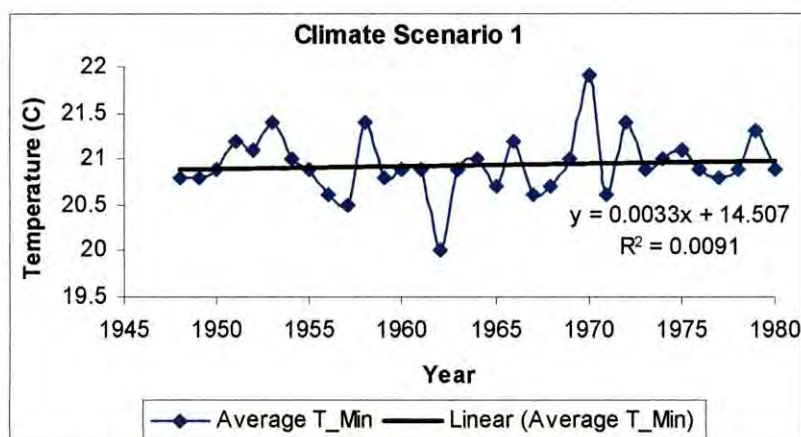


Figure 5.6 Average annual minimum temperature (1948-1980) of Comilla

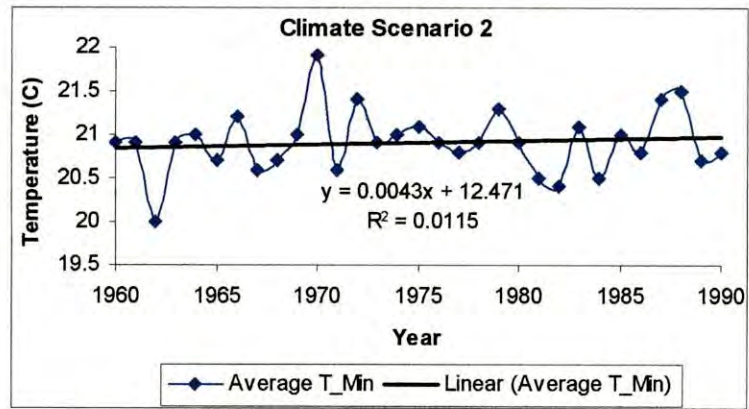


Figure 5.7 Average annual minimum temperature (1960-1990) of Comilla

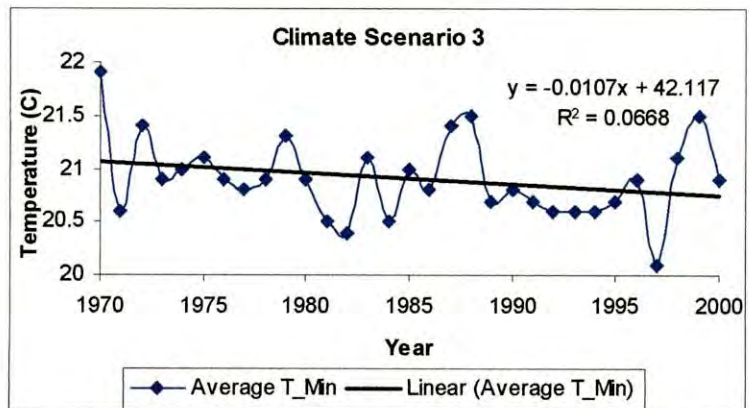


Figure 5.8 Average annual minimum temperature (1970-2000) of Comilla

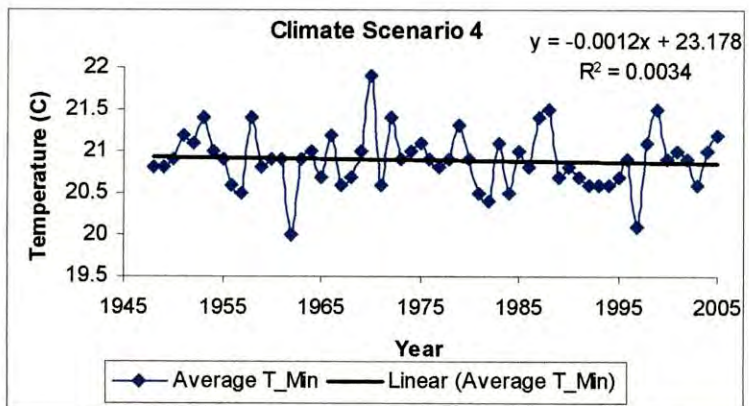


Figure 5.9 Average annual minimum temperature (1948-2005) of Comilla

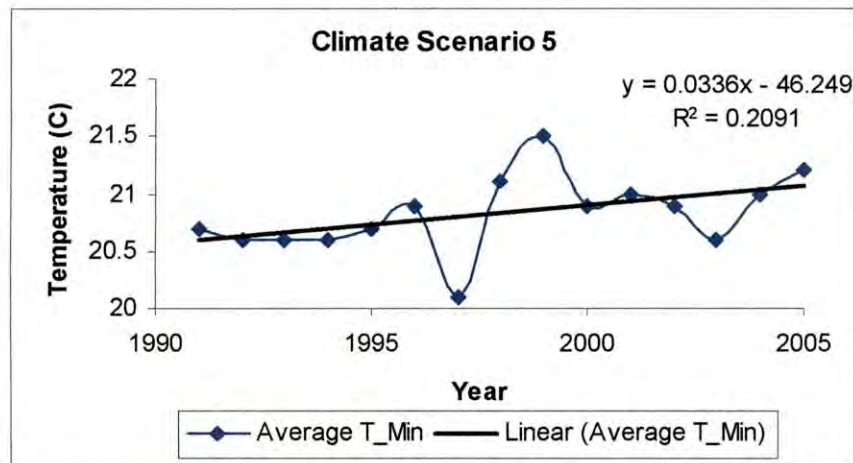


Figure 5.10 Average annual minimum temperature (1991-2005) of Comilla

5.2.2 Rainfall Trends

Rainfall represents one of the primary indicators for climate change. In Comilla the rainfall has its own seasonal pattern. The trends for the rainfall over Comilla for four seasons (pre-monsoon, monsoon, post- monsoon and winter) and on annual basis have been obtained for overall period 1948-2005.

a) Trend of Annual Rainfall

During the Climate Scenario 1 (1948-1980) and Climate Scenario 2 (1960-1990), the total annual rainfall had a decreasing trend with $R^2 = 0.3381$ and 0.1128 respectively, which were not statistically significant (Figure 5.11 and Figure 5.12). While, during the Climate Scenario 3 (1970-2000), the total annual rainfall had a statistically insignificant increasing trend with $R^2 = 0.0469$ (Figure 5.13) too. The overall Climate Scenario 4 (1948-2005), exhibited a decreasing trend of total annual rainfall with $R^2 = 0.167$ (Figure 5.14), which was not statistically significant. Climate Scenario 5 (1991-2005) shows the resent trend of total annual rainfall which has an increasing trend with $R^2 = 0.0021$ (Figure 5.15).

The trend analysis of annual rainfall revealed that there was a decreasing trend throughout the period 1948-2005, with the exception of an increasing trend during the periods of 1970-2000 and 1991-2005. However, all these trends were not statistically significant.

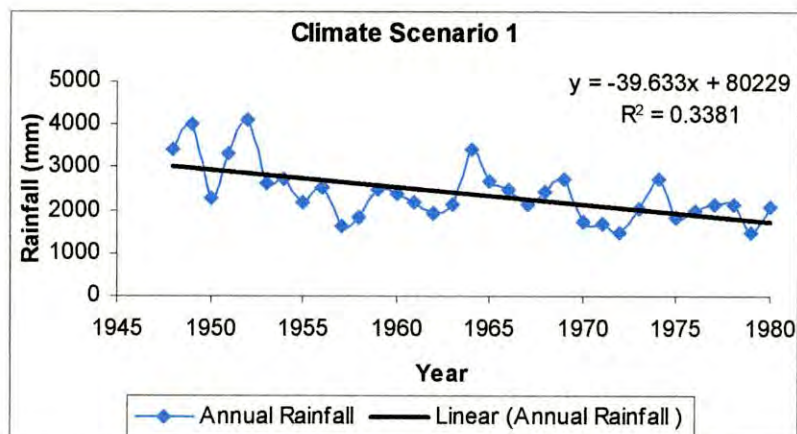


Figure 5.11 Total annual rainfall (1948-1980) of Comilla

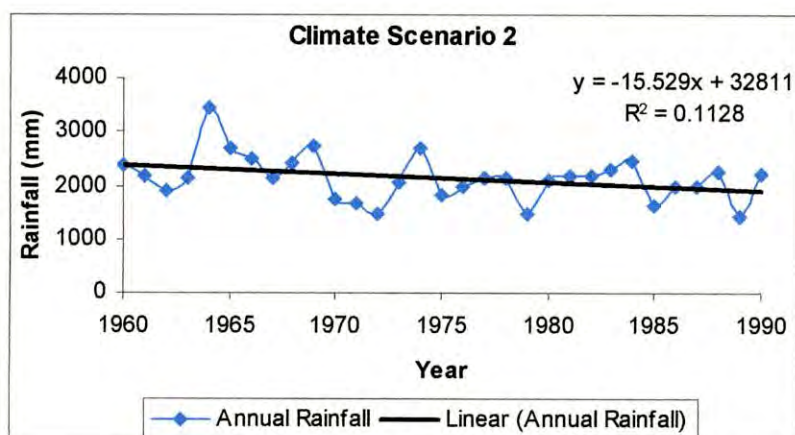


Figure 5.12 Total annual rainfall (1960-1990) of Comilla

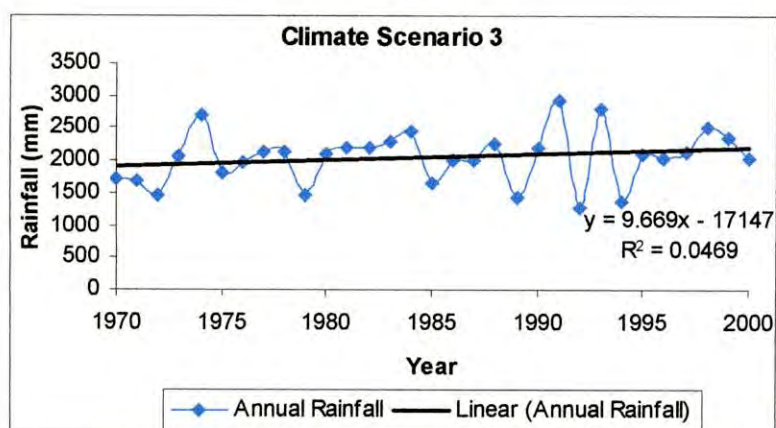


Figure 5.13 Total annual rainfall (1970-2000) of Comilla

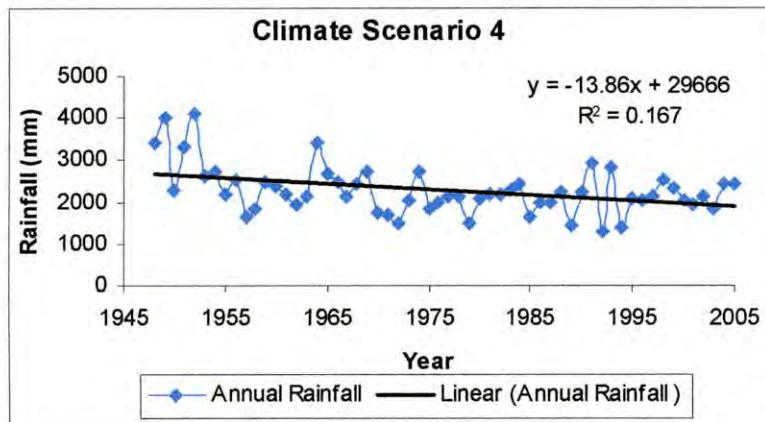


Figure 5.14 Total annual rainfall (1948-2005) of Comilla

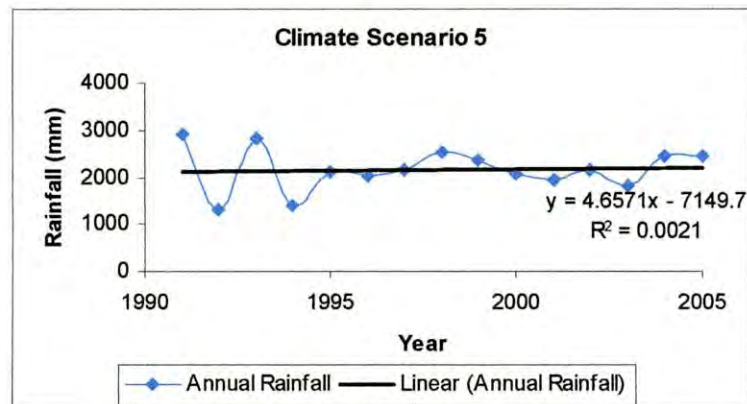


Figure 5.15 Total annual rainfall (1991-2005) of Comilla

b) Trend of Seasonal Rainfall

The trends of seasonal rainfall over Comilla for the period 1991-2005 were shown in Figures 5.16 to 5.19. In pre-monsoon season (March, April, May) (Figure 5.16) a decreasing trend of rainfall was found, with $R^2 = 0.0531$ which was not statistically significant. Figure 5.17 shows that during monsoon (June, July, August) seasonal rainfall had an increasing trend with $R^2 = 0.0334$.

The rainfall in post-monsoon season (September, October, November) exhibited an increasing trend with $R^2 = 0.0852$ which was not statistically significant (Figure 5.18). However, in case of winter season (December, January, February), the rainfall had a significant decreasing trend (Figure 5.19) with $R^2 = 0.2235$.

The trend analysis of seasonal rainfall for the period 1991-2005 could reveal that rainfall in pre-monsoon and winter season had a decreasing trend whereas it had an increasing trend during monsoon and post-monsoon seasons.

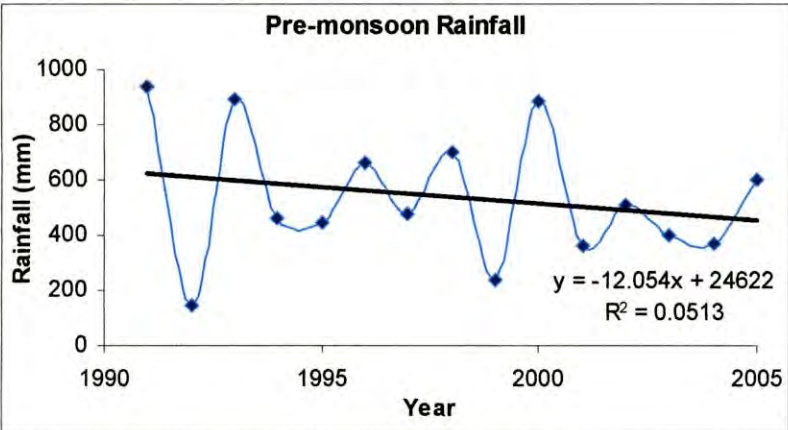


Figure 5.16 Trend of pre-monsoon rainfall during the period 1991-2005 of Comilla

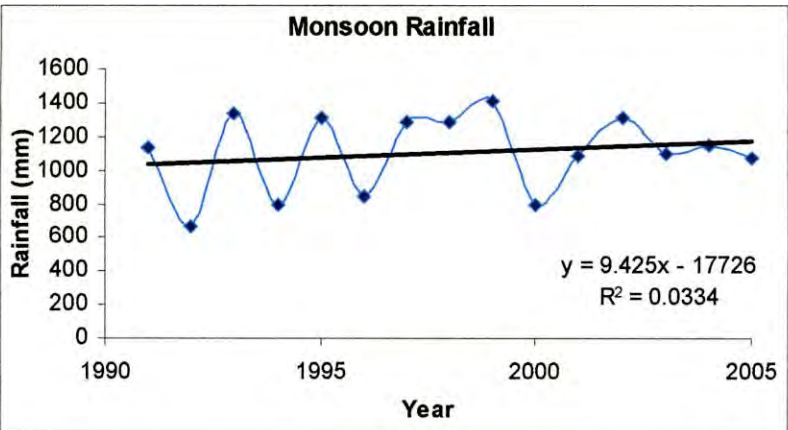


Figure 5.17 Trend of monsoon rainfall during the period 1991-2005 of Comilla

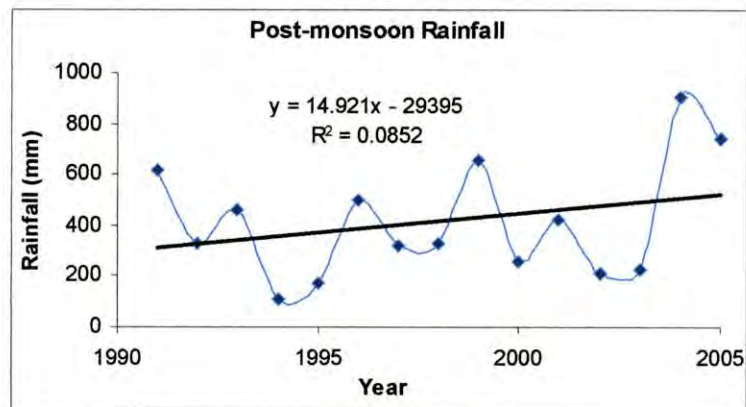


Figure 5.18 Trend of post-monsoon rainfall during the period 1991-2005 of Comilla

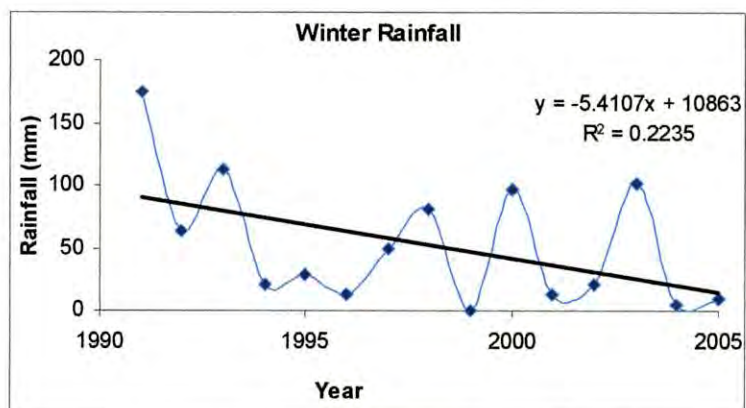


Figure 5.19 Trend of winter rainfall during the period 1991-2005 of Comilla

5.3 Trend Analysis of Climate Change of Dinajpur District

The results from the statistical analysis using annual average maximum and minimum temperature and total precipitation for the time period of 1948 to 2005 of Dinajpur district have been presented in the following sections.

5.3.1 Temperature trends

Temperature represents the primary indicator for climate change. In Bangladesh as well as in Dinajpur district 1999 was the warmest year during the period of 1948-2005. In 1999 the average annual maximum temperature was 30.5°C and the average annual minimum temperature was 20.7°C in Dinajpur district.

a) Trend of Average Annual Maximum Temperature

During Climate Scenario 1(1948-1980) and Climate Scenario 2 (1960-1990) the average annual maximum temperature had a decreasing trend with $R^2 = 0.1086$ and $R^2 = 0.3275$ (Figure 5.20 and Figure 5.21) respectively.

In Climate Scenario 3 (1970-2000), the average annual maximum temperature had also a decreasing trend with $R^2 = 0.0771$ which was not statistically significant (Figure 5.22). The trend of average annual maximum temperature (Figure 5.23) for the overall Climate Scenario 4 (1948-2005) of Dinajpur district exhibited a decreasing trend with $R^2 = 0.2754$. Climate Scenario 5 (1991-2005) shows the recent trend of average annual maximum temperature which has a decreasing trend with $R^2 = 0.0884$ (Figure 5.24).

During 1948-1980, 1960-1990, 1970-2000 and 1991-2005 the average annual maximum temperature exhibited a decreasing trend and there was an overall decreasing trend of average annual maximum temperature through the period of 1948-2005.

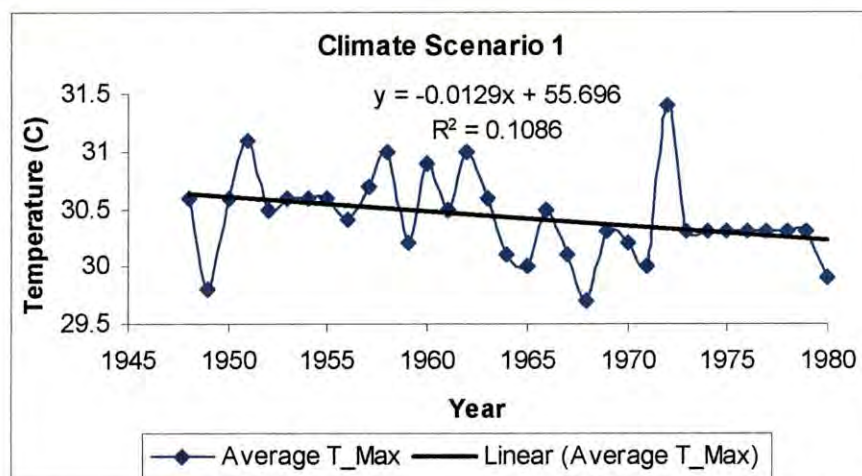


Figure 5.20 Average annual maximum temperature (1948-1980) of Dinajpur.

