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Climatic Change and its Impact on Wheat Production in Dinajpur District: Modeling and Quantitative Analysis

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University of Rajshahi

Dedicated to

My Aunt Syeda Monnujan Begum,

My Uncle Syed Aminur Rahman,

My Teacher Late Syed Fauzul Kabir

and The People of Bangladesh

Declaration

I hereby declare that the thesis titled "**Climatic Change and Its Impact on Wheat Production in Dinajpur District: Modeling and Quantitative Analysis**" is the result of my own research work undertaken by the Department of Statistics, University of Rajshahi, Bangladesh. This thesis has not been submitted for any degree or award anywhere.

9.5.2010

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Certificate

This is to certify that the thesis titled **"Climatic Change and Its Impact on Wheat Production in Dinajpur District: Modeling and Quantitative Analysis"** is a research work, carried out by **Syeda Jahanara Afrose,** for the degree of Doctor of Philosophy, in the Department of Statistics, University of Rajshahi, Bangladesh. This thesis has not been submitted for any degree or award anywhere.

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Abstract

Dinajpur is the leading district for wheat cultivation in Bangladesh and wheat is much sensitive to climatic variation and change. An attempt has made to study the climatic change and its impact on wheat production in Dinajpur district and both the secondary and primary data are collected in this respect. The historical climatic data are collected for 1948-2004 which contain a missing of 8 years during 1973-1980. Primary data are collected by a sample survey to know the people's perception regarding change of climatic behavior on wheat production over the period. In this study, climatic trend and variability of Dinajpur district are examined for 19 climatic variables in decadal, annual, seasonal [three crop seasons like Rabi =(November-February), Prekharif =(March-May) and Kharif =(June-October)], monthly and wheat growing period using exploratory data analysis (EDA) tools such as boxplot, stem-and-leaf display, median polish table etc. Different robust and nonrobust measures are used and outliers are detected. Residual's stationarity is checked by Box-Pierce test statistic and normality is tested by RM (rescaled moment) test. Upward trend is found in means of monthly total rainfall and average cloud, relative humidity, relative humidity at mourning, relative humidity at evening, wet bulb temperature, wind speed, maximum wind speed and minimum temperature (slight) and downward trend is observed in their coefficient of variations (CVs). Both the variations and means for average difference of dry and wet bulb temperature, difference in mourning and evening relative humidity, evaporation and range temperature demonstrate downward trend. The monthly means of average maximum temperature and sunshine hour indicate downward trend and their CVs indicate upward trend. The average dry bulb temperature follows upward trend in Rabi and Kharif season and downward trend in Prekharif season. The average soil temperature at the depth of 5cm follows upward trend during 1987-2000 and sunshine hour show downward trend in all the three seasons during 1989-2004. The total rainfall shows upward trend in February, April, May, September, October and December but it does not show any trend in January, March, June, July, August and November. Time series properties of climatic (monthly data) and wheat production data are investigated from fitted ARIMA models based on minimum root mean square forecasting error of 24 and the values for 2005 to 2008 and 2009 to 2012 are forecasted from selected models. The missing values are forecasted by fitting ARIMA models. The year 1981 of the variables AMNT, AWBT, AWS, ARH and ARH(0-12) are detected as outlier in fitting the models during 1981-2004 and the outliers are replaced by the forecasted observations from the data during 1982-2004. The square root transformed monthly data of total rainfall during 1948-2004 follow ARIMA (100) (111) model and the ADBT follow ARIMA (011) (101). The production of wheat during 1949-2001 in

Dinajpur district primarily follow upward linear trend and residuals are departed from normality but support non-autocorrelated structure and one outlier is identified in 1982 from the plot of deletion Studentized residuals. We have got an opposite conclusions from outlier corrected data. Structural change is observed in 1976 and the data for 1949 to 1975 and 1976 to 2001 separately follow AR (1) models but not for the overall period. The corrected data set during 1949-2001 adequately fits the 1st order Piecewise Autoregressive Model PAR(1) [suggested by Imon (2007)]. It may be mentioned that the reason for not considering the wheat production during 1948-2004 is that the data during that period do not adequately fit PAR(1) model. To quantify the impact of climatic change on wheat production during the period of 1948-2004 we have tried to fit a multiple regression model of wheat production data on climatic data (Nov-Mar) where one dummy variable is taken for the structural change in wheat production data in 1976. Multicollinearity among the predictor variables and normality and stationarity for the residuals are checked. Strong evidence is not found for multicollinearity and first order autocorrelated structure is found in the residuals. The parameters have been estimated using Cochrane-Orcutt iterative procedure where residuals follow normality and stationarity after removing two hi-leverages and two outliers and we observe no significant coefficient except dummy variable and this may be due to technological change such as high yielding variety, improved physical inputs like irrigation, fertilizer, pesticide etc. In the survey, hundred percent (100%) respondents have opined that there is a change in climate than previous time and the changing behavior of climate has severely affected the crop production, acreage under crop and the total process of production as a whole. Insufficient rain in Rainy season, lesser coldness in Winter season, lesser temperature in Summer and lesser dew in Autumn are experienced by them. Stormy and dusty wind does not blow as it blew before and cold affects people at night in the month of Choitra (mid March- mid April). Due to the unusual behavior of climate wheat production has suffered a lot. According to them, Changes of temperature are affecting the production of wheat greatly and they think those to be the most potential reasons. Changing of climate may pose a big and devastating threat to the production of wheat and 88% people opine that the cultivation of wheat in future may fall under a serious threat.

Contents

List of Tables

List of Figures

Glossary

TR	Total Rainfall
FZR	Frequency of Zero Rain
TFIR	Total Frequency of Insignificant Rain
AC	Average Cloud
AWS	Average Wind Speed
AMWS	Average of Maximum Wind Speed
ARH	Average Relative Humidity
ARH(0)	Average Relative Humidity at morning
ARH(12)	Average Relative Humidity for Evening
ARH(0-12)	Difference of Average Relative Humidity of Morning and Evening
ADBT	Average Drybulb Temperature
AE	Average Evaporation
AIC	Akaik information criteria
AMNT	Average Minimum Temperature
AMXT	Average Maximum Temperature
AO	Arctic Oscillation
ARNT	Avarage Range Temperature
ASH	Average Sunshine hour
AST	Average Soil Temperatur
AT(D-W)	Difference of Average Drybulb and Wetbulb Temperature
AWBT	Average Wetbulb Temperature
BAU	Business As Usual
CCC	Canadian Centre for Climate Model
CFC	Cloro floro carbons
CH4	Mithen

MXR	Maximum Rain
CO2	Carbon di Oxaide
CV	Coefficient of Variation
EDA	Exploratory Data Analysis
ENSO	El Nino Southern Oscillation
GCM	Global Climate Model / General Circulation Model
GFDL	Geophysical Fluid Dynamics Laboratory
GHG	Green house gasses
GISS	Goddard Institute for Space Studies
GSO	Greenhouse gas plus sulphate aerosol plus ozone forcing
IPCC	Inter-governmental Panel on Climate Change
MSL	V-Mexical and SanLuis RioColorado Vallys
N2O	Nitrus oxaide
NAO	North Atlantic Oscillation
OLS	Ordinary Least Squares Regression
PDF	Probability Density Function
QBO	Quasi-Biennial Oscillation
SAR	Second Assessment Report of the IPCC
SMR	Summer Monsoon Rainfall
SRES	Special Report on Emissions Scenarios
SST	Sea Surface Temperature
UKMO	United Kingdom Meteorological Office
WMO	World Meteorological Organisation
YMV	Yaqui and Mayo Valleys

Chapter 1

Chapter 1

Background of the Study

1.1 Introduction

Climate indicates long term average weather condition of a specific area of the earth while weather is the state of the atmosphere at a specific time. Climate plays a vital role on life and human activities. It deals with atmosphere, Radiation, Air and Water. Climatology refers to the study of climate or science of climate. It came from the Greek word 'Klima' and 'Logus'. Klima means slope of the earth, while Logus means discourse or study [Lenka (1998)]. Temperature, humidity, precipitation, wind speed, atmospheric pressure, sunshine hour, cloudiness, soil temperature, soil moisture, evaporation, evapotranspiration, radiation, dew, fog etc. are climatic parameters. However earth's climate is a complex system which indicates global atmosphere, oceans, cryosphere land surface, biosphere etc. All natural, human and biological systems of the earth are profusely influenced by the climatic system. If the climatic system gives negative signal then all natural, human and biological systems lose their normal behavior. Sometimes some known and unknown reasons influence the climatic factors. This is a major point to consider or to be taken into account. Effect of rising GHG gasses can cause surface warming by 1.5 to 4.5 degree centigrade (global mean temperature) by the middle of next century as indicated by Haughton's study (1990). But CHANDLER(1993) demonstrated that only 1-2degree centigrade global mean temperature increase can cause a much greater increase in maximum temperatures within a short period [Kobiljski and Dencic (2001)]. The variation and change in climate may affect almost all sectors like forestry, ecosystems, coastal zones, agriculture, fisheries, animal production, land use, water resources, water quality, desertification, energy developments, human health and livelihood etc. Among them agriculture is one of the most sensitive sector and variation in climatic factors influence overall agriculture and plant life. Furthermore, weather and climate are the most significant factors in determining plant growth and productivity despite of technological advances like improved crop varieties and irrigation systems [Kobiljski and Dencic (2001)]. Crop yields are affected by variations in climate factors such as air temperature and precipitation and the frequency and severity of extreme events like droughts, floods, hurricanes, windstorms, and hail [Alexandrov and Hoogenboorn (2000)]. Even minor fluctuations of climate over a few years can influence agricultural production, particularly crop production. Since climate largely determine the capacity of production in a zone; for example, land may remain fallow and unfit to grow crops without rain where irrigation also depends on rain, so clear understanding of climate and its impact on crop is very important for production. Billions of people of this earth suffer from serious food shortage. So to fulfill the basic need like food security by reducing fluctuation in production people should be more conscious and careful in practice about crop environment and crop management. The frequent failure of crop production may occur due to unfavorable climate and weather condition. As a result, widespread distress and famine may wait for mankind.

1.2 Some Basics of Climate and Their Role on Agriculture

Climate plays a direct role on agricultural output in the world from per-humid to arid areas. So the world vegetation from the ice caps at the poles to evergreen forests and rice swamps directly depends on climate zonation with this relation. With the same consideration of climatic function the interaction of different climatic parameters affect growth and development of all flora and fauna directly and indirectly. Crop productivity is influenced by climate through the agronomical, physiological and morphological direction. In this way role of climate means role of its parameters such as temperature, relative humidity, wind speed, precipitation, sunshine hour etc.

1.2 .1 Temperature

Temperature refers to intensity aspects of heat and energy, which creates speed of molecules in a body. Variation in temperature occurs due to variation in isolation on account of rotation of earth and location of the place. It also affects crops in various forms and ways. Plant growth and yield are highly temperature dependent in most cases and effects of temperature increase are different in different regions for the individual crop) [Kobiljski and Dencic (2001)].

In case of optimum temperature for optimum growth, Plants absorb CO_2 for photosynthesis and convert that CO_2 to sugar for its energy and growth. Increased temperature can increase the transpiration rate and reduce the moisture level for plant growth through decreasing rainfall. Crop yield can be reduced due to shortening of growing period because of increased temperature.

Excess temperature causes heat injury, retards growth, irreparable damage to cells and citoplasms. It also retards growth of fruit formulation and maturity. Flowers do not open fully or fail to open. Besides these there are other affects of excess temperature such as killing of the tissues, sunburn and sun scaled in leaves and fruits. On the other hand, low temperature causes 1ow growth and death of tissues, prevents formation of chlorophyll and yellowing of leaves. Very low temperature causes freezing of plant tissues and finally leads to their death (Lenka (1998)].

Temperature change has direct impact on pest and diseases of crop plant .Many bacterial and fungal diseases reach severe level with increase temperature and precipitation. Crop growth night temperature is more important than the day temperature for rubber, sugarbeet, potato etc. Stem growth, quality, earliness or intensity of flowering and fruit development depend on temperature rhythms. Changes in temperature regime can stop plant growth and flowering. Many vegetables are more sensitive to temperature variation. It is thought that each crop requires a definite summation of temperature units from its sowing to harvesting i.e., crop maturity depends on those of the total temperature units. An increase in daily temperature shortens the crop duration and a decrease in daily temperature prolongs the duration.

The soil temperature depends on radiation balance, albedo of the soil, its moisture and air constants (degree of saturation) and factors affecting evaporation from the soil. It is also affected by slope and mountain barriers (lee side and wind side). Crop growth germination, root/shoot growth etc. depend more on soil temperature than on atmospheric temperature. If a temperate crop is transferred to tropical conditions it adapts to higher temperature regimes. Optimum temperature for many crops in temperate areas is about 20 degree centigrade and for tropical it is 25-27 degree centigrade. Low soil temperature is harmful for germination and root growth.

1.2.2 Precipitation and Rainfall

Falling of water in solid or liquid form to the earth surface is defined as precipitation whose different forms are rain, snow, ice, hail or sleet and which are separated form the different form of condensation like fog, dew, mist, smog etc. Rain is the most important form of precipitation. The intensity of rain is based on rate of fall. The amount of precipitation of any type, primarily liquid is defined as Rainfall which is measured by a rain gauge. Types of rainfall are convectional, orographic, cyclonic or frontal. Any and all forms of water, liquid or solid, that falls from clouds and reaches the ground. These include drizzle, freezing drizzle, freezing rain, hail, ice crystals, ice pellets and snow grains. The amount of fall is usually expressed in inches of liquid water depth of the substance that has fallen at a given point over a specified time period.

Rain, the most important form of precipitation, has significant impact on the agricultural field, soil moisture regime, crop phenology, crop productivity and so on. Excessive rainfall causes flood and less rainfall may cause drought. Both of these phenomena hamper agricultural crop production.

1.2.3 Humidity

Humidity is the amount of water vapor in the air. Absolute humidity considers the mass of water vapor present per unit volume of space and it is usually expressed in grams per cubic meter. Relative humidity considers the ratio of the actual vapor pressure of the air to the saturated vapor pressure and it is usually expressed in percentage. Humidity varies with the variation of temperature. As temperature rises relative humidity falls and vice versa without change in content of water vapor in the atmosphere. Humidity affects agriculture crops through evaporation, transpiration and condensation. In that sense it plays important role on crop production process such as flowering, ripening etc.

1.2.4 Wind Speed

Wind is nothing but the air in motion, which is mainly caused by pressure changes and temperature variation. Generally air flows horizontally in relation to the earth's surface. There are four areas of wind that are measured: direction, speed, character (gusts and squalls), and shifts. Surface winds are measured by wind vanes and anemometers while upper level winds are detected through pilot ballons, rawin or aircraft reports. The wind velocity may remain constant if temperature and humidity profile remain constant in the early morning.

Wind is an important environmental element for life and it controls the exchange of atmospheric constituents between the crop and the surrounding air. It helps in transferring O_2, CO_2 and water vapor and affects crop in various ways. It influences evaporation, transpiration, and evapotranspiration. If wind speed is increased, evaporation and evapotranspiration are also increased; as a result leaves vibration, leaf temperature respiration etc. increase and photosynthesis is reduced with stomata closing. Higher velocity of wind creates harmful and destructive effects through breaking and / or uprooting plants, lodging several crops and there by grain yield is affected. Heavy wind during flowering reduces pollination, causes flower-shed, increases sterility and reduces fruit sets. On the other hand lower velocity makes beneficial effects. Gentle wind increases turbulence in the crop canopy and improve grain yield [Lenka (1998)]. Again

1.2.8 Sunshine Hour

Adequate sunshine and proper sunshine hour are essential for plant growth and reproduction. Poor crop growth may occur due to lack of bright sunshine. Intense light protects the plants against injury. Daylight duration is important for raising crops in different latitudes and it influences on the flowering time of plants. Sunlight plays an important role on stomata opening and photosynthetic capacity also. Poor light may cause different disease, structural changes and alteration of color. It may be mentioned that there are some crops which grow better in shadow rather than bright sunlight.

hot wind can reduce plant growth but hot windy day is more tolerable than a hot humid day.

1.2.5 Cloud

Cloud is the aggregate of minute droplets of water and/or ice particles in air above the ground level. Cloud is formed in the atmosphere due to condensation of water vapor. Condensation nuclei such as in smoke or dust particles form a surface upon which water vapor can condense.

1.2.6 Evaporation and Evapotranspiration

Evaporation is the process by which a liquid like water is transformed into a gaseous state, such as water vapor. It is the opposite process of condensation. Evaporation is most important element when the crop is sown in the field. Evapotranspiration is the total amount of water that is transferred from the earth's surface to the atmosphere. It comprises of liquid or solid water and the transpiration from plants. Each plant needs some water for its growth and development and transpiration of water is also a part of plant's life function. Transpiration is proportional to the amount of plant growth. The larger the crop the greater is the amount of water evaporated by it [Warrington (1990)].

1.2.7 Pressure

Pressure is the force per unit area which is exerted by the weight of the atmosphere above a point on or above the earth's surface. So the pressure exerted by the atmosphere at a given point is called as the atmospheric pressure and the atmospheric pressure at mean sea level, usually determined from the observed station is defined as sea level pressure. Measurements of pressure can be expressed in millibars, in inches or in millimeters of mercury. General pressure is the atmospheric pressure at the center of a high or low.

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1.2.9 Fog

A visible aggregate of minute water droplets in the atmosphere at or near the surface of the earth, reducing horizontal visibility to less than 5/8 statute miles. It is created when the temperature and the dew point of the air have become the same, or nearly the same, and sufficient condensation nuclei are present.

1.2.10 Dew

Dew is the condensation in the form of small water drops on grass and other small objects near the ground when the temperature is fallen on the dew point(the temperature to which air must be cooled at a constant pressure to become saturated), generally during the nighttime hours.

1.2.11 Moisture

It refers to the water vapor content in the atmosphere or the total water liquid, solid or vapor in a given volume of air.

1.3 Climate and Wheat Production

Wheat has narrower adaptability to temperature and moisture variation. Wheat production is less in low latitude than the high latitude though wheat grows in tropical, subtropical, temperate and in cold region beyond 60^0NL. The tolerable temperature range for wheat production is 3.5^0C to 35^0C and the optimum temperature range is 20^0C to 25^0 C. For ripening stage, 14^0C to 15^0C is optimum and 25^0 C above is harmful. The wheat germination can be delayed in dry soils even in irrigated soils than in moist soils [Lenka (1998)]. One degree centigrade temperature increase with no change in precipitation would decrease wheat yield by about 5% in main core cropping regions. Two degree centigrade temperature increase combined with decreased precipitation could reduce average yield by 20%.

1.4 Climate Characteristics of Bangladesh

Bangladesh belongs to East of South Asian Subcontinent. On the basis of climatic factors, the location of Bangladesh is in the tropical monsoon climatic region. Here geographical location is situated between 20°34 and 26°33 on the North latitude and 88°01 and 92°41 in the East longitude of South Asia. In consideration with other monsoon climatic regions Bangladesh is greatly influenced because of its particular geographical location. It also enjoys some benefits for its special location. But in hilly areas of south eastern regions of Bangladesh she has less plain land. This country is surrounded by different categories of land level. On the east there is range of hills of Asam, on the north there is plateu of Meghaloya and on the north of the north there is the Himalaya. On the South there is the Bay of Bengal, on the Western side there is plain land of West Bangal, and on the west of the west there is plain land of the Ganges. The changes of seasons in the South-East subcontinent causes difference of temperature and it causes changes of windflaw and rainfall; Bangladesh is influenced by all these in her climatic condition. In the summer the flow of monsoon of Indian Ocean moves towards the entering gate of the Bay of Bengal. Here lies Bangladesh. At the end of this season, monsoon wind takes this outlet again to go out from South-East Asia. For this reason, Bangladesh experiences in her climatic condition, the presence of monsoon climate. In the winter, the extremely cold wind from Siberian pressure centre blows towards the south. This wind cannot enter into South-East Asian Subcontinent defying the Himalaya. Again through the western Jet stream of upper troposphere, cold wind of Eurosia enters the northern gate way of India, Bangladesh also experiences the influence of this cold wind. In winter one wave of the western Jet flow of the upper troposphere of mid latitude region blows by the southern side of the Himalaya. Wind comes down widely form this Jet flow and a high pressure is created on the North-West India and it is called subtropical high pressure. From this high pressure wind blows to- wards the north-East, North and North West, which is known as winter monsoon wind. South East facing Wind flaw blows over Bangladesh and reaches the Bay of Bengal.

In the summer, monsoon wind carrying huge amount of water vapor from the Bay of Bengal reaches Bangladesh and in the Rainy season in Bangladesh about 80-90 percent relative humidity remains in the air. This is not found and experienced any where in the Globe. In the Rainy reason in Bangladesh the sky gets heavily covered with thick cloud. July is found to be most cloudy month in Bangladesh and in June, except Dinajpur every corner of Bangladesh experiences average presence of cloud in the sky from 70 to 80 percent. District of Dinajpur experiences in average 60 percent cloud in the sky. The months of August and September see slow departure of clouds from the sky and in the month of October it gets speed. In October, Divisions of Dhaka and Rajshahi experience average 25 percent cloud in the sky. Other spots of the country experience on average 40-45 percent cloudness in the sky.

South-East coastal zones and half part of the west of Bangladesh experience 80-85 percent of total rainfall of the year and other parts of Bangladesh enjoy 70-75 percent rainfall. The district of sylhet being hilly region enjoys immense rainfall (200 cm). The adjacent spot of sylhet, the valley of Meghalaya sees more than 300 cm yearly rainfall. Facing obstruction in Meghalaya, the monsoon wind moves towards the west losing its humidity and the drops of rain it holds gets lesser. So the west part experiences scanty rainfall. The middle region of the country enjoys also scanty drops of rainfall. It is lesser than 100 cm.

January is the coldest month in Bangladesh. In this month, the North-West part of the country experiences 17°C temperature on average and East-South part experiences gradual rise of temperature; coastal area of this country experiences about 20°C on average. The North-West and North-East part of the country feel bitter cold at dead of night. The temperature reaches 0°C or below at dead of night in Thakurgaon and Northern part of Nilphamari at the end of December and at the beginning of January. In January the average maximum temperature remains between 24°C and 27°C across the country. For the years 2000-2003, Bangladesh experiences the average sunshine hour 6.46 in a year where the sunshine hour 7.66 is the highest in Rabi season and 4.91 is the lowest in Kharif season on average. This country also experiences the sunshine hour 7.73 in wheat growing period (November-March) and 7.44 in Prekharif season on average.

Bangladesh also enjoys 2340mm rainfall over the year on average and she also enjoys 1765.50mm in Kharif season, 512.96mm in Prekharif season, 62.38mm in Rabi season and 121mm in wheat growing period (November to March). The division of Rajshahi enjoys the lowest rainfall (1485.3mm on average) and the division of Sylhet enjoys the highest rainfall (3921mm on average) for a year. Some maps of Bangladesh are given in Appendix [Figure 1A.8 to Figure 1A.10] to show the divisional climatic pattern.