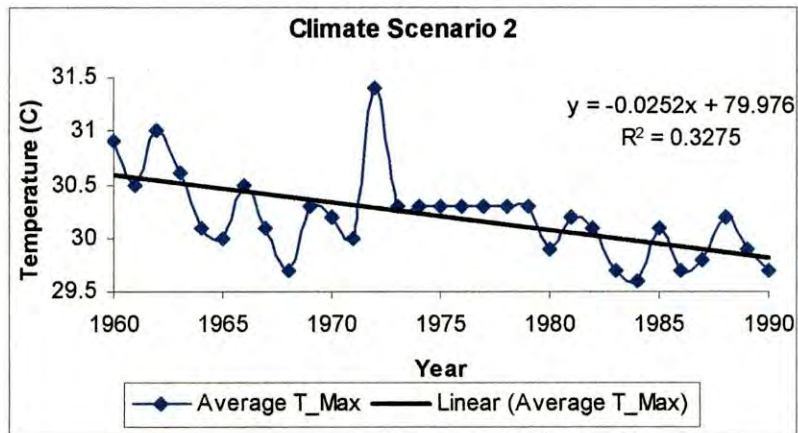


Figure 5.21 Average annual maximum temperature (1960-1990) of Dinajpur.

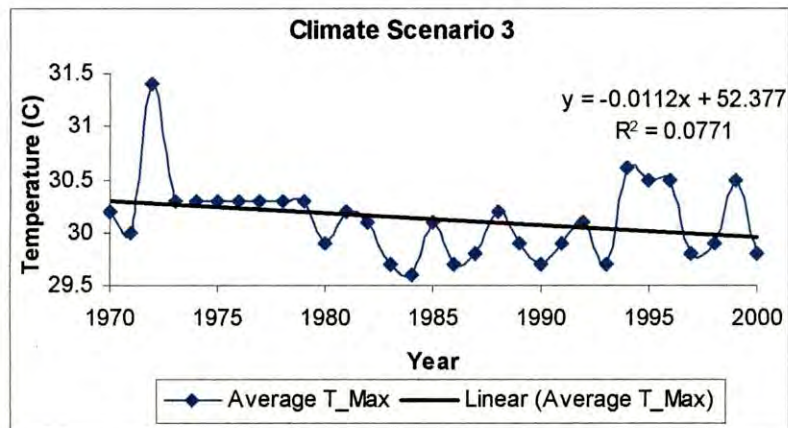


Figure 5.22 Average annual maximum temperature (1970-2000) of Dinajpur.

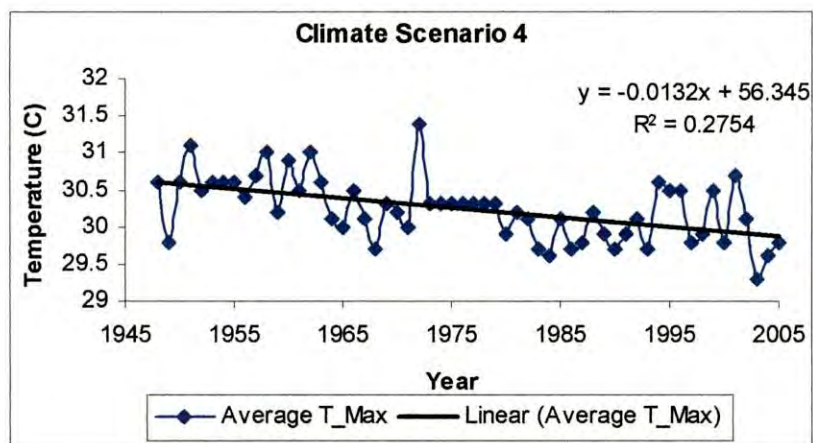


Figure 5.23 Average annual maximum temperature (1948-2005) of Dinajpur.

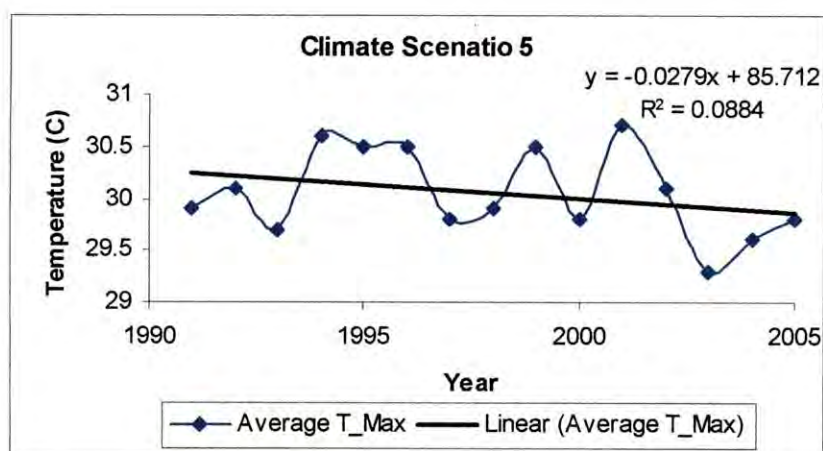


Figure 5.24 Average annual maximum temperature (1991-2005) of Dinajpur.

b) Trend of Average Annual Minimum Temperature

The trends of the average annual minimum temperature over Dinajpur for the period 1948-2005 were shown in Figures 5.25 to 5.29. Figure 5.25 shows that during Climate Scenario 1 (1948-1980), the average annual minimum temperature has an increasing trend with $R^2 = 0.0972$. Climate Scenario 2 (1960-1990) exhibits a decreasing trend with $R^2 = 0.0076$ which is not statistically much significant (Figure 5.26).

During Climate Scenario 3 (1970-2000), the average annual minimum temperature had an increasing trend (Figure 5.27) with $R^2 = 0.0276$ which was not statistically significant. For the overall period of 1948-2005, Figure 5.28 shows that the annual minimum temperature had an increasing trend with $R^2 = 0.111$. Climate Scenario 5 (1991-2005) shows the recent trend of average annual minimum temperature which has an increasing trend with $R^2 = 0.364$ (Figure 5.29).

Therefore, it could be revealed that though there was a decreasing trend during 1960-1990; the annual average minimum temperature had an increasing trend through the period of 1948-2005; and the trend was not much statistically significant.

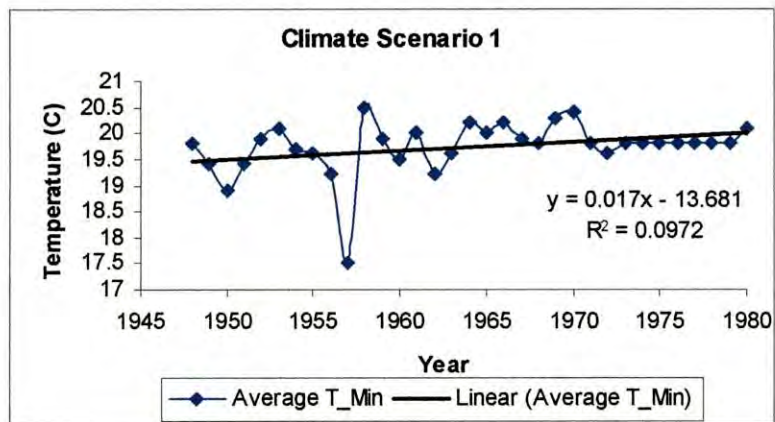


Figure 5.25 Average annual minimum temperature (1948-1980) of Dinajpur

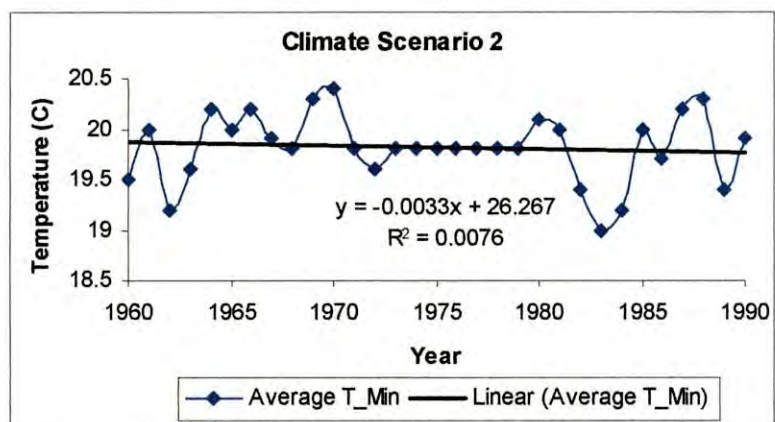


Figure 5.26 Average annual minimum temperature (1960-1990) of Dinajpur

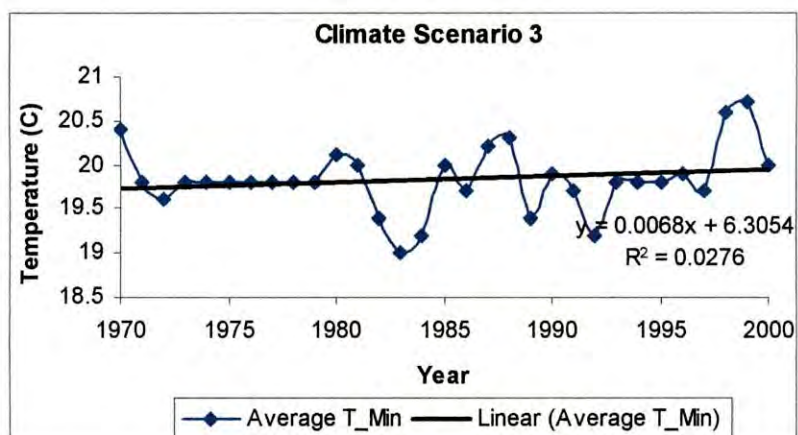


Figure 5.27 Average annual minimum temperature (1970-2000) of Dinajpur

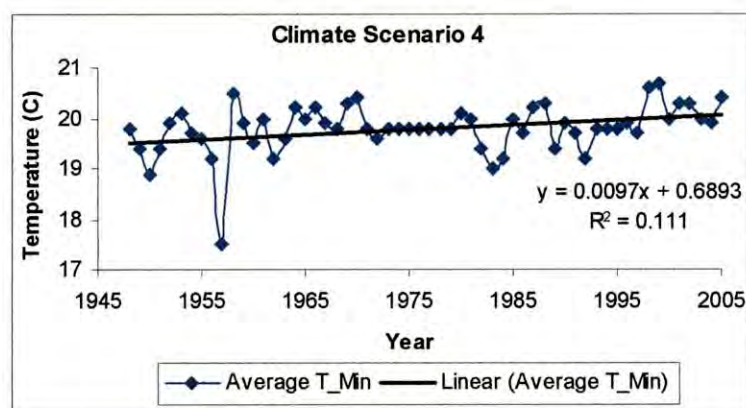


Figure 5.28 Average annual minimum temperature (1948-2005) of Dinajpur

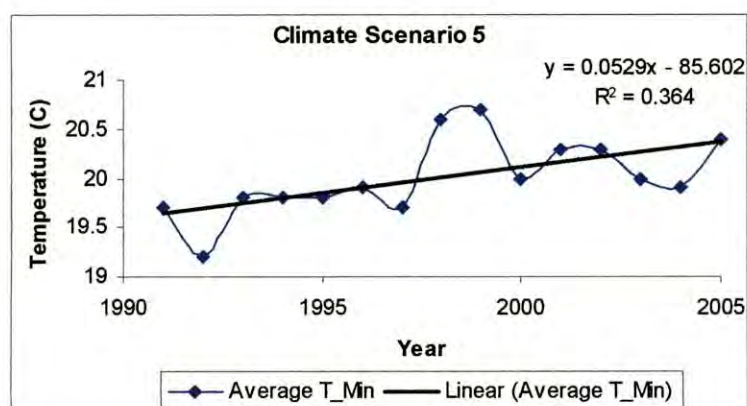


Figure 5.29 Average annual minimum temperature (1991-2005) of Dinajpur

5.3.2 Rainfall Trends

Rainfall is one of the primary indicators for climate change. In Dinajpur the rainfall has its own seasonal pattern. The trends for the rainfall over Dinajpur for four seasons (pre-monsoon, monsoon, post- monsoon and winter) and on annual basis have been obtained for overall period 1948-2005.

b) Trend of Annual Rainfall

During the Climate Scenario 1 (1948-1980) the total annual rainfall had a decreasing trend with $R^2 = 0.0008$ which was not statistically significant (Figure 5.30). While, during the Climate Scenario 2 (1960-1990) and Climate Scenario 3 (1970-2000), the total annual rainfall had an increasing trend with $R^2 = 0.2026$ and $R^2 = 0.1289$ (Figure 5.31 and Figure 5.32). These trends were not statistically significant too. The overall climate scenario 4 (1948-2005), exhibited an increasing trend of total annual rainfall with $R^2 = 0.1776$ (Figure 5.33). Climate Scenario 5

(1991-2005) shows the resent trend of total annual rainfall which has an increasing trend with $R^2 = 0.2363$ (Figure 5.34).

The trend analysis of annual rainfall revealed that there was an increasing trend throughout the period 1948-2005, with the exception of a decreasing trend during the periods of 1948-1980.

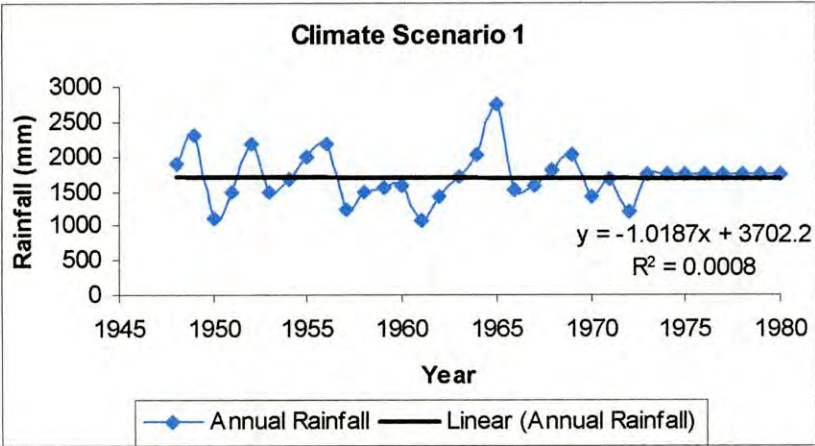


Figure 5.30 Total annual rainfall (1948-1980) of Dinajpur

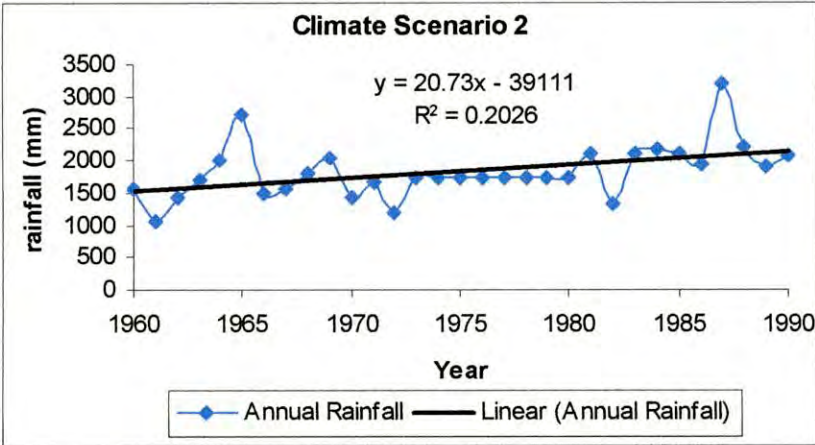


Figure 5.31 Total annual rainfall (1960-1990) of Dinajpur

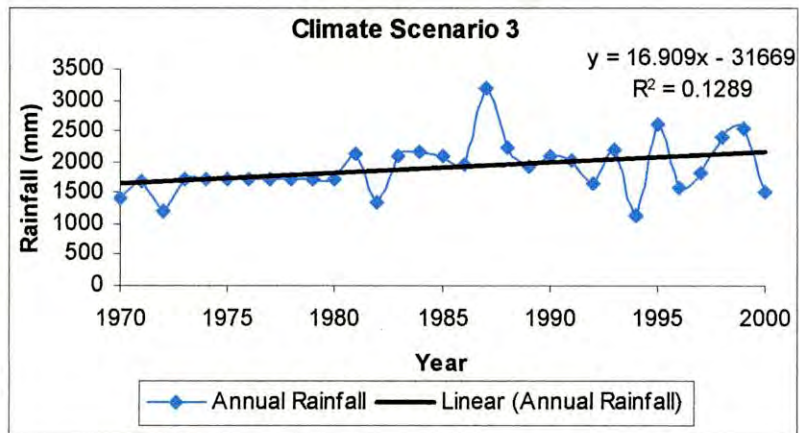


Figure 5.32 Total annual rainfall (1970-2000) of Dinajpur

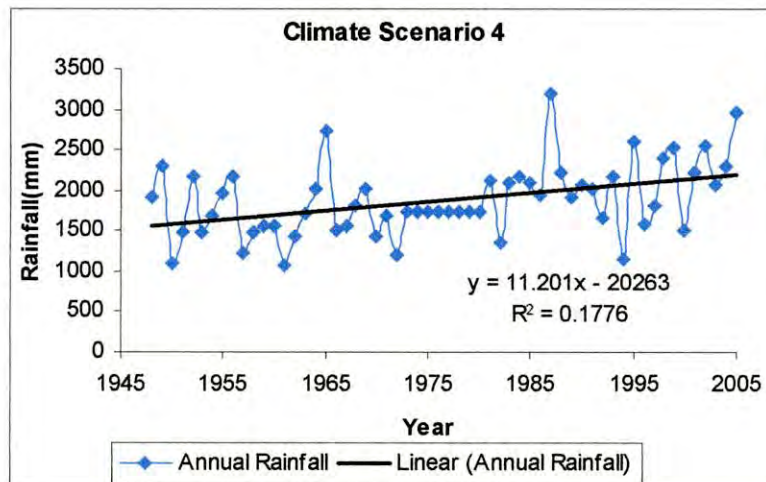


Figure 5.33 Total annual rainfall (1948-2005) of Dinajpur

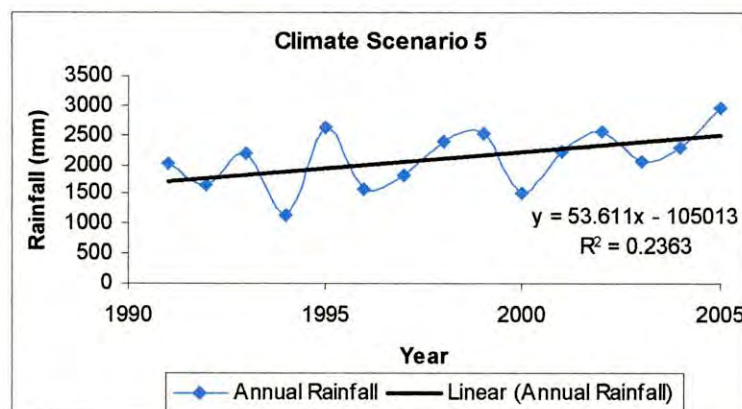


Figure 5.34 Total annual rainfall (1991-2005) of Dinajpur.

b) Trend of Seasonal Rainfall

The trends of seasonal rainfall over Dinajpur for the period 1991-2005 were shown in Figures 5.35 to 5.38. In pre-monsoon season (March, April, May) (Figure 5.35) an increasing trend of rainfall was found, with $R^2 = 0.1279$. Figure 5.36 shows that during monsoon (June, July, August) seasonal rainfall had an increasing trend with $R^2 = 0.2165$.

The rainfall in post-monsoon season (September, October, November) exhibited an increasing trend with $R^2 = 0.0402$ which was not statistically significant (Figure 5.37). However, in case of winter season (December, January, February), the rainfall had a decreasing trend (Figure 5.38) with $R^2 = 0.0275$.

The trend analysis of seasonal rainfall for the period 1991-2005 could reveal that rainfall in winter season had a decreasing trend whereas it had an increasing trend during pre-monsoon, monsoon and post-monsoon seasons.

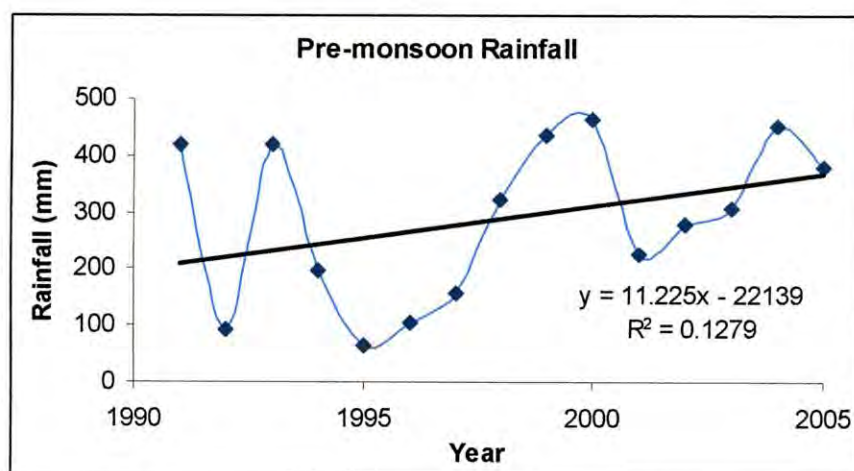


Figure 5.35 Trend of pre-monsoon rainfall during the period 1991-2005 of Dinajpur

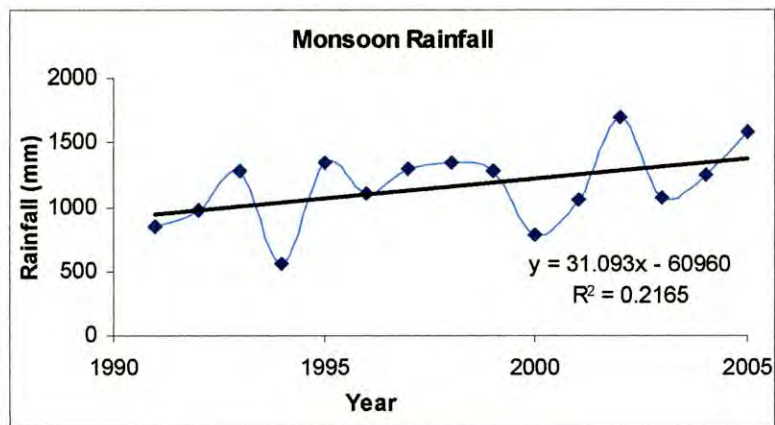


Figure 5.36 Trend of monsoon rainfall during the period 1991-2005 of Dinajpur

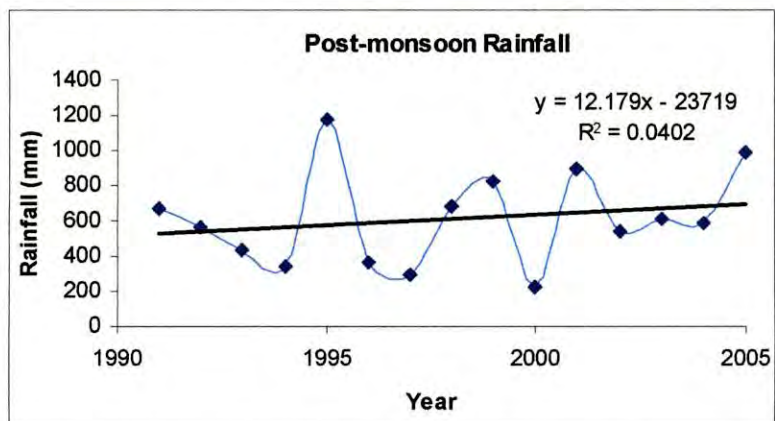


Figure 5.37 Trend of post-monsoon rainfall during the period 1991-2005 of Dinajpur

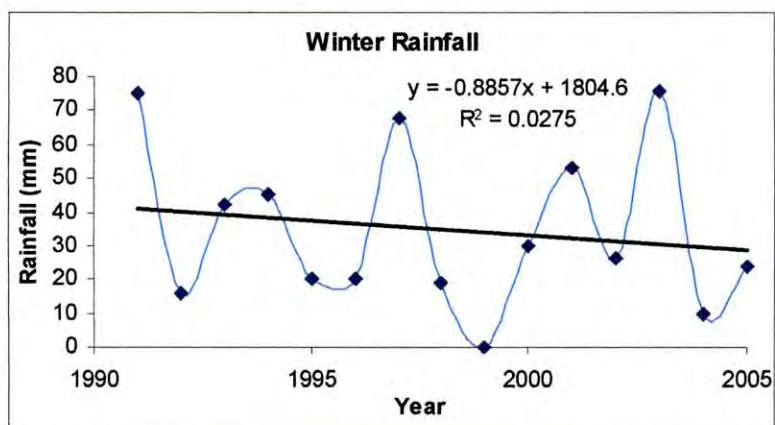


Figure 5.38 Trend of winter rainfall during the period 1991-2005 of Dinajpur.

5.4 Trend Analysis of Climate Change of Bogra District

The results from the statistical analysis using annual average maximum and minimum temperature and total precipitation of Bogra district for the time period of 1948 to 2005 have been presented in the following sections.

5.4.1 Temperature trends

Temperature represents the primary indicator for climate change. In Bogra district 1999 was the warmest year during the period of 1948-2005. In 1999 the average annual maximum temperature was 31.1°C and the average annual minimum temperature was 21.6°C.

a) Trend of Average Annual Maximum Temperature

During Climate Scenario 1(1948-1980), the average annual maximum temperature had a statistically insignificant decreasing trend with $R^2 = 0.0132$ (Figure 5.39). Climate Scenario 2 (1960-1990) shows that the average annual maximum temperature had an increasing trend with $R^2 = 0.0041$ (Figure 5.40) which was not statistically significant.

In Climate Scenario 3 (1970-2000), the average annual maximum temperature had an increasing trend with $R^2 = 0.0982$ which was not much statistically significant (Figure 5.41). The trend of average annual maximum temperature (Figure 5.42) for the overall Climate Scenario 4 (1948-2005) of Bogra district exhibited a decreasing trend with $R^2 = 0.0322$ which was not statistically significant. Climate Scenario 5 (1991-2005) shows the recent trend of average annual maximum temperature which has also a decreasing trend with $R^2 = 0.2569$ (Figure 5.43).

During 1948-1980 and 1991-2005, the average annual maximum temperature exhibited a decreasing trend, which has affected the overall climate scenario of 1948-2005. The average maximum temperature of the year 2004 has dropped sharply. It was 27.5°C. There was a statistically insignificant decreasing trend of average annual maximum temperature through the period of 1948-2005.

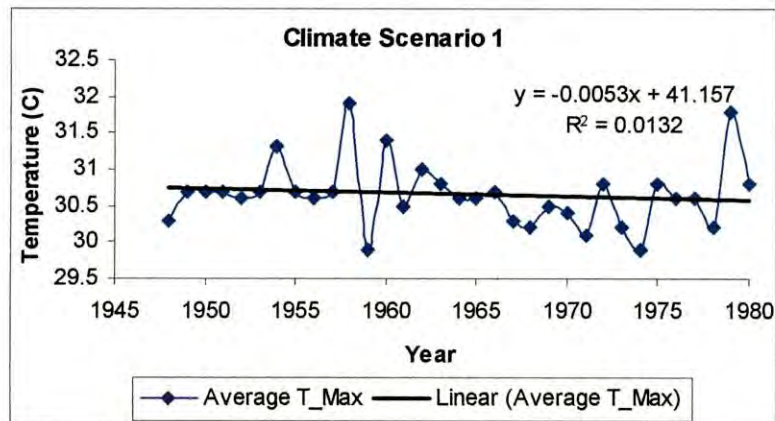


Figure 5.39 Average annual maximum temperature (1948-1980) of Bogra

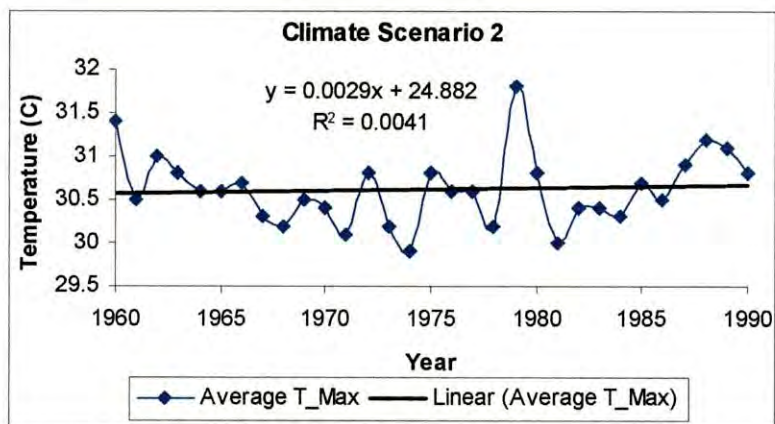


Figure 5.40 Average annual maximum temperature (1960-1990) of Bogra

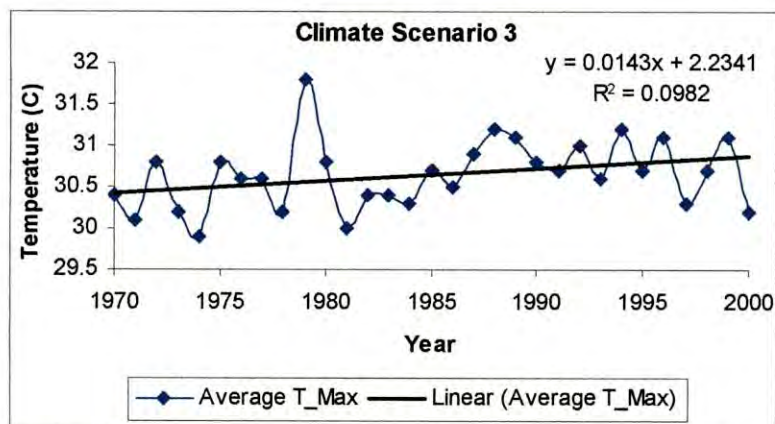


Figure 5.41 Average annual maximum temperature (1970-2000) of Bogra

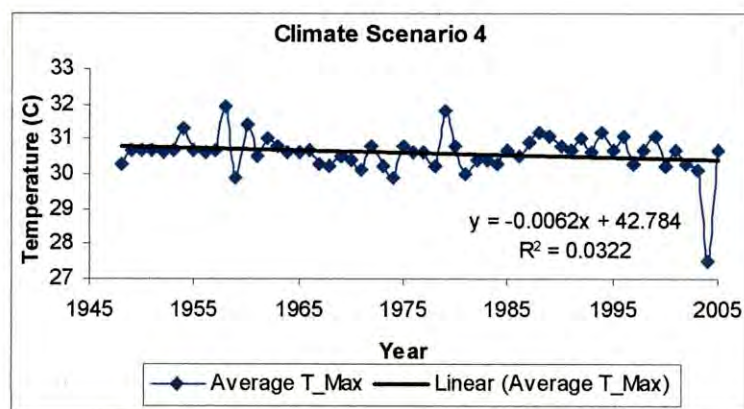


Figure 5.42 Average annual maximum temperature (1948-2005) of Bogra

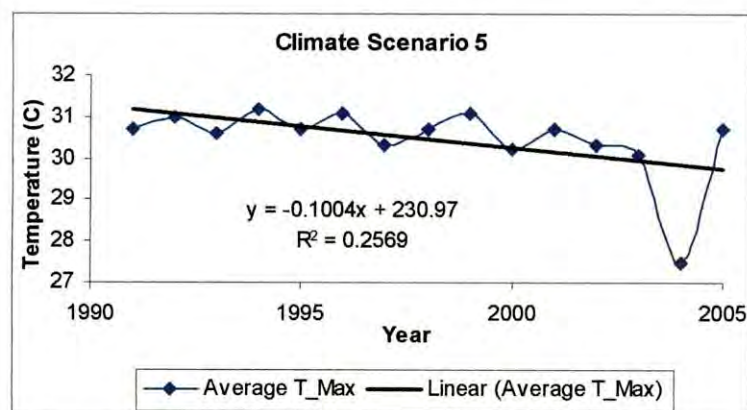


Figure 5.43 Average annual maximum temperature (1991-2005) of Bogra

b) Trend of Average Annual Minimum Temperature

The trends of the average annual minimum temperature over Bogra for the period 1948-2005 were shown in Figures 5.44 to 5.48. Figure 5.44 shows that during Climate Scenario 1 (1948-1980), the average annual minimum temperature has a decreasing trend with $R^2 = 0.0099$ which is not statistically significant. Climate Scenario 2 (1960-1990) and Climate Scenario 3 (1970-2000) exhibit an increasing trend with $R^2 = 0.0514$ and $R^2 = 0.2076$ (Figure 5.45 and Figure 5.46) respectively. For the overall period of 1948-2005, Figure 5.47 shows that the annual minimum temperature had an increasing trend with $R^2 = 0.1736$ which was statistically very insignificant. Climate Scenario 5 (1991-2005) shows the recent trend of average annual

minimum temperature which has an increasing trend with $R^2 = 0.3956$ (Figure 5.48). In 2004 the average annual minimum temperature has sharply increased to 23°C. Therefore, it could be revealed that though there was a decreasing trend during 1948-1980; the annual average minimum temperature had an increasing trend through the period of 1948-2005.

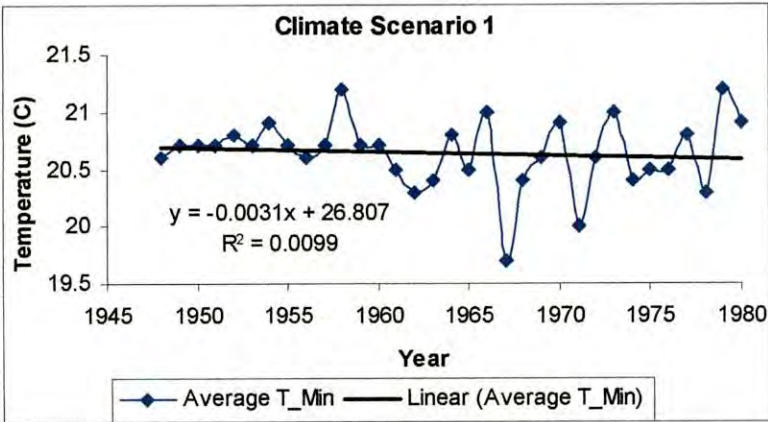


Figure 5.44 Average annual minimum temperature (1948-1980) of Bogra

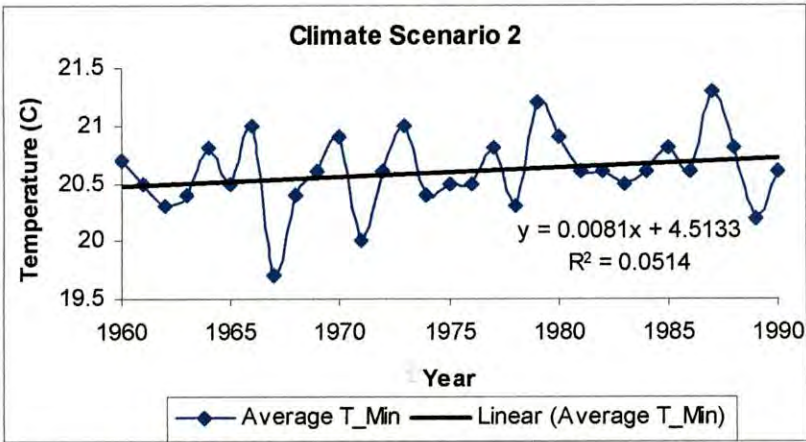


Figure 5.45 Average annual minimum temperature (1960-1990) of Bogra

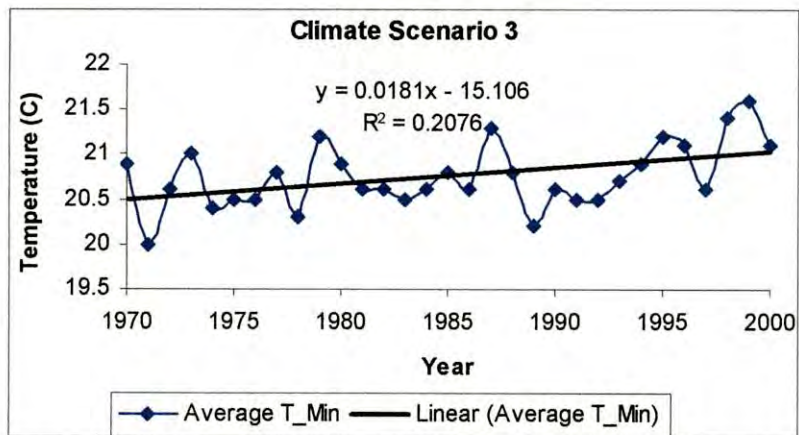


Figure 5.46 Average annual minimum temperature (1970-2000) of Bogra

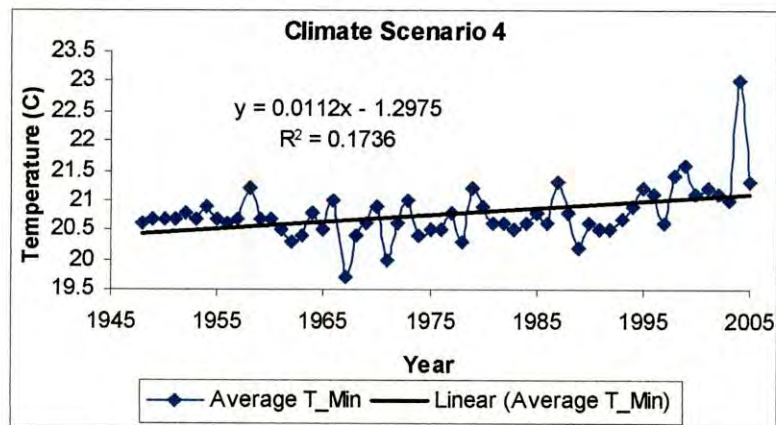


Figure 5.47 Average annual minimum temperature (1948-2005) of Bogra

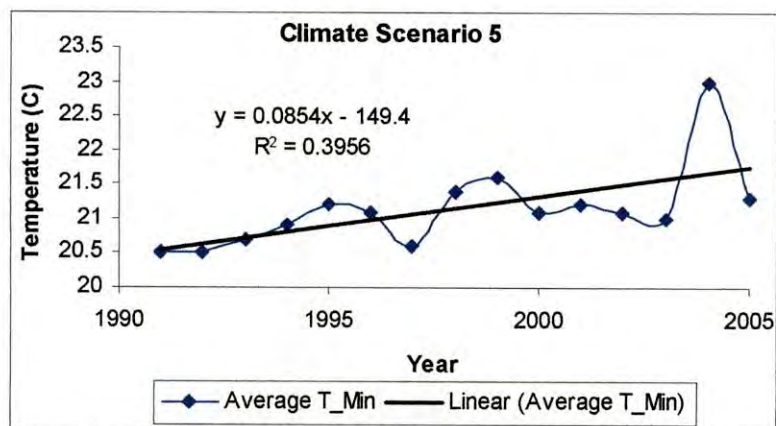


Figure 5.48 Average annual minimum temperature (1991-2005) of Bogra

5.4.2 Rainfall Trends

Rainfall represents one of the primary indicators for climate change. In Bogra the rainfall has its own seasonal pattern. The trends for the rainfall over Bogra for four seasons (pre-monsoon, monsoon, post- monsoon and winter) and on annual basis have been obtained for overall period 1950-2005.

a) Trend of Annual Rainfall

During the Climate Scenario 1 (1950-1980) the total annual rainfall had an increasing trend with $R^2 = 0.0285$ which was not statistically significant (Figure 5.49). During the Climate Scenario 2 (1960-1990) and Climate Scenario 3 (1970-2000), the total annual rainfall had also an increasing trend with $R^2 = 0.2386$ and $R^2 = 0.0097$ (Figure 5.50 and Figure 5.51). These trends were not statistically significant too. The overall climate scenario 4 (1950-2005), exhibited an increasing trend of total annual rainfall with $R^2 = 0.0794$ (Figure 5.52). Climate Scenario 5 (1991-2005) shows the recent trend of total annual rainfall which has an increasing trend with $R^2 = 0.0115$ (Figure 5.53). It has a slight increasing trend.

The trend analysis of annual rainfall revealed that there was an increasing trend throughout the period 1948-2005.