Bangladesh experiences 31.46°C of maximum temperature and 19.3°C of minimum temperature and 25.38°C of mean temperature on average for a year. The difference between maximum and minimum temperature in Bangladesh is 12.17°C on average. Among six divisions, the division of Khulna in Bangladesh experiences the highest maximum temperature and the division of Sylhet experiences the lowest maximum

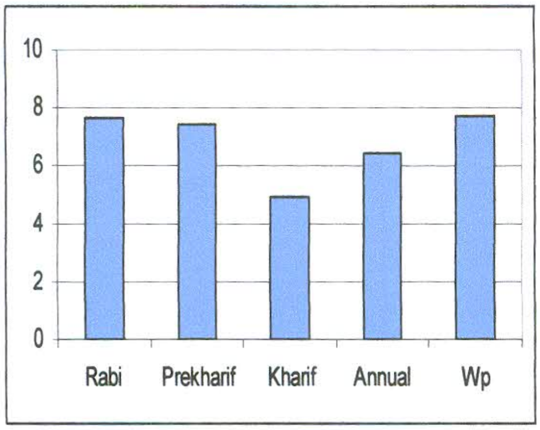

Figure 1.1 ASH over Bangladesh

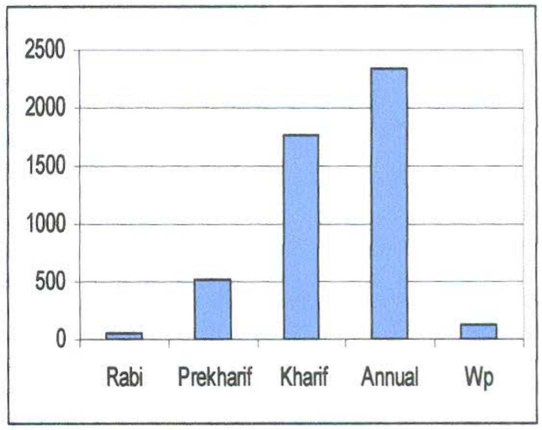

Figure 1.2 TR over Bangladesh

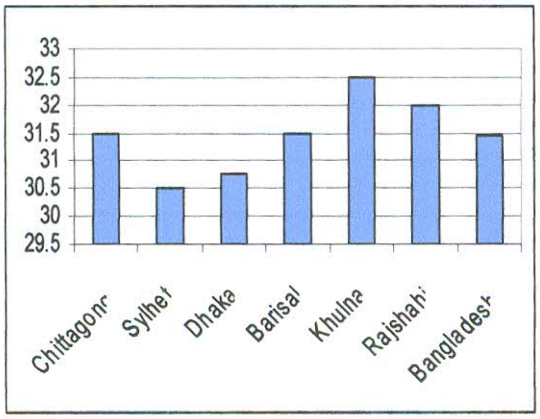

Figure 1.3 AAMXT over Bangladesh

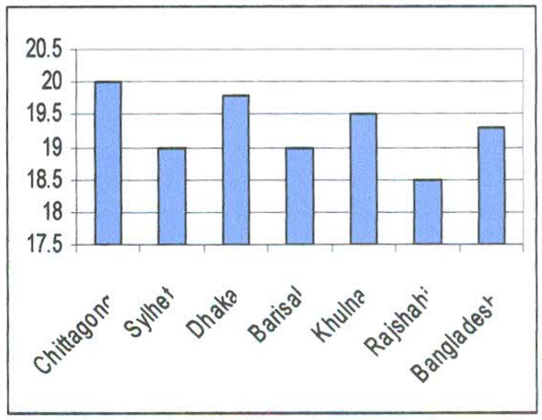

Figure 1.4 AAMNT over Bangladesh

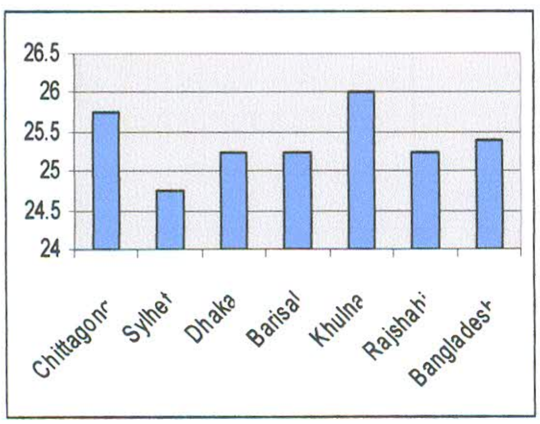

Figure 1.5 ADBT over Bangladesh

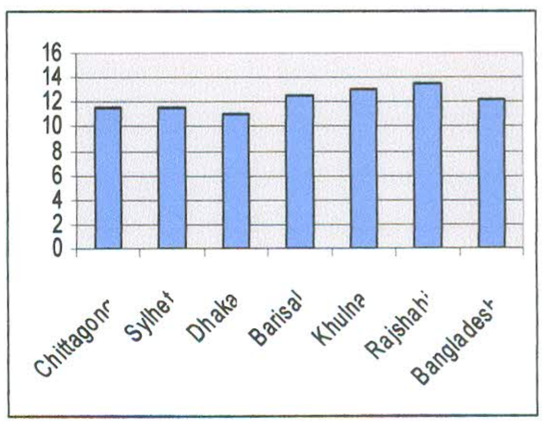

Figure 1.5 ARNT over Bangladesh

[ASH-Average sunshine hour, TR-Total rainfall, AADBT-Annual average dry bulb temperature, AAMXT-Annual average maximum temperature, AAMNT-Annual average minimum temperature, AARNT-Annual average range temperature]

temperature on average for a year. The division of Chittagong has the highest minimum temperature of 20°C and the division of Rajshahi has the lowest minimum temperature of 18.5°C on average in a year. The division of Khulna also has the highest annual average temperature of 26°C and the division of Sylhet has the lowest annual average temperature of 24.75°C on average. The difference between maximum and minimum temperature is the highest (13.50°C on average) in Rajshahi division and the lowest (11°C) in Dhaka division.

Seasons of a certain region are mainly associated with the position of the earth axis and the position of the sun. Bangladesh has a tropical climate with three main seasons- Pre monsoon hot season (March to May), Rainy Monsoon season (June to October) and a cool dry Winter season(November to February) and as well as three agriculture-based seasons are recognized in Bangladesh like Rabi (November to February), Prekharif (March to May) and Kharif (June to October).

On the other hand traditionally Bangladesh is called the country of six seasons and which is recognized as "Sororitur Desh" i.e. country of six seasons. According to Bangla calender the six seasons are Grisma, Barsa, Sarat, Hemonto, Shit and Basanta and every season is comprised of two Bangla months. Grisma is comprised of Baishak and Jayistha(mid April-mid June), Barsa is comprised of Ashar and Sraban (mid June-mid August), Sharat is comprised of Bhadro and Aswin(mid August-mid October), Hemanto is comprised of Kartik and Agrahayan (mid October-mid December), Shit is comprised of Poush and Magh (mid December-mid February) and Bosonto is comprised of Falgun and choitra(mid February-mid April). Grisma comes to us with storm (Norwester), heat and immense fruits, Barsa comes to us taking the monsoon rain in river, pond, canal and field with many frogs, Sharat comes to us taking dew with the flower sheuli, and kash, ripen Palm and the white and bright shining moon, Hemonto comes to us with golden paddy in field, Shit comes to us with juice of Date tree and several types of pitha (Cake) and Bosonto comes to us taking many flowers with the great song of Cuckoo.

Besides this some times climatic seasons of Bangladesh are divided into four parts according to monsoon wind generally such as Pre-monsoon, Southwest Monsoon(rainy), Post Monsoon(autumn) and Winter and the seasons are comprised of the month March through May, June through September, October and November and December through

February, respectively. High temperature range, occurrence of thunderstorms and variability in wind direction are the main characteristics of the Pre-monsoon season.

1.5 Climate and Wheat Cultivation in Dinajpur District

Bangladesh is an agro-based overpopulated country where wheat is being considered as the second staple food of the people. Basically, wheat cultivation became important during the great famine in 1943 due to acute food shortage. Since then food shortage in Bangladesh has been continued in different stages. But since 1976, the production and expansion of wheat cultivation got a new dimension which focused an outstanding achievement with high yield variety (HYV) of wheat program to face the problem of food deficiency in Bangladesh [Ahmed and Meisner (1996)]. The climate of Dinajpur District is temperate and pleasant which is remarkable for high temperature, humidity and coldness. The winter is more prolonged in Dinajpur District compared to other parts of the country and it is continued from October to March. The soil is sandy loam and pH ranges are between 4.0 and 5.5. The average temperature between 100°C to 300°C, rainfall 53cm and humidity between 57% to 78% prevail during November to March is suitable for wheat cultivation. With these climatic conditions, Dinajpur produces the highest amount of wheat in Bangladesh. The acreage under wheat cultivation is also high scaled. But in recent years wheat cultivation in Dinajpur district is decreasing and after 2000 the trend in wheat production in this district also registers decreasing trend.

1.6 The Earth's Greenhouse Effect

Earth's climate may be sensitive to the atmospheric concentrations of gases and that may create a greenhouse effect during more than a century. In 1681 Edme Mariotte noted that the Sun's light and heat pass through glass and other transparent materials easily but heat does not pass from other sources. In the 1760s Horace Benedict de Saussure's conducted an experiment to test the ability for generating an artificial warming of the Earth's surface and to provide an early analogy to the greenhouse effect using a 'heliothermometer'(panes of glass covering a thermometer in a darkened box). A concept was also recognized that the air itself could trap thermal radiation. In 1824, Joseph Fourier, citing Saussure, argued that the temperature of the Earth can be augmented by the interposition of the atmosphere because heat in the state of light finds less resistance in penetrating the air than in repassing into the air when converted into non-luminous heat .In 1836, Pouillit argued that the atmospheric stratum exercises a greater absorption upon the terrestrial than on the solar rays. However, responsible substance in the atmosphere for this absorption was not clearly identified. John Tyndall (1861) identified the absorption of thermal radiation by complex molecules through laboratory experiments as opposed to the primary bimolecular atmospheric constituents O_2 and molecular nitrogen and noted that changes in the amount of any of the radiatively active constituents of the atmosphere such as water (H_2O) or CO_2 could have produced 'all the mutations of climate. Svante Arrhenius (1896) suggested that a 40% increase or decrease in the atmospheric abundance of the trace gas CO_2 might trigger the glacial advances and retreats based on a climate prediction on greenhouse gases and one hundred years later CO_2 varied by this amount between glacial and interglacial periods. G. S. Callendar (1938) found that a doubling of atmospheric CO_2 concentration resulted in an increase in the mean global temperature of 2°C, with considerably more warming at the poles, and linked increasing fossil fuel combustion with a rise in CO_2 and its greenhouse effects solving a set of equations linking greenhouse gases and climate change. It appeared in the best laboratory observations that atmospheric carbon dioxide would be a gradual increase in the mean temperature of the colder regions of the Earth. CH_4, N_2O and CFCs were widely recognized as greenhouse gases from 1970s. Scientists have determined that human activities have become a dominant force and most responsible for the warming observed over the past 50 years. Human-caused climate change has resulted primarily from changes in the amounts of greenhouse gases in the atmosphere, but also from changes in aerosols and from changes in land use. The probabilities of certain types of weather events are affected for climate changes. Some weather phenomena such as heat waves and heavy downpours have become more frequent and intense, while others like extreme cold events have become less frequent and intense for the increased earth's average temperature. By the 1970s, the importance of aerosol-cloud effects in reflecting sunlight was known and atmospheric aerosols were being proposed as climate-forcing constituents. Moreover, the increase in sulphate aerosols was anthropogenic and linked with the main source of CO_2 and burning of fossil fuels. Thus, the current picture of the atmospheric constituents driving climate change contains a much more diverse mix of greenhouse agents.

1.7 Climate Change

Climate change means change of frequency and intensity pattern among climatic factors such as precipitation, temperature, sunlight, wind etc. More precisely, the weather changes collectively make up the climate change. In addition to these factors there are several physical events of climate change among which (1) mountain buildings, (2) volcanic eruptions (3) variation in sea level (4) continental drift (5) carbon dioxide concentration in the atmosphere (6) change in intensity of solar radiation including sunspot cycles and (7) variation in earth's orbit around the sun are important. However, earth's climate is a complex system and more recent general consensus is that rapid increase of green house gases, primarily water vapors, carbon-dioxide, ozone, methane, nitrous oxide, sulphates etc. in the earth's atmosphere are some important factors of climate change. It is said that emission of carbon dioxide comes from fossil fuels like burning of coal, natural gas and oil, destruction of large forests, burned or decomposed trees while emission of methane comes from wetlands, rice paddles, livestock and decomposition of annual manure and emission of sulphate comes from industry. These phenomena reflect sunlight away from the earth.

IPCC working Group 1(2001) reported that the global mean sea level will rise by 0.09 to 0.88 meters between 1990 and 2100 [SMRC report no. 6, 2001].IPCC (2001) reported that the global average surface air temperature has increased by 0.6^0C during the last century and by 0.15^0C per decade during the past three decades and global sea level has increased by 10-20cm during that period. WMO (1991, 1995) reported that the global mean surface air temperature has been increased by 0.3^0C to 0.6^0C over the last 100 years including five global average warmest years till 1980. IPCC(1990) reported that world temperature will increase by 1.5^0C - 4.5^0C degree by 2060 since 1880 associated with doubling of carbon dioxide from the projections of GCM model. The global mean surface air temperature will increase about 2^0C degree centigrade by the year 2100 with average of 1^0C -3.5^0C degree centigrade. Houghton et al. (1990, 1996) mentioned that the global warming is a challenging subject in climate research and it has been observed that global mean surface air temperature has risen by 0.6^0C during the 20^{th} century and much of the increase has occurred in last three decades and most significantly in winter and spring over the Northern Hemisphere continents [Houghton et al. (2001)]. Charney(1979) estimated that the atmospheric temperature will rise 1.5^0C-4.5^0C for the double concentration of CO_2 in the atmosphere. It was indicated from the observations for China that long term temperature substantialy rises with magnitudes comparable to the global mean[Wang and Gong (2000), Wang et al.(2001)]. The number of extreme cold and hot days showed downward trend for the Northern Hemisphere in U.S. [Gaetano (1996); Karl et al. (1996)]. A decreasing number of cold days were detected in Central and Northern Europe [Heino et al., 1999]. The frequency of cold extremes during the second half of 20th century in China showed decreasing trend [Frich et.al (2002); Zhai and Pan (2003); Qian and Liu (2004)].The number of days with heavy rainfall was increased in the US [Karl et al (1996)] and Japan [Iwashima and Yamamoto (1993)]. The frequency of extreme rainfall has slightly decreased for majority of selected stations in Southeast Asia but annual rainfall from extreme rainfall events has increased [Manton et al. (2001)]. In Maldives the increasing trend was observed in mean, maximum and minimum temperature and atmospheric pressure and both temperature and pressure have indicated the fluctuation with the periodicity of 3-5 years [SMRC report no.6 (2001)].

Chowdhury and Debsarma (1992) obtained increasing tendency of lowest minimum temperature over Bangladesh from their study. A study done by Warrick et al. (1994) on variations of temperature and rainfall for Bangladesh indicated that mean annual temperatures have been expressed as a departure from the reference period 1951-1980.It is also observed that the Bangladesh region has been getting warmer on the prescribed time scale. From the later part of the last century, there has been increase in temperature by 0.5^{0}C on average. This variation of mean annual temperature over Bangladesh follows closely to the Northern hemisphere land temperature in which a warming trend is demonstrated during 1910-1940 and a slight cooling trend until mid-1970s and after that period again warming feature is observed [Folland et. al 1990 (1992)]. But the variability of monsoon rainfall has a definite decreasing trend in the recent decades [Karmokar (2001)]. The trend analysis of annual rainfall for the Bangladesh for the period 1870-1991 does not show any distinct long-term trend in mean annual rainfall. But the decadal analysis on mean annual total rainfall over Bangladesh indicated an increase over the period. It increased by 421mm from 1948-50 to 1951-60, then decreased by from 148mm 1951-60 to 1961-70 and increased again by 37mm and 290mm in the next two decades, respectively. These figures indicate the increasing tendency in the decadal mean annual total rainfall over Bangladesh. The increase in temperature and rainfall induce natural disasters, which directly affect the environment in general and the agriculture sector in particular.

Recent climatic changes in Bangladesh has been reported in the book entitled "Recent climatic changes in Bangladesh"[SMRC No. 4, 2000]. The mean minimum and maximum temperature of Bangladesh for the period 1961-90 showed increasing trend in some seasons. Among them some are significant trend. The annual mean maximum temperature over Bangladesh has followed significant decreasing trend up to 1975 and after that period very significant increasing trend was observed. The annual mean minimum temperature over Bangladesh has made significant increasing trend up to 1978 and then it followed insignificant decreasing trend. Both the overall annual mean minimum temperature and annual mean temperature over Bangladesh for the period 1961-90 showed slight upward trend. The seasonal rainfall over Bangladesh showed a positive trend except post monsoon period. In the post monsoon season, it showed a negative trend.

1.8 Impact of Climatic Change

The increasing surface temperatures would melt the ice of high altitudes and polar caps and extend the upper layers of World Ocean by adding those melted ice to the total volume of World Ocean. As a result mean sea level will increase [Titus and Bath (1984); Emery and Aubrey (1989); IPCC (1990); Wigley and Raper (1992); Gornitz (1995); Singh et al.(2000 and 2001a); Singh (2001). The higher world temperatures will increase the hydrological cycle activity through precipitation and evaporation. But the local or regional changes can be different. Climate change may affect on forestry and ecosystems, coastal zones, agriculture, fisheries water resources and energy developments [Reilly and Tomas (1993)].The variations of high frequency extreme events in association with monthly- to-seasonal fluctuations can exert a tremendous influence on the natural environment and human activity [Katz and Brown (1992); Karl et al. (1995); Houghton et al. (2001)]. The effects through crop yield reduction, loss of fertile soils, increased cost of production gave large negative results in the US [Smith and Tirpak (1989)]. For example, the yield of rice declined by 15% for 1degree centigrade mean temperature increase in the growing season [Peng et al (2004)]. Recent studies on climate forecasts and adaptation indicated that American agriculture will be resilient to climate change [Crosson 1993, Kaiser et al. (1993) and Mendelsohn, Nordhaus and Show (1994)]. The agriculture of other developed countries with temperate climates may react similarly but in developing countries and in tropical and subtropical areas it may be less adaptable and show different responds.

The large scale disaster and disruption like Sahelian drought in Africa, Rajstan drought in India, 1866 famine in Orissa, Bengal famine of 1943, Moharastra drought, Nigerian drought of 1972-74 etc. are example of natural calamities caused due to climatic variation with crop failure.

Bangladesh is also most vulnerable to climate change like other least developed nations of the world. About 62% of the total area of Bangladesh was inundated in 1988 and about 68% of the total area was inundated in 1998 with the widespread flood. The great cyclone heated the coastal area of Bangladesh in April, 1998 and 138,868 people had died. According to study of Singh et al. (2000 and 2001a) and Singh (2001) the alarming high rate of sea level rise were observed along the coasts of Bangladesh and Maldives.

The annual Mean Tidal Level of Visakhapatnam [East coastal station of India (1937-1991)], Mumbai [West coastal station of India (1878-1991)] and Kochi [West coastal station of India (1939-1991)] showed increasing trend of 1.2mm/year, 0.9mm/year and 0.8mm/year, respectively[SMRC report no.7, 2002]

Antel (1995) mentioned that the increased atmospheric carbon-di-oxide can raise plant productivity through carbon-di-oxide fertilization and can cause changes in temperature, rainfall, solar radiation and wind patterns and that can influence either positively or negatively on plant and animal productivity. He agreed that the agricultures of poorest countries are most vulnerable and least capable of adaptation to climate Change or other climate change disruptions.

1.9 Assessment of Climate Impact on Agriculture

Though Global climate change will affect in several sectors including economic and agriculture sector, the agriculture sector is the most sensitive and vulnerable. World agriculture is very much dependent on climate resources without considering developing and developed countries [Downing, 1996; Watson et al 1996]. Actually many researches have been conducted on assessment of the potential impact of climate change on agriculture at global, national and regional level [World Bank Technical Paper No. 402]. For example, Kaiser and Crosson (1995) and Mendelsohn (1996) worked on US agriculture, Kane et al.(1992), Karim et al(1994), Reilly(1995), Sonka (1992) worked on world agriculture, Mendelsohn (1996), Sanghi et al.(1997) worked on Brazil agriculture, Jin et al.(1994) worked on China agriculture, Strzepek et al.(1994) worked on Egypt agriculture, Mendelsohn (1996), Rao and Sinha(1994) worked on India Agriculture, Qureshi and Iglesias(1994) worked on Pakistan Agriculture, Schulze et al.(1993) worked on Southern Africa Agriculture, Parry et al.(1992) worked on Southeast Asia, Vidanage and Abeygunawardena (1994) work on Sri Lanka Agriculture.

Kaiser et al. (1995) analyzed the potential agronomic effects of several climate change scenarios on wheat, corn and soybeans farming in the US and they found the negative impact on all crop yields.

Dadhwal (1989) studied the effect of temperature on wheat in India by sowing the crop on different dates.

Ahmed S.M and Meisner C.A (1996) described in their book entitled "Wheat Research and Development in Bangladesh" that wheat is more vulnerable to weather hazards. As quoted from Mr. Brammer is that "Wheat is close to its ecological limit". The authors further mentioned that the period of cool winter is most suitable for existing wheat varieties. They identified that late sowing, low radiation, high humidity, high temperature are responsible for sterility in wheat crop, even if Boron is adequate in soil. Boron deficiency in soil, pest and disease, reduced solar radiation due to consecutive foggy days, high or very low ambient temperature, water logging and soil nutrient deficiency singly or combindely may also cause wheat sterility. The most sensitive stage of a wheat plant to environment begins from the time of emergence as mentioned by them.

The impact of 1°C increase for growing season temperature is shown in the following comparison table exerted from the article of You et al (2005):

Study	Crop	Location	Impact
Nichalls(1997)	Wheat	Australia	+30~+50%
Lobell & Asner(2003)	Corn, Soybean	USA	-17%
Peng et al (2004)	Rice	Philippines	-10%
Their Study	Wheat	China	-2%~-5%

Several general circulation models such as GFDL, GISS, UKMO, CCC etc. are innovated to measure the impact of climate warming. The five climatic variables like temperature, humidity, surface pressure and two dimensions of wind precipitation are used for controlled runs with the changes of carbon dioxide until they reach an equilibrium level. The degree of variability such as extreme events is not apparent with those GCM climate projections like the real climate. GCMs cannot study the detailed impact at a small spatial scale. These models are not adequate for feedback of many climatic variables including water vapor, snow and sea ice, cloud cover etc. [World Bank Technical Paper No. 402.]

1.10 Approaches for Assessment of Climate Impact on Agriculture

Impact of climate change on agriculture can vary in many aspects. It can differ according to the approach of assessment, the specified climate change scenarios, the geographic coverage, the considered agri-food sectors etc. However three approaches are recognized to understand the relationship between climate and agriculture and there is no universal accepted approach for assessment the impacts of climate change on agriculture. The three approaches are:

1. Crop yield analysis
2. Spatial analysis
3. Agriculture system analysis

Crop yield analysis is the most common approach among a variety of analytical techniques to examine the possible impact of climate change on crop productivity levels (Bootsma et al., 1984; Lough et al., 1983).The Crop yield analysis determines the impact of changed environments on crop productivity levels and generally the analysis estimates the climatic impact on crop productivity levels. To assess this impact there are two types of studies are conducted as the following:

(a) Studies Based on Surveys of Expert's Opinion

These studies are based on the expert's accumulated knowledge about the expected climatic change and the climatic requirements of crops. The NDU (1980) studied the crop productivity analysis employing expert opinion and this approach was utilized to estimate both the extent of expected climate warming and the concomitant impacts on selected crop yields.

(b) Studies Relying on Crop Productivity Models

These studies are based on statistical (regression) and/or simulation techniques and these types of models are developed to a large extent [Baier (1979); Biswas (1980)].

Regression models estimate yields as a function of multiple predictor variables and the regression equation have been developed by using historical climatic and yield data for specific crops in particular areas and the model is used to predict the changes in yields expected due to changes in climate (Lough et. al, 1983, Santer, 1984).

Simulation models have also been applied to assess the impacts of climatic change on crop yields [Terjung et al. (1984a, b); Waggoner (1983)]. These models are developed by combining a set of mathematical equations based on experiments or knowledge of specific plant processes (Photosynthesis, respiration and transpiration) and their interactions with the environment (climate and soils).Simulation models are based on crop-climatic processes and hence can be applied to environmental conditions other than the current.