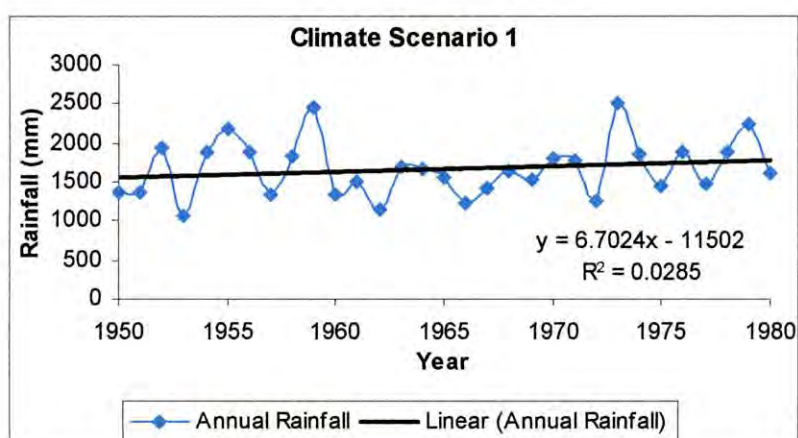


Figure 5.49 Total annual rainfall (1950-1980) of Bogra

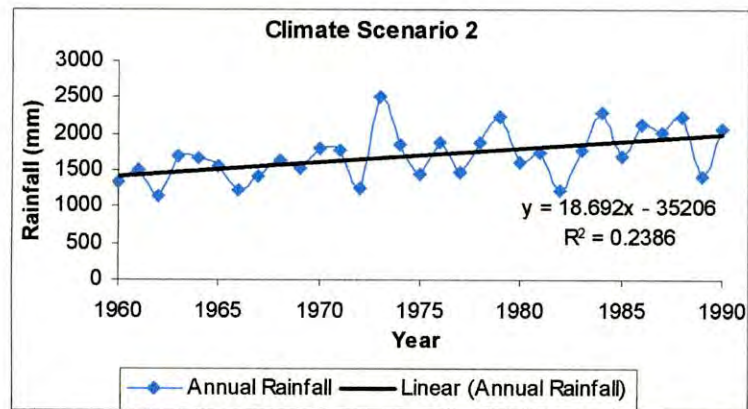


Figure 5.50 Total annual rainfall (1960-1990) of Bogra

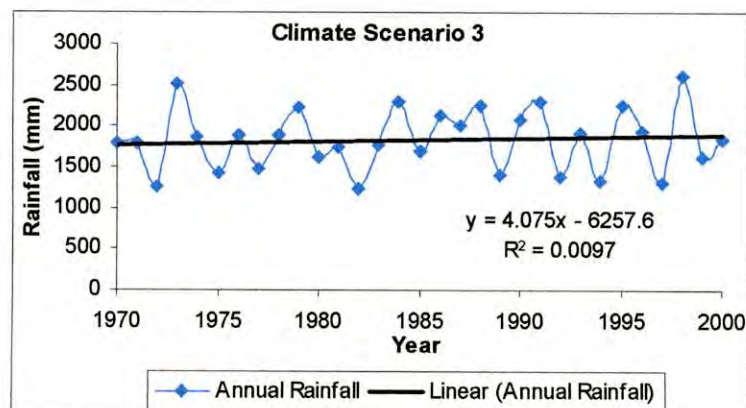


Figure 5.51 Total annual rainfall (1970-2000) of Bogra

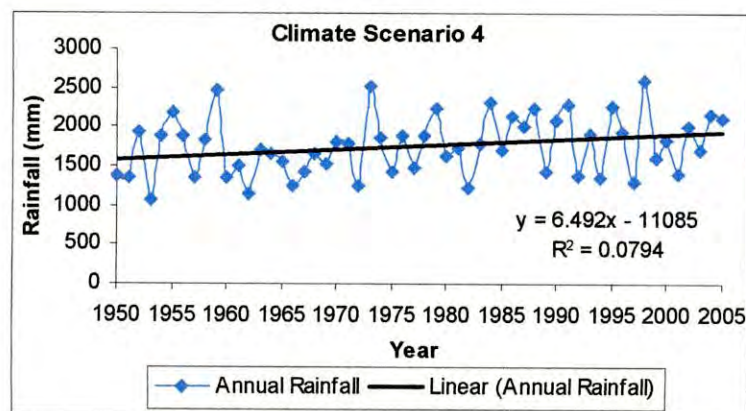


Figure 5.52 Total annual rainfall (1950-2005) of Bogra

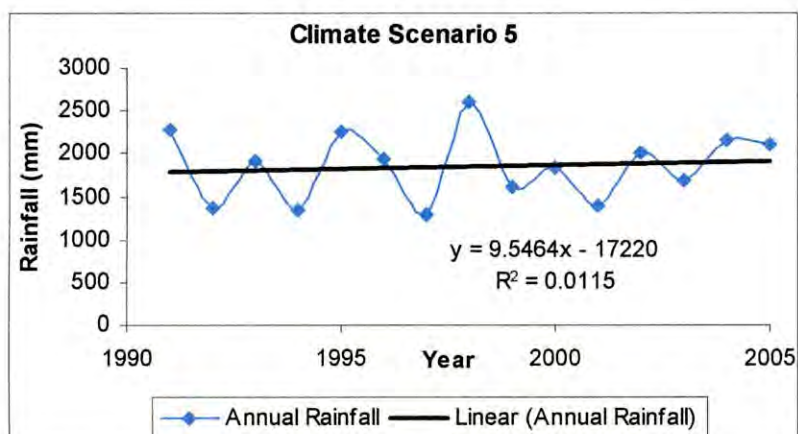


Figure 5.53 Total annual rainfall (1991-2005) of Bogra

b) Trend of Seasonal Rainfall

The trends of seasonal rainfall over Bogra for the period 1991-2005 were shown in Figures 5.54 to 5.57. In pre-monsoon season (March, April, May) (Figure 5.54) a slight increasing trend of rainfall was found, with $R^2 = 0.003$ which was not statistically very significant. Figure 5.55 shows that during monsoon seasonal (June, July, August) rainfall had also an increasing trend with $R^2 = 0.0277$.

The rainfall in post-monsoon season (September, October, November) exhibited a decreasing trend with $R^2 = 0.0001$ which was not statistically significant (Figure 5.56). However, in case of winter season (December, January, February), the rainfall had a statistically significant decreasing trend (Figure 5.57) with $R^2 = 0.2509$. During period 1991-2005 winter season of several years had gone fully dry with zero precipitation.

The trend analysis of seasonal rainfall for the period 1991-2005 could reveal that rainfall in post-monsoon and winter season had a decreasing trend whereas it had an increasing trend during pre-monsoon and monsoon seasons.

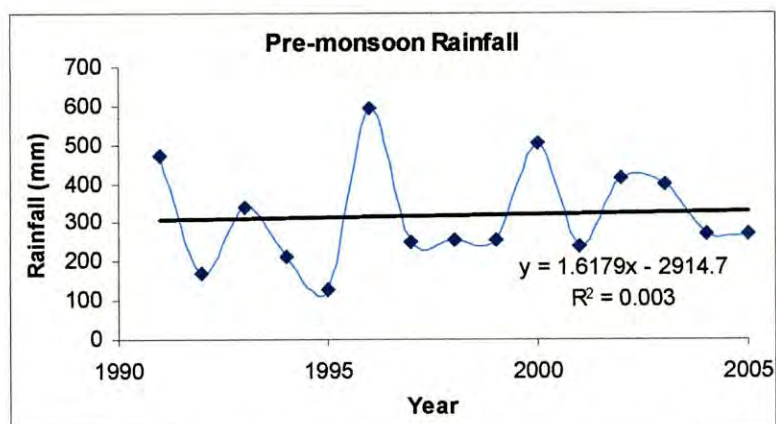


Figure 5.54 Trend of pre-monsoon rainfall during the period 1991-2005 of Bogra.

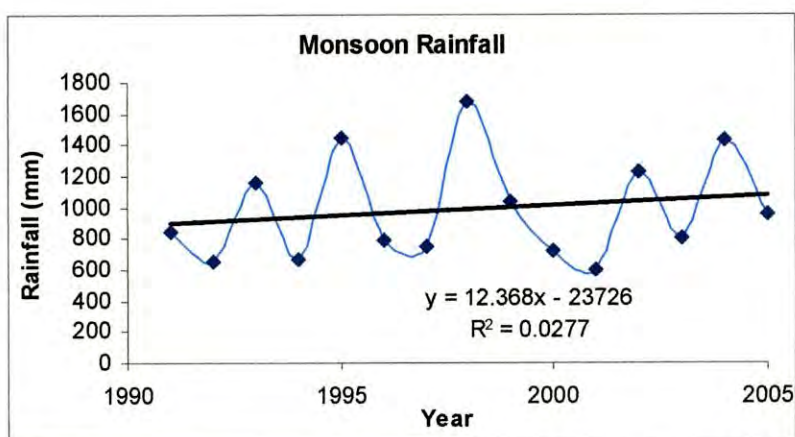


Figure 5.55 Trend of monsoon rainfall during the period 1991-2005 of Bogra

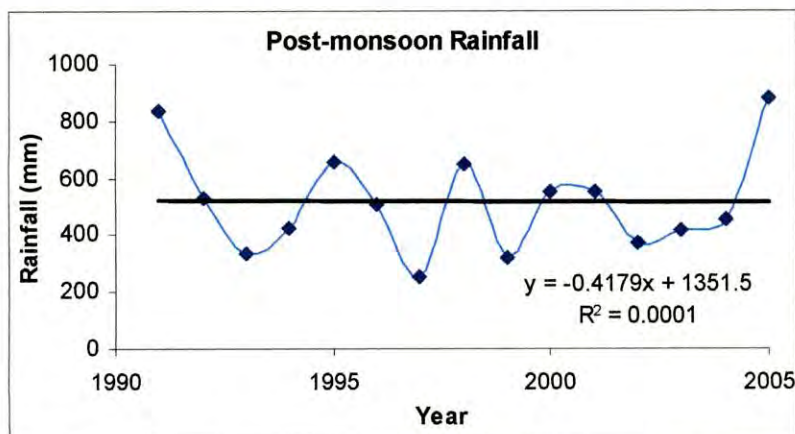


Figure 5.56 Trend of post-monsoon rainfall during the period 1991-2005 of Bogra

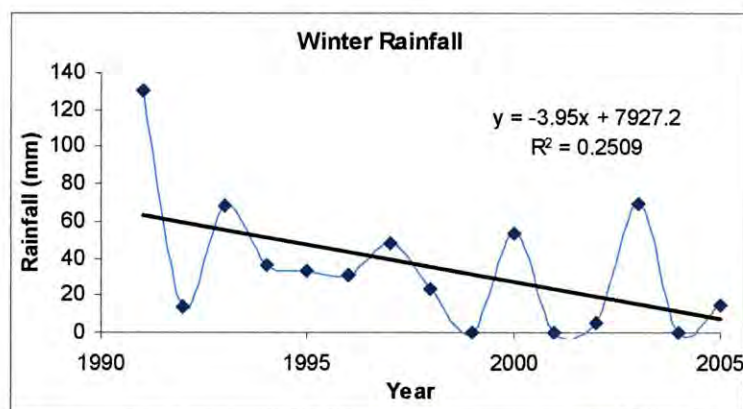


Figure 5.57 Trend of winter rainfall during the period 1991-2005 of Bogra.

5.5 Trend Analysis of Climate Change of Jessore District

The results from the statistical analysis using annual average maximum and minimum temperature and total precipitation of Jessore district for the time period of 1948 to 2005 have been presented in the following sections.

5.5.1 Temperature trends

Temperature represents the primary indicator for climate change. Like overall Bangladesh in Jessore district 1999 was the warmest year during the period of 1948-2005. In this year the average annual maximum temperature was 32.3°C and the average annual minimum temperature was 21.3°C.

a) Trend of Average Annual Maximum Temperature

During Climate Scenario 1(1948-1980), the average annual maximum temperature had a statistically insignificant decreasing trend with $R^2 = 0.0067$ (Figure 5.58). Climate Scenario 2 (1960-1990) and Climate Scenario 3 (1970-2000), show that the average annual maximum temperature had a significant increasing trend with $R^2 = 0.1643$ and $R^2 = 0.5514$ (Figure 5.59 and Figure 5.60). During the period 1970-2000 average maximum temperature has a sharp increasing trend.

The trend of average annual maximum temperature (Figure 5.61) for the overall Climate Scenario 4 (1948-2005) of Jessore district exhibited an increasing trend with $R^2 = 0.3522$ which was not statistically significant. Climate Scenario 5 (1991-2005) shows the recent trend of

average annual maximum temperature which has also an increasing trend with $R^2 = 0.2906$ (Figure 5.62).

During 1948-1980, the average annual maximum temperature exhibited a decreasing trend; otherwise there was an increasing trend of average annual maximum temperature through the period of 1948-2005.

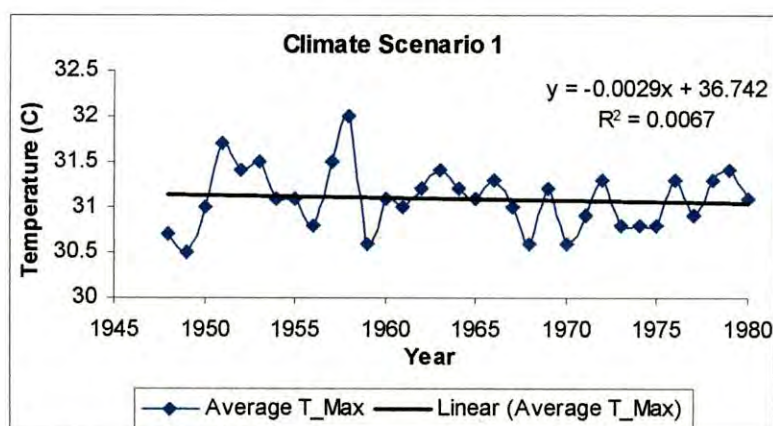


Figure 5.58 Average annual maximum temperature (1948-1980) of Jessore.

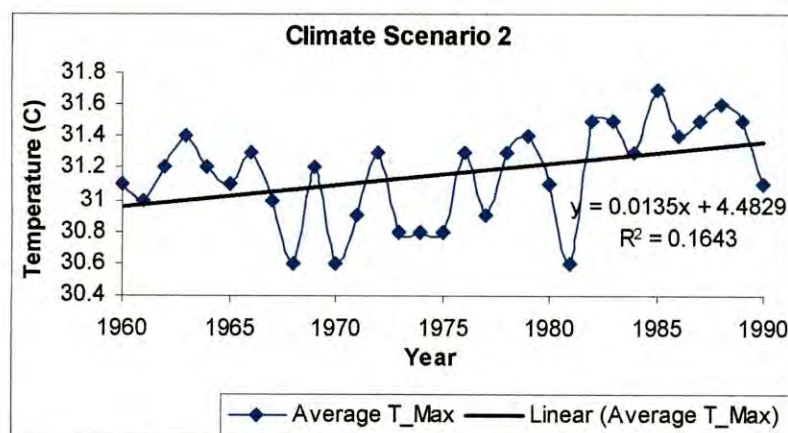


Figure 5.59 Average annual maximum temperature (1960-1990) of Jessore.

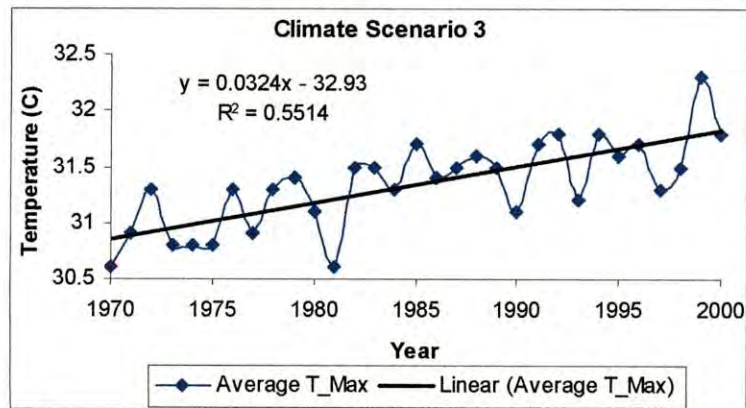


Figure 5.60 Average annual maximum temperature (1970-2000) of Jessore.

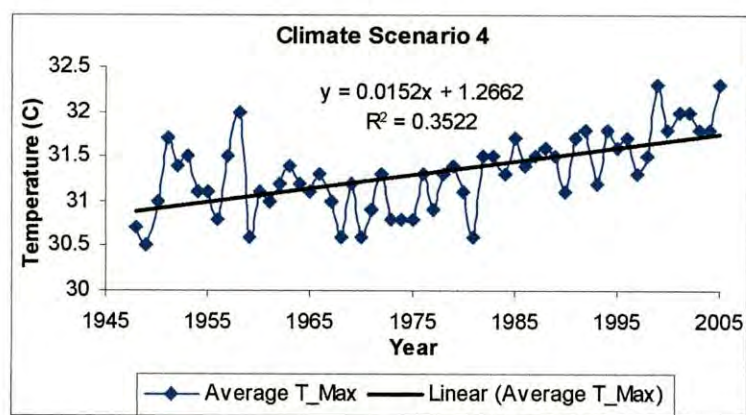


Figure 5.61 Average annual maximum temperature (1948-2005) of Jessore.

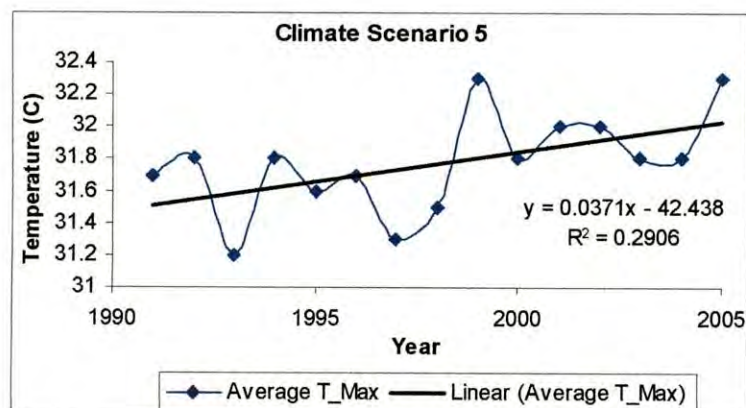


Figure 5.62 Average annual maximum temperature (1991-2005) of Jessore.

b) Trend of Average Annual Minimum Temperature

The trends of the average annual minimum temperature over Jessore for the period 1948-2005 were shown in Figures 5.63 to 5.67. Figure 5.63 and 5.64 show that during Climate Scenario 1

(1948-1980) and Climate Scenario 2 (1960-1990) the average annual minimum temperature had a statistically insignificant increasing trend with $R^2 = 0.0639$ and $R^2 = 0.0374$.

During Climate Scenario 3 (1970-2000), the average annual minimum temperature had a significant increasing trend (Figure 5.65) with $R^2 = 0.1781$. For the overall period of 1948-2005, Figure 5.66 shows that the annual minimum temperature had an increasing trend with $R^2 = 0.1794$. Climate Scenario 5 (1991-2005) shows the recent trend of average annual minimum temperature which has also an increasing trend with $R^2 = 0.107$ (Figure 5.67).

Therefore, it could be revealed that the annual average minimum temperature had an increasing trend through the period of 1948-2005.

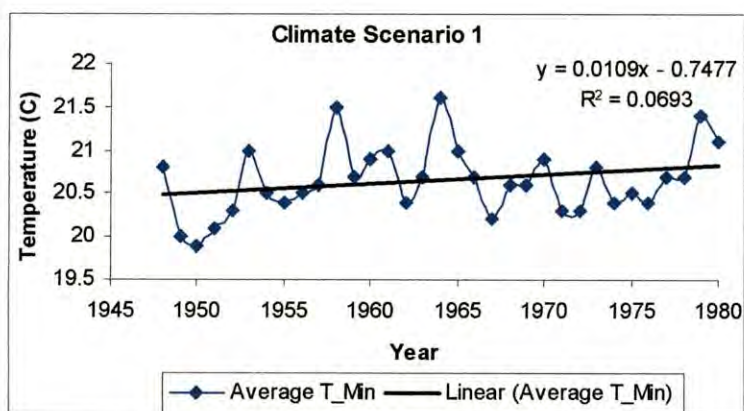


Figure 5.63 Average annual minimum temperature (1948-1980) of Jessore.

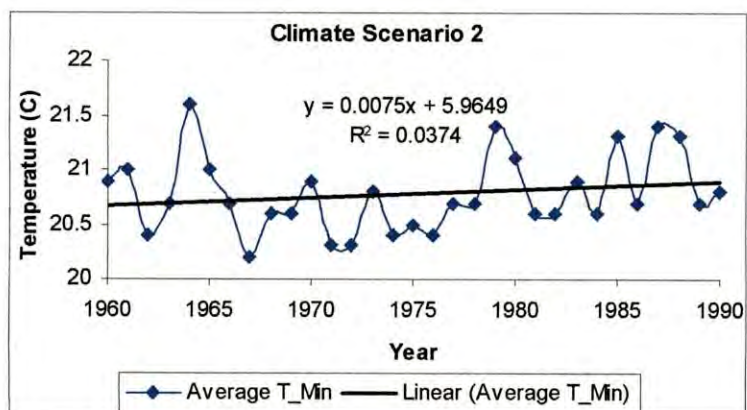


Figure 5.64 Average annual minimum temperature (1960-1990) of Jessore.

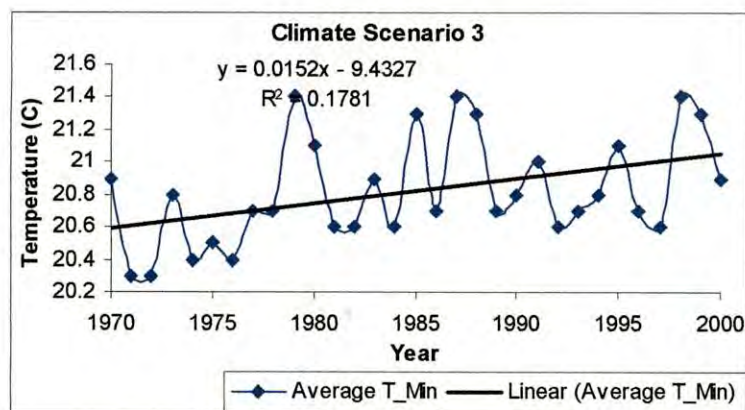


Figure 5.65 Average annual minimum temperature (1970-2000) of Jessore.

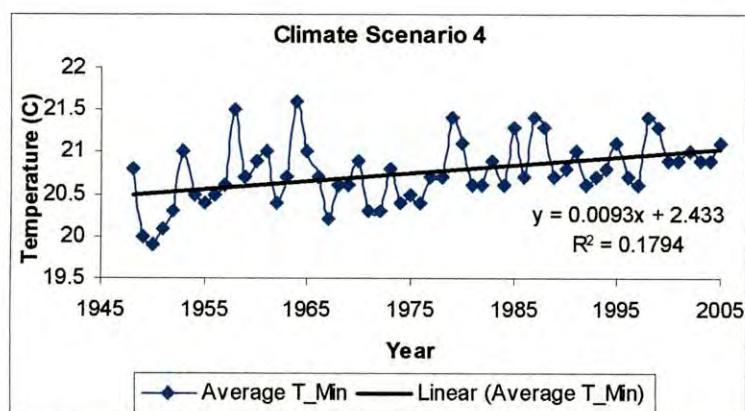


Figure 5.66 Average annual minimum temperature (1948-2005) of Jessore.

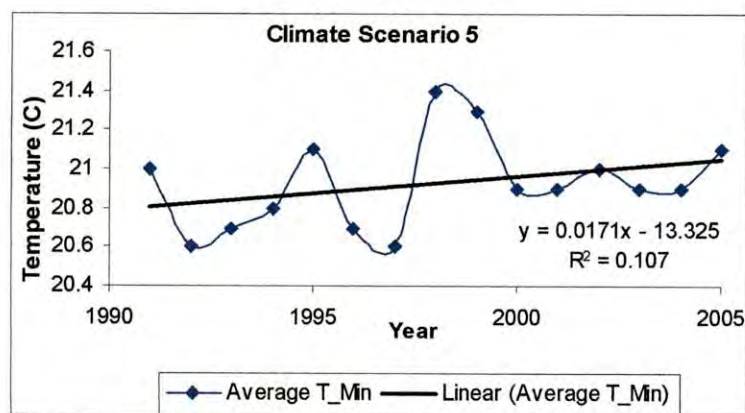


Figure 5.67 Average annual minimum temperature (1991-2005) of Jessore.