Besides these procedures impact of climate change on crop growth, development, water use and productivity of crop can be quantified by the measurement of direct effects of modified weather parameters and CO_2 on crop growth in phytotron, glass houses etc and these approaches are costly.

1.11 Literature and Criticism

1.11.1 Linear Trend and Time Series Analysis

Guhathakurata and Rajeevan (2007) conducted linear trend analysis to examine the long term trend pattern for the rainfall over India. They analyzed new monthly, seasonal and annual rainfall for 36 meteorological subdivision of India using the monthly data for the period of 1901-2003 and mentioned that the new rainfall series is temporally as well as spatially homogenous. They also analyzed the monthly contribution for every monsoon months to annual rainfall over different subdivisions and for the southwest monsoon season. They found decreasing trend in Tharkand, Challisgarh, Keral and increasing trend in eight subdivisions. Contribution of June, July and September rainfall to annual rainfall was decreasing for few subdivisions while contribution of August rainfall was increasing in few other subdivisions. The mean rainfall 286.5mm of July was the highest and contributed 24.2% of annual rainfall (1182.8mm). August rainfall contributed 21.2%, June rainfall contributed 13.8% and September rainfall contributed 14.2%, June to September rainfall contributed 74.2% (877.2mm). August rainfall exhibited significant increasing trend while contribution of July rainfall exhibited decreasing trend. June rainfall exhibited increasing trend in almost 19 subdivisions and decreasing trend in 17 subdivisions.

Ichiyanagi (2007) investigated spatial and temporal variability in monthly, seasonal and annual precipitation patterns over Nepal. He found that maximum annual precipitation increased with altitude for elevations below 2000m but decreased for elevations of 2000-3500m.He observed a negative relationship between annual precipitation and elevation only in western Nepal. In Central Nepal annual precipitation averaged on a 0.25^0 grid exceeded 3000mm/year but it was less than 1000mm/yr over north western mountains in Nepal. He also observed only winter precipitation over western Nepal was heavier than precipitation over central and eastern Nepal. A time series of standardized precipitation anomalies averaged over Nepal revealed no significant long term trends and almost no stations exhibited significant long-term trends (by Kendall's rank correlation analysis). A correlation analysis between summer monsoon precipitation and All Indian Rainfall (AIR) index revealed positive correlations in western Nepal and negative correlations in eastern Nepal. He also found a positive correlation and no negative correlation between Summer Monsoon Precipitation and the Southern Oscillation Index in western and eastern Nepal. He observed moist air from the Arabian Sea suppressed precipitation over western Nepal and cold dry air from the Tibetan plateau suppressed precipitation over Eastern Nepal.

Labajo et al (2007) analyzed daily maximum atmospheric pressure at ground level for each of the weather stations during the period of 1961-2003 taking the anomalies with the difference between the daily value and mean daily value for each day of the year. They used the p05 and p95 percentiles as the thresholds for the extreme values of the anomaly series and found a decreasing annual trend for lowest values of the series of the annual frequency and increasing trend for highest values of the series of the annual frequency.

Murphy and Timmbal (2007) reviewed the recent climate variability and climate change in Southern Australia and mentioned that the South Eastern Australia suffered from low rainfall for 10 years beginning from 1997 to 2006 where 61% rainfall declined in Autumn (March-May).They also mentioned that the daily maximum temperatures are rising as well as minimum temperatures except for cooler nights in autumn in the southwest of SEA closely related to lower rainfall. A similar decline in rainfall was also occurred in the southwest of Western Australia around 1970 which has many common features with the SEA decline. SEA rainfall is usually produced by mid latitude storms and fronts, interactions with the tropics through continental scale cloud bands and cut off lows. ElNino-Southern Oscillation impacts on SEA rainfall as the Indian Ocean but neither has a direct influence in autumn. Trends have been found in both hemispheric and local circulation features.

Su et al (2006) analyzed recent trends in observed temperature and precipitation extremes for the period 1960-2002 in the Yangtze River basin, China and tried to identify whether frequency or intensity of extreme events increased with climate warming. They observed a positive trend in annual and seasonal mean maximum and minimum temperature and found the strongest trend in winter mean minimum temperature. They also found significant increasing trend for 1-day extreme temperature in summer and minimum temperature in winter but they did not find any significant trend for 1-day maximum temperature. They observed significant decreasing trend for a number of cold days (≤ 0^0C and ≤ -10^0C) and a minor decreasing trend for a number of hot days (daily value≥35^0C). They observed significant trend in summer rainfall but no statistically significant change is observed in heavy rain intensity. They again observed a significant positive trend for the number of rainstorm days with the daily rainfall ≥50mm and a minor increasing trend for 1day, 3day and 7day extremes.

Gong and Ho (2004) analyzed the intra-seasonal variability during winter time temperature through November to March over East Asia for the past few decades whether the daily temperature has become more variable with the warming. They observed that the intra-seasonal variance generally decreases which implied that the daily temperature are becoming less variable. The rate of change was -0.49C per decade and it was equivalent to -3.59% per decade. There was no dominant trend for coefficients of skewness in the north eastern portion of China and the changes are more robust except negative skewed trend in north Eastern China. They found that the frequency of low temperature extremes increased at a rate of change of 0.26 days per decade with 95% confidence level and mentioned that both the Siberian high and Artic Oscillation (AO) exerted a notable influence on the temperature variance. They further mentioned that intra seasonal variance of the Siberian high and Arctic Oscillation were significantly correlated with the temperature variance and the seasonal mean state of the Arctic Oscillation which influenced the temperature variance by modulating the high frequency components of the Siberian high. The intra-seasonal variance of the Siberian high tends to decline at a rate of change of -10.7% per decade with the 99% significant level and the mean wintertime Arctic Oscillation have strengthened in the last few decades.

Gong et al. (2004) analyzed the daily precipitation amount of the semi-arid region over China during May to September for the period 1956-2000 to examine the changing pattern and observed slightly decreasing trends with significant changes in some aspects. They found that rainy days were reduced by about 8 days over the period 1950 to 1990.They also observed stronger significant intensity for the number of days with light rain (<10mm per day) but moderate and above moderate rain did not show that. For the long duration precipitation (≥3days) they found decreasing linear trend where the rate was -5.6% per 10 years and for the frequency of long dry spells (≥10 consecutive days) they found the rate 7.2% per 10 years while no evident trend was observed in maximum daily rainfall. The median of maximum rain showed a step like drop in the beginning of 1979 and the notable low values until the early 1990s. They mentioned that about 90% of the long term changes in the number of rainy days were reduced for the reduction of the days with light rain. They further mentioned that the decreasing number of rainy days were consistent with the observed reduction in cloudiness and humidity in northern China. From Kaiser's analysis (1998, 2000) they exerted that the cloudiness shows decreasing trend in much of the country.

Gong et al. (2003) analyzed the weekend effect in diurnal temperature range (DTR) in China for the period 1955-2000 where weekend effect was defined as the average DTR for Saturday through Monday minus the average DTR for Wednesday through Friday. They observed that the weekend effect in DTR has the opposite signal between winter (December to February) and summer (June to August). They found positive weekend effect in association with the increased maximum temperature and total irradiance but decreased relative humidity in Wintertime DTR and much stronger and significant negative weekend effect in association with the decreased maximum temperature and total solar irradiance but increased relative humidity and a greater number of rainy days in summertime DTR.

Gong et al.(2003) studied the trends in frequency and duration of dry spells for the summer–half-year season (April-September) in China during the late twentieth century (1956-2000).They defined a dry spell by the number of consecutive days without measurable precipitation and observed the significant changes for the frequency of short dry spells (length<10 days) in North, Northeast and Southwest China and obtained the significant trend for the frequency of long dry spells (length≥10days) in North and Northeast China and found no remarkable trend in other regions.

Kelly (2000) investigated the time series properties for temperature and GHG series and he found out that the unit root for the temperature series can not be rejected and forcing from greenhouse gas concentrations is very similar to a time trend. He mentioned that there is the possibility that the temperature rise is due to log run cycles, and that the relationship between temperature and GHGs is spurious.

Hendry and Juselius (1999) explained about the cointegration analysis. They showed that the classical assumption of stationarity in econometric theory reveal the invalidity in economic forecasting through the graphical representation. They discussed the importance of stationarity for empirical modeling and mentioned the effects of incorrectly assumed stationarity. They explained the basic concepts of nonstationarity, noted some sources of nonstationarity and formulated a class of nonstationarity process. They again presented an analysis that can be transformed by means of differencing and

Rahman and Alam (1995-1996) studied the rainfall of High Barind Region for the period of 1967 to 1992 and analyzed the pattern of rainfall variability by using regression trend analysis technique with the determination of R^2.

Karmokar (1997) analyzed the rainfall and temperature data for 19 selected stations of Bangladesh during the period of 1948-1990 using linear trend regression technique and observed increasing trend.

1.11.2 ARIMA Modeling

Garcia-Barron L and Fernandapita MA (2004) fitted ARIMA models for long-term monthly series of maximum and cointegrating combinations. Moreover, they described that how to test for unit roots and cointegration illustrating the analysis with Monte Carlo simulations and empirical examples.

Bolstad (1998) analyzed landscape and temporal patterns of temperature in the Southern Appalachian Mountains of North America. They found that temperatures decrease with altitude at mean rates of 7^0C /km (max temp) and 3^0C /km (min temp). Average daily temperature range decreases as elevation increases from 14^0C at 700m to 7^0C at 1440m and daily temperature range are typically higher in Spring and daily maximum temperature above frost canopy averaged 1.4^0C higher at a south facing station relative to a comparable north west facing station and above canopy daily minimum temperature were depressed at a valley bottom.

Stern and Kaufmann (1997) investigated the time series properties of global climate variables and detected attribute of climate change. They examined the presence or absence of stochastic trend using three different tests in a selected group of global climate change data for the longest time series available. Through statistical test, they indicated that climate change occurred over the last 140 years but that is not due to anthropogenic forcing. They found that radiative forcing changes due to atmospheric concentrations of CO_2, CH_4, CFCs and N_2O emissions. The solar irradiance contains a unit root while temperature does not. They found that concentration of stratospheric sulphate aerosols emitted by volcanoes is stationary. The radiative forcing variables cannot be aggregated into a deterministic trend which might explain the changes in temperature.

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1.11.2 ARIMA Modeling

Garcia-Barron L and Fernandapita MA (2004) fitted ARIMA models for long-term monthly series of maximum and minimum temperatures from South-Western Spanish during the period 1882-1999. Jeong (2001) examined the statistical characteristics of precipitation in Seoul using ARIMA model for the period 1777-1907 (traditional

Chugugi data) and 1908-1997 (modern data). Pan et. al. (2005) developed a time series model to forecast climatic data in Batticaloa District of Sri Lanka during the period 1900-2003. Khummongkol fitted ARIMA model for the time series of monthly rainfall amount during the years 1974-2003 in their article "Water Resource Management Using Multiobjective Optimization and Rainfall forecast. Weesakul and Lowanichchai (2005) forecasted annual rainfall in every part of Thailand using autoregressive moving average model (ARMA). Lemi (2005) also used ARIMA model to analyze rainfall. Sun H. and Koch M. (2001) analyzed the daily precipitation and discharges of the Apalachicola Bay of New Florida by using the techniques of Box-Jenkins ARIMA models method (1976).

1.11.3 Exploratory Analysis

Mosteller and Tukey (1977) analyzed the climatic data by using the exploratory data analysis (EDA) tools and techniques. Tukey innovated the EDA tools such as Boxplot, Stem-and-leaf display, Median polish table etc. They used Median polish table to investigate the within and between years variability for the two-way tables together.

1.11.4 Probability and Descriptive Analysis

Rahman(1999), Sinha (1997), Hossain (1997), Hossain and Hossain(1996a), Sinha and Paul (1992), Islam (1980), Stern (1980), Mehdi (1976), Yap (1973), Mooley (1973), Fitzpatrick and Krishnan (1967), Eichmeier and Baten (1962), Gabriel and Neumann (1957) and Besson (1924) analyzed the rainfall data for different periods at different places. They constructed several types of probabilistic models such as Markov Chain Model, Log Normal model, Gamma, Pearson type-1, Pearson type-II, Geometric, Gamma etc.

Hossain (1997) analyzed the rainfall for Mymensingh for the period of 1975 to 1995 and applied the same technique as Talukder did in 1988.

Ali et al (1994) studied the rainfall of Mymensingh for the period of 1975 to 1993.They analyzed weekly rainfall and computed wet dry rainfall ratio. They tried to classify the weeks as early drought, late drought and mid drought.

Ahmed (1994) studied the rainfall for 19 stations of Bangladesh for the period of 1959 to 1988. They computed mean, standard deviation (SD) and coefficient of correlation. They also estimated the coefficient of variation (CV) for monsoon and seasonal rainfall amount. They estimated the correlation coefficient between monsoon duration and onset dates. They also estimated between monsoon rainfall amount and onset dates.

Sinha and Islam (1994) described the impact of the pattern of daily rainfall for Rainy Season on agriculture of Bangladesh using the same data used by Sinha (1989).

Samad and Alam (1993) analyzed the rainfall for 20 greater districts of Bangladesh for the period of 1961-1990 and used linear trend technique to observe the spatial and temporal variability of rainfall. They accomplished the test of equality of two means to show the variability for pre and post 1975 during Rabi season and the month of March for selected stations.

Roy et.al (1990) studied the annual rainfall of Bangladesh and observed that the rainfall of maximum stations follow normal distribution. He also did a periodogram analysis.

Talukder et al (1988) studied the daily rainfall of 10 different but evenly distributed locations of Bangladesh for the period of 1980 to 1985. Firstly they computed mean, SD and CV for each month and for monsoon season for each location. They classified the months based on the amount of rainfall according to the suggested method of Handa and Sreenath (1983). They found out the frequency distribution of rainy days over months and determined the relationship between two consecutive months using correlation coefficient. They classified the months of a year as Drought, Normal and Abnormal based on rain receiving pattern.

Katz (1974) studied the rainfall data of State college, Pennsylvania for the period of 1950 to 1969 and proposed a recurrence relation for the number of wet days in a fixed period of time.

1.11.5 Impact of Climate on Different Food Production

Fraisse (2007) explored the associations between soyabean yield in eastern Paraguay and the El Nino Southern Oscillation (ENSO) phases and they computed the yield residuals from the trend of the historical soyabean yield data for the period of 1991/1992 to 2002/2003 to remove the effect of technological advances and investigated the differences in mean precipitation among ENSO phases under the context of crop development phases. They simulated the CSM-CROPGRO soyabean model for two important soyabean producing areas in Paraguay and explored the influences of El Nino Southern Oscillation (ENSO) on mean precipitation during planting, blooming, seed pudding and from young pods to physiological maturity by tests of differences.

Lobell et al (2005) assessed the impact of recent climate changes on wheat yield trends by simulating the wheat yields and climatic data for YMV and MSLV in Mexico during 1987-2002 for the process based CERES-Wheat crop growth model. They determined the relationship between the first differences (year to year changes) of wheat yield and relevant climatic variables like the average minimum and maximum temperatures and solar radiation during January-April, the main months of wheat growth, by using multiple regression technique. They found that wheat yield have increased by 25% over the past two decades and they also found that raising wheat yield can be attributed to climatic trends much in Northwest states which is depended upon particular cooling of growing season night temperatures. The effect of temperature on rates of several processes, including crop development , photosynthesis, transpiration, leaf growth, grain filling vernalization are modeled in the CERES crop growth model. They performed an independent statistical analysis to determine the relationship between the first differences (year to year changes) of yield and relevant climatic variables. They found high correlation between observed and simulated yield anomalies ($r = 0.87$ for YMV and 0.72 for MSLV) over the entire crop growing period by using the correlation coefficients. They again observed that yields increased by 86.6 ± 27.6 kg $ha^{-1}yr^{-1}$ in YMV and 114.1 ± 33.8 kg $ha^{-1}yr^{-1}$ in MSLV which correspond to a $25.8 \pm 8.2\%$ and $32.5 \pm 9.6\%$ increase respectively over the 15 period. According to the simulation results of CERES model, changes in yield due to climatic trends were $25.5 + 10.1\%$ in YMV and $22.0 \pm 12.4\%$ in MSLV. The climatic trends can explain roughly 100% of the yield increase in YMV and 70% of the yield increase in MSLV over the past 15 years [According to CERES model]. They examined the relationships between individual climatic variables and yield changes and showed that the singular night time temperature are important for both YMV and MSLV and assessed the impact of each climatic variable on yield trend by multiplying the trend in that variable by the yield response and got significant positive impact of recent decreases in average minimum temperature in YMV which alone could explain $85 \pm 27\%$ of the yield increase and slightly cool night temperature in MSLV could explain $22 \pm 8\%$ of the observed trend.

You et al (2005) determined the impact of global warming on Chinese wheat productivity through the direct assessments on the impact of observed climate change on past wheat yield growth for the years 1979-2000. They used Chinese crop specific panel data set for 1979-2000 to investigate the climate impact on Chinese wheat yield growth for 22 major wheat producing provinces of China. In the analysis they used the climatic data temperature, rainfall and solar radiation during the wheat growing seasons by province and include the major physical inputs such as land, labor, chemical fertilizer, seeds, pesticide, machinery, irrigation and other physical inputs, regional production specialization, climatic variables like temperature, rainfall and solar radiation, a set of regional dummy variables and two institution change dummy variables. To separate the nonclimatic effect on crop yield they included crop inputs, technology, management, land equality and chemical fertilizers. They used time specific dummy variables to reflect the two major policy changes in the early 1980s and late 1990s.They also used a time trend to represent the factor due to technological change during this period. Finally they used a Cobb-Douglas form of wheat yield function as follows:

$$l\text{nYield}_{it} = (\alpha_0 + \alpha_1 t) + \sum_j \beta_j \ln X_{jit} + \gamma \ln S_{it} + w \ln \text{Climate}_{it} + \sum_{r=2}^{7} \delta_r D_r + \sum_{l=1}^{2} r_l D_l + \varepsilon_{it} \qquad (1.1)$$

where ln is natural log, t = 1, 2, ..., 22 denotes observations from the years from 1979 to 2000.Yield_{it} refers to wheat yield for Chinese province i at time t (the time trend from 1979 to 2000); X represents the conventional inputs per hectare of sown wheat area including seeds, fertilizer, pesticide, machinery, and other inputs such as irrigation, manure, and animal power; S denotes the share of wheat area in total sown area, reflecting the regional specialization (including land quality) in wheat production; Climate is the climate variables including temperature, rainfall and solar radiation during wheat growing season. They approximated the solar radiation with cloud cover expressed in percentage such as the higher the cloud cover, the weaker the run radiation. They included a set of regional dummy variables, $D_{r,}$ to represent time-persistent, regional difference in social, economic and natural endowments not accounted for by other variables. Time-specific dummy variables, $D_{l,}$ capture the effects of two major policy reforms in agriculture from 1979 to 1985, and from 1995 to 2000. α, β, γ, w, δ, r, are parameters to be estimated, and ε is the error term. They performed Augmented – Dickey-Fuller Unit Root test to test the stationarity of both dependent and independent variables and did not found any problems. Then they applied the least square method to estimate the parameter and detected autocorrelation problems. Then they estimated the model using autoregressive error model with one year lag (AR1) and examined constant variance error assumptions (no heteroscedasticity) by plot of the residuals and predicted values using ARI estimation. They found that the regression equation reasonably holds the assumption. They also examined the plot between the predicted value and time trend and found no autocorrelation problem. Then they checked the assumptions of normal distribution for errors, outliers, and linearity and found that the assumptions are hold. They estimated the equation with both fixed-effects and random-effects but found little difference and detected that the temperature has a significantly negative effect on wheat yield and found 1% increase in wheat growing season temperature reduces the wheat yields by about 3%. They defined $Yield^{Climate}$ as:

$$\ln Yield^{Climate} = \ln Yield_{it} - (\alpha_0 + \alpha_1 t) - \sum_{j=1}^{5} \beta_j \ln X_{jit} - \gamma \ln S_{it} - \sum_{r=2}^{7} \delta_r D_r - \sum_{l=1}^{2} r_l D_l \qquad (1.2)$$

Peng et al (2004) showed a negative response of rice yields to increased minimum but not maximum temperature.

Scian (2004) developed statistical regression model to detect the effects of weather on wheat yields for the period 1977-1999 applying two types of time scales such as 10 day intervals(D) and phenological phases(P) where the parameters were accumulated rainfall, minimum and maximum mean temperature, total soil water storage, the ratio of actual evapotranspiration to potential evapotranspiration obtained from a water balance model. The moisture anomaly index and the Palmar drought severity index were calculated according to Palmars model. They showed the best correlation between the times of year and the phenological phases and grain yield by using Pearson correlation formulae with 5% significance level.

Attri and Rathore (2003) assessed the impact of climate change on crop productivity by simulating the impact of projected climate change on wheat crop in India. They projected the climate change scenarios [by the middle of the current century] based on the latest studies and quantified the impact of concurrent changes of temperature and CO_2 on the growth development and yields of wheat in Northwest India using a state of the art dynamic simulation model. They observed 29-37% enhancement of yield under rainfed conditions and 16-28% enhancement of yield under irrigated conditions in different genotypes under modified climate such as Tmax+1.0^{0}C, Tmin+1.5^{0}C and 2*CO_2.

Wilkens and Singh (2001) predicted effects of temperature and photoperiod on crop development and yield by simulating the CERES crop growth models which determine the duration and timing of phenological events by accumulate the heat units or thermal time. Temperature functions and derivatives in the CERES models directly influence phasic development of cereal crops, growth, soil temperature, soil water balance and nitrogen transform where phasic development of cereal crops are an ordered sequence of process including sowing, emergence, floral initiation, anthesis and maturity.

Stone (2001) assessed individual impacts of each climatic variable on yields trend and got a greater rates of plant respiration during warmer nights. They got significant positive impact of recent decreases for minimum temperature in YMV which explained 85 ± 27% of the yield increase. They got only 22 ± 8% of yield increase for slight cooling of night temperature in MSLV.

White and Reynolds (2001) discussed physiological perspective on modeling temperature response on wheat and maize crops based on process based models of wheat and maize. They mentioned that grain number, grain filling rate, grain filling duration are main yield determinants in the CERES model. Grain filling rate is also very sensitive to temperature .Wheat grain filling rate decreases as the mean temperature falls.

Lal et al (1996, 1998 b) projected an increase of CO_2 from 463 to 627 PPMV. They also projected an increase in maximum and minimum temperatures by 0.47^0C and 1.10^0C , respectively, during the winter season over northwest India by the middle of the current century under equivalent CO_2 and aerosols forcing using global climate model scenarios from the IPCC (Houghton et al,1996). The uncertainties associated with the projected warming were of the order of 1.5^0C. Further there is considerable uncertainty in the magnitude of changes in climatic parameters of repair scale, particularly at the regional level.

Kaiser et al. (1995) analyzed the potential agronomic effects of several climate change scenarios on wheat, corn and soybeans farming in the US. They found the negative impact on all crop yields.

Bell and Fisher (1994) got significant negative yield responses to higher night temperatures and estimated that 10% reduction of yield for raising 1^0C minimum temperature with a smaller and statistically insignificant effect of day time temperature and solar radiation.

Karim et al (1996) conducted a simulation study for rice and wheat crop by using CERES-Rice and CERES-Wheat models to assess the vulnerability of foodgrain production in Bangladesh to potential climate change. They found that the higher temperature reduced the yields. They also found that wheat yield increases with the increase of CO_2 level.

1.11.6 Criticism

For getting the climate change scenario several studies have been performed based on General Circulation Model. But this approach is very limiting for the tremendous variation across models in each location. Probability analysis is conducted for this purpose where the probability distribution is assumed to be constant but in probability analysis it may not be constant. A few study have been done on the effect of climate variables with a few climatic factors by some authors in Bangladesh but these studies suffer from many problem such as authors did not search within and between year variability and trend and they did not investigate the time series properties, they have also ignored the stationary properties of the relevant variables, they did not check the property of residuals and outliers from diagnostic viewpoint, they did not use updated statistical tools and test procedure to draw valid inference. But most time series data may show the non-stationary in character and climatic variables may show within and between year variability in different angle and regression of one non-stationary series on another may give the so called spurious regression and lead to incorrect statistical inferences.

1.12 Rationale of the Study

Global agriculture will face the problems of a changing climate in coming decades [IPCC (1990a, 1992)]. Scientists are increasingly certain that the rise in global temperatures over the last 140 years is partially due to increasing concentrations of greenhouse gases. The global mean temperature has risen by 7°C since 1860. Over the same period, CO_2 concentrations have increased 46 percent. On the other hand the world population will be double by about the year 2060 [International Bank for Reconstruction and Development/World Bank (1990)]. Despite technological advances such as improved crop varieties and irrigation systems, climate is still key factor for agricultural productivity and crop yield growth has slowed since 1990 [Evenson and Gollins (2003b), Rosegrant and Cline (2003)]. Furthermore climate may vary and change with time and space and warming may affect agriculture sector as a whole through changing yields, changing water availability, affecting soil condition etc. The effect of climate on agricultural productions is important for local, regional, national and global scales [Kaufmann and Snell (1997); Frecton et al (1999); Gadgil et al. (1999)]. But continued crop yield increases are necessary to feed the world in the 21st century [Rosegrant and Cline (2003), Cassman (1999)]. So food security remains a challenge particularly in developing countries and this challenge is made worse by the adverse effect of predicted climate change in most food insecure developing countries (Rosenzwieg and Parry (1994)]. Bangladesh is one of the least developed nations of the world which may also be one of the vulnerable to climate change and variability. Wheat is the second most important cereal crop after rice in Bangladesh and it occupies 5.53 percent of the total cereal acreage contributing 5.87 percent of total cereal production. Wheat yield is much sensitive to climate variation and change. Temperature variation is the notable factor for wheat cultivation. Dinajpur is the highest wheat producing district of Bangladesh. But long-term effect of climate change on wheat production has not been critically examined in Dinajpur district. Therefore, in this study, I intend to examine some statistical aspects of the climate change in Dinajpur district and its impact on wheat cultivation and production by using exploratory data analysis, time series modeling and forecasting and public opinion survey. Since wheat production has a significant impact in the food security management and in the economy of Bangladesh and it may be affected by the climate change pattern with global or local scale temperature, humidity, sunshine hour etc., so to make the proper production policy of wheat we need to analyze the time series properties of wheat production in Bangladesh. In this research I consider Dinajpur district as our study area which has a long tradition of wheat cultivation and currently is one of the largest wheat producing area in Bangladesh.

1.13 Objectives of the Study

(a) General Objective

The general objective of the study is to examine whether the climate changes or not and how it is related to wheat production in Dinajpur district. This will be assessed with the help of empirical time series analysis and exploratory data analysis for the several long period climatic and production data series (1948-2004). Data has been examined and explored for decadal, annual, seasonal, monthly and for wheat growing period such as November to February.

(b) Specific Objectives

(i) To analyze the within and between year variability and trend pattern of studied climatic variables in different aspects

(ii) To detect outliers for characterizing the extreme events of different climatic and production variables

(iii) To investigate the time series properties of different climatic and wheat production variables

(iv) To assess the direction and extent of climate change

(v) To examine the stability and structural change in wheat production

(vi) To assess the impact of climate change on wheat cultivation through farmer's opinion survey

(vii) To assess the increasing /deteriorating factors of wheat production

(viii) To fit a model of per acreage wheat production

1.12 Organizations of the Thesis

The thesis consists of eight chapters. "Background of The Study" has been included in Chapter 1. "A Bird View of Geographical and Climatic Characteristics of Dinajpur District" has been discussed in Chapter 2. Chapter 3 deals with Sources of data and this nature and methods of analysis. Results of Trend and Variability Pattern of Climatic Variables in Dinajpur District by exploratory analysis have been discussed in Chapter 4. In the 5th chapter, Time Series Properties of Climatic and Wheat Production Data in Dinajpur District have been included. "Assessment for Impact of Climate Change on Wheat Production in Dinajpur District: A Regression Analysis Approach" has been included in Chapter 6. In the 7th chapter, People's Perception about Climate Change and Wheat Production in Dinajpur has been discussed. Summary Results and Scope of further research based on the findings of the study have been included in Chapter 8.

Chapter 2

Chapter 2

A Bird View of Geographical and Climatic Characteristics of Dinajpur District

2.1 Introduction

In the prehistoric and historic age, Dinajpur was a very big and notable part of ancient Barindra, pundra and Gaur. At the earlier stage of that period Debkot, Dhangarh, Mohastangarh, Garh pingoli, Dharmogarh, Gunjagarh, Mohastangarh and Vitorgarh were in the area of Dinajpur for a long time. According to Renel's map of Bangla and Bihar in 1778, the name of Dinajpur town was Rajganj. Once, king Ganesh ruled the territory of Dinajpur. He took a disguised name, 'Dinwaj and the name Dinajpur was named after his name. The area of Dinajpur came under the control of British administration in 1765. It was declared as a district first by the East India Company in 1786. The then Dinajpur district was comprised of Panchagarh, Thakurgaon, West Dinajpur, Moldoha, Bogra, Rajshahi and some area of Dhaka [Hossain (1965)].The territory of the present Dinajpur District during the undevided Bengal became a subdivision of the then Dinajpur District in 1860. The West Dinajpur was separated from other parts of Dinajpur during the period of partition in 1947 and it was included with west Bengal of India at that time. After the partition in 1947, Pakistan came into existence and Dinajpur District took a form taking Thakurgaon and Panchagarh. But after the Independence in 1971, Thakurgaon and Panchagarh each got the status of a district in 1984.

It is known that once the big-bodied river Karotoa flew through the eastern side of Dinajpur and at that time the river Karotoa was with swift current. Three rivers-Karotoa, Atrai and Jamuna were known as Tri-current Rivers. The Earthquake of 1787 made the river Karotoa narrower and it gave birth to a river, Teesta, which is now flowing by the district of Rangpur. In the ancient period Dinajpur was known as Fish-country [Hossain (1965)].

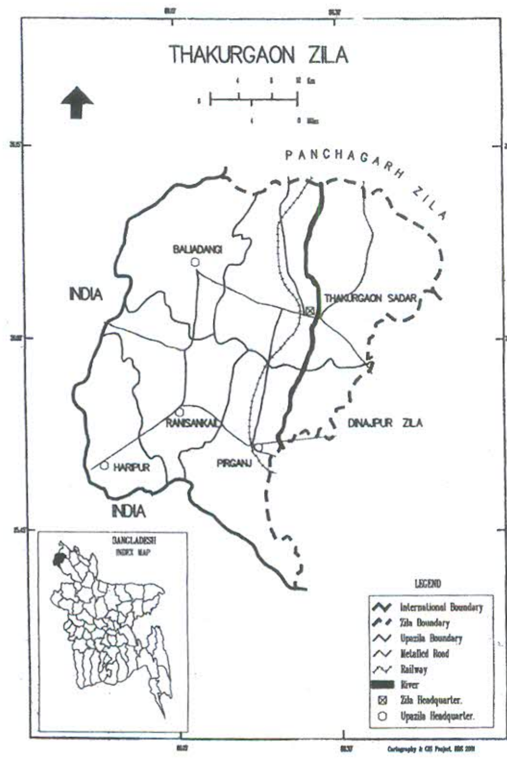
According to Population Census 2001, the total population in Present Dinajpur district was 2643000 and it was 2.12% of the total population and the density of population was 705 per sq.km while the total population in former Dinajpur district was 4694000 what was 3.77% of the total population of Bangladesh and the density of population was 768 per sq.km in this district. (Population cesus 2001, BBS report). The literacy rate was 40.70 of the population 7 years and above. The economy of Dinajpur District is mainly agro based where 59.81% holdings are farm among 454021 holdings. The district is famous for rice production. It is a food surplus district in Bangladesh. There are many crops such as rice, wheat, sugarcane, vegetables etc. are produced here. In addition to, several fruits like Litchi, Mango, Jackfruit, Pineapple, Guava are grown here. Moreover, it is rich with varieties fish and forest resources. The non-farm activities of this district are poor.

According to Population census of Pakistan of 1951, the area of that Dinajpur District was 2535sq.m and the number of people per sq. mile was 544. There were 2197 villages with total population of 1378816, the literacy rate was 7.77% in 1921, 6.22% in 1931, 9.74% in 1941 and 20.35% in 1951.The total cultivable land was 1231696 acres and it had two crop seasons called Rabi and Bhadoi and the share of cultivable area was 75.92%, share of cultivable waste was 12.28%, share of jungles and forests were 3.62% share of uncultivable waste was 8.18%.

At present the total area enjoyed by the district of Dinajpur is 3437.98sq.km. It has 13 Upazilas named Birampur, Birganj, Biral, Bochaganj, Chirirbandar, Phulbari, Ghoraghat, Hakimpur, Kaharole, Khansama, Dinajpur Sadar, Nawabganj and Parbatipur. Main occupation of people is agriculture (42.85**%), for agricultural labor is 29.19%.** Among the farm households, about 40% are landless, 30% are small farmers, 25% are medium farmers and 5% are large farmers. About 19.45sq.km is reverine and 78.87 sq.km is underforest in Dinajpur District. Per capita cultivable land of this district is 0.05 hectare. It is famous as rice growing area and the soil is more appropriate for root crop. It is also famous for Litchi and Mango. In ancient period, Dinajpur was called as Motso desh, country of fish and till 19th century, tiger and leapord were found in Dinajpur district. At present fish is scanty and tiger is not found, but several mamals are found including Dolphin. Dinajpur district does not possess many low lying areas, beels or marshy places and thus the aquatic flora are not rich. People of this district took part in the Tebhaga Movement and also had significant contribution in the War of Liberation.

2.2 Geographical Location

The district of Dinajpur situated between 25^0 13 and 25^0 54 on the north latitudes and between 88^0 23 and $89^0$18 on the east longitudes now and the district is bounded by Panchagarh and Thakurgaon district on the north. On the south it is bounded by Joypurhat, Gaibanda district and India, on the east by Rangpur and Nilphamari district and on the west by the West Bengal, India. The map – 1, 2 and 3 shows the boundary area of Thakurgaon, Panchagarh and Dinajpur districts.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PANCHAGARH ZILA
INDIA
BALIADANGI
THAKURGAON SADAR
RANISANKAIL
DINAJPUR ZILA
HARIPUR
PIRGANJ
INDIA
BANGLADESH INDEX MAP
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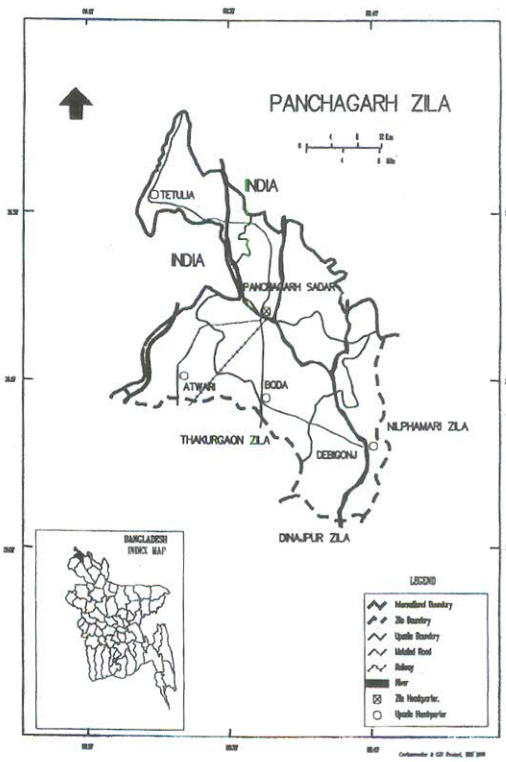
International Boundary
Zila Boundary
Upazila Boundary
Metalled Road
Railway
River
Zila Headquarter.
Upazila Headquarter.

1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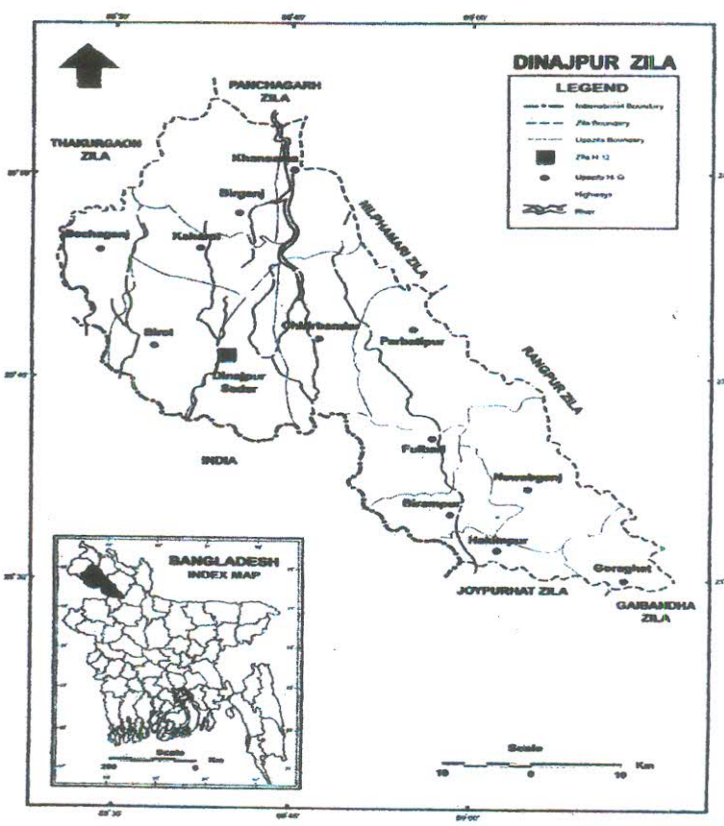
DINAJPUR ZILA
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Chirirbandar
Parbatipur
Dinajpur Sadar
RANGPUR ZILA
INDIA
Fulbari
Nawabganj
Birampur
Hakimpur
Ghoraghat
JOYPURHAT ZILA
GAIBANDHA ZILA
BANGLADESH INDEX MAP
Scale
Km

3

2.3 Characteristics of Soil

The land of Dinajpur district experiences old Himalayan Piedmont plain in most of its part. It also sees an old of the Teesta alluvial fan with a braid river landscape. Complex soil patterns of broad sandy or loamy ridges inter mixed with shallow channels or basins are found in this district. But the district mainly enjoys loamy soils. Two groups of soil such as kiar and poli are experienced. The soil of Barind tract in south east region of this district experiences the old alluvium taking the form of mixed brown and grey silty loam and the central part of meander floodplains along the river little Jamuna and the valley of karotoa river.

The former Dinajpur district had 326420ha high land, 251966 ha medium high land and 4485 ha midium low land among the total land of 582871ha. Land for settlement was 60139ha, pond and water bodies were 3650ha, river was 4966ha among the total land 68755ha. At present Dinajpur district possesses 153561ha high land, 146324ha medium high land and 2482ha midium low land among 302367ha total land. Land for settlement 34095ha, pond and bodies 2341ha, river 2390ha among the total land 38826 are in present Dinajpur district (2002).

2.4 Climate

The district of Dinajpur experiences temperate and pleasant climate. It shows high temperature, humidity and coldness. The mean temperature of this district ranges from 10.7^{0}C to 22.8^{0}C during winter and it varies from 23.4^{0}C to 34.1^{0}C during summer. Summer spans from April to June and winter spans from October to March. The month of July and August enjoy heavy rainfall in most of the period. The month of January experiences about 81% humidity and the month of July experiences about 87% humidity in the air. Annual average highest temperature is 33.5°C, lowest temperature is 10.5°C and annual rainfall is 2536 mm.

2.4.1 Soil Moisture

The weekly soil moisture (at different depth) for the year 2004 and 2005 is presented in Table 2.1. Average weekly soil moisture (at the depth of 5cm) of Dinajpur District was 18.13% for 2004 and 17.45% for 2005 and minimum moisture was 11.59% and 7.49% and maximum moisture was 35.44% and 27.03% respectively. Figure 2.2 and Figure 2.3 display the diagrams of weekly soil moistures (at the depth of 5 cm) for the year 2004 and 2005, respectively.

Table 2.1Weekly Soil Moisture (WSM) in 2004 and 2005

Level of WSM	2004					2005				
	5cm	10cm	20cm	30cm	50 cm	5cm	10cm	20cm	30cm	50 cm
Minimum	11.59	10.89	9.77	9.31	12.14	7.04	7.86	7.49	7.93	7.78
Maximum	35.44	29.12	46.56	26.62	25.24	27.03	23.55	23.01	24.51	24.49
Mean	18.13	17.41	18.04	18.54	18.59	17.45	16.57	16.73	17.13	18.11

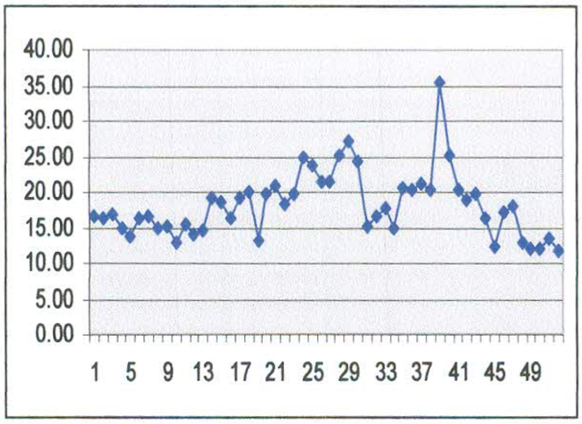


Figure 2.2 Line diagram of WSM for 2004

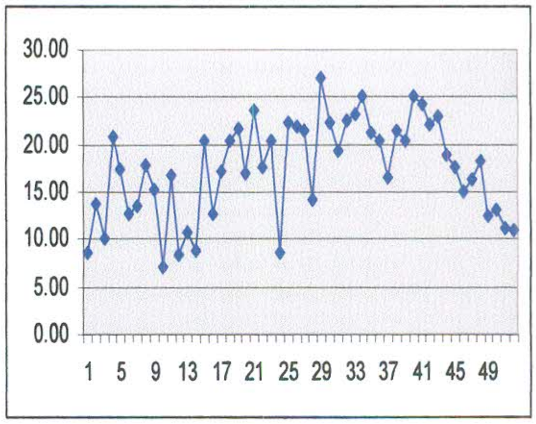


Figure 2.3 Line diagram of WSM for 2005

Table 2.2 represents monthly average soil moisture at different depths of soil for the years 2004 and 2005. In the year 2004, the month of July of Dinajpur District experiences the highest soil moisture (24.53%) at the depth of 5cm, 22.60% at the depth of 10 cm, 21.94% at the depth of 20cm, 22.29% at the depth of 50cm while at the depth of 30cm the month of September experiences the highest soil moisture and the month of December experiences the lowest soil moistures 12.25%(at the depth of 5cm), 12.07% (at the depth of 10cm), 12.70% (at the depth of 20cm), 13.45% (at the depth of 30cm) and 15.34% (at the depth of 50cm), respectively. In the year 2005, the month of October experiences the highest soil moisture (22.65%) at the depth of 5cm and the month of October experiences the highest soil moistures 20.63% at the depth of 10cm, 20.85% at the depth of 20cm, 20.78% at the depth of 30cm, respectively. At the depth of 50cm, the highest soil moisture (22.21%) is experienced in the month of June. On the other hand, the lowest soil moisture (10.74%) at the depth of 5cm, 10.91% at the depth of 10cm, 10.92% at the depth of 20cm, 12.27% at the depth of 30cm and 12.83% at the depth of 50cm are experienced in the year 2005. Figure 2.4 and Figure 2.5 display the monthly soil moisture for 2004 and 2005 at different depths of soil.

Table 2.2 Monthly Soil Moisture (MSM) in 2004 and 2005

	Soil moisture 2004					Soil moisture 2005				
Month	**5cm**	**10cm**	**20cm**	**30cm**	**50cm**	**5cm**	**10cm**	**20cm**	**30cm**	**50cm**
Jan	16.13	16.25	17.28	18.09	18.28	14.08	13.84	13.76	13.90	14.57
Feb	15.41	16.73	17.90	20.76	17.26	14.77	13.26	13.56	15.10	15.66
Mar	14.38	15.66	16.07	16.01	16.95	10.74	10.91	10.92	12.27	12.83
Apr	18.27	15.56	15.52	15.12	15.53	14.73	13.81	13.87	14.34	14.25
May	18.48	15.52	14.75	15.43	16.87	20.02	18.85	18.54	19.32	18.70
Jun	22.47	19.97	20.15	22.09	21.72	18.28	19.46	20.03	18.53	22.21
Jul	24.53	22.60	21.94	21.66	22.29	21.26	20.39	20.55	20.30	21.66
Aug	16.93	18.20	17.99	20.19	19.36	22.23	20.63	20.85	20.78	21.71
Sep	24.26	22.17	21.93	23.21	22.00	19.66	17.47	19.19	18.92	20.52
Oct	20.96	20.23	20.20	20.53	21.22	22.65	20.09	19.01	20.11	21.63
Nov	15.33	15.26	20.73	17.23	17.22	16.75	15.03	15.56	16.18	17.46
Dec	12.25	12.07	12.70	13.45	15.34	11.86	13.29	13.62	14.39	15.11

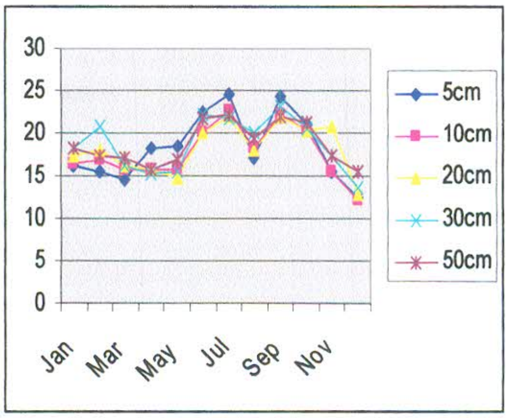


Figure 2.4 Line diagram of MSM in 2004

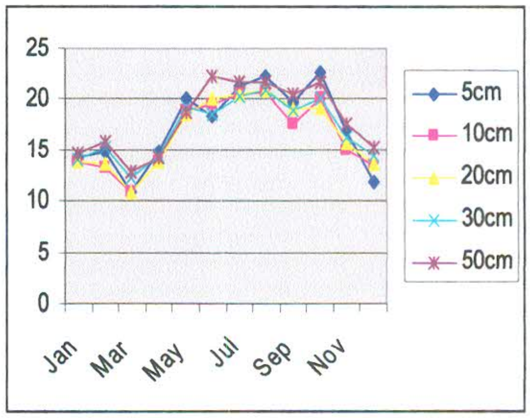


Figure 2.5 Line diagram of MSM in 2005

The average annual soil moistures (AASM) of Dinajpur district were 18.28%, 17.52%, 18.10%, 18.65% and 18.67% for the depth of 5cm, 10cm, 20cm, 30cm and 50cm respectively in 2004 and in 2005 they were 17.25%, 16.42%, 16.62%, 17.01% and 18.03% respectively. The average soil moistures (ASM) for wheat growing period of Dinajpur district were 14.70% 15.19% 16.93% 17.11% and 17.01% for the depth 5cm, 10cm, 20cm, 30cm and 50cm respectively in 2004 and in 2005 they were 13.64%, 13.27%, 13.48%, 14.37%, and 15.13% for the depth 5cm, 10cm, 20cm and 30cm and 50cm respectively. In 2004, the Kharif season of Dinajpur district experiences the highest soil moisture for different depths of soil and the Rabi season experiences the lowest soil moisture for the depth of 5cm and 10cm at the depth of 20cm, 30cm and 50cm. The Prekharif season experiences the highest soil moisture. In 2005, Kharif

Season also experiences the highest soil moistures for different depths and Rabi season also experiences the lowest soil moisture except the depth of 50 cm and at the depth of 50 cm Prekharif season experiences lowest soil moisture [Table 2.3]. Figure 2.6 and Figure 2.7 display the multiple bar diagram of average soil moisture for seasonal, annual and wheat growing period at different depths of Soil.