5.5.2 Rainfall Trends

Rainfall represents one of the primary indicators for climate change. In Jessore the rainfall has its own seasonal pattern. The winter season almost remain dry or negligible precipitation. The

trends for the rainfall over Jessore for four seasons (pre-monsoon, monsoon, post- monsoon and winter) and on annual basis have been obtained for overall period 1948-2005.

b) Trend of Annual Rainfall

During the Climate Scenario 1 (1948-1980) the total annual rainfall had a statistically insignificant decreasing trend with $R^2 = 0.0003$ (Figure 5.68). During the Climate Scenario 2 (1960-1990) and Climate Scenario 3 (1970-2000), the total annual rainfall had an increasing trend with $R^2 = 0.0573$ and $R^2 = 0.0006$ (Figure 5.69 and Figure 5.70). These trends were not statistically significant too. The overall climate scenario 4 (1950-2005), exhibited an increasing trend of total annual rainfall with $R^2 = 0.0752$ (Figure 5.71). Climate Scenario 5 (1991-2005) shows the resent trend of total annual rainfall which has an increasing trend with $R^2 = 0.1788$ (Figure 5.72). It has a slight increasing trend.

The trend analysis of annual rainfall revealed that there was an increasing trend throughout the period 1948-2005, with the exception of a decreasing trend during the periods of 1948-1980.

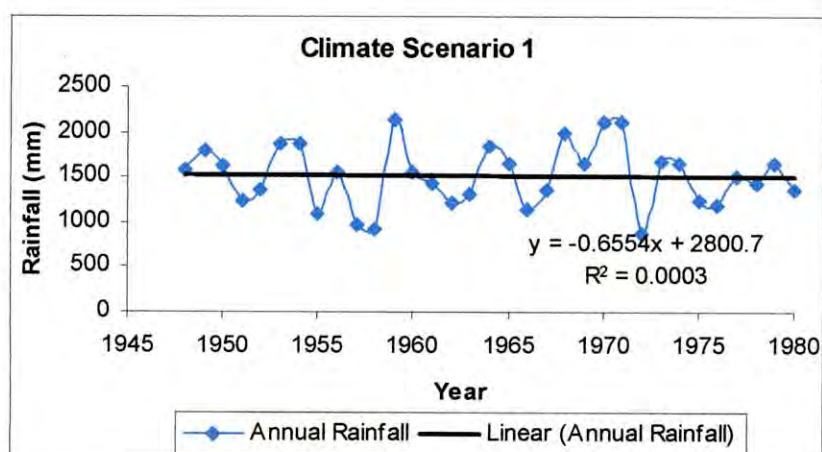


Figure 5.68 Total annual rainfall (1948-1980) of Jessore.

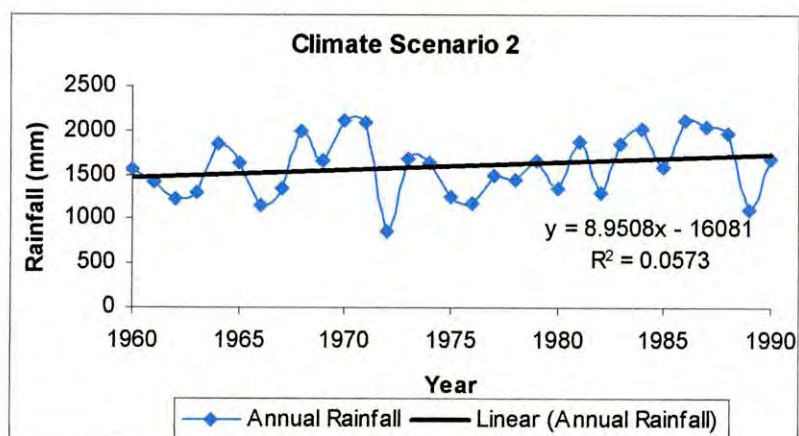


Figure 5.69 Total annual rainfall (1960-1990) of Jessore.

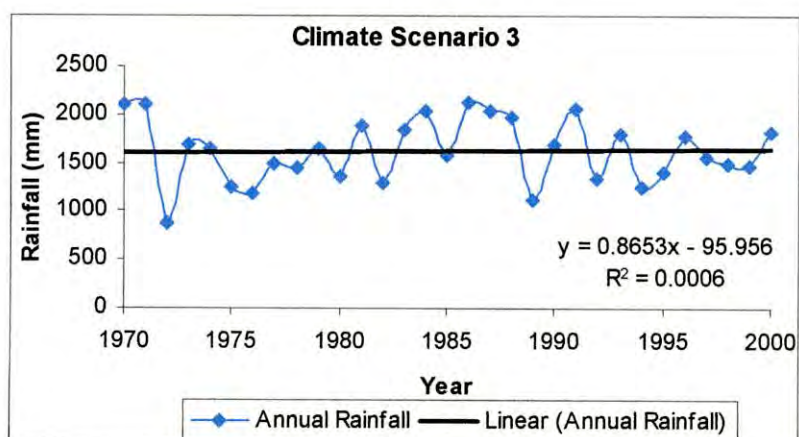


Figure 5.70 Total annual rainfall (1970-2000) of Jessore.

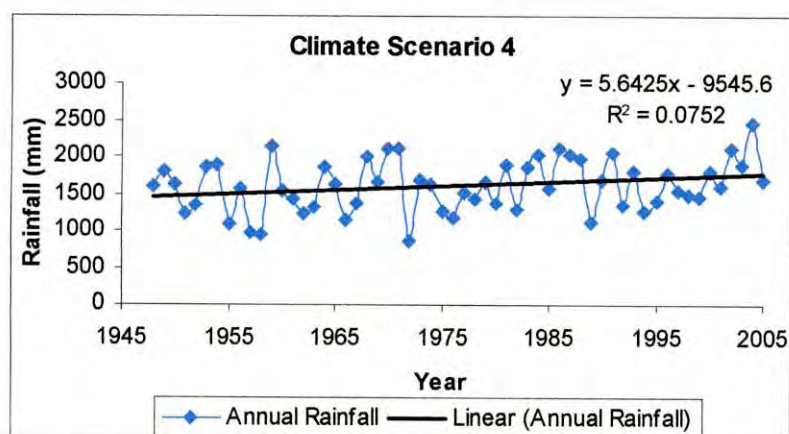


Figure 5.71 Total annual rainfall (1948-2005) of Jessore.

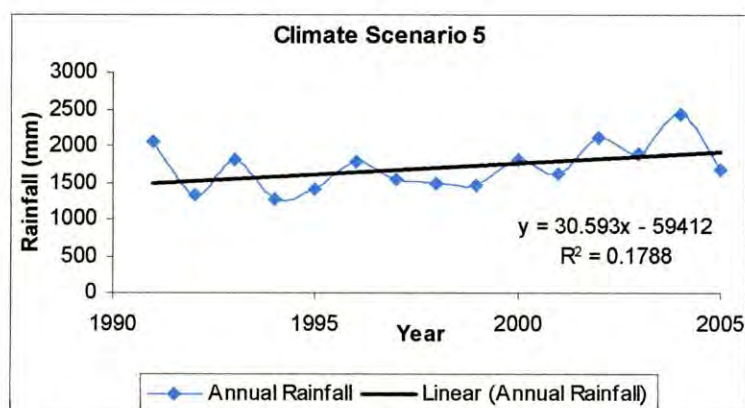


Figure 5.72 Total annual rainfall (1991-2005) of Jessore.

b) Trend of Seasonal Rainfall

The trends of seasonal rainfall over Jessore for the period 1991-2005 were shown in Figures 5.73 to 5.76. In pre-monsoon season (March, April, May) (Figure 5.73) a slight increasing trend of rainfall was found, with $R^2 = 0.0052$. Figure 5.74 shows that during monsoon (June, July, August) seasonal rainfall had also an increasing trend with $R^2 = 0.0164$.

The rainfall in post-monsoon season (September, October, November) exhibited a sharp increasing trend with $R^2 = 0.3352$ (Figure 5.75). However, in case of winter season (December, January, February), the rainfall had a significant decreasing trend (Figure 5.76) with $R^2 = 0.4284$. During period 1991-2005 winter season of several years had gone fully dry with zero precipitation.

The trend analysis of seasonal rainfall for the period 1991-2005 could reveal that rainfall in winter season had a sharp decreasing trend whereas it had an increasing trend during pre-monsoon, monsoon seasons and post-monsoon.

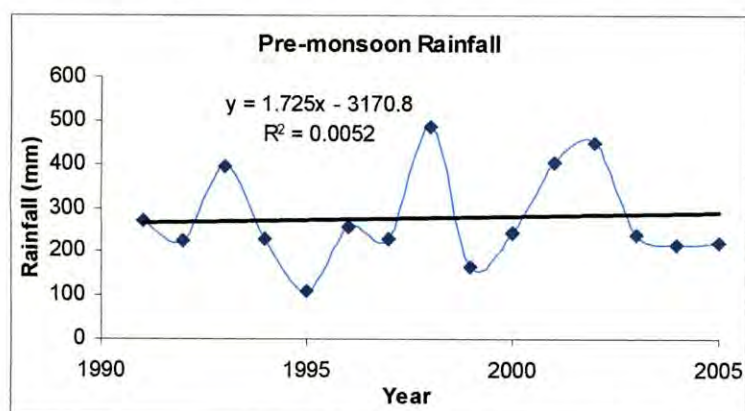


Figure 5.73 Trend of pre-monsoon rainfall during the period 1991-2005 of Jessore.

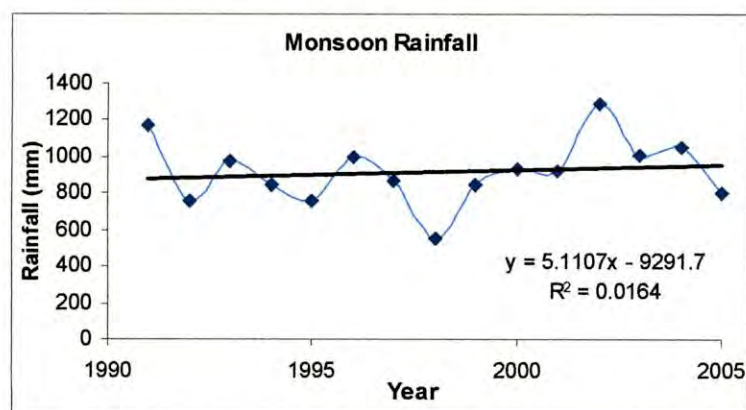


Figure 5.74 Trend of monsoon rainfall during the period 1991-2005 of Jessore.

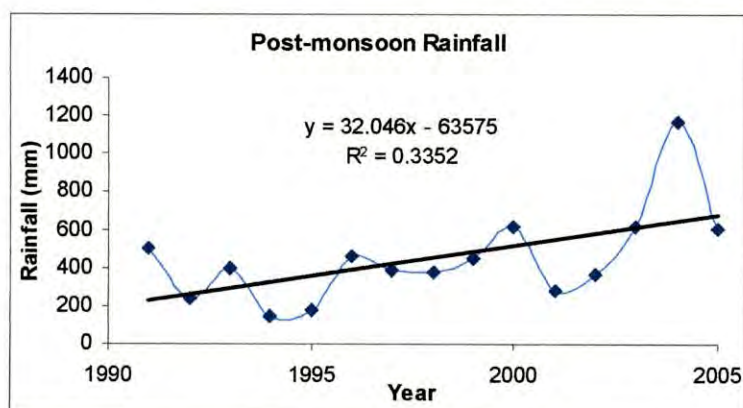


Figure 5.75 Trend of post-monsoon rainfall during the period 1991-2005 of Jessore.

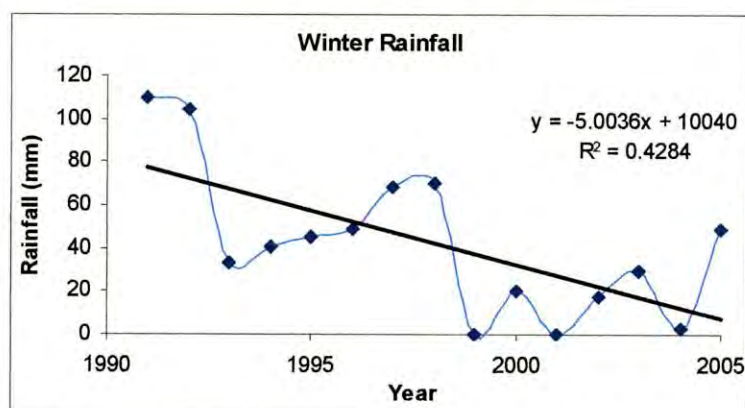


Figure 5.76 Trend of winter rainfall during the period 1991-2005 of Jessore.

5.6 Probable Impacts of Climate Change on Agriculture

The results of the analysis for investigating the probable impacts of recent temperature and rainfall changes on rice (Local T. Aman), wheat, potato and Pulse (Mungbean) production are presented in the following sections.

5.6.1 Impacts of Climate Change on Rice (Local Transplant Aman)

a) Correlation with Temperature

Figure 5.77 shows the yield trend of Local Transplant Aman rice during the period 1992-2004. It shows an increasing trend. In the analysis average seasonal (growing season) maximum and minimum temperature have been considered. The average temperature has been taken for time period of transplanting to harvest. The time period for transplanting is end of June to early September and the time of harvest is December to early January. So the seasonal average maximum and seasonal average minimum temperature were considered for the month of June to January. The yield of Aman with response to both seasonal average maximum temperature and seasonal average minimum temperature during the period 1992-2004 was found to have an increasing trend (Figure 5.78 and Figure 5.79).

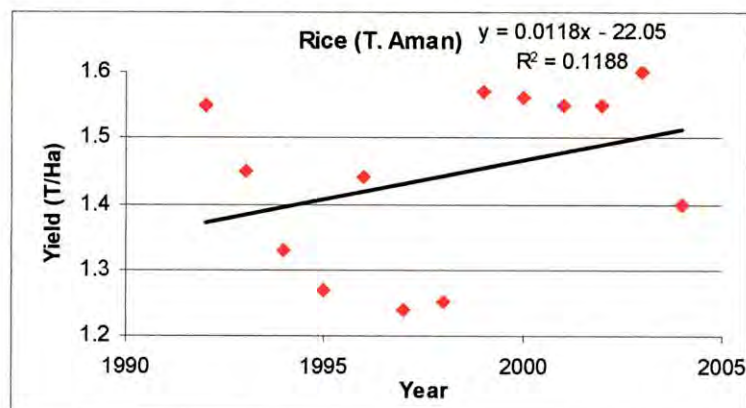


Figure 5.77 Variation of T. Aman yield during the period 1992-2004.

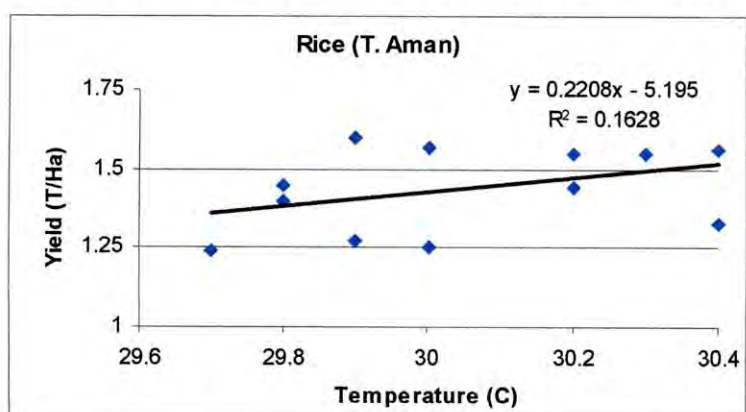


Figure 5.78 Variation of T. Aman yield with response to seasonal average maximum temperature during 1992-2004.

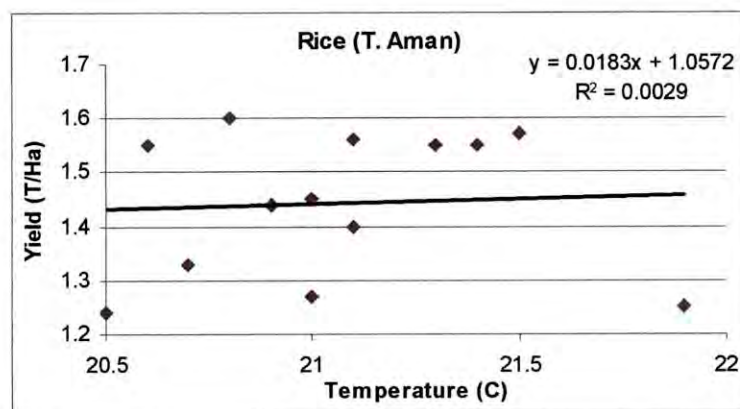


Figure 5.79 Variation of T. Aman yield with response to seasonal average minimum temperature during 1992-2004.

b) Correlation with Seasonal Rainfall

The trend of yield of T. Aman in response to the seasonal total rainfall (Figure 5.80) has shown a decreasing trend. The rainfall has been considered for the month of June to January. It includes the time of transplanting and harvest. One extra month, June, before transplantation has been considered in order to count the impact of soil water content on crop production.

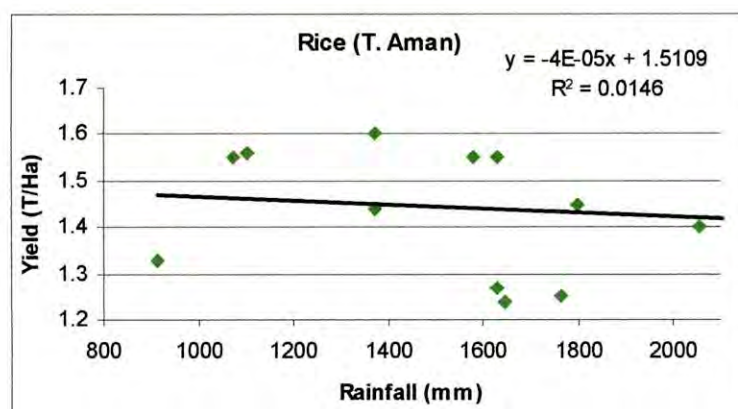


Figure 5.80 Variation of T. Aman yield with response to seasonal total rainfall during 1992-2004.

5.6.2 Discussion on Probable Impacts of Climate Change on Rice Production

From overall climate scenario it can be seen that the annual average maximum temperature has an increasing trend during the period 1948-2005. The recent climate change scenario (1991-

2005) for annual average maximum temperature also shows an increasing trend. On the other hand, the overall climate scenario for annual average minimum temperature has a statistically insignificant decreasing trend. The recent climate scenario for annual average minimum temperature and annual rainfall show an increasing trend. The production of Aman rice had an increasing trend during the period 1992-2004. The yield has increased with both the seasonal average maximum temperature with correlation coefficient: 0.40 and seasonal average minimum temperature with correlation coefficient: 0.05, but decreased with seasonal rainfall with correlation coefficient:-0.12. So it can be said that the seasonal average maximum might have a positive impact on the T. Aman yield. The increase of yield may occur for several reasons. The proper use of fertilizer, harvesting method, following metrological forecasts, proper use of pesticides, proper land management etc might have increased Aman production. Moreover, the seasonal average maximum and minimum temperature and the seasonal rainfall might be favorable for the Aman production for that period in Comilla district. The yield of T. Aman in 1992 and 2004 were 1.55 (T/Ha) and 1.4 (T/Ha) respectively. But the overall scenario shows an increasing trend. The reason of decrease in yield in 2004 may be the flood of that year.

5.6.3 Impacts of Climate Change on Wheat

a) Correlation with Temperature

Figure 5.81 shows the yield trend of wheat during the period 1992-2005. It shows a decreasing trend. In the analysis average seasonal (growing season) maximum and minimum temperature have been considered. The average temperature has been taken for time period of transplanting to harvest. The time period for transplanting is November to December and the time of harvest is March to mid April. So the seasonal average maximum and seasonal average minimum temperature were considered for the month of November to April. The yield of wheat with response to both seasonal average maximum temperature and average minimum temperature during the period 1992-2005 was found to have an increasing trend (Figure 5.82 and Figure 5.83). In Dinajpur district the average maximum temperature had a decreasing trend and the average minimum temperature had an increasing trend for the period 1991-2005. The affect of global warming is observed for this period in this zone.

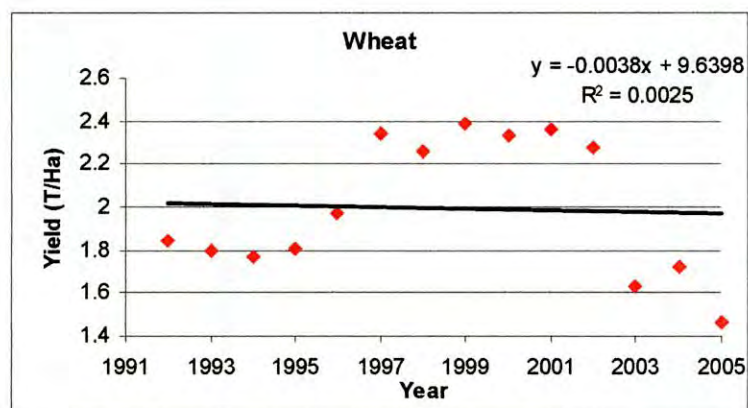


Figure 5.81 Variation of wheat yield during the period 1992-2005.