Table 2.3 ASM for Seasonal, Annual and WP at Different Depth of Soil

Season	Soil Moisture 2004					Soil Moisture 2005				
	5cm	10cm	20cm	30cm	50cm	5cm	10cm	20cm	30cm	50cm
Rabi	14.78	15.08	17.15	17.38	17.02	14.37	13.86	14.13	14.89	15.70
Prekharif	17.05	15.58	15.44	15.52	16.45	15.16	14.52	14.44	15.31	15.26
Kharif	21.83	20.63	20.44	21.54	21.32	18.96	18.05	18.40	18.46	20.04
Annual	18.28	17.52	18.10	18.65	18.67	17.25	16.42	16.62	17.01	18.03
WP	14.70	15.19	16.93	17.11	17.01	13.64	13.27	13.48	14.37	15.13

*WP= Wheat growing period

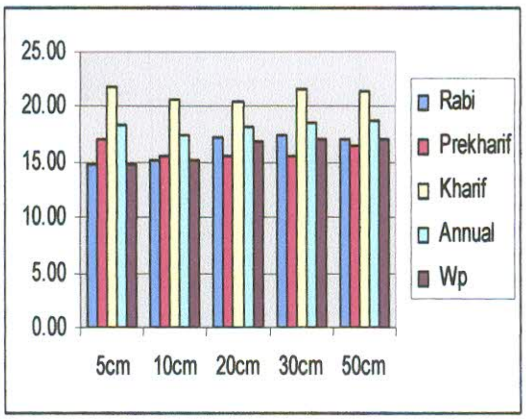


Figure 2.6 Bar diagram of ASM for 2004

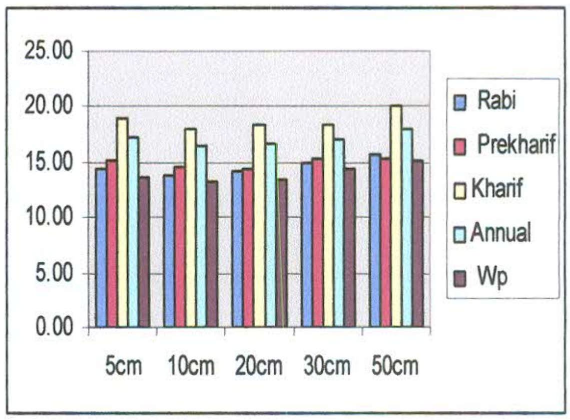


Figure 2.7 Bar diagram of ASM for 2005

2.4.2 Soil Temperature

The district of Dinajpur experiences the average annual soil temperature (AST) of 25.90^{0}C, 26.34^{0}C, 26.31^{0}C, 26.23^{0}C and 26.20^{0}C for the depth of 5cm, 10cm, 20cm, 30cm and 50cm, respectively. Average soil temperatures at the depth of 5cm, 10cm, 20cm, 30cm and 50cm for wheat growing period are 20.40^{0}C, 21.08^{0}C, 21.21^{0}C, 21.40^{0}C and 21.67^{0}C, respectively. The Kharif season experiences the highest average soil temperature and the Rabi season experiences the lowest average soil temperature in Dinajpur district [Table 2.4]. Figure 2.8 displays the multiple bar diagram of average soil temperature for seasonal, annual and wheat growing period at different depths.

Table 2.4 AST for Seasonal, Annual and WP at Different Depth

Season	Average Soil Temperature				
	5cm	10cm	20cm	30cm	50cm
Rabi	19.47	20.24	20.54	20.88	21.32
Prekharif	27.74	27.97	27.48	27.05	26.52
Kharif	29.95	30.24	30.23	30.01	29.92
Annual	25.90	26.34	26.31	26.23	26.20
WP	20.40	21.08	21.21	21.40	21.67

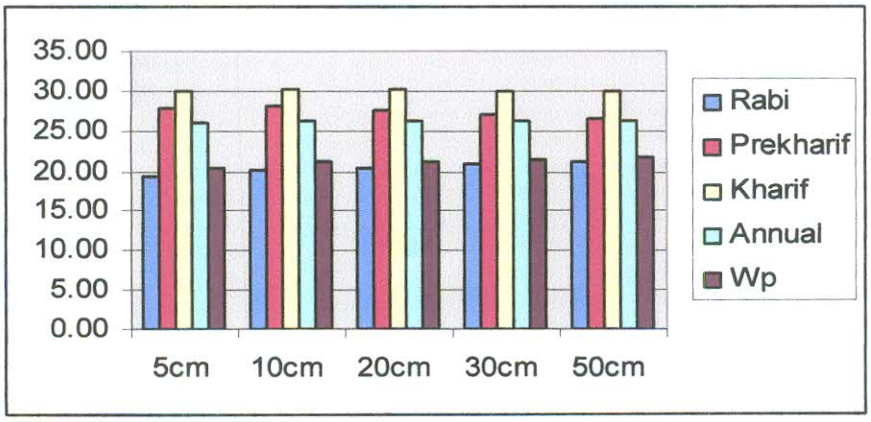


Figure 2.8 Bar diagram of AST for seasonal, annual and WP at different depth

2.4.3 Sunshine hour

The district of Dinajpur experiences annual average sunshine hour of 6.46, annual minimum sunshine hour of 5.89 and annual maximum sunshine hour of 7.17. The average sunshine hour (ASSH) for wheat growing period was 7.31, the minimum sunshine hour was 6.66 and maximum sunshine hour was 8.24. The Prekharif season of Dinajpur district experiences highest average sunshine hour 7.50 and the Kharif season experiences lowest average sunshine hour, minimum sunshine hour of 6.36 and maximum sunshine hour of 8 [Table 2.5]. Figure 2.9 displays the bar diagram of maximum, minimum and average sunshine hour for seasonal, annual and wheat growing period and Figure 2.10 displays the bar diagram of average, minimum and maximum monthly sunshine hour.

Table 2.5 ASSH for Seasonal, Annual and WP

Variable	Mean	Minimum	Maximum
Rabi	7.09	6.36	8
Prekharif	7.50	6.34	8.53
Kharif	5.34	4.45	6.19
Annual	6.46	5.89	7.17
WP	7.31	6.66	8.24

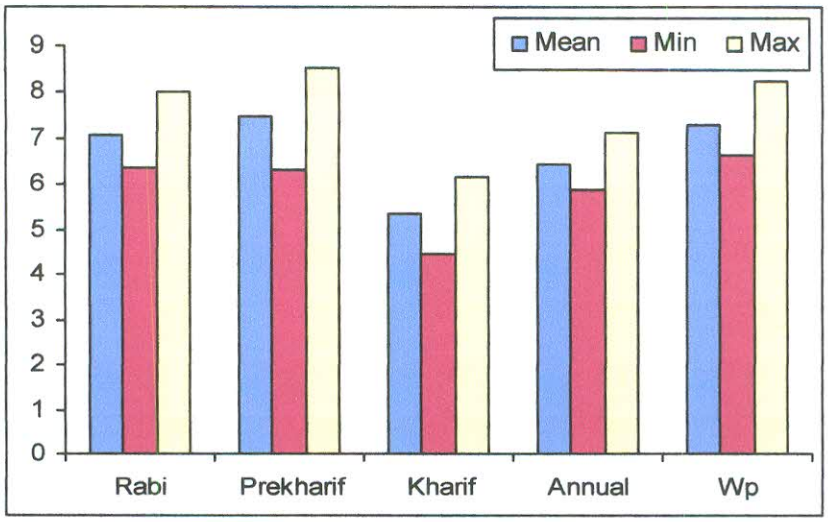


Figure 2.9 Bar diagram of ASSH for Seasonal, Annual and WP

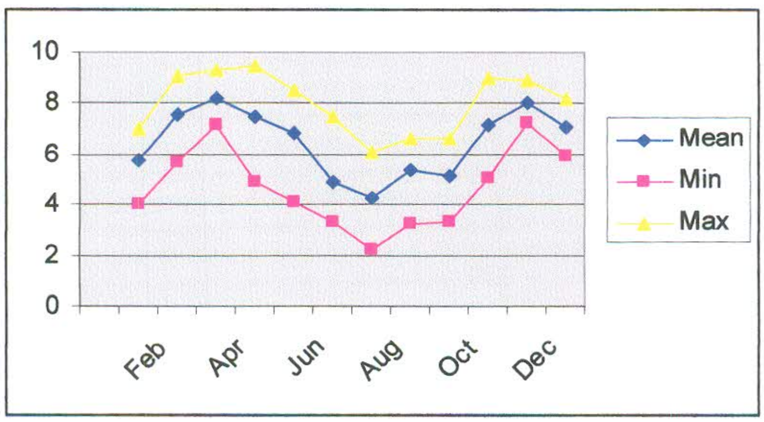


Figure 2.10 Bar diagram of Monthly Sunshine Hour

2.4.4 Evaporation

The district of Dinajpur experiences annual average evaporation of 34.98, annual minimum evaporation of 27.75 and annual maximum evaporation 40.17 over a period of 1987 to 2000. Average evaporation (AE), minimum evaporation, and maximum evaporation for wheat growing period (WP) of this district were 27.54, 23.4 and 30.4, respectively. The Prekharif season experiences the highest evaporation and the Rabi season experiences the lowest evaporation for each case of average, minimum and maximum [Table 2.6]. Figure 2.11 displays the bar diagram of evaporation for seasonal, annual and wheat growing period and Figure 2.12 displays the bar diagram of monthly average evaporation.

Table 2.6 AE for Seasonal, Annual and WP During 1987-2000

Variable	Mean	Minimum	Maximum
Rabi	22.60	19.25	25.5
Prekharif	50.33	35.33	63.67
Kharif	35.69	25	40.8
Annual	34.98	27.75	40.17
WP	27.54	23.4	30.4

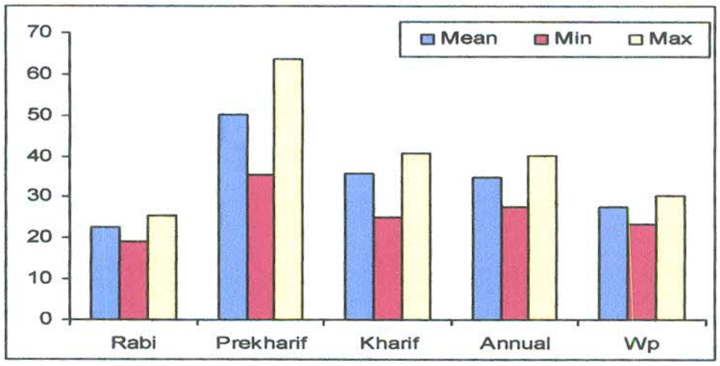


Figure 2.11 Bar Diagram of Evaporation for Seasonal, Annual and WP

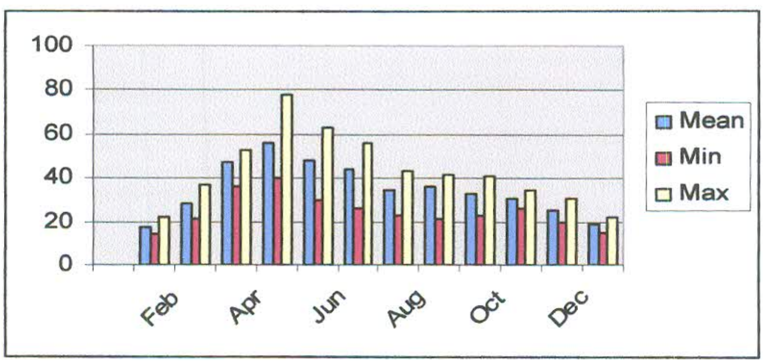


Figure 2.12 Bar diagram of Monthly average Evaporation

The area of Dinajpur grows 4696321mt of wheat in the area of 5831750 acres over the years 1948-2004. It grows about 0.03% during 1948-1950, 0.15% during 1951-60, 0.35% during 1961-1970, 4.03% during 1971-1980, 25.48% during 1981-1990, 44.51% during 1991-2000 and 25.46% during 2001-2004.The cultivated land of wheat covers about 0.11% during 1948-1950, 0.48% during 1951-60, 0.83% during 1961-1970, 4.67% during 1971-1980, 27.18% during 1981-1990, 43.25% during 1991-2000 and 23.48% during 2001-2004.In wheat growing season, we have the decadal means for TR, AC, ARH, AMWS, AWS, ASLP, AMXT, AMNT, ARNT, ADBT, AWBT are 39.5mm, 0.906octas, 69.55%, 5.03knots, 0.883knots, 1013.3mb, 27.62^{0}C, 13.55^{0}C, 14.07^{0}C, 20.17^{0}C and 16.5^{0}C while decadal coefficient of variations are 62.79%, 33.00%, 5.14%, 50.9%, 74.52%, 0.01974%, 2.259%, 1.276%, 5.351%, 5.35%, 2.62%, respectively. The yearly mean for the climatic variables of TR, AC, AMXT, AMNT, ARNT, ADBT, AWBT, AT(D-W), AST(5), ARH, ARH(12), ARH(0), ARH(0-12), AMWS, AWS, ASLP, AE, ASH are 42.25mm, 0.938octas, 27.6^{0}C, 13.6^{0}C, 14^{0}C, 20.1^{0}C, 16.5^{0}C, 3.6^{0}C, 20.4^{0}C, 70.02%, 60.19%, 89.62%, 29.42%, 5.018knots, 0.872 knots, 1013mb, 27.54% 7.319, respectively while the coefficient of variations are observed 94.49%, 38.7%, 2.94%, 4.71%, 7.37%, 3.9%, 3.89%, 17.8%, 3%, 6.458%, 9.903%, 4.038%, 10.65%, 56.16%, 80.37%, 0.049%, 0.049%, 6.79%, respectively during the years 1948-2004. The trend for the variables of TR, AMNT, AWBT, AWS, AMWS, ARH and AST are observed to be upward and the trend for the variables of FZR, AMXT, ARNT, AT (D-W), AE, ARH (0-12), FZR, ASLP, ASH are found to be downward where ADBT shows slight upward trend. An attempt has been made to investigate the time series properties of wheat production data from 1948 to 2004 in Dinajpur district. Figure 2.13 to Figure 2.28 display the TS plots and trends of climatic variables in Dinajpur District during wheat growing period over the years 1948-2004. The trends in total rain, maximum rain, average ADBT, average FADBTT, average AMNT, average AWBT, average ARH show upward trend, while the trends in average AMXT, average ARNT, average frequency of INSR, average AT(D-W), average ARH(0-12), average ASLP and average AMWS show downward trend.

[TR-Total rainfall, AC-Average cloud, ARH-Average relative humidity, ARH (0-12) AMWS,-Average maximum wind speed, AWS-Average wind speed, ASLP-Average sea level pressure, AMXT-Average maximum temperature, AMNT-Average minimum temperature, ARNT-Average range temperature, ADBT-Average dry bulb temperature, AWBT-Average wet bulb temperature, FADBTT-Frequency of average dry bulb temperature which is greater than 20 ^{0}C and AFINSR- average frequency of insignificant rain]

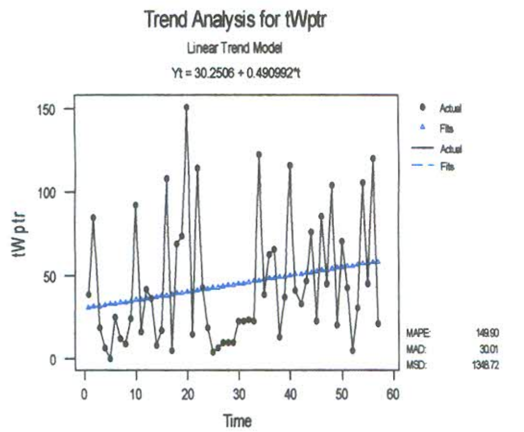


Figure 2.13 TS plot of total rain in wp

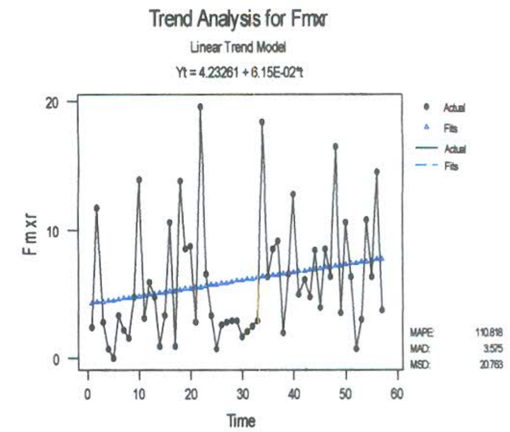


Figure 2.14 TS plot of total maximum rain in wp

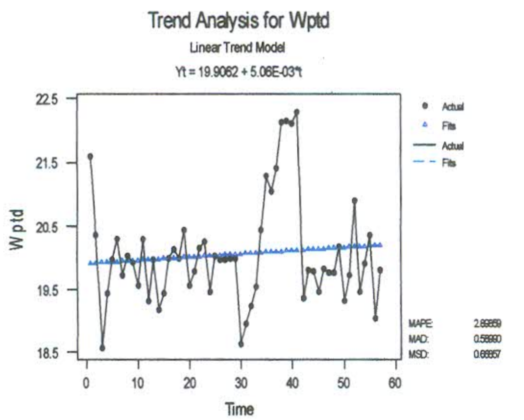


Figure 2.15 TS plot of average ADBT in wp

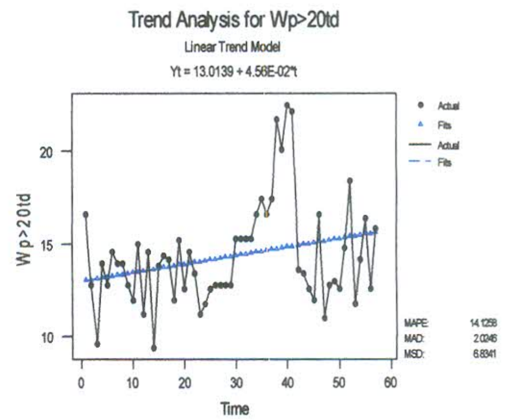


Figure 2.16 TS plot of average freq. for FADBTT in wp

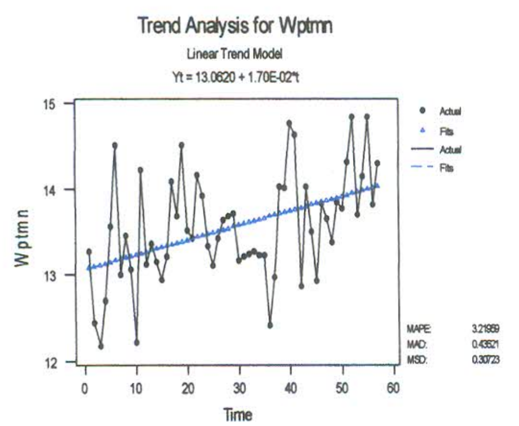


Figure 2.17 TS plot of average AMNT in wp

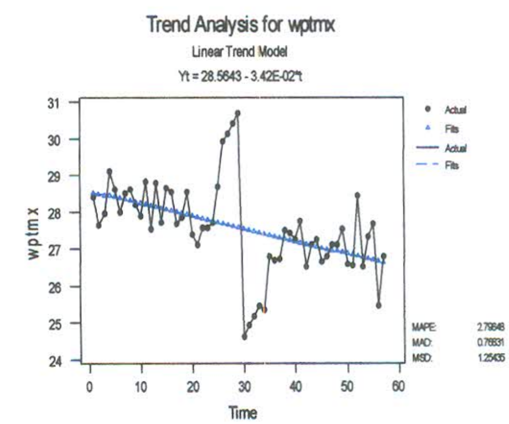


Figure 2.18 TS plot of average AMXT in wp

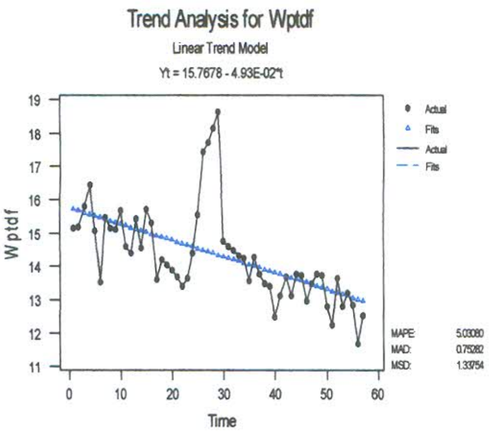


Figure 2.19 TS plot of average ARNT in wp

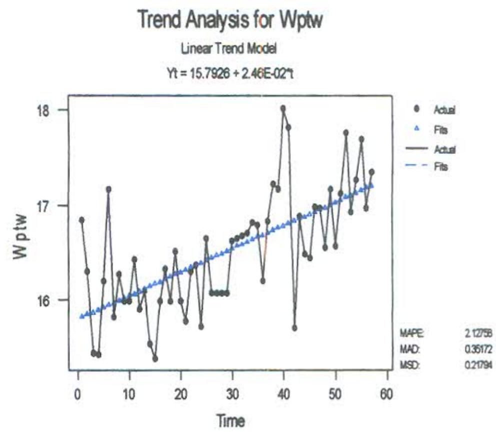


Figure 2.20 TS plot of average AWBT in wp

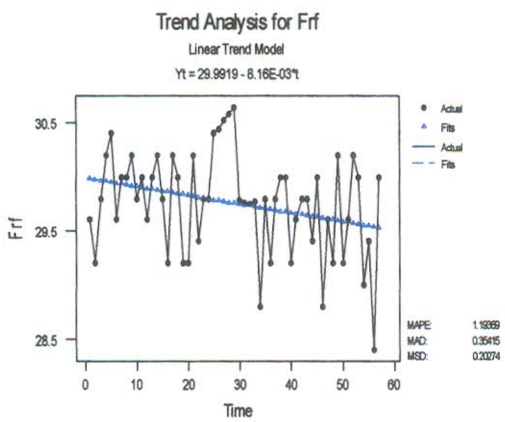


Figure 2.21 TS plot of AFIR in wp

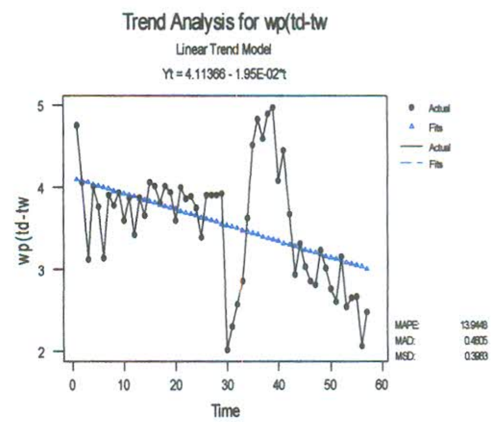


Figure 2.22 TS plot of average AT(D-W) in wp

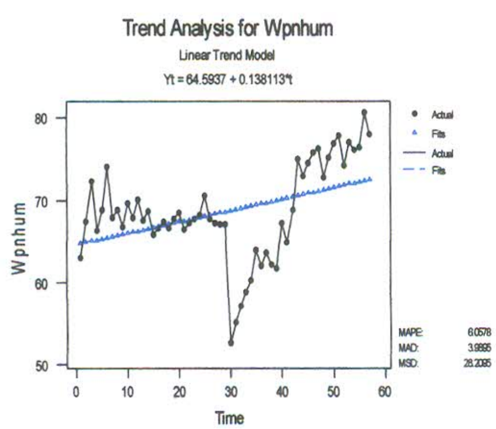


Figure 2.23 TS plot of average ARH in wp

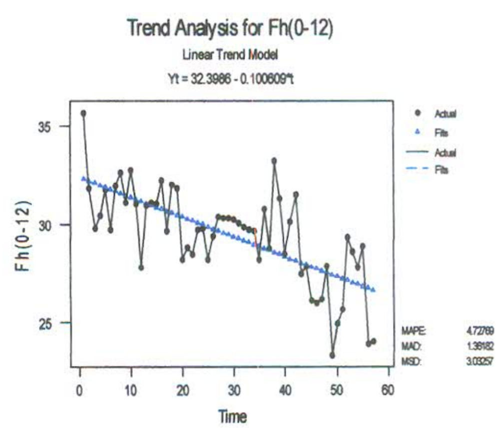


Figure 2.24 TS plot of average ARH (0-12) in wp

like vultures, kites, hawks, owls, crows, cuckoos, kingfishers, green pegions, wood pegion, doves, the water birds coot, the moorhen and several kinds of herons and cranes enrich the beauty of nature of this district. Different categories of reptiles and snakes like the poisonous cobra, karait, king cobra, banded karait are found in this district and sometimes the python are found. Once Dinajpur was famous for huge fish but now supply of fish is scanty. The Rohit, Boal, Magur, Pabda, Shol, Gari, Cheng, Koi etc. are now found to some extent.