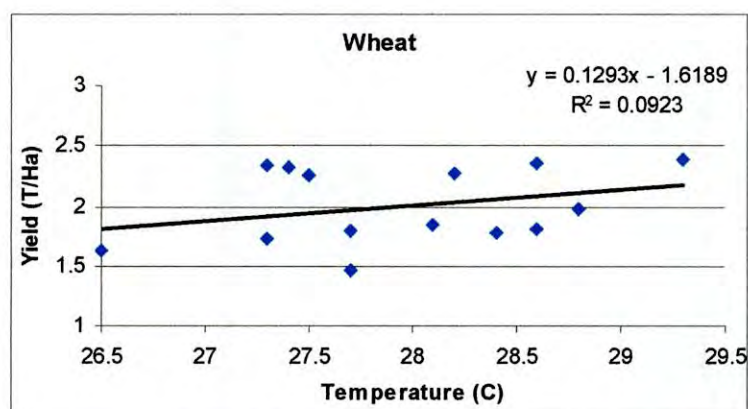


Figure 5.82 Variation of wheat yield with response to seasonal average maximum temperature during 1992-2005.

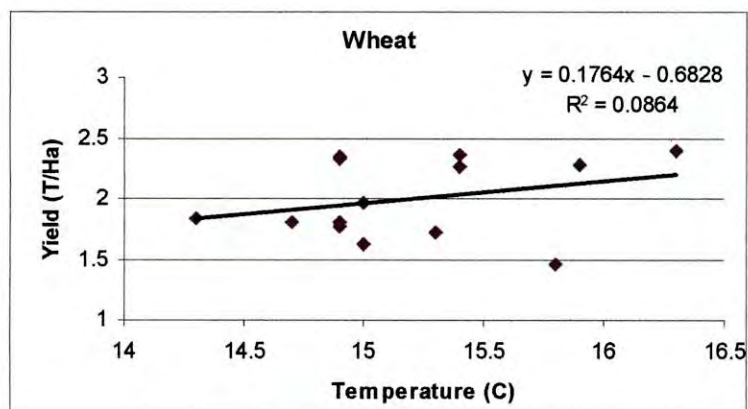


Figure 5.83 Variation of wheat yield with response to seasonal average minimum temperature during 1992-2005.

b) Correlation with Seasonal Rainfall

The trend of yield of wheat in response to the seasonal total rainfall (Figure 5.84) has shown a decreasing trend. The rainfall has been considered for the month of October to April. It includes the time of transplanting and harvest. One extra month, October, before transplantation has been considered in order to count the impact of soil water content on wheat production.

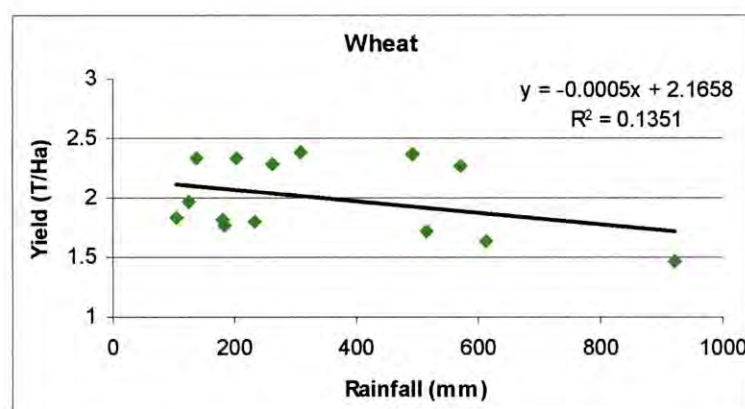


Figure 5.84 Variation of wheat yield with response to seasonal total rainfall during 1992-2005.

5.6.4 Discussion on Probable Impacts of Climate Change on Wheat Production

From overall climate scenario (1948-2005) and the recent climate change scenario (1991-2005) of Dinajpur district it can be seen that the annual average maximum temperature had a decreasing trend. On the other hand, the overall climate scenario and the recent climate scenario for annual average minimum temperature had an increasing trend. The production of wheat in this district had a decreasing trend during the period 1992-2005. The production of wheat has increased with both the seasonal average maximum temperature with correlation coefficient: 0.30 and seasonal average minimum temperature with correlation coefficient: 0.29, which are not much significant. But the production has decreased with seasonal rainfall with correlation coefficient: -0.37, as many wheat diseases thrive in damp weather. This decrease in production can occur for several reasons. As the annual average maximum temperature showed a decreasing trend and the annual average minimum temperature showed an increasing trend the affect of global warming might be observed in this zone. Increase in temperature either maximum or minimum can make many agricultural areas less productive. The yield rate of wheat decreases mainly due to relatively higher temperature and shortening of cold season. As the annual average

minimum temperature of Dinajpur district had shown an increasing trend (1991-2005), wheat production could be affected by this climate parameter. Again excess, untimely and uneven distribution of seasonal rainfall could hamper the production. Other related factors like improper use of fertilizer might have an impact on the production. The increase of wheat production with seasonal average maximum and seasonal average minimum temperature might be due to the satisfaction of optimum temperature condition for wheat production. The yield of wheat in 1992 and 2004 were 1.84 (T/Ha) and 1.46 (T/Ha) respectively. Its yield decreased about 20%.

5.6.5 Impacts of Climate Change on Potato (Local)

a) Correlation with Temperature

Figure 5.85 shows the yield trend of potato during the period 1992-2004. It shows an increasing trend. In the analysis average seasonal (growing season) maximum and minimum temperature have been considered. The average temperature has been taken for time period of transplanting to harvest. The time period for transplanting is mid September to mid November and the time of harvest mid January to March. So the seasonal average maximum and seasonal average minimum temperature were considered for the month of September to March. The yield of potato with response to seasonal average maximum temperature during the period 1992-2004 was found to have a decreasing trend (Figure 5.86) and average minimum temperature for the same period had an increasing trend (Figure 5.87). In Bogra district the average maximum temperature had a decreasing trend and the average minimum temperature had an increasing trend for the period 1992-2004 which may be favorable for the potato production.

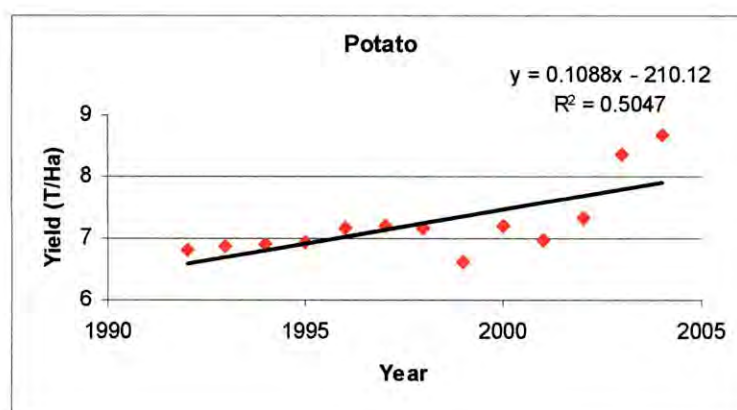


Figure 5.85 Variation of potato yield during the period 1992-2004.

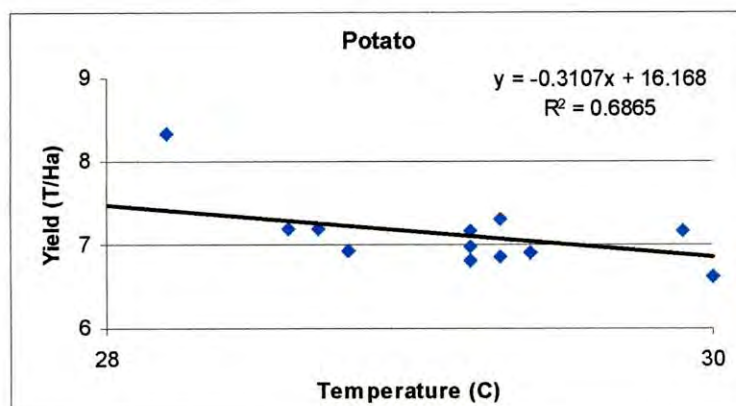


Figure 5.86 Variation of potato yield with response to seasonal average maximum temperature during 1992-2004.

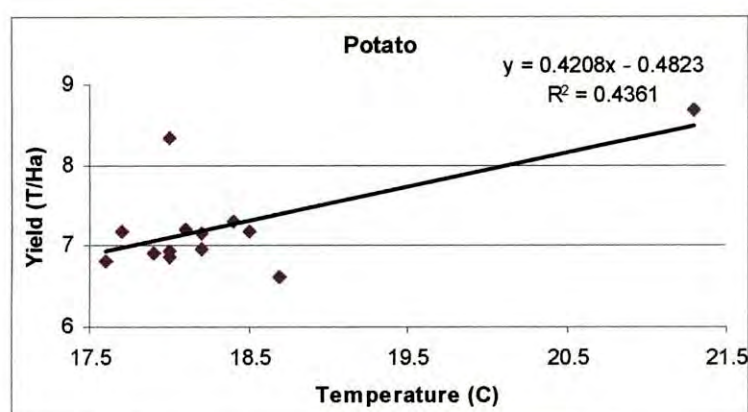


Figure 5.87 Variation of potato yield with response to seasonal average minimum temperature during 1992-2004.

b) Correlation with Seasonal Rainfall

The trend of yield of potato in response to the seasonal total rainfall (Figure 5.88) has shown an increasing trend. The rainfall has been considered for the month of September to March. It includes the time of transplanting and harvest.

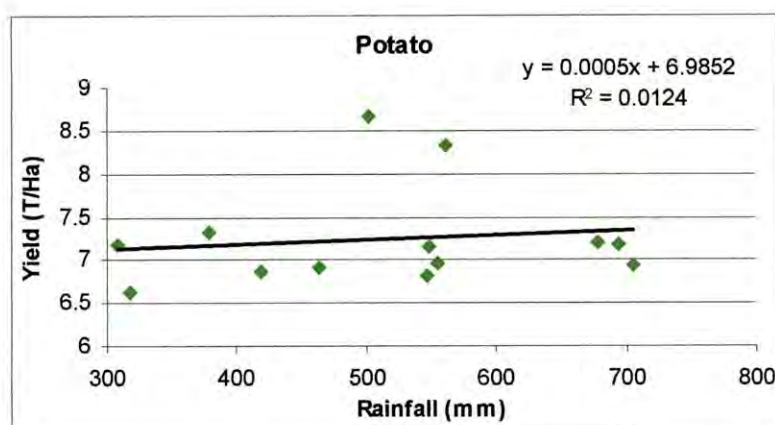


Figure 5.88 Variation of potato yield with response to seasonal total rainfall during 1992-2004.

5.6.6 Discussion on Probable Impacts of Climate Change on Potato Production

From overall climate scenario (1948-2005) and the recent climate change scenario (1991-2005) of Bogra district it can be seen that the annual average maximum temperature had a decreasing trend. On the other hand, the overall climate scenario and the recent climate scenario for annual average minimum temperature had an increasing trend. The production of potato in this district had an increasing trend during the period 1992-2004. The production of potato has decreased with the seasonal average maximum temperature with correlation coefficient:-0.83 and has increased with the seasonal average minimum temperature with correlation coefficient: 0.66. The production has also increased with seasonal rainfall with correlation coefficient:-0.11. Seasonal average maximum temperature and seasonal average minimum temperature had an impact on potato yield but there is no significant relation of potato yield and seasonal rainfall. The increase in production may occur for several reasons. As the annual average maximum temperature showed a decreasing trend and the annual average minimum temperature showed an increasing trend the effect of global warming might be negligible in this zone. The annual average minimum temperature and the annual precipitation of Bogra district had shown an increasing trend (1991-2005) and potato production could be increased by the change of these climate parameters. Other related factors like adequate use of fertilizer, proper irrigation might have an impact on the production. Potato is a heat tolerant crop also, so increasing temperature didn't have adverse impact on its production. The increase of potato production with the seasonal average minimum temperature also might be due to the satisfaction of optimum temperature

condition for the production. The yield of potato in 1992 and 2004 were 6.81(T/Ha) and 8.67 (T/Ha) respectively. Its yield increased about 27%.

5.6.7 Impacts of Climate Change on Pulse (Mungbean)

a) Correlation with Temperature

Figure 5.89 shows the yield trend of Mungbean during the period 1992-2004. It shows a sharp decreasing trend. In the analysis average seasonal (growing season) maximum and minimum temperature have been considered. The average temperature has been taken for time period of transplanting to harvest. The time period for transplanting is mid August to mid September and the time of harvest mid November to mid December. So the seasonal average maximum and seasonal average minimum temperature were considered for the month of August to December. The yield of mungbean with response to seasonal average maximum temperature and average minimum temperature during the period 1992-2004 was found to have a decreasing trend (Figure 5.90 and Figure 5.91). In Jessore district both the annual average maximum temperature and average minimum temperature had an increasing trend for the period 1991-2005. The affect of global warming can be observed in this zone which may have caused a sharp decrease of mungbean production.

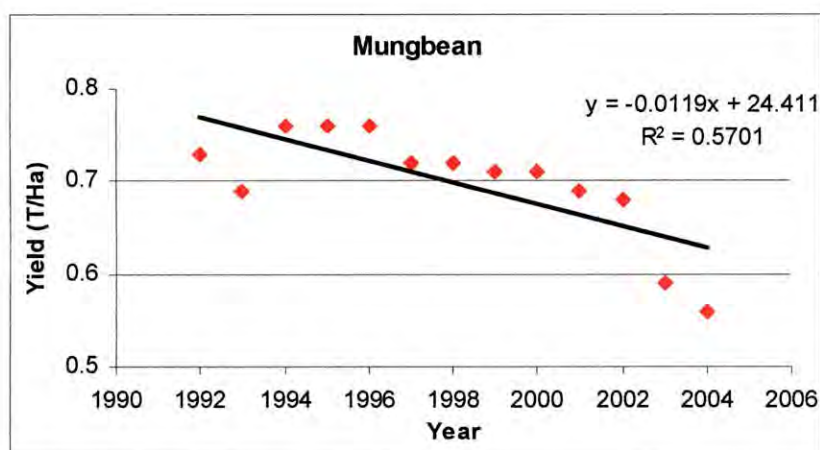


Figure 5.89 Variation of mungbean yield during the period 1992-2004.

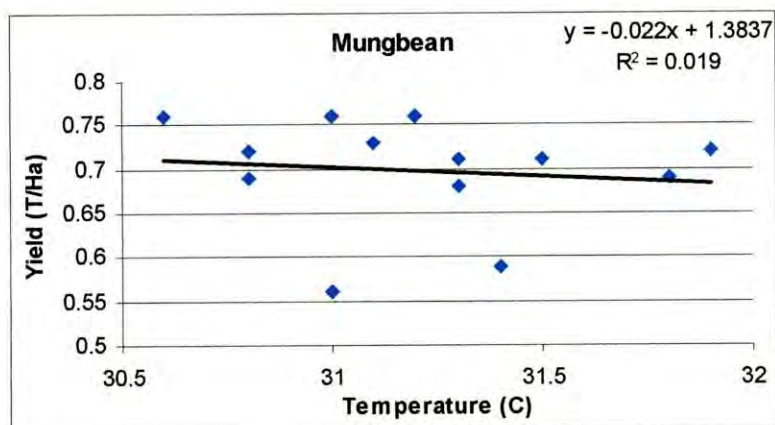


Figure 5.90 Variation of mungbean yield with response to seasonal average maximum temperature during 1992-2004.

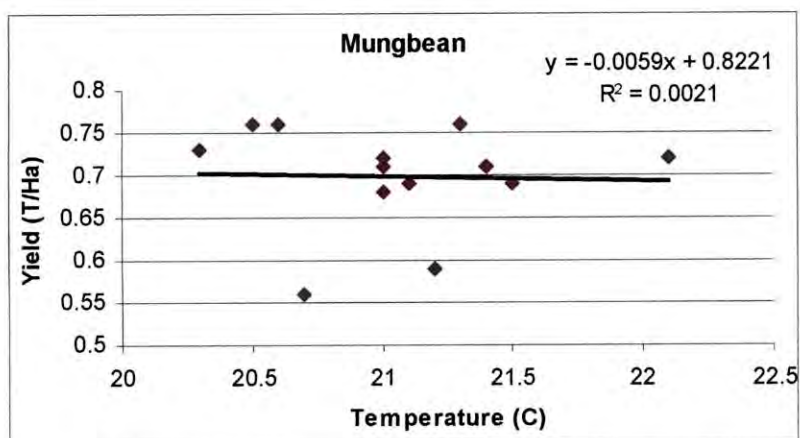


Figure 5.91 Variation of mungbean yield with response to seasonal average minimum temperature during 1992-2004.

b) Correlation with Seasonal Rainfall

The trend of yield of mungbean in response to the seasonal total rainfall (Figure 5.92) has shown a decreasing trend. The rainfall has been considered for the month of July to December. It includes the time of transplanting and harvest. One extra month, July before transplantation has been considered in order to count the impact of soil water content on mungbean production. Excess rainfall may have an adverse impact on production.

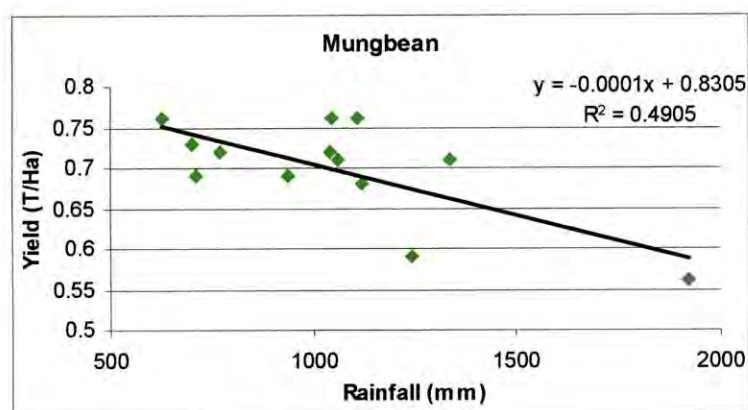


Figure 5.92 Variation of mungbean yield with response to seasonal total rainfall during 1992-2004.

5.6.8 Discussion on Probable Impacts of Climate Change on Mungbean Production

From overall climate scenario (1948-2005) and the recent climate change scenario (1991-2005) of Jessore district it can be seen that the annual average maximum temperature had a sharp increasing trend. On the other hand, the overall climate scenario and the recent climate scenario for annual average minimum temperature had also an increasing trend. The production of mungbean in this district had a statistically significant decreasing trend during the period 1992-2004. The production of mungbean has decreased with both the seasonal average maximum temperature and seasonal average minimum temperature with correlation coefficient -0.14 and -0.05 respectively. The production has also decreased with seasonal rainfall with correlation coefficient “-0.70. So mungbean yield could be affected by excess rainfall if Jessore district. The decrease in production can occur for several reasons. Productivity of pulses in Bangladesh is low and unstable compared to that of wheat or rice. The major constraints on productivity are that pulses in general have genetically low yield potential—particularly the indigenous varieties. It is very sensitive to too much water and fertilizer and often shows negative response to these factors. It is more sensitive to climatic factors such as excess soil moisture, humidity and rainfall, terminal heat stress, and soil factors, when compared with cereals. As the annual average maximum temperature and annual average minimum temperature showed an increasing trend the affect of global warming might be observed in this zone quite clearly. Increase in temperature either maximum or minimum can make many agricultural areas less productive. Production could be decreased by this climate parameter. Again excess, untimely and uneven distribution of seasonal

rainfall could hamper the production. Other related factors might have an impact on the production. It can be said that the production of mungbean is severely hampered to some extent because of climate variability like uneven distribution and excess rainfall which causes flooding/ water logging and abrupt rise of temperature in Jessore District. The yield of mungbean in 1992 and 2004 were 0.73 (T/Ha) and 0.56 (T/Ha) respectively in Jessore district. Its yield decreased by about 23%.

5.7 Calibration of EPIC Model

Model calibration is indispensable before the prediction of yields of the agricultural products like rice, wheat, pulses and potato for the next fifty years on model based simulation,.

If “site-specific” input data and the “site-specific” model parameters are available for EPIC model, the highest simulation accuracy of yield ($R^2 \approx 0.99$) can be obtained. But this condition cannot be attained for regional study. The lowest simulation accuracy ($R^2 < 0.10$) is not accepted. Therefore, it is necessary to get more “site-specific” input data and the “site-specific” model parameters in order to improve the yield simulation accuracy of EPIC model in regional study.

Figures 5.93, 5.94, 5.95 and 5.96 show the model calibration for rice, wheat, potato and mungbean respectively. It has been seen from model calibration of rice that the coefficient of determination $R^2 = 0.8205$ which is acceptable. For wheat, potato and mungbean the coefficient of determination is $R^2 = 0.8453$, $R^2 = 0.9254$ and $R^2 = 0.8287$ respectively. These results show a successful model calibration.

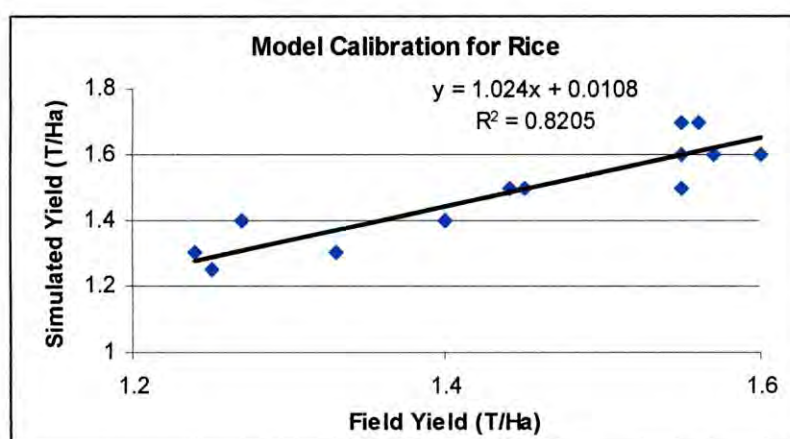


Figure 5.93 The comparison between simulated and field yield of rice (T. Aman).

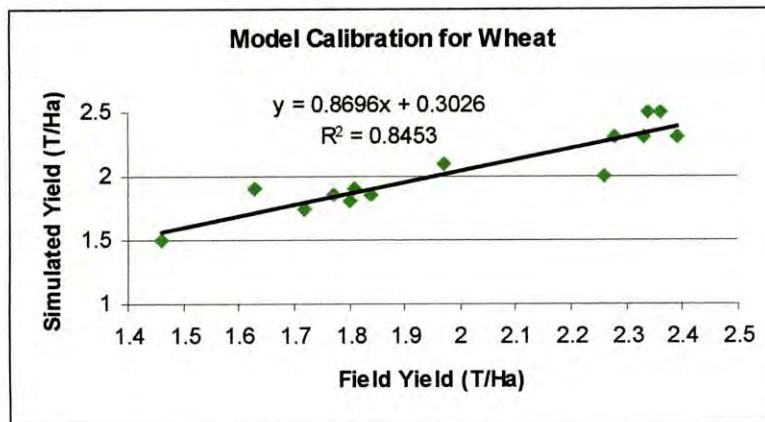


Figure 5.94 The comparison between simulated and field yield of wheat.

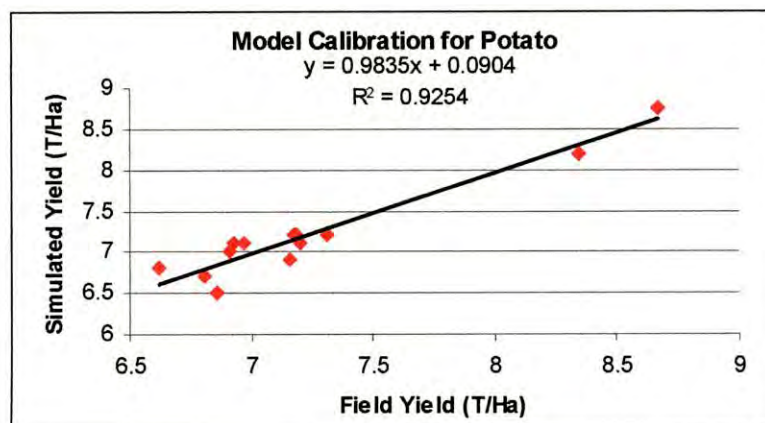


Figure 5.95 The comparison between simulated and field yield of potato.

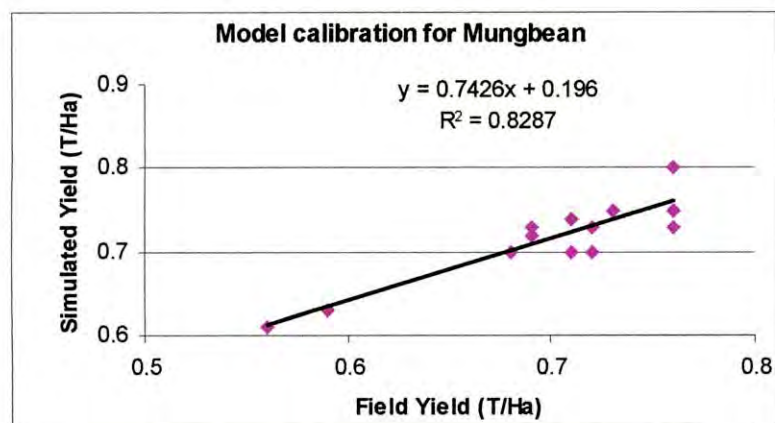


Figure 5.96 The comparison between simulated and field yield of mungbean.

5.8 Simulation Studies

Simulation study has been conducted on Rice (Locat T.Aman), wheat, potato (Local) and pulse (mungbean) using climate data on rainfall, maximum and minimum temperature, solar radiation and various other data of weather stations of Comilla, Dinajpur, Bogra and Jessore respectively. After successful calibration of the EPIC model with the field data, the future production of the respective crops has been predicted up to the year of 2050. The predicted crop yields were shown in the Figure 5.97, 5.98, 5.99 and 5.100.

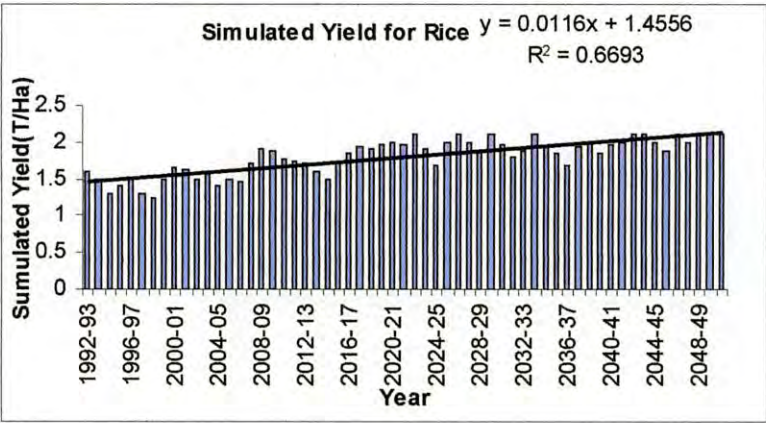


Figure 5.97 Predicted rice (T. Aman) yield up to the year 2050.

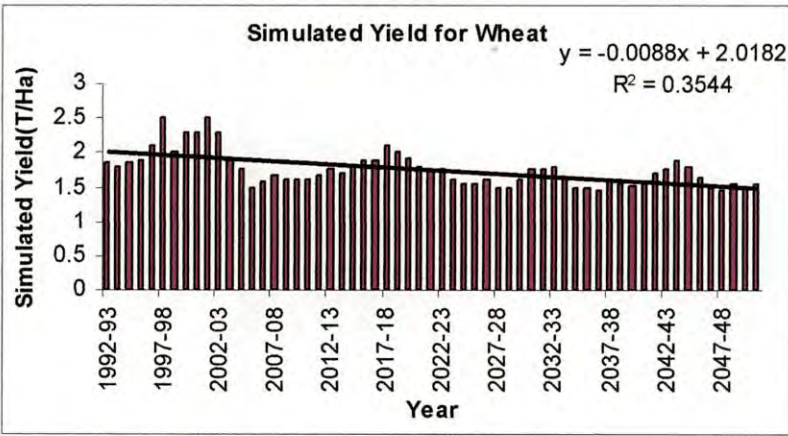


Figure 5.98 Predicted wheat yield up to the year 2050.

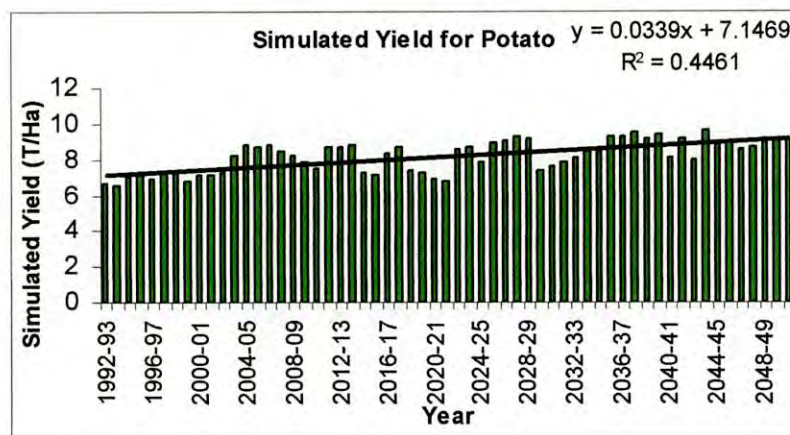


Figure 5.99 Predicted potato yield up to the year 2050.

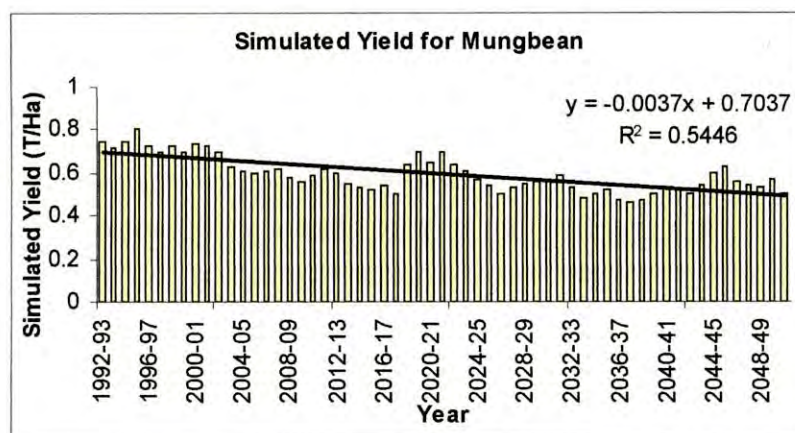


Figure 5.100 Predicted mungbean yield up to the year 2050.

The above figures show that except potato and T. Aman rice, other crops i.e. wheat and mungbean will have a decreasing trend of yield. In the event of climate change the cropping pattern of the respective regions may change considerably.

CONCLUSION AND RECOMMENDATIONS**6.1 Conclusion**

Bangladesh is endowed with a climate, which is favorable for the cultivation of wide range of both tropical and temperate crops. Production of crops are being hampered to some extent because of climate variability like- excess, un-timely, uneven distribution of rainfall, which occurs flooding, water logging and droughts, abrupt rise of temperature etc.

The main objectives of this study aimed at the statistical analysis of the recent observed trend of climate change scenarios and most importantly investigation on the impacts of climate change on crop agriculture. The prediction of the yields of the agricultural products like rice, wheat, pulses and potato for the next fifty years on model based simulation was carried on in this study.

Following are the major findings from this study:

- From the study it has been revealed that except potato and T. Aman rice, other crops i.e. wheat and mungbean exhibited a decreasing trend of yield during the period of 1992-2004. In the event of climate change the cropping pattern of the respective study regions may change considerably.
- During the trend analysis of climate change for the period of 1948-2005, the average annual maximum temperature of Comilla and Jessore district exhibited a statistically insignificant increasing trend. In Jessore the average annual maximum temperature in 1948 and 2005 was 30.7°C and 32.3°C respectively. But Dinajpur and Bogra district it exhibited a decreasing trend during the period of 1948-2005.
- In Comilla the average annual minimum temperature of the period 1948-2005 shows a statistically insignificant decreasing trend; on the other hand it shows an increasing trend for Dinajpur, Bogra and Jessore district.
- The trend analysis of annual rainfall revealed that there was a decreasing trend only in Comilla district and an increasing trend in Dinajpur, Bogra and Jessore district throughout the period 1948-2005.
- During the assessment of the impact of climate change on the crop yield it has been revealed that the yield trend of Local T. Aman rice during the period 1992-2004 shows an increasing trend in Comilla district. The proper use of fertilizer, harvesting method,

following metrological forecasts, proper use of pesticides, proper land management etc might have increased Aman production in Comilla district. The impact of global warming has not been observed in this zone. The yield trend of wheat during the period 1992-2005 shows a decreasing trend in Dinajpur district. The production has decreased with seasonal rainfall as many wheat diseases thrive in damp weather. Excess seasonal rainfall and the increase of the annual average minimum temperature of Dinajpur could affect the wheat yield. The yield of wheat in 1992 and 2004 was 1.84 T/Ha and 1.46 T/Ha respectively. Its yield decreased about 20%. The yield trend of potato in Bogra district shows an increasing trend. Potato is a heat tolerant crop also, so increase of average annual minimum temperature in Bogra during didn't have adverse impact on its production. The yield trend of mungbean shows a sharp decreasing trend in Jessore district. The yield of mungbean in 1992 and 2004 was 0.73 T/Ha and 0.56 T/Ha respectively in Jessore district. Its yield decreased by about 23%. As the annual average maximum temperature and annual average minimum temperature of Jessore showed an increasing trend, the affect of global warming might be observed in this zone quite clearly which might have an adverse affect on mungbean production.

- This study successfully demonstrated EPIC model applicability in predicting the future crop yield up to year 2050. The model predicted yields of potato and Aman rice had an increasing trend and wheat and mungbean had a decreasing trend. From the simulated results we can draw the conclusion that global warming will be particularly harmful on few crops of few zones. So in order to reduce the negative impact of global warming, it is necessary for agricultural scientists to develop entirely new crop varieties designed to be more productive under changed climate conditions, and for governments to advise farmer on how to adjust to alternative climates in the future.

6.2 Recommendations

Most of the people of the study areas are farmers who depend on agriculture either directly or indirectly. People at those vulnerable areas require adaptation measures to cope up with the vulnerable climate satiation.

- Improvement in the crop-based weather and flood forecasting systems, etc. are some of the adaptation measures that would also be urgently required. Early warning system

should be strengthened to inform the farmers about their roles in an adverse weather condition on the basis of specific information analysis.

- The Department of Agricultural Extension (DAE) can provide extension message on the basis of agro-meteorology and agro-climatic data and forecast the sowing/transplanting time and possible yields of crops to the farmers.
- Change of crop type, crop rotation or shifting cropping calendar can implemented for increasing the yield of specific crop in a specific district.
- Efforts should be taken with the aim to increase food production through the expansion of irrigation, flood protection embankments, with the support of modern agricultural Technology especially HYV seeds and fertilizers to achieve national self-sufficiency in food grains.
- An agro-meteorological centre could be established with the main function to analyze agro-meteorological and agro-climatic data and forecast the sowing/transplanting time and possible yields of crops to the farmers as well as to provide agro-meteorological advises.
- Management packages should be made available to the farmers with adequate extension services. Successful adaptation of the management packages, as envisaged, would enable farmers to grow additional amounts of cereals annually.
- Long-term investments for the development of infrastructure and research may play a vital role in adapting in adversities. Research efforts should be geared up for varietal breakthrough in genetic engineering.

6.3 Recommendation for Further Studies

- To obtain the actual scenario of crop yield, farmers' wisdoms are badly needed. In the future study field survey can be done to get more precise result.
- In this study recommended fertilizer and irrigation data were used to predict the future crop yield with the model based simulation. More realistic result will be obtained if actual farmer's management data which widely varies in the small geographic scale could be collected.

- This study has been carried out with the local varieties of the crops. Future studies can be carried out with the HYV varieties.
- In the present study soil salinity has not been considered. But in few districts like Jessore, soil salinity is alarming. Crop yield is hampered by this. So in future study of the crop yield in connection with this parameter can be studied.
- The concept of cost management can be in the further study.

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APPENDIX 1

Output Data of Statistical Analysis

Table A1.1: Data of average annual maximum temperature, average annual minimum temperature and annual rainfall of Comilla district for the period 1048-2005

Year	Average Annual Maximum Temperature (°C)	Average Annual Minimum Temperature (°C)	Annual Rainfall (mm)
1948	30.3	20.8	3402
1949	30	20.8	4005
1950	29.5	20.9	2290
1951	28.7	21.2	3310
1952	28.6	21.1	4127
1953	29.8	21.4	2603
1954	30.5	21	2731
1955	30.2	20.9	2170
1956	30.5	20.6	2527
1957	30.8	20.5	1632
1958	31.2	21.4	1852
1959	30.1	20.8	2465
1960	30.9	20.9	2393
1961	30.4	20.9	2178
1962	30.8	20	1916
1963	30.2	20.9	2123
1964	30.3	21	3432
1965	30.4	20.7	2680
1966	30.7	21.2	2491
1967	30	20.6	2150
1968	30.1	20.7	2416
1969	30.5	21	2739
1970	30.3	21.9	1732
1971	30.1	20.6	1680
1972	30.8	21.4	1471
1973	29.7	20.9	2054
1974	29.6	21	2700
1975	29.8	21.1	1813
1976	29.6	20.9	1965
1977	29.3	20.8	2125
1978	30.2	20.9	2123
1979	30.3	21.3	1461
1980	29.9	20.9	2093
1981	29.3	20.5	2198
1982	29.8	20.4	2185
1983	30	21.1	2286

1984	30.2	20.5	2439
1985	30.5	21	1641
1986	30.6	20.8	1992
1987	30.4	21.4	1991
1988	30.3	21.5	2249
1989	30.1	20.7	1439
1990	30	20.8	2211
1991	29.8	20.7	2914
1992	30.5	20.6	1285
1993	30	20.6	2802
1994	30.5	20.6	1384
1995	30.4	20.7	2102
1996	30.6	20.9	2036
1997	29.9	20.1	2134
1998	30	21.1	2518
1999	30.6	21.5	2351
2000	30.3	20.9	2044
2001	30.6	21	1950
2002	30.5	20.9	2136
2003	30.2	20.6	1825
2004	30.2	21	2424
2005	30.6	21.2	2424

Table A1.2: Data of average annual maximum temperature, average annual minimum temperature and annual rainfall of Dinajpur district for the period 1048-2005.

Year	Average Annual Maximum Temperature (°C)	Average Annual Minimum Temperature (°C)	Annual Rainfall (mm)
1948	30.6	19.8	1910
1949	29.8	19.4	2299
1950	30.6	18.9	1093
1951	31.1	19.4	1479
1952	30.5	19.9	2180
1953	30.6	20.1	1483
1954	30.6	19.7	1688
1955	30.6	19.6	1979
1956	30.4	19.2	2180
1957	30.7	17.5	1237
1958	31	20.5	1488
1959	30.2	19.9	1562
1960	30.9	19.5	1566
1961	30.5	20	1068
1962	31	19.2	1435

1963	30.6	19.6	1703
1964	30.1	20.2	2015
1965	30	20	2734
1966	30.5	20.2	1507
1967	30.1	19.9	1570
1968	29.7	19.8	1815
1969	30.3	20.3	2030
1970	30.2	20.4	1423
1971	30	19.8	1678
1972	31.4	19.6	1202
1973	30.3	19.8	1728
1974	30.3	19.8	1728
1975	30.3	19.8	1728
1976	30.3	19.8	1728
1977	30.3	19.8	1728
1978	30.3	19.8	1728
1979	30.3	19.8	1728
1980	29.9	20.1	1728
1981	30.2	20	2117
1982	30.1	19.4	1342
1983	29.7	19	2100
1984	29.6	19.2	2165
1985	30.1	20	2097
1986	29.7	19.7	1951
1987	29.8	20.2	3206
1988	30.2	20.3	2221
1989	29.9	19.4	1913
1990	29.7	19.9	2081
1991	29.9	19.7	2012
1992	30.1	19.2	1649
1993	29.7	19.8	2179
1994	30.6	19.8	1142
1995	30.5	19.8	2613
1996	30.5	19.9	1587
1997	29.8	19.7	1809
1998	29.9	20.6	2391
1999	30.5	20.7	2536
2000	29.8	20	1498
2001	30.7	20.3	2226
2002	30.1	20.3	2549
2003	29.3	20	2057
2004	29.6	19.9	2293
2005	29.8	20.4	2975

Table A1.3: Data of average annual maximum temperature, average annual minimum temperature and annual rainfall of Bogra district for the period 1048-2005.

Year	Average Annual Maximum Temperature (°C)	Average Annual Minimum Temperature (°C)	Annual Rainfall (mm)
1948	30.3	20.6	-
1949	30.7	20.7	-
1950	30.7	20.7	1377
1951	30.7	20.7	1351
1952	30.6	20.8	1927
1953	30.7	20.7	1058
1954	31.3	20.9	1890
1955	30.7	20.7	2193
1956	30.6	20.6	1872
1957	30.7	20.7	1345
1958	31.9	21.2	1834
1959	29.9	20.7	2462
1960	31.4	20.7	1348
1961	30.5	20.5	1493
1962	31	20.3	1132
1963	30.8	20.4	1694
1964	30.6	20.8	1653
1965	30.6	20.5	1550
1966	30.7	21	1234
1967	30.3	19.7	1428
1968	30.2	20.4	1648
1969	30.5	20.6	1531
1970	30.4	20.9	1794
1971	30.1	20	1779
1972	30.8	20.6	1247
1973	30.2	21	2516
1974	29.9	20.4	1854
1975	30.8	20.5	1432
1976	30.6	20.5	1882
1977	30.6	20.8	1479
1978	30.2	20.3	1884
1979	31.8	21.2	2227
1980	30.8	20.9	1616
1981	30	20.6	1739
1982	30.4	20.6	1223
1983	30.4	20.5	1768
1984	30.3	20.6	2303
1985	30.7	20.8	1693
1986	30.5	20.6	2140

1987	30.9	21.3	2014
1988	31.2	20.8	2250
1989	31.1	20.2	1413
1990	30.8	20.6	2077
1991	30.7	20.5	2291
1992	31	20.5	1367
1993	30.6	20.7	1908
1994	31.2	20.9	1342
1995	30.7	21.2	2257
1996	31.1	21.1	1926
1997	30.3	20.6	1301
1998	30.7	21.4	2601
1999	31.1	21.6	1610
2000	30.2	21.1	1838
2001	30.7	21.2	1393
2002	30.3	21.1	2011
2003	30.1	21	1692
2004	27.5	23	2157
2005	30.7	21.3	2119

Table A1.4: Data of average annual maximum temperature, average annual minimum temperature and annual rainfall of Jessore district for the period 1048-2005.