2.7 Flora

Many types of trees and plants like Banyan, Peepul, Pakar, Simul, Nim, Mango, Jackfruit, Babla, Sal, Jam, Guava, Banana, Bel, Tamarind, Palas and Hijal are seen everywhere in Dinajpur District. Mehogony, Debdaru, wild bemboo, palm (tal), date (kejur) etc. are also grown here. The nol khagra, sola, floats for fishing nets, water lilies, lotus etc. are also seen in this district.

2.8 Crop area

The net cropped area of Dinajpur district is 278668 ha. The total cultivated area is 294362 ha during 1980-81 to 2003-04. Among them three crop area is 20% (54360 ha), two crop area is 66% (183883 ha) and single crop area is 14% (40425 ha). Out of the total cultivated area 75% (403323 ha), 11%, 4% and 2% were devoted to rice, wheat potato maize including other crops, respectively. Intensity of cropping was 85.62% and irrigated land was 81% [Report 2004, DAE Dinajpur].

Table 2.7 Percentage Share of Several Cropped Area during 1980-81 to 2003-04

Crops	1980-81	1984-85	1989-90	1994-95	1999-00	2003-04
Total cropped area	1858543	1750000	1975000	1800000	2305000	2080710
Wheat	10.9137	8.8851	9.4841	12.2939	15.7987	15.7240
Maize	0.0964	0.0657	0.0046	0.0189	0.0319	0.7925
IRRI/Boro	0.9768	1.9960	7.8841	14.8928	21.4200	24.2701
Aus	25.9991	24.6166	9.2494	6.1194	3.4733	4.2243
Aman	47.8340	49.7369	54.8309	47.8733	44.8967	46.3568
Potato	1.1974	1.3583	1.4428	1.8044	2.2169	2.8913
Masur	0.1305	0.1309	0.3534	0.4008	0.2564	0.3030
Mung	0.0831	0.0471	0.2051	0.2317	0.1718	0.1375
Kheshari	0.0834	0.0669	0.2762	0.2861	0.1729	0.0690
Mustered	2.4213	2.4660	2.1114	1.9789	1.8631	1.5194
Till	0.0920	0.0883	0.6575	0.6806	1.1698	1.5271
Sugarcane	1.9203	2.3574	2.3818	2.5089	1.9289	2.1346
Tobacco	0.0864	0.0914	0.0592	0.0248	0.0197	0.0154
Ground Nut	0.0008	0.0040	0.0058	0.0078	0.0022	0.0351

Figure 2.29 Bar diagram of total cropped area

Figure 2.30 Bar diagram of wheat

Table 2.7 shows the percentage share of several cropped area during 1980-81 to 2003-04. The percentage share of wheat cultivated area decreased from 10.9% in 1980-81 to 8.89% in 1984-85 and then it increased from 8.89% in 1984-85 to 15.79% in 1995-00 and it again decreased from 15.79% in 1995-00 to 15.72% in 2003-04.The percentage share or Maize cultivated area decreased from 0.096 percent in 1980-81 to 0.0189% in 1994-95 and it again increased from 0.0189 percent in 1980-81 to 0.79% in 2003-04. The percentage of IRRI/Boro cultivated area increased from 0.97% in 1980-81 to 24.27% in 2003-04. The percentage of Aus cultivated area decreased from 25.9 in 1980-81-00 to the lowest of 3.45% in 1999-00 and 4.22% in 2003-2004. The percentage of Aman cultivated area increased from 47.83% in 1980-81 to 54.83% in 1989-90 and then it decreased to 47.87% in 1994-95 and after then it again decreased from 47.87% in 1994-95 to 46.35% in 2003-04.The percentage of potato cultivated area increased from 1.19% in 1980-81 to 2.89% to 2003-04. The percentage of Masur cultivated area increased from 0.1305% in 1980-81 to 0.4008% in 1994-95 and then it decreased from 0.4008% in 1994-95 to 0.2564% in 1995-00 and again it increased from 0.2564% in 1995-00 to 0.3030% in 2003-04. The percentage of Mung cultivated area decreased from 0.08% in 1980-81 to 0.04% in 1984-85. Bar diagram of cropped area under different crops are shown in Figure 2.29 to Figure 2.36.

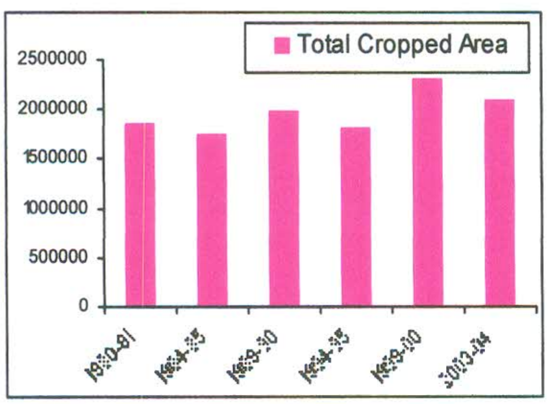


Figure 2.29 Bar diagram of total cropped area

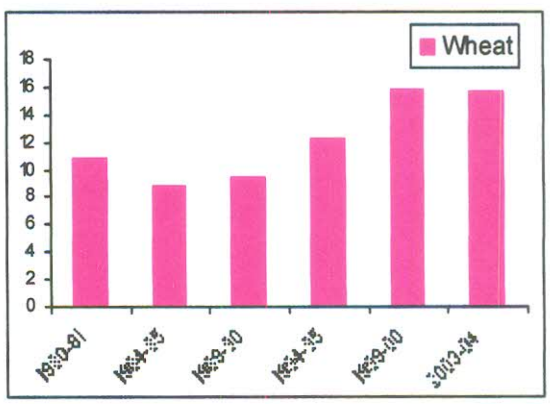


Figure 2.30 Bar diagram of wheat

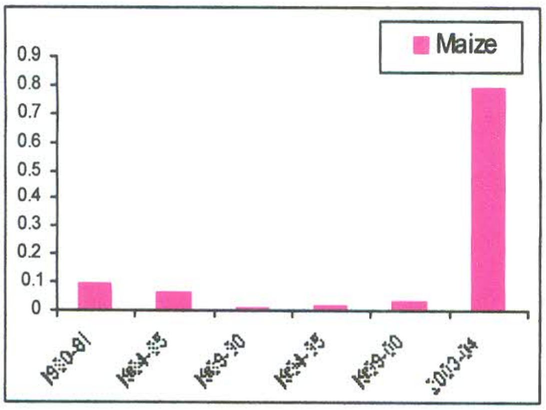


Figure 2.31 Bar diagram of Maize

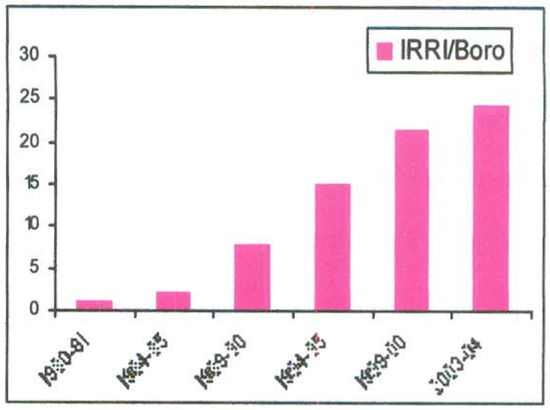


Figure 2.32 Bar diagram of IRRI/Boro

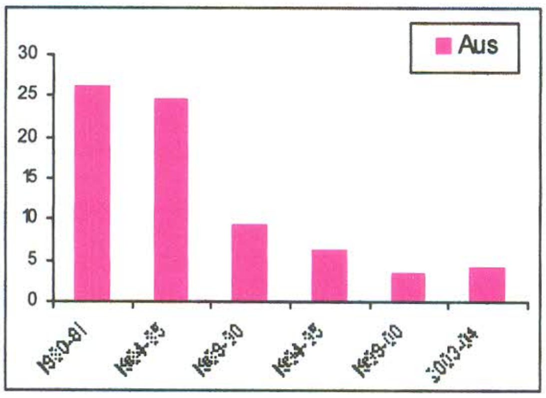


Figure 2.33 Bar diagram of Aus

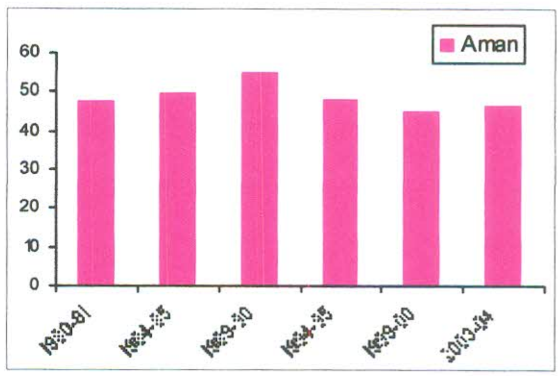


Figure 2.34 Bar diagram of Aman

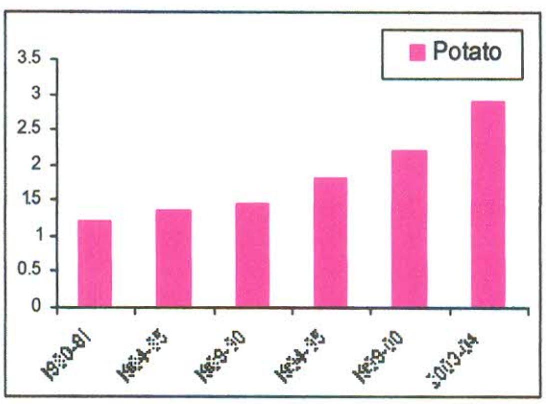


Figure 2.35 Bar diagram of Potato

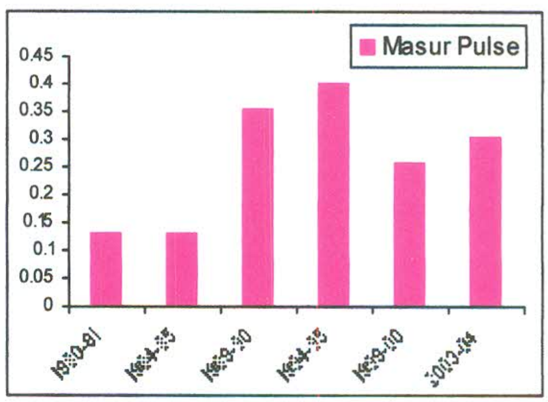


Figure 2.36 Bar diagram of Masur Pulse

Table 2.8 shows the area (in acres) and production (in mts) for total Rice, Aus, Aman, Boro in Dinajpur district and Table 2.9 shows the area (in acres) and production of Wheat and Maize (in mts). Bar diagram for area and production of total Rice, Aus, Aman, Boro, Wheat and Maize are shown in Figure 2.37 to Figure 2.40.

Table 2.8 Area and Production of Total Rice, Aus, Aman and Boro

	Total Rice		Aus		Aman		Boro	
Year	Area	Production	Area	Production	Area	Production	Area	Production
1947-48	881400	313657	150900	42979	730000	270473	500	203
1950-51	930300	336447	180000	58240	750000	278113	300	91
1960-61	970200	419794	199300	74436	768900	344644	2000	711
1970-71	1396650	664273	489920	192187	893380	462714	13350	9368
1980-81	1386020	718644	483205	193775	884660	505567	18155	21344
1990-91	1425000	1052000	215360	88510	1057600	793460	152550	169890
2000-2001	1569000	1444000	42040	30840	1034270	799250	492910	613610
2003-2004	1497000	1390000	27130	23780	964550	725330	504990	640880

*unit of area in acres and unit of production in metric tons

Table 2.9 Area and Production of Wheat and Maize

	Maize			Wheat	
Year	Area	Production	Year	Area	Production
1947-48	700	132	1947-48	2000	406
1950-51	3000	676	1950-51	2700	544
1960-61	4600	1717	1960-61	4500	1321
1970-71	2520	902	1970-71	6730	2738
1980-81	1792	485	1980-81	202835	150968
1990-91	220	40	1990-91	206970	156600
2000-2001	1020	860	2000-2001	344930	324590
2003-2004	16490	24060	2003-2004	327170	216280

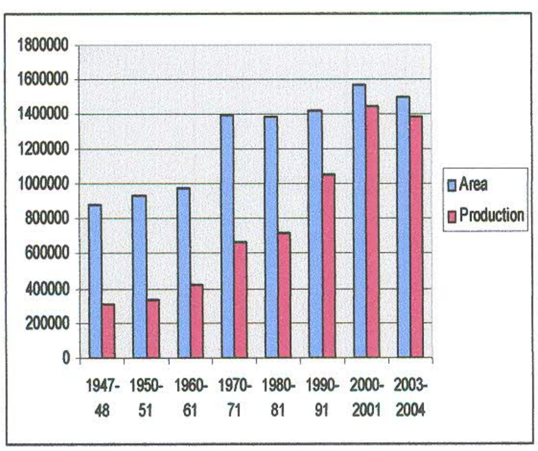


Figure 2.37 Bar Diagram of area and production for Total Rice

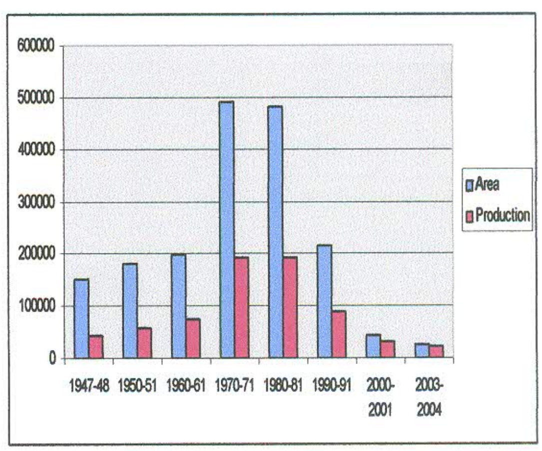


Figure 2.38 Bar Diagram of area and production for Aus

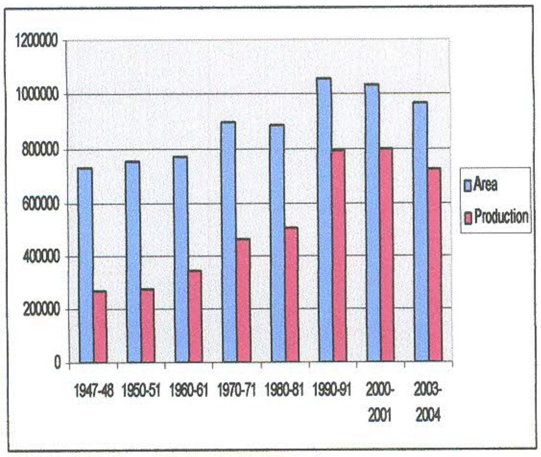


Figure 2.39 Bar Diagram of area and production for Aman

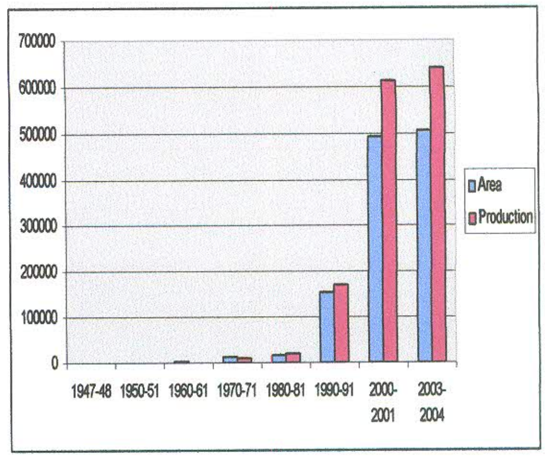


Figure 2.40 Bar Diagram of area and production for Boro

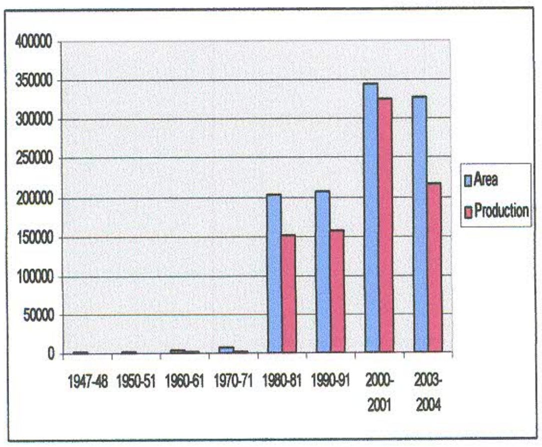


Figure 2.41 Bar Diagram of area and production for Wheat

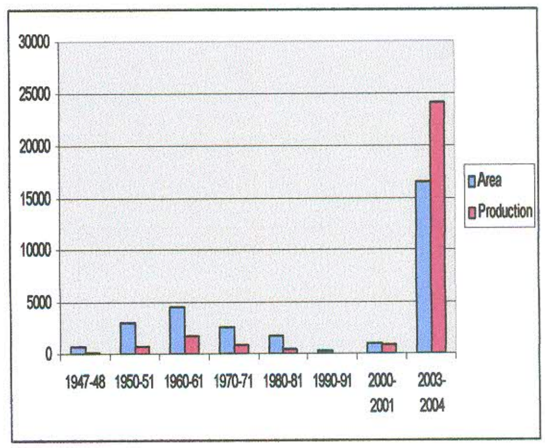


Figure 2.42 Bar Diagram of area and production for Maize

Chapter 3

Chapter 3

Materials and Methods

3.1 Introduction

Classical parametric statistics suffer a huge set back in practice because of their strong dependence on extraneous assumption that do not usually hold in a real world problem. It often becomes irrelevant particularly in time ordered data. In this thesis the historical time ordered data are used. Time series is thought of as a realization of a stochastic process. The main target of time series analysis is to find a useful model to reveal a time structured relationship among some variables or events and model helps to forecast the variables. It may be mentioned that exploratory data analysis (EDA) methods are used primarily to explore the data before using more traditional methods, or to examine the residuals from a model. We study the trend and variability pattern of the data by using modern exploratory data analytic tools and techniques. We construct model for the data by using Univariate Box-Jenkin's modeling techniques and it is hoped that the models have similar properties to those of the generating mechanism of the stochastic process. 1^{st} order Piece wise autoregressive [PAR(1)] model, as suggested Imon (2007) and regression analysis approach with its diagnostics are used in the thesis. An opinion survey is also conducted to know the views of farmers regarding impacts of climate change on wheat production.

3.2 Sources of Data and Its nature

According to the objectives of the thesis, we have tried to collect both the secondary and primary data on climatic factors and the production of wheat as well as the acreage of wheat to furnish the research work.

3.2.1 Secondary Data Collection

The secondary data on climatic factors of Dinajpur district are collected from the Bangladesh Meteorological Department, Agargaon, Dhaka, Bangladesh and the data on production and acreage of wheat are collected from the book "A Data Base on Agriculture and Food grains in Bangladesh (1947-48 to 1989-90)" written by Mohammad Abdul Hamid Ph.D and "Statistical Year book of Bangladesh" published by the Bangladesh Bureau of Statistics(BBS).

1. Temperature: The daily and monthly average temperature data on minimum, maximum, dry bulb mean and wet bulb mean are collected for the period of 1948 to 2004. The measurement units are taken in degree centigrade.

2. Rainfall: The daily and monthly total rainfall data are collected for the period of 1948 to 2004. The measurement units are taken in millimeter.

3. Humidity: The daily and monthly relative humidity data on average, morning and evening in percentage are collected for the period of 1948 to 2004.

4. Wind speed: The daily and monthly wind speed data on maximum and mean are collected for the period of 1948 to 2004.The measurement units are taken in knots.

5. Sea level pressure: The daily and monthly average sea level pressure data are collected for the period of 1948 to 2004. The measurement units are taken in milibar.

6. Sunshine hour: The daily and monthly sunshine hour data are collected for the period of 1989 to 2004.

7. Cloudiness: The daily and monthly cloudiness data are collected for the period of 1948 to 2004.The measurement units are taken in octas.

8. Evaporation: The daily and monthly percentage of evaporation data are collected for the period of 1987 to 2000.

9. Soil temperature: The daily and monthly soil temperature data in degree centigrade at the depth of 5cm, 10cm, 20cm, 30cm and 50cm are collected for the period of 1987 to 2000.

10. Soil moisture: The weekly soil moisture data at the depth of 5cm, 10cm, 20cm, 30cm and 50cm are collected for the period of 2001, 2002 and 2003.

11. Production of wheat: The annual data on wheat production in metric ton are collected for the period of 1947-48 to 2003-2004.

12 Acreage of wheat cultivation: The acreages of wheat cultivation in acres are collected for the period of 1947-48 to 2003-2004.

3.2.2 Primary Data Collection

To have practical view of climate change and its impact on wheat production in Dinajpur district we collected the primary data through an opinion survey from the three new born districts of Dinajpur such as Panchagarh, Thakurgaon and Dinajpur district which were divided in 1984. There are 13 Upazilas in the newborn district of Dinajpur, 5 Upazilas in Panchagarh and 5 Upazilas in Thakurgaon. The survey is conducted among the farmers of 6 Mauzas and the Mauzas such as Chotacheng gram and Lakshmipur are selected from Hakimpur Upazila of Dinapur district, Khudrabanshbari and Uttar Maheshpur are selected from Ranishankail Upazila of Thakurgaon District and Sukhati and Fatehpur are selected from Atwari Upazila of Panchagarh district. Sample areas are selected through simple random sampling technique without replacement. We select three Upazilas according to the rank for the rate of total wheat production and total wheat cultivated area of 23 Upazilas of Dinajpur region for the three years 2002-2003, 2003-2004 and 2004-2005 and then we select three Mauzas among the Mauzas of three selected Upazilas according to the rank of the rate of total wheat production and total wheat cultivated area of 23 Upazilas of Dinajpur region for the three years 2002-2003, 2003-2004 and 2004-2005. For the purpose of ranking we collect the secondary data for wheat cultivated area and production for 23 Upazilas from District Agricultural Extension office and we observe that Hakimpur of Dinajpur district was the highest wheat yielding Upazila, Atwari of Panchagarh district was the lowest wheat yielding Upazila and Ranisankail of Thakurgaon District held the 7th position in rank.