Year	Average Annual Maximum Temperature (°C)	Average Annual Minimum Temperature (°C)	Annual Rainfall (mm)
1948	30.7	20.8	1586
1949	30.5	20	1787
1950	31	19.9	1619
1951	31.7	20.1	1230
1952	31.4	20.3	1355
1953	31.5	21	1861
1954	31.1	20.5	1879
1955	31.1	20.4	1096
1956	30.8	20.5	1559
1957	31.5	20.6	979
1958	32	21.5	930
1959	30.6	20.7	2137
1960	31.1	20.9	1556
1961	31	21	1421
1962	31.2	20.4	1221
1963	31.4	20.7	1300

1964	31.2	21.6	1855
1965	31.1	21	1640
1966	31.3	20.7	1152
1967	31	20.2	1358
1968	30.6	20.6	1995
1969	31.2	20.6	1661
1970	30.6	20.9	2108
1971	30.9	20.3	2103
1972	31.3	20.3	870
1973	30.8	20.8	1678
1974	30.8	20.4	1640
1975	30.8	20.5	1243
1976	31.3	20.4	1179
1977	30.9	20.7	1500
1978	31.3	20.7	1438
1979	31.4	21.4	1651
1980	31.1	21.1	1358
1981	30.6	20.6	1879
1982	31.5	20.6	1295
1983	31.5	20.9	1848
1984	31.3	20.6	2031
1985	31.7	21.3	1576
1986	31.4	20.7	2118
1987	31.5	21.4	2039
1988	31.6	21.3	1976
1989	31.5	20.7	1117
1990	31.1	20.8	1686
1991	31.7	21	2052
1992	31.8	20.6	1333
1993	31.2	20.7	1802
1994	31.8	20.8	1260
1995	31.6	21.1	1397
1996	31.7	20.7	1775
1997	31.3	20.6	1553
1998	31.5	21.4	1490
1999	32.3	21.3	1467
2000	31.8	20.9	1811
2001	32	20.9	1611
2002	32	21	2120
2003	31.8	20.9	1892
2004	31.8	20.9	2444
2005	32.3	21.1	1678

Table A1.5: Data of Annual pre-monsoon, monsoon, post-monsoon and winter rainfall of Comilla district for the period 1991-2005.

Year	Pre-monsoon (mm)	Monsoon (mm)	Post-monsoon (mm)	Winter (mm)
1991	938	1134	617	175
1992	150	674	325	64
1993	891	1330	463	113
1994	459	792	111	21
1995	444	1310	172	29
1996	665	846	500	13
1997	476	1284	324	49
1998	700	1290	329	81
1999	238	1413	657	0
2000	887	796	261	97
2001	360	1086	419	13
2002	507	1305	212	20
2003	401	1094	226	101
2004	367	1148	904	4
2005	599	1072	744	9

Table A1.6: Data of Annual pre-monsoon, monsoon, post-monsoon and winter rainfall of Dinajpur district for the period 1991-2005.

Year	Pre-monsoon (mm)	Monsoon (mm)	Post-monsoon (mm)	Winter (mm)
1991	419	842	676	75
1992	93	975	565	16
1993	419	1278	440	42
1994	196	564	337	45
1995	64	1352	1177	20
1996	105	1101	361	20
1997	157	1292	292	68
1998	324	1351	687	19
1999	435	1273	828	0
2000	465	782	221	30
2001	227	1049	897	53
2002	279	1701	543	26
2003	305	1066	610	76
2004	453	1247	583	10
2005	381	1578	992	24

Table A1.7: Data of Annual pre-monsoon, monsoon, post-monsoon and winter rainfall of Bogra district for the period 1991-2005.

Year	Pre-monsoon (mm)	Monsoon (mm)	Post-monsoon (mm)	Winter (mm)
1991	472	851	838	130
1992	170	650	533	14
1993	340	1164	336	68
1994	212	670	424	36
1995	125	1441	658	33
1996	592	792	511	31
1997	251	751	251	48
1998	253	1679	646	23
1999	255	1037	318	0
2000	506	729	550	53
2001	239	599	555	0
2002	412	1226	373	5
2003	399	803	420	70
2004	272	1428	457	0
2005	268	957	879	15

Table A1.8: Data of Annual pre-monsoon, monsoon, post-monsoon and winter rainfall of Jessore district for the period 1991-2005.

Year	Pre-monsoon (mm)	Monsoon (mm)	Post-monsoon (mm)	Winter (mm)
1991	271	1170	501	110
1992	224	762	243	104
1993	394	977	398	33
1994	227	843	149	41
1995	111	763	178	45
1996	258	1001	457	49
1997	231	864	390	68
1998	487	553	380	70
1999	163	851	453	0
2000	245	934	612	20
2001	402	924	285	0
2002	447	1290	365	18
2003	240	1008	614	30
2004	217	1050	1174	3
2005	219	802	608	49

Table A1.9: Data of seasonal average maximum temperature, seasonal average minimum temperature, total seasonal rainfall, area of cultivation and production of Local T. Aman rice for the period 1992-2004.

Year	T. Max (°C)	T. Min (°C)	Seasonal Rainfall (mm)	Area of Cultivation (Ha)	Production(M.T)
1992	30.3	20.6	1072	57986.6	89800
1993	29.8	21	1799	49108	71040
1994	30.4	20.7	914	50261.3	66760
1995	29.9	21	1629	59811.7	76130
1996	30.2	20.9	1371	49974	72050
1997	29.7	20.5	1647	46214.5	57290
1998	30	21.9	1764	40057.5	49900
1999	30	21.5	2113	43612.4	68470
2000	30.4	21.1	1105	44421.7	69120
2001	30.2	21.3	1577	40196.9	62330
2002	30.3	21.4	1629	43725.7	67840
2003	29.9	20.8	1374	24527.7	39300
2004	29.8	21.1	2053	19172	26669

Table A1.10: Data of seasonal average maximum temperature, seasonal average minimum temperature, total seasonal rainfall, area of cultivation area and production of wheat for the period 1992-2005.

Year	T. Max (°C)	T. Min (°C)	Seasonal Rainfall (mm)	Area of Cultivation (Ha)	Production(M.T)
1992	28.1	14.3	104	93384	171450
1993	27.7	14.9	232	86476	152900
1994	28.4	14.9	184	89551.6	158840
1995	28.6	14.7	181	93339.4	168750
1996	28.8	15	124	100328.3	197850
1997	27.3	14.9	138	125677.4	293870
1998	27.5	15.4	571	139683.4	316180
1999	29.3	16.3	307	147368.3	351820
2000	27.4	14.9	203	139586.3	324590
2001	28.6	15.4	493	143078.7	337190
2002	28.2	15.9	263	139056	317450
2003	26.5	15	614	132399.2	216280
2004	27.3	15.3	515	112085	192385
2005	27.7	15.8	920	101655	147945

Table A1.11: Data of seasonal average maximum temperature, seasonal average minimum temperature, total seasonal rainfall, area of cultivation and production of potato for the period 1992-2004.

Year	T. Max (°C)	T. Min (°C)	Seasonal Rainfall(mm)	Area of Cultivation (Ha)	Production(M.T)
1992	29.2	17.6	547	8824	60095
1993	29.3	18	418	9067	62195
1994	29.4	17.9	464	9150	63265
1995	28.8	18	705	9113.4	63100
1996	29.9	18.2	549	9101.3	65200
1997	28.6	17.7	308	9322	66915
1998	29.2	18.5	695	17352.7	124440
1999	30	18.7	318	18336	121400
2000	28.7	18.1	679	16964.2	122155
2001	29.2	18.2	555	15497.2	108030
2002	29.3	18.4	378	16460.4	120355
2003	28.2	18	562	20023.6	167045
2004	23.7	21.3	502	25420	220269

Table A1.12: Data of seasonal average maximum temperature, seasonal average minimum temperature, total seasonal rainfall, area of cultivation and production of mungbean for the period 1992-2004.

Year	T. Max (°C)	T. Min (°C)	Seasonal Rainfall(mm)	Area of Cultivation (Ha)	Production(M.T)
1992	31.1	20.3	702	2560	1870
1993	30.8	21.1	938	2584	1785
1994	31.2	20.6	627	2157	1635
1995	30.6	21.3	1048	2060	1565
1996	31	20.5	1108	2057.8	1560
1997	30.8	21	1043	1993	1430
1998	31.9	22.1	770	1975	1415
1999	31.3	21.4	1060	1983	1400
2000	31.5	21	1337	1883.8	1300
2001	31.8	21.5	711	1932.3	1305
2002	31.3	21	1120	1784.6	1050
2003	31.4	21.2	1243	1700	960
2004	31	20.7	1919	1681.4	935

Table A2.1: Cropping calendar of Bangladesh.

CROPPING CALENDAR OF BANGLADESH												
CROP	পৌ	মাঘ	ফালগুন	চৈত্র	বৈশাখ	জ্যৈষ্ঠ	আষাঢ়	শ্রাবণ	ভাদ্র	আশ্বিন	কার্তিক	অগ্রহায়ণ
	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
CEREALS												
Aus(Local Broadcasted)												
Aus(HYV Transplant)												
Aus (HYV Broadcasted)												
Aman(Local Broadcasted)												
Aman(Local Transplant)												
Aman(HYV Transplant)												
Boro(Local Transplant)												
Boro(HYV Transplant)												
Wheat												
Maize												
TUBERS												
Potato												
PULSES												
Lentil												
Chickpea												
Mungbean												
Blackgram												
OILSEEDS												
Soybean												
Soybean												
Mustard/Rape												
Groundnut												
Groundnut												
Sesame												
Sesame												
Sunflower												
VEGETABLES												
Bottle Gourd												
Bitter Gourd												
Cucumber												
Snake Gourd												
Sweet Gourd												
Cauliflower												
Chinese Cabbage												
Radish												
Indian Spinach (Pui Sak)												
Leaf amaranth (Lai Sak)												
Stem amaranth (Danta Sak)												
Kang kong (Kolmi Sak)												
Egg Plant												
Tomato												
Green Pea												
Hyacinth Bean												
Yard long bean												
Okra												
Onion												
Spinach												
FRUITS												
Papaya												
FIBRE												
Jute (Capsularies)												
Jute (Oltorius)												

Explanatory key

Rice Growing Seasons Aus Aman Boro

Shade Indicates Seed Bed
HYV: High Yielding Variety

Prepared by National Data Bank

Table A2.2: Total Carbon (T/Ha) and Nitrogen (T/Ha) in the soil of different zones.

Table 15. Changes in total Carbon (%), total Carbon (t/ha) and total nitrogen (%) in the 0-15 cm layers of different soils during the Period 1967-97 in Bangladesh

Location/Soil Series	Land type	Physiographic unit/AEZ	Total Carbon (%) change			Total Carbon (t/ha) change			Total N (%) change		
			1967-68	1997-98	%	1967-68	1997-98	%	1967-68	1997-98	%
1. Atwari	Highland	OHP/AEZ 1	1.58	1.65	+ 4.4	30.96	31.97	+ 3.3	3.25	3.53	+ 8.6
2. Jagdal	Highland	OHP/AEZ 1	0.94	0.60	- 36.2	17.51	10.50	- 40.0	1.97	0.99	- 49.7
3. Kaunia	Highland	TF/AEZ 2	0.92	0.83	- 9.8	16.54	14.29	- 13.6	1.73	1.63	- 5.8
4. Pirgacha	Highland	TF/AEZ 2	0.64	0.85	+ 32.8	10.95	14.66	+ 33.9	1.11	1.08	- 2.7
5. Chandra	Highland	BT/AEZ 26	0.65	0.83	+ 27.7	13.39	16.29	+ 21.6	1.38	1.81	+ 31.6
6. Belabo	Highland	BT/AEZ 26	0.63	0.80	+ 27.0	12.84	15.10	+ 17.6	1.41	1.52	+ 7.8
7. Gopalpur	Highland	GF/AEZ 11	1.10	0.89	- 19.1	23.45	17.44	- 25.6	2.32	1.38	- 40.5
8. Sara	Med.Lowland	GF/AEZ 11	0.88	0.86	- 2.3	18.74	17.51	- 6.6	2.02	1.86	- 7.9
9. Garuri	Med.Lowland	BF/AEZ 9	1.03	1.27	+ 23.3	22.00	23.64	+ 7.5	2.53	2.68	+ 5.9
10. Tarakanda	Med.Lowland	BF/AEZ 9	0.79	0.69	- 12.7	15.57	12.60	- 19.0	1.57	1.29	- 17.8
11. Sonatala	Med.Lowland	MRF/AEZ 16	1.26	0.68	- 46.0	24.78	11.81	- 52.3	2.37	1.31	- 44.7
12. Tippera	Med.Lowland	MRF/AEZ 16	0.78	0.62	- 20.5	16.78	11.84	- 29.4	1.73	1.17	- 32.4
13. Burichang	Med.Lowland	MRF/AEZ 16	1.45	1.25	- 13.8	33.75	26.46	- 21.6	2.95	2.00	- 32.2
14. Goyaiphat	Highland	SKF/AEZ 20	1.00	0.90	- 10.0	23.56	17.77	- 24.6	2.64	1.99	- 24.6
15. Demra	Highland	MT/AEZ 28	1.10	1.0	- 9.1	23.35	21.59	- 7.5	2.80	2.44	- 12.8
16. Noadda	Highland	MT/AEZ 28	0.80	0.70	- 12.5	17.09	15.39	- 9.9	1.80	1.60	- 11.1
17. Mirsarai	Med.Lowland	CCP/AEZ 23	0.78	0.96	+ 23.0	14.81	17.05	+ 15.1	1.85	2.02	+ 9.2
18. Noapara	Med.Lowland	CCP/AEZ 23	0.95	1.40	+ 47.4	21.39	27.10	+ 27.7	2.78	3.06	+ 10.1
19. Jhinaighati	Highland	NEP/AEZ 22	0.51	0.60	+ 17.6	12.01	12.12	+ 0.92	1.22	1.29	+ 5.7
20. Pritimpasa	Highland	NEP/AEZ 22	0.60	1.33	- 16.9	37.44	26.88	- 28.2	4.76	3.29	- 30.9

OHP = Old Himalayan Piedmont Plain

TF = Tista Floodplain

BT = Barind Tract

GF = Ganges Floodplain

BF = Brahmaputra Floodplain

MRF = Meghna River Floodplain

SKF = Surma Kushiara Floodplain

MT = Madhupur Tract

CCP = Chittagong Coastal Plain

NEPP = North Eastern Piedment plain

Source : Land Degradation Situation in Bangladesh, Soils Division, BARC, 1999.

Source: (Karim and Iqbal, 2002)

Table A2.3: pH content in the soil of different zones.

Table 17. Changes in pH, CEC, available P and S content in the 0-10 cm layers of different soils during the period 1967-97 in Bangladesh

Location/Soil Series	Land type	Physiographic unit/AEZ	pH (1:2.5) Change			CEC (me/kg) change			Avail P (mg/100g) Change			Avail S (ppm) Change		
			1967- 68	1997- 98	%	1967- 68	1997- 98	%	1967- 68	1997- 98	%	1967- 68	1997- 98	%
1. Atwari	Highland	OHP/AEZ 1	5.71	5.58	-2.3	2.7	2.8	+3.7	3.7	2.7	-27.0			
2. Jagdal	Highland	OHP/AEZ 1	5.30	5.40	+1.9	2.3	2.9	+26.0	5.4	8.5	+57.4			
3. Kaunia	Highland	TF/AEZ 2	5.47	5.78	+5.7	1.7	1.5	-11.8	6.5	6.1	-6.2			
4. Pirgacha	Highland	TF/AEZ 2	5.47	4.91	-10.2	2.5	0.50	-60.0	7.1	8.1	+14.1			
5. Chandra	Highland	BT/AEZ 26	5.33	5.34	+0.2	1.5	1.6	+6.7	1.4	1.0	-28.6			
6. Belabo	Highland	BT/AEZ 26	5.67	4.97	-12.3	2.1	2.2	+4.8	2.7	4.0	+48.1			
7. Gopalpur	Highland	GF/AEZ 11	8.13	8.05	-1.0	47.4	35.6	-24.9	1.3	1.6	+23.0			
8. Sara	Med.Lowland	GF/AEZ 11	7.70	7.68	-0.3	17.8	18.8	+5.6	7.3	4.3	-41.1			
9. Garuri	Med.Lowland	BF/AEZ 9	7.47	7.03	-5.9	34.9	24.0	-31.2	4.1	6.9	+68.3			
10. Tarakanda	Med.Lowland	BF/AEZ 9	6.49	5.69	-12.3	13.6	5.0	-63.2	5.6	4.2	-25.0			
11. Sonatala	Med.Lowland	MRF/AEZ 16	6.60	6.46	-2.1	12.6	11.2	-11.1	5.2	8.0	+53.8			
12. Tippera	Med.Lowland	MRF/AEZ 16	6.32	6.62	+4.7	2.9	4.5	+13.8	4.5	9.4	+108.9			
13. Burichang	Med.Lowland	MRF/AEZ 16	6.25	5.55	-11.2	7.3	9.3	+27.4	0.6	0.5	-16.7			
14. Goyaiphat	Highland	SKF/AEZ 20	5.36	5.21	-2.8	2.5	2.4	-4.0	0.9	1.6	+77.8			
15. Demra	Highland	MT/AEZ 28	5.49	4.74	-13.7	5.6	4.9	-12.5	2.6	0.9	-65.4			
16. Noadda	Highland	MT/AEZ 28	5.40	4.72	-12.6	0.8	1.0	-25.0	1.0	1.6	+60.0			
17. Mirsarai	Med.Lowland	CCP/AEZ 23	5.42	5.89	-8.3	6.0	2.5	-58.3	0.5	1.0	+100.0			
18. Noapara	Med.Lowland	CCP/AEZ 23	6.19	5.55	-10.3	10.4	8.0	-23.1	0.3	0.4	+33.3			
19. Jhinaighati	Highland	NEP/AEZ 22	5.20	4.06	-21.9	0.4	0.5	+25.0	0.9	1.8	+100.0			
20. Pritimpasa	Highland	NEP/AEZ 22	5.10	4.98	-2.4	1.4	1.2	-14.3	2.7	1.4	-48.1			

OHP = Old Himalayan Piedmont Plain

TF = Tista Floodplain

BT = Barind Tract

GF = Ganges Floodplain

BF = Brahmaputra Floodplain

MRF = Meghna River Floodplain

SKF = Surma Kushiya Floodplain

MT = Madhupur Tract

CCP = Chittagong Coastal Plain

NEPP = North Eastern Piedmont plain

Source : Land Degradation Situation in Bangladesh, Soils Division, BARC, 1999

Source: (Karim and Iqbal, 2002)

APPENDIX 3

PREDICTED CROP YIELD

Table A3.1: Predicted yield of local T. Aman, wheat, potato and mungbean on model based simulation up to year 2050.

Year	T. Aman (T/Ha)	Wheat (T/Ha)	Potato (T/Ha)	Mungbean (T/Ha)
1992-93	1.6	1.85	6.7	0.75
1993-94	1.5	1.8	6.5	0.72
1994-95	1.3	1.85	7	0.75
1995-96	1.4	1.9	7.1	0.8
1996-97	1.5	2.1	6.9	0.73
1997-98	1.3	2.5	7.2	0.7
1998-99	1.25	2	7.2	0.73
1999-00	1.5	2.3	6.8	0.7
2000-01	1.65	2.3	7.1	0.74
2001-02	1.63	2.5	7.1	0.73
2002-03	1.5	2.3	7.2	0.7
2003-04	1.6	1.9	8.2	0.63
2004-05	1.4	1.75	8.75	0.61
2005-06	1.5	1.5	8.72	0.6
2006-07	1.47	1.58	8.76	0.61
2007-08	1.7	1.67	8.4	0.62
2008-09	1.9	1.6	8.2	0.58
2009-10	1.87	1.62	7.9	0.56
2010-11	1.76	1.6	7.51	0.59
2011-12	1.73	1.67	8.65	0.62
2012-13	1.7	1.75	8.67	0.6
2013-14	1.59	1.7	8.74	0.55
2014-15	1.49	1.83	7.3	0.53
2015-16	1.7	1.9	7.1	0.52
2016-17	1.86	1.9	8.31	0.54
2017-18	1.94	2.1	8.73	0.5
2018-19	1.91	2	7.4	0.64
2019-20	1.98	1.93	7.2	0.7
2020-21	2	1.8	6.9	0.65
2021-22	1.97	1.73	6.8	0.7
2022-23	2.1	1.75	8.5	0.64
2023-24	1.9	1.6	8.7	0.61
2024-25	1.68	1.54	7.79	0.57
2025-26	1.99	1.55	8.92	0.54

2026-27	2.1	1.6	9	0.5
2027-28	2	1.47	9.3	0.53
2028-29	1.87	1.49	9.1	0.55
2029-30	2.1	1.6	7.4	0.56
2030-31	1.96	1.76	7.62	0.57
2031-32	1.8	1.75	7.9	0.59
2032-33	1.88	1.8	8.02	0.53
2033-34	2.1	1.65	8.4	0.48
2034-35	1.95	1.5	8.4	0.5
2035-36	1.86	1.48	9.23	0.52
2036-37	1.69	1.46	9.21	0.47
2037-38	1.93	1.61	9.52	0.46
2038-39	1.99	1.55	9.1	0.47
2039-40	1.85	1.52	9.4	0.5
2040-41	1.97	1.56	8.1	0.53
2041-42	2	1.7	9.1	0.52
2042-43	2.1	1.76	8	0.5
2043-44	2.11	1.9	9.6	0.54
2044-45	2	1.78	8.8	0.6
2045-46	1.89	1.65	8.9	0.63
2046-47	2.1	1.5	8.6	0.56
2047-48	2	1.45	8.73	0.54
2048-49	2.11	1.55	9.2	0.53
2049-50	2.12	1.48	9	0.57
2050-51	2.1	1.54	9.1	0.5