The target population (respondent) of the study are the 50 and above 50 aging farmers and agricultural workers of sample area. Personal interview approach is followed for data collection from field and the investigators personally contact with the respondents. They clearly explain the objectives of the survey and the requirements of the data to the respondents to obtain the required information accurately and try to reduce the possibility of non-response error. Three hundred thirteen (313) farmers [aging 50 years and above] of the selected Mauzas are interviewed who opine regarding the climate change of Dinajpur District.

For data collection instruments one set of questionnaire is developed to collect information on various issues of climate change. The draft questionnaire is pre-tested and reviewed with study target group in the field in order to test the validity and suitability of questions and to ascertain the time length of interview as well as sequence of questions. After analysis of pre-test results, the questionnaire are modified, rephrased and edited in the light of feedback received from analysis and then it is finalized for data collection.

3.3 Exploratory Data Analysis

3.3.1 Concept of Exploratory Data Analysis

Exploratory data analysis (EDA) methods are used primarily to explore the data before using more traditional methods, or to examine residuals from a model. These methods are particularly useful for identifying extraordinary observations and noting violations of traditional assumptions, such as nonlinerity or nonconstant variance. J.W. Tukey, a great statistician of the last century, with his co-researchers [Tukey, 1977, Mosteller and Tukey, 1977, Vellman and Hoaglin, 1981] demonstrated ample weakness of classical parametric statistics to handle real world data due to its strong dependence on extraneous assumptions and advocated for EDA methods. EDA employs a variety of techniques to maximize insight into a data set, uncover underlying structure, extract important variables, detect outliers and anomalies, test underlying assumptions, develop parsimonious models and determine optimal factor setting. Most EDA techniques are graphical in nature with a few quantitative techniques. The reason for the heavy reliance on graphics is that graphics is the best means through which data can speak itself without assumptions, models, hypothesis and even without concept of probability.

3.3.2 Techniques of EDA

A variety of exploratory data analysis techniques are available in the literature (Velleman and Hoaglin, 1981). Among them stem-and-leaf plot, boxplot (box-and-whiskers plot), letter values, median polish, resistant line, resistant smooth and rootogram have become very popular with the statisticians. We use boxplots to assess and compare sample distributions. This plot consists of the median, first and third quartiles and upper and lower inter quartile ranges. Here we try to plot our data in a box whose mid point is the sample median, the top of the box is the third quartile (Q3) and the bottom of the box is the first quartile (Q_1).The upper whisker extends to this adjacent value-the highest data value within the upper limit-Q3+1.5(Q3-Q1) and similarly the lower whisker extends to this adjacent value- the lowest value within the lower limit – Q3-1.5(Q3-Q1). The stem-and-leaf plot is used to examine the shape and spread of sample data. The plot is similar to a histogram on its side, however, instead of bars, digits from the actual data values indicate the frequency of each bin (row) and thus it becomes more informative than the histogram. We consider an observation to be unusually large or small when it is plotted beyond the whiskers and they are treated as outliers. Median Polish fits an additive model to a two-way design. This procedure is similar to analysis of variance, except medians are used instead of means, thus adding robustness against the effect of outliers.

3.4 Time Series Analysis

3.4.1 Time Series

A time series is a collection of observations collected against the order of time. Time series is thought of as a realization of a stochastic process. The classical statistical techniques are sometimes irrelevant for time ordered data. A time series Y_t is generated by random input for every values of t generally. So Y_t is a random variable and a time series $Y_{t1}, Y_{t2}, \ldots, Y_{tN}$ is a group of random variable for all values of t . It can be thought that any time series is generated by a stochastic or random process and a data set for a particular sample of the underlying stochastic process is defined as a realization. The main target of time series analysis is to find a useful model to reveal a time structured relationship among some variables or events where model help forecasting the variables.

3.4.2 White Noise Process

A white noise process is a sequence $\{\varepsilon_t\}_{t=-\infty}^{\infty}$ whose elements have zero mean, constant variance and uncorrelated over time.

3.4.3 Lag Operator

The lag operator L is defined to be a linear operator such that for any value y_t, $L^i(y_t) = y_{t-i}$. Thus L^i preceding y_t simply means to lag y_t by i periods. The lag operator follows some properties as given below:

(i) The lag of a constant is a constant : $Lc = c$

(ii) The distributive law holds for lag operators

(iii) The associative law of multiplication holds for lag operators

(iv) L raised to a negative power is actually a lead operator

For a<1, the infinite sum $(1+aL+a^2 L^2+\ldots\ldots)y_t = y_t/(1-aL)$

3.4.4 Stationary and Nonstationay Process

A time series which possesses constant mean, variance and autocorrelation function through time, is defined to be covariance stationary process or weakly stationary process.

If the entire probability distributions of a series come from the same distribution where the distribution functions are independent of time then it is defined to be strong stationary process. But if a time series does not hold stationarity, it can be defined as nonstationary series.

3.4.5 Stationary Mean and Differencing

A time series which contains stationary mean, returns fairly quickly to a constant mean and a single mean can be computed for this time series. But if a time series does not hold stationarity with constant mean, we can make it stationary with constant mean by differencing the data as follows:

$$w_t = y_t - y_{t-1}, \tag{3.1}$$

where w_t is the first differenced series for an original series y_t and the procedure as mentioned above (3.1) for computing the first differences in a series y_t is called the first differencing. If the resulting series does not create a constant overall mean after the first differencing, we can apply again the similar first differencing techniques in the first differenced series w_t as follows:

$$z_t = w_t - w_{t-1} \tag{3.2}$$

$$= (y_t - y_{t-1}) - (y_{t-1} - y_{t-2}) \tag{3.3}$$

and the computed series of z_t is known as the second differenced series for the original series y_t. This computing procedure to obtain z_t from y_t is known as second differencing where we actually compute first differences in w_t.

The degree of differencing is generally denoted by d. We set $d = 1$ for first differencing and $d = 2$ for second differencing. $d>2$ is almost never needed for the lack of constant mean in the original data. If the successive changes are computed between the observations for a series separated by just one time period the differencing is defined to be the nonseasonal or regular differencing for the series. The series is said to be integrated if the differencing is needed to achieve the stationarity. The series is defined as integrated of order 1 if $d=1$ which is denoted by $I(1)$ and the series is defined as integrated of order 2 which is denoted by $I(2)$. The series is said to be level stationary series if $d=0$ which is denoted by $I(0)$. If the successive changes are computed between the observations of a series separated by s time periods for shifting the constant mean with seasonal fashion, the differencing is said to be seasonal differencing where s be the number of seasons, For example, $s=4$ for quarterly data, $s=12$ for monthly data and so forth. A series can be differenced nonseasonally, seasonally or both the ways. The degree of seasonal differencing is denoted by D and that can be computed as follows if $d=0$.

$$w_t = z_t - z_{t-s} \tag{3.4}$$

To remove any large seasonal shifts in the level of the series we usually set $D=1$. If we use both the nonseasonal and seasonal differencing in a series the result will be the same for either one may be done first.

3.4.6 Box-Cox Transformation for Variance Stabilization

Sometimes it can be needed a transformation in a series for the lack of constant variance. If the standard deviation of a series is proportional to its level we can create a new series with a constant variance by taking the natural logarithms. If the variance of the original series is proportional to its level we can create a new series with a constant variance by taking the transformation of square root. These two transformations are mostly useful in practice but we can make many other transformations if necessary. The log and square root transformations are members of a family of power transformations called the Box-Cox transformation (Box and Cox, 1964). So, with this transformation we can define a new transformed series y_t' as

$$y_t' = \frac{y_t^{\lambda} - 1}{\lambda} \tag{3.5}$$

where λ is a real number and y_t must not be negative time series. So if we observe some negative values in a data series we are to add a positive constant to original series y_t for getting the positive values. After modeling the data we may return forecasts of this series to the correct overall level by subtracting the same constant from the forecasted values. From the equation (3.5) we get the square root transformation for $\lambda = \frac{1}{2}$ and the natural log transformation for $\lambda \to 0$. If the variance tends to rise as the level of the series rises we can set the values for $\lambda < 1$ if the variance tends to fall as the level of the series rises we can set the values for $\lambda > 1$ and we can have a good power transformation for a data series by careful visual inspection of the time series plot and we can confirm the best transformation by further inspection of the plots after various transformation.

3.4.7 Autocorrelation

Autocorrelation measures the direction (positive or negative) and strength of the relationship among the observations within a single time series y_t when the observations are separated by k time periods where $k=1, 2, 3...., k$. We can create the two random variables y_t and y_{t+k} to determine one correlation coefficient for one value of k. Thus many autocorrelation coefficients can be obtained for a single time series y_t, one for each k. Since we lose another observations on y_{t-k} for each time period k increases by one, the maximum value of k is some what less than n and a rough rule is to choose $k \leq n/4$ where n is the sample size. The population autocorrelation coefficient at various lags $k=1, 2,.., k$ can be defined as

$$\rho_k = cov(y_t, y_{t+k}) / \sigma_y^2 \tag{3.6}$$

where $\sigma_y^2 = E(y_t - \mu_y)^2$, $\mu_y = E(y_t)$ and $cov(y_t, y_{t+k}) = E(y_t - \mu_y)(y_{t+k} - \mu_y)$

For a stationary series $cov(y_t, y_{t+k})$ and therefore ρ_k are independent of t and they depend only on k, the number of time periods separating y_t and y_{t+k}.

The sample autocorrelation coefficient provides an estimate of ρ_k and this can be computed as

$$\hat{\rho}_k = \frac{\sum_{t=1}^{n-k}(y_t - \bar{y})(y_{t+k} - \bar{y})}{\sum_{t=1}^{n}(y_t - \bar{y})^2} \tag{3.7}$$

The resulting set of values is known as the sample autocorrelation function (SACF). The approximated standard error for $\hat{\rho}_k$ [Bartlett (1946)] is

$$s(\hat{\rho}_k)=\left(1+2\sum_{j=1}^{k-1}\hat{\rho}_j^2\right)^{\frac{1}{2}} n^{-\frac{1}{2}}. \qquad (3.8)$$

Since the sample value of ρ_k may differ from zero for the cause of sampling variation we can test the significance of sample autocorrelation by comparing it with its standard error.

For testing a linear association in the population between y_t and y_{t+k}, we can set the null hypothesis

$H_o : \rho_k = 0$

against the alternative hypothesis

$H_1 : \rho_k \neq 0$

and then we compute the approximate t statistic

$$t = (\hat{\rho}_k - \rho_k)/\, se(\hat{\rho}_k) \qquad (3.9)$$

where t is the ratio of the statistic $\hat{\rho}_k$ to its standard error $se(\hat{\rho}_k)$ since ρ_k is hypothesized to be zero. If t is significant at $\alpha\%$ (generally 5%), we reject the null hypothesis.

Again we can plot the set of ρ_k values against the different values of k to present the sample autocorrelation function in graphical form. The two dashed lines are drawn on either side along with their standard error limit from zero. If mean of a series is stationary, the values of ρ_k will tend to quick decay toward zero and in practice the values of ρ_k will contain below their two standard error limits by about lag 5 or lag 6 and the computed values of the approximate t statistic will less or fall to about 1.6 by about lag 5 or 6. For each k we offset the column of y_t observations by k time periods to create the column y_{t+k}.

3.4.8 Partial Autocorrelation

Partial autocorrelation measures the autocorrelation between two random variables y_t and y_{t+k} ignoring the intervening random variables $y_{t+k-1}, y_{t+k-2}, \ldots, y_{t+1}$ for a data. For the set of following K regression equations:

$y_t = C_1 + \phi_{11}\, y_{t-1} + e_{1t}$

$y_t = C_2 + \phi_{21}\, y_{t-1} + \phi_{22}\, y_{t-2} + e_{2t}$

$$\cdot \qquad (3.10)$$
$$\cdot$$
$$\cdot$$

$$y_t = C_k + \phi_{k1}\, y_{t-1} + \phi_{22}\, y_{t-2} + \ldots\ldots + \phi_{kk}\, y_{t-k} + e_{kt}$$

the last coefficient ϕ_{kk} is considered as population partial autocorrelation coefficient at lag $k = 1, 2, \ldots\ldots, K$ for each equation and the sample partial autocorrelation coefficient $\hat{\phi}_{kk}$ can be estimated by taking into account the intervening random variables simultaneously where the resulting set of values is defined as sample partial autocorrelation function (SPACF). We can present the set of values SPACF graphically, by the length of the bar against each value of k where dashed are drawn on either side of zero at each lag k from two standard error limits. We can compare the value of sample statistic with its standard error to test the significance. We can gauge the significance of each $\hat{\phi}_{kk}$ by comparing it with the standard error

$$s\left(\hat{\phi}_{kk}\right) = n^{-\frac{1}{2}}. \qquad (3.11)$$

3.5 Box-Jenkins Modeling Strategy

The strategy for Box-Jenkins modeling has the following stages:

I. Identification

In the identification stage first we try to feel the nature of the possible time structured pattern of the data from the time series plot and attempt to identify a model that seems to be consistent with the data and that has the fewest coefficients needed to adequately explain the behavior of the data. Correlogram and partial correlogram are used to identify the ARIMA process purely.

II. Estimation

In the estimation stage we estimate the parameter for the tentative model.

III. Diagnostic Checking

Diagnostics checking are necessary for uncovering the possible lack of fit. If we find the adequacy of fit, the model can be ready to use. If we find any inadequacy, the process can be repeated till to get a suitable model.

IV. Principle of Parsimony

Principle of Parsimony is a fundamental idea of Box-Jenkins approach. In this approach we eliminate any needless coefficient to incorporate possible smallest number of coefficients in a model for which we can appropriately fit the data. We can select the parsimonious model by trial and error method based on principle of parsimony which can give better forecasts than the over-parameterized model. The aim of parsimony is to approximate the true data generating process and not to develop the exact process.

3.6 ARIMA Model

ARIMA model describes how a time series variable is related to its own past values and it helps to forecast the unknown future values in a time series. Forecast by using ARIMA model is better than the forecasts by using the ordinary arithmetic mean of a time series. In time series data it is appealing to give more weight to the most recent observations and less weight to the successive past observations than the data return regularly to a fixed overall level. ARIMA model can produce the best weighted average forecasts for a single time series based on the Box-Jenkins modeling philosophy because the Box-Jenkins modeling strategy is designed to help for choosing an appropriate ARIMA model. Theoretically if we can select the appropriate ARIMA model it can give the best forecast with the minimum mean squared forecast error. Note that data about 50 or more observations are needed to build ARIMA model with the sample data.

The assumption of ARIMA Model is that the time series generated by ARIMA process is stationary. In practice we deal with the weak form of stationarity generally but if the random shocks are Gaussian then the weak and strong form of stationary are identical. To stabilize the variance (if necessary) over time for a data series, required transformation can be done and to stabilize the mean over time, differencing or seasonal differencing or both can be used after stabilizing the variance.

Natural logarithms produce a new series with constant variance when the standard deviation of a series is proportional to its level and square root transformation induces a constant variance when the variance of the original series is proportional to its level. Generally inferential procedure depends on the normality assumption and transformation to have a constant variance makes the data near to normality and in this respect Box-Cox transformation is most popular.

The combined multiplicative non-seasonal ARIMA *(p, d, q)* model is as follows;

$$\phi(L)\Delta^d y_t = C + \theta(L)e_t \tag{3.12}$$

$\Delta^d = (1 - L)^d$ (The *d* order differencing operator)

$\phi(L) = (1 - \phi_1 L - \phi_2 L^2 - ......\phi_3 L^3 - ...... - \phi_p L^p)$ (The *p* order AR operators)

$\theta(L) = (1 - \theta_1 L - \theta_2 L^2 - ......\theta_3 L^3 - ...... - \theta_q L^q)$ (The *q* order MA operators)

Where e_t is random shocks, C is the constant and y_t is any time series.

If difference is not necessary to achieve stationarity, $d = 0$ and the model is reduced to ARMA.

3.6.1 Theoretical Correlogram for Identification of ARIMA Model

To identify an ARIMA model in practice we first construct the correlogram for Sample Auto-correlation Function (SACF) and Sample Partial Autocorrelation Function (SPACF) for a data series and then we compare the correlogram of SACF and SPACF with some common theoretical correlograms of ACF and PACF. Each ARIMA model has a theoretical correlogram for associated autocorrelation function (ACF) and partial autocorrelation function (PACF). In the theoretical correlogram associated with AR(p) process, ACF decays exponentially to zero and PACF shows significant spike at lag *1, 2......, p*. When $\phi_i>0$, the ACF decays all on the positive side, and the PACF has p number of significant positive spike. When $\phi_i<0$, the ACF decays with alternating signs. For the stationary AR process of order *p* we have the following characteristics:

1. For the theoretical correlogram ACF decays, either exponentially or with a dumped sine wave pattern or with both of these patterns.

2. For the theoretical correlogram PACF has spikes through lag *p*, then all zeros. (Some values before lag *p* could be zero; the main point is that the last nonzero value occurs at lag *p*.)

For the theoretical correlogram of MA(*q*) process we have the following characteristics.

1. For an MA theoretical correlogram, ACF has spike through lag *q*, then all zeros. (Some values before lag *q* could be zero; the main point is that the last nonzero values occur at lag *q.)*

2. For an MA theoretical correlogram, PACF decays.

3. For a mixed theoretical correlogram, both the ACF and PACF decay.

For the integrated series, the SACF decays slowly and thus the rest of the patterns may be obscure. We may uncover those obscure patterns by differencing.

In practice we compare a sample correlogram with the similar theoretical correlogram and choose the model corresponds to the process whose theoretical correlogram match with the sample correlogram. Then we estimate and check the tentative model if it is adequate.

3.6.2 ARIMA Modeling

The SACF and SPACF can give much information about the pattern of data series. For ARIMA modeling we should consider the overall pattern of $\hat{\rho}_k$ and $\hat{\phi}_{kk}$ coefficients. An SACF can show moderately large waves that reflect only sampling variation. Every large spike or wave in an SACF and SPACF is not our attention since SACF coefficients are often correlated with each other. In practice, we should mark the non-seasonal $\hat{\rho}_k$ values that are about 1.6 times or more their standard errors in absolute value and the seasonal $\hat{\rho}_k$ values that are about 1.25 or more their standard errors in absolute value in the SACF. In the SPACF we should mark the $\hat{\phi}_{kk}$ values that are two or more times their standard errors in absolute value. After the identification of model we estimate the parameters by using OLS and MLE method and check the goodness of fit by using *t* or *F* statistic if the estimated residuals are Gaussian white noise and we select the model finally.

3.6.3 Checking ARIMA Model

Insignificant pattern of autocorrelation (SACF) constructed from the residuals can ensure adequacy of an ARIMA model. Again, if normality assumption holds we can examine the significance of coefficient at the estimation stage by performing the approximate t test. We can check the normality examining the histogram and normal probability plot of residuals. There are many other approaches for checking model adequacy such as Akaike information criteria (AIC), Baysian information criteria (BIC), Schwartz criteria (SC) etc. which can reduce the sum of squares for the estimated residuals of model. The model can be selected [by choosing the appropriate lag in the model against for p and / or q] for the minimum sum of squares of the estimated residuals. The criteria that select the more parsimonious model is known as model selection criteria. Note that when we include additional lags in a model, the loss of degrees of freedom can reduce the forecasting performance of the fitted model.

3.6.4 Forecasting

An appropriate ARIMA model provides minimum mean squared error forecasts among all linear univariate models with fixed coefficients. It can produce point forecasts for each time period and we can have interval forecasts constructing a confidence interval around each point forecast. To have the 95% interval for each forecast we can use the formulae $f \pm 2s$, where f denotes a forecast and s is its standard error. The forecasts for a stationary model converge to the mean of the series and the speed of converging movement depends on the nature of the model and for nonstationary model the forecasts do not converge to the mean.

3.7 Diagnostic Checking and Its Techniques

Diagnostic checking is necessary to check the model adequacy. Several types of spurious character such as nonstationarity, nonnormality, violation of structural stability, multicollinearity, heteroscadasticity, unusual observations etc. are found. A Model may loss its appropriateness and suffers with lack of best fitting due to spurious characters. In time series data we can use the different types of diagnostics techniques such as histogram of residuals, normal plot of residuals, residual versus fits, residual versus order of the data, residual versus predictor variables through raw residuals, standardized residuals, studentized residuals, studentized deleted residuals, press residuals etc. The normality test may perform better in modified residuals than the raw residuals [Cook and Weisberg, 1982; Wetherill, 1986]. We have described some diagnostic techniques which are used in this thesis.

3.7.1 Checking Normality and RM Normality Test

Normality is very important issue for statistical inference. In time series analysis many diagnostic issues such as tests for stationarity and test for autoregressive structure largely depend on normality of errors of the model. Normal probability plot and the Jarque-Bera test are very popular in this respect [Pindyck and Rubinfeld (1997)]. In the normal probability plot we plot the normalized ordered residuals against their expected values assuming normal distribution. The Jarque-Bera (JB) test is an analytic test that considers the skewness and kurtosis of the residuals in it. The JB test statistic is defined as

$$JB = \frac{n}{6}\left[S^2 - \frac{(K-3)^2}{4}\right] \tag{3.13}$$

where S and K are the sample skewness and kurtosis of the least squares residuals. The JB statistic follows a chi-square distribution with 2 degrees of freedom. Although JB test is very popular in time series it has a well-known disadvantage that it suffers from super normality [see Wetherill (1989)] and this normality test performs poorly when the true errors come from non-normal distribution. Imon (2003) pointed out that the sample moments, coefficient of skewness and kurtosis used in the JB statistic are shrunk. So he suggested a method based on rescaling the moments (RM) and those are used to compute skewness and kurtosis of residuals. His proposed RM test statistic is defined as

$$\mathrm{RM} = \frac{\mathrm{nc}^3}{6}\left[\mathrm{S}^2 - \frac{(\mathrm{K}-3)^2}{4}\right] \tag{3.14}$$

Where $c = \dfrac{n}{n-p}$ where p is the number of parameters of the model. So it is interesting that there exists a nice and simple relationship between these two tests and RM test appears to have more power than the JB test.

3.7.2 Checking White Noise Error

The residuals of an adequate model should be approximately white noise. For a white noise process autocorrelations are zero. Therefore, the significance of the residual autocorrelations is often checked by comparing with approximate two standard error bounds $\pm 2/\sqrt{T}$, where T is the sample size used in computing the estimates. Plots of autocorrelation along with the approximate standard error bounds are helpful to take the decision. To test whether a time series consists simply of random values (white noise) Box-Pierce and Ljung and Box (1978) statistic can be used. For the overall acceptability of residual's autocorrelation Box-Pierce test statistic is used and it is defined as

$$Q_m = n(n+2)\sum_{l=1}^{m}\frac{r_l^2}{n-1} \tag{3.15}$$

where r_l is the sample autocorrelation at lag l, m is the maximum lag of interest, and n is the number of observations. If n is much greater than m and if the null hypothesis of white noise is correct, then Q_m has a chi-square distribution with m degrees of freedom.

3.7.3 Checking Structural Stability and Piecewise Autoregressive Model

Violation of structural stability is a common problem in regression and time series analysis. As a consequence of a certain event the existing relationship between two variables could be changed. For a model after the structural break two intercepts (former and present), two slopes or both the intercepts and slopes may be different or some other combinations of parameters may be found. If structural break occurs in a linear regression model or in a linear trend model in time series, we can use the piecewise linear model to handle this situation. But in time series structural break could occur in other types of models. Imon (2007) suggested a piecewise autoregressive (PAR) model to detect structural break in the first order autoregressive scheme. This model is specially useful when we observe that the data follow first order autoregressive AR(1) scheme separately in both before and after the structural break, but their autoregressive nature is not visible when the two parts are combined together.

Let us consider a linear trend model where the errors follow AR (1). We consider the simplest form of it which is given by

$$y_t = \beta_0 + \beta_1 t + u_t \tag{3.16}$$

with

$$\mathrm{u}_t = \mathrm{u}_{t-1} + \varepsilon_t \tag{3.17}$$

Where ε_t is white noise. In this situation a first order difference will make the series stationary as we observe from (3.16) and (3.17) that

$$\Delta y_t = \beta_1 + \varepsilon_t \tag{3.18}$$

Now if a structural change occurs after t_0, Imon (2007) defined a piecewise first order autoregressive [PAR(1)] model as

$$Y_t = \beta_0 + \beta_1 t + \beta_2(t-t_0)\, D_t + u_t \tag{3.19}$$

Where $u_t = u_{t-1} + \varepsilon_t$ and

$$D_t = \begin{cases} 1 & t > t_0 \\ 0 & t \le t_0 \end{cases} \tag{3.20}$$

A simple hypothesis test H_0: $\beta_2 = 0$ based on the estimators obtained from (3.19) will confirm whether any structural break has been occurred at the time $t = t_0 + 1$. This point is known as structural change point (SCP) showed that for a PAR(1) model, a first order difference yields.

$$\Delta y_t = \beta_1 + \beta_2 D_t + \varepsilon_1 \tag{3.21}$$

Where D_t is defined D_t as defined in (3.20) with the first observation missing. Thus a PAR(1) model is trend stationary. Imon (2007) showed that the residuals obtained from this model should behave as normal at every point except the point $t=t_0+1$ and it might be identified as an outlier.

3.7.4 Checking Multicollinearity

Lack of orthogonality creates collinearity in the data. The severe nonorthogonality may cause the problem of multicollinearity and detecting this collinear problem becomes difficult. In practice, the problem of multicollinearity occurs when some of the x variables are highly correlated. It is not a specification error and it can not be explored with regression residual. It violates no regression assumptions. Unbiased and consistent estimates can be occurred and their standard errors can be estimated correctly. The only effect is to make hard to get estimates with small standard error. There is no unique method for detecting multicollinearity for measuring its strength and observed high R^2. Few significant t ratios are used as a rule of thumb for detecting multicollinearity. Eigen values and conditional index are also used to measure the strength of multicollinearity.

Multicollinearity is associated with unstable estimated regression coefficients and indication of multicollinearity appears as instability in the estimated coefficients as follows:

1. Large changes in estimated coefficient when a variable is added or deleted.

2. Large changes in the estimated coefficients when a data point is altered or dropped.

3. The algebric signs of estimated coefficients do not confirm to prior expectations or

4. Coefficients of variables that are expected to be important have large standard errors (small t-values).

Multicollinearity can be investigated thoroughly by examining the value of R^2 that results from regressing each of the predictor variables against all the others. The relationship between the predicator variables can be judged by examining the quantity of Variance Inflation Factor (VIF). But R_j^2 be the square of the multiple correlation coefficient that results when the predictor variable X_j is regressed against all the other predictor variables and then the variance inflation factor for the X_j is defined as

$$VIF_j = \frac{1}{1-R_j^2} \; j = 1,\dots, p \tag{3.22}$$

where p is the number of predictor variables. R_j^2 can be close to 1 and VIF_j can be large. If values of variance inflation factors greater than 10 the data have the collinearity problem. R_j would be zero and VIF_j would be one if the predictor variables are orthogonal and the deviation of VIF_j value from 1 indicates departure from orthogonality and tendency toward collinearity. As R_j^2 tends toward 1, indicating the presence of a linear relationship in the predicator variable, the VIF for $\hat{\beta}_j$ tends to infinity. The VIF in excess of 10 is an indication of multicollinearity which may cause problems in estimation.

A common approach to multicollinearity problem is to omit explanatory variables. The value of the determinant near zero of the correlation matrix indicates that some or all explanatory variables are highly correlated which indicates that at least one of the predictors is a linear function of one or more other predictors. The value of the determinant equal to zero indicates a singular matrix.

3.8 Variable Selection Procedures

In variable selection procedures the variables are included or deleted from the regression equation one at a time and involve examining only a subset of all possible equations. The procedures can be classified into two broad categories:

1. Forward selection procedure

The forward selection procedure starts with no predictor variables, only a constant term in the model and sequentially adds a variable according to the maximal contribution to the dependent variable. So at each step, a variable is added, whose t statistic is maximum. In subsequent stages, the predictor is selected that makes the next largest contribution to the prediction. The procedure continues until each of the selected predictors in the model is a significant predictor where as none of the unselected predictors in the model is a significant predictor. This procedure has two limitations. Some of the variables never get into the model and hence their importance is never determined. Another limitation is that a variable once included in the model remains there throughout the process, even if it loses its stated significance, after the inclusion of other variable(s).

2. Backward elimination procedure

The backward elimination procedure begins with all the variables in the model and proceeds by eliminating the less important variable one by one. One variable is dropped at a time against the smallest insignificant t values and the process continues until no variable can be removed according to the elimination criterion.

3.9 Durbin-Watson Statistic

Autocorrelated errors can be detected by the Durbin-Watson statistic and the test is based on the assumption that successive errors are correlated, namely,

$$\varepsilon_t = \rho\varepsilon_{t-1} + w_t \quad |\rho| < 1 \tag{3.23}$$

Where ρ is the correlation coefficient between ε_t and ε_{t-1} and w_t is normally independently distributed with zero mean and constant variance. The Durbin-Watson statistic is defined as

$$d = \frac{\sum_{t=2}^{n}(e_t - e_{t-1})^2}{\sum_{t=1}^{n} e_t^2} \tag{3.24}$$

Where e_i is the i-th ordinary least squares (OLS) residual. The Statistics d is used for testing the null hypothesis Ho: $\rho = 0$ against an alternative H1 : $\rho > 0$, ε's are uncorrelated since ρ is unknown, the parameter ρ is estimated as

$$\hat{\rho} = \frac{\sum_{t=2}^{n} e_t\, e_{t-1}}{\sum_{t=1}^{n} e_t^2} \tag{3.25}$$

The relationship between d and $\hat{\rho}$ is

$$d = 2(1 - \hat{\rho}), \tag{3.26}$$

where d has a range of 0 to 4. Since $\hat{\rho}$ is an estimate of ρ, so d is close to 2 when $\rho = 0$ and near to zero when $\rho = 1$. The closer the sample value of d to 2, the firmer the evidence that there is no autocorrelation present in the error. Evidence of autocorrelation is indicated by the deviation of d from 2. For $d < d_L$, Ho may be rejected, for $d > d_U$, we can not reject Ho and for $d_L < d < d_U$, the test may be inconclusive.

Durbin-Watson statistic was small enough to conclude the positive autocorrelation. An additional variable was uncovered that had been responsible for the appearance of autocorrelation. Durbin-Watson statistic and the pattern of residuals indicate dependence between residuals in adjacent time periods. The Durbin-Watson statistic is not designed to measure higher order time dependence and may not yield much valuable information.

3.10 Removal of Autocorrelation and Cochrane-Orcutt iterative procedure

Auto correlated errors can create nonlinearity in a model which can be detected from the residuals plot and the Durbin Watson statistic. Least square estimate is not possible for the autocorrelated models directly and a transformation with the unknown autocorrelation parameter is needed. For this type of nonlinear model, many methods are used to estimate the parameter. Among them we have described the Cochrane-Orcutt iterative procedure (1949) used in the thesis.

If we assume a model

$$Y_t = \beta_0 + \beta_1 x_t + \varepsilon_t , \tag{3.27}$$

we can express

$$\varepsilon_t = y_t - \beta_0 - \beta_1 x_t \text{ and} \tag{3.28}$$

$$\varepsilon_{t-1} = y_{t-1} - \beta_0 - \beta_1 x_{t-1} . \tag{3.29}$$

Again we can write

$$y_t - \beta_0 - \beta_1 x_t = \rho\ (y_{t-1} - \beta_0 - \beta_1 x_{t-1}) + w_t \text{ and} \tag{3.30}$$

$$y_t - \rho y_{t-1} = \beta_0 (1-\beta) + \beta_1 (x_t - \rho x_{t-1}) + w_t . \tag{3.31}$$

Then the following form

$$\dot{y}_t = \dot{\beta}_0 + \dot{\beta}_1 \dot{x}_t + w_t \tag{3.32}$$

Where

$\dot{Y}_t = y_t - \rho y_{t-1}$, $\dot{X}_t = x_t - \rho x_{t-1}$, $\dot{\beta}_0 = \beta_0 (1-\rho)$ and $\dot{\beta}_1 = \beta_1$,

represents a linear model with uncorrelated errors. After using OLS in (3.32) we can get $\hat{\beta}_0 = \dfrac{\dot{\beta}_0}{1-\hat{\rho}}$ and $\hat{\beta}_1 = \dot{\beta}_0$ which satisfy the assumption of uncorrelated errors. Since the value of ρ is unknown, Cochrane and Orcutt (1949) have proposed an iterative procedure.

1. Compute the OLS estimates of β_0 and β_1 by fitting model to the data,

2. Estimate ρ using the calculated residuals,

3. Fit the equation for $y_t - \hat{\rho}y_{t-1}$ and $x_t - \hat{\rho}x_{t-1}$ and obtain $\hat{\beta}_0$ and $\hat{\beta}_1$ using y,

4. Examine the residuals of the newly fitted equation. If the new residuals continue to show autocorrelation, repeat the entire procedure If the new residuals show no autocorrelation, the procedure is terminated and the fitted equation for the original data $\hat{y}_t = \hat{\beta}_0 + \hat{\beta}_1 x_t$.

If the first application of Cochrane-Orcutt procedure does not yield non-autocorrelated residuals one should look for alternative methods for removing autocorrelation.

3.11 Unusual Observations and Its Identification Procedures

The unusual observations which come from the other population and do not follow the distribution of majority points can create different problem in analysis. They can make invalid or opposite inference influencing the results unduly. Three types of unusual observations are identified in regression analysis. They are outlier, high leverage point and influential observation and they can interact each other. Many methods are innovated for detecting unusual observations and for measuring their effects on various aspects of the analysis. Chatterjee and Hadi in 1988 mentioned that, measures may be based on any one of the quantities of Residuals, Remoteness of points in the XY space, Influential curve (centre of confidence ellipsoids), volume of confidence ellipsoids, likelihood function, subset of regression coefficients and eigen structure of X.

3.11.1 Detection of Outliers

In an analysis, an observation or a group of observations different from the majority observations are known as outliers. Outliers can influence the fitted model in a large extent and model may loss its appropriateness in several forms such as lack of best fit, resulting in non-normal residuals etc. Some important assumption may be violated due to influence of outlier and spurious results can be created. Sometimes outlier can change the stationarity property, the autoregressive structure and many other characteristics of a time series data. But the outliers could be a real part of data or could be an error due to incorrect recording. The real outliers are more difficult to handle than the latter kinds [Fox (1972), Kleiner *et al.* (1979), Martin (1980), Martin *et al.* (1983)]. In time series data we can try to detect outliers primarily by examining the time series plot visually. For the detection of outlier formal procedures are available and at present a number of methods are also available in time series data [Gounder *et al.* (2007)]. Chatterjee and Hadi (1988) pointed that residuals play an important role in regression diagnostics and no analysis is completed without a thorough examination of the residuals. Standardized residual plot can be preferable to detect the presence of outliers in the data where Standardized residuals greater than some number such as 3.0, 3.5 or 4.0 may be important under consideration. In case some residuals might be unduly large. We have discussed some residual based measures for the detection of outlier for the regression model

$$Y = X\beta + \varepsilon, \tag{3.33}$$

where the errors are assumed to be independent and have the same variance, identity and to assess the appropriateness of the model it is necessary to ensure whether the assumptions about the errors are reasonable. But from the ordinary least square estimate we estimate the residuals r as the following equation below. The residual vector obtained from the model can be written as

$$\hat{\varepsilon} = r = Y - \hat{Y} = (1 - H)\varepsilon \tag{3.34}$$

where $H = X(X^T X)^{-1} X^T$

or in scalar form, $\hat{\varepsilon}_i = r_i = y_i - \hat{y}_i$ (3.35)

$$r_i = \varepsilon_i - \sum_{j=1}^{n} h_{ij}\varepsilon_j, i = 1,2,...,n \tag{3.36}$$

where h_{ij} is the *ij*-th element of H.

The estimated residuals r are related with ε by the Hat matrix H where r can be reasonable substitute for ε if h_{ij}'s are sufficiently small and the OLS residuals can not be independent unless H is diagonal and they do not have the same variance unless the diagonal elements of H are equal, because

$$Var(r_i) = \sigma^2(1 - h_{ii}) \tag{3.37}$$

So the transformed residuals can be more preferable than OLS residuals for the detection of outlier and the transformed version instead of OLS residuals r_i can be expressed as the following formula

$$f(r_i, \sigma_i) = \frac{r_i}{\sigma_i} \qquad (3.38)$$

where σ_i is the standard deviation of the *i*-th residual.

If we replace the σ_i by $\sqrt{r^T r}$ such as

$$a_i = \frac{r_i}{\sqrt{r^T r}} \qquad i = 1,2,\ldots,n\ , \qquad (3.39)$$

the transformed residual is defined to be *i*-th normalized residual.

If we replace σ_i as follows

$$d_i = \frac{r_i}{\hat{\sigma}}, \text{ where } \hat{\sigma} = \sqrt{\frac{r^T r}{n-p}}, \qquad (3.40)$$

the transformed residual is defined to be *i*-th standardized residual.

If we replace σ_i by $\hat{\sigma}\sqrt{1-h_{ii}}$ as follows

$$e_i = \frac{r_i}{\hat{\sigma}\sqrt{1-h_{ii}}}, i = 1, 2, \ldots\ldots, n. \qquad (3.41)$$

the transformed residual is defined to be internally Studentized residual.

If we replace σ_i by an estimate of σ^2 based on a data set with the *i*-th observation deleted, this deleted scaled residual is defined to be externally Studentized residual which can be estimated as the following formula

$$\dot{e}_i = \frac{y_i - x_i^T \hat{\beta}^{(-i)}}{\hat{\sigma}^{(-i)}\sqrt{1-h_{ii}}} = \frac{r^{(-i)}}{\hat{\sigma}^{(-i)}\sqrt{1-h_{ii}}}, i = 1, 2, \ldots\ldots, n. \qquad (3.42)$$

Where $\hat{\sigma}(-i)^2 = \frac{1}{n-p-1}\sum_j (y_j - x_j^T \hat{\beta}^{(-i)})^2$

Atkinson (1981) prefers e_i and $\dot{e}_i$ for the detection of outliers. Behnken and Draper (1972), Davies and Hutton (1975), and Huber (1975) recommended that the externally

Studentized residuals are more appropriate than the internally studentized residuals for identifying outliers since the effect of i-th observation is more preferable in case of former.

3.11.2 Identification of High-Leverage Points

The high-leverage points are those for which the input vector x_i is far from the rest of the data and which was mentioned by Hocking and Pendleton (1983). Identification of high leverage points mainly depends on the prediction or hat matrix. The diagonal elements of the Hat (prediction) matrix $h_{ii} = x_i^T (X^T X)^{-1} x_i$ play an important role for determining high-leverage points through their fitted values, magnitude of residuals and variance-covariance structure where the observations corresponding to excessively large values of $h_{ii} = x_i^T (X^T X)^{-1} x_i$ are treated as high-leverage points. The property like $0 \le (h_{ii} + r_i^2 / r^T r) \le 1$ implies that observations with large h_{ii} tend to have small residual and therefore go undetected in the usual plots of residuals". For identifying high-leverage points, some common suggested cut-off points for h_{ii} are:

(a) Huber (1977, 1981) pointed that the reciprocal of h_{ii} can be thought of as the equivalent number of observations that determines $\hat{y}_i$ and Huber (1981) proposed that common suggested cut off points for h_{ii} with

$$h_{ii} \ge 0.2, \qquad (3.43)$$

(b) Hoaglin and Welsch (1978) suggested twice-the-mean rule that cut off points for h_{ii} with $h_{ii} \ge \frac{2p}{n}$ and (3.44)

Vellman and Welsch(1981) suggested thrice-the-mean rule that cut off points for h_{ii} with

$$h_{ii} \ge \frac{3p}{n} \qquad (3.45)$$

(c) If a regression model contains a constant term and the rows of X are $i.i.d.$ $N_p(\mu, \Sigma)$,

then $$\frac{n-p-1}{p} \frac{h_{ii} - \frac{1}{n}}{1 - h_{ii}} \approx F_{(p, n-p-1)}, \qquad (3.46)$$

$$h_{ii} \geq \frac{nF(p)+(n-p-1)}{nF(p)+n(n-p-1)}, \tag{3.47}$$

as high-leverage points, where F is the $100(1-\alpha)$ point of $F_{(p,n-p-1)}$.

The leverage of an observation can also be measured by the Mahalanobis distance (MD) but this distance suffers from both masking and swamping due to nonrobustness. Rousseeuw and van Zomeren (1990) proposed robust distance using minimum volume ellipsoid [MVE, Rousseeuw ,1985] to remove the problems of masking, swamping of multiple outliers. Hadi (1992) pointed out "... in the presence of a high-leverage point the information matrix may breakdown and hence the observation may not have the appropriate leverage". In this connection, Hadi (1992) introduced potentials based on single case deletion and defined as

$$h_{ii} = x_i^T (X_{(i)}^T X_{(i)})^{-1} x_i, i = 1,2,...,n \tag{3.48}$$

Where $X^{(-i)}$ is the matrix without the *i*-th observation. Observations corresponding to excessively large potential values are considered as high-leverage points. It is reported that the presence of multiple high leverage points may cause masking and/or swamping. For this, some outliers and leverage points go undetected (masking) and/or some innocent observations reveal as outliers or leverage points (swamping).

3.11.3 Identification of Influential Observations

Cook's distance, DFFITS or DFBETAS are most popular identification techniques for influential observations but these techniques are not described here because the identified influential observations are not presented in the thesis.

Chapter 4

Chapter 4

Trend and Variability Pattern for Climatic Variables in Dinajpur District

4.1 Introduction

To investigate the climatic pattern of Dinajpur District we study the trend and variability pattern for several climatic phenomena by using exploratory data analysis techniques (EDA). We measure within and between-decade variability of annual, seasonal and wheat growing period climatic data for 5 decades (from 1951-60 to 1991-2000) using nonrobust measures like mean and the coefficient of variation (CV) and robust measures like median, 5% trimmed mean, coefficient of variation with respect to median (CV(Med)), coefficient of variation with respect to trimmed mean (CV(TRM)), the percentage ratio of quartile deviation to median (QD/Med) and the percentage ratio of quartile deviation to trimmed mean (QD/TRM). We also study their trends over the period. To investigate within-year seasonal and monthly pattern and variability of climatic data during 1948-2004, we construct boxplots primarily. We investigate the within-year and between-year seasonal and monthly variation and effects combindely employing median polish in the year-season and year-month two-way classification tables. We fit the trend regression lines taking those median polished seasonal and monthly effects for climatic variables. Besides these trends we fit the trend lines for annual, seasonal, monthly climatic data. We check the stationarity of residuals to test whether the trend is deterministic or stochastic by using ACF and PACF display and Box-Pierce test statistic. We also check the normality of those residuals by normal probability plot and the rescaled moments (RM) test for normality [Imon (2003)].

4.2 Analysis and Results

4.2.1 Annual Data

We conduct within and between-decade variability analysis for annual data of climatic variables such as TR, AC, ARH, AMWS, AWS, ASLP, AMXT, AMNT, ARNT, ADBT, AWBT, in respect of both robust and nonrobust measurements.

Table 4.1 Within-Decade Variability for Annual Data

Annual	Mean	Median	Tr Mean	StDev	Min	Max	Q1	Q3	QD	CV	CV (Med)	(QD/ Med)	CV (TRM)	QD/ TRM	Range
TR	1579	1727	1579	684	401	2117	1033	2052	509.5	43.319	39.606	29.5	43.319	32.267	1716
AMXT	30.44	30.51	30.442	0.51	29.76	31.1	30	30.895	0.47	1.665	1.662	1.54	1.665	1.544	1.31
AMNT	19.71	19.77	19.714	0.24	19.37	20	19.5	19.931	0.231	1.238	1.234	1.168	1.238	1.172	0.583
ARNT	10.73	10.55	10.726	0.51	10.24	11.5	10.3	11.225	0.455	4.736	4.814	4.312	4.736	4.242	1.26
ADBT	24.909	24.902	24.909	0.268	24.634	25.34	24.69	25.129	0.218	1.0759	1.07622	0.875	1.07592	0.8752	0.708
AMWS	5.92	5.12	5.92	2.33	3.3	9.21	3.99	8.26	2.135	39.36	45.508	41.7	39.358	36.064	5.91
ARH	74.49	73.7	74.49	2.73	71.91	78.9	72.4	77	2.315	3.665	3.704	3.141	3.665	3.108	6.99
AC	2.817	2.754	2.817	0.33	2.461	3.21	2.51	3.161	0.328	11.82	12.092	11.91	11.821	11.644	0.749
AWBT	21.604	21.648	21.604	0.254	21.352	21.98	21.37	21.817	0.2235	1.1757	1.17332	1.03	1.17571	1.03	0.631
AWS	1.196	1.101	1.196	0.6	0.493	2.09	0.7	1.742	0.522	50.08	54.405	47.41	50.084	43.645	1.601
ASLP	1007.6	1007.6	1007.6	0.2	1007.3	1008	1007	1007.7	0.15	0.0199	0.01985	0.0149	0.01985	0.0149	0.5

Table 4.1 shows the results of within-decade variability analysis. We find the first highest variation for the decadal AWS, second highest variation for the decadal AMWS and third highest variation for the decadal TR in terms of CV, CV(Med), QD/Med and QD/TRM while we get the lowest variation for decadal ASLP and then decadal ADBT.

Table 4.2 Between-Decade Variability for Annual Data

Variable	Decade	1951-60	1961-70	1971-80	1981-90	1991-00	Variable	Decade	1951-60	1961-70	1971-80	1981-90	1991-00
TR	Mean	1664	1727	401.4	2117	1987	AMXT	Mean	31.07	30.51	30.72	29.76	30.2
	CV(%)	18.44	26.4	70.63	21.26	23.7		CV(%)	1.571	1.39	1.758	1.223	1.19
AC	Mean	2.55	2.46	2.75	3.21	3.11	AMNT	Mean	19.6	20	19.8	19.4	19.9
	CV(%)	8.24	5.92	12.8	6.98	8.24		CV(%)	3.466	1.844	0.298	5.507	2.2
ARH	Mean	73.7	72.84	75.09	71.91	78.9	ARNT	Mean	11.5	10.6	10.9	10.4	10.2
	CV(%)	2.86	1.64	2.53	4.55	2.13		CV(%)	8.24	6.16	5.44	7.42	5.21
AMWS	Mean	3.3	4.68	5.12	9.21	7.3	ADBT	Mean	24.803	24.92	24.9	25.34	24.6
	CV(%)	23.09	47.66	40.12	21.47	25.38		CV(%)	1.451	0.919	0.606	2.96	1.09
ASLP	Mean	1007.8	1007.3	1007.7	1007.5	1007.6	AWBT	Mean	21.35	21.39	21.65	21.65	21.98
	CV(%)	0.099	0.029	0.009	0.05955	0.05954		CV(%)	1.218	1.131	1.497	3.13	1.64

Table 4.2 presents the results of between-decade variability analysis for Annual climatic data and we have presented the nonrobust decadal averages and variations of climatic variables in terms of mean and CV. The variable of TR has the highest average in 4^{th} decade and lowest average in 3^{rd} decade while the variation is highest in 3^{rd} decade and lowest in 1^{st} decade. The variable of AC has the highest average in 4^{th} decade and lowest in 1^{st} decade while the variation appears to be the highest in 3^{rd} decade and lowest in 2^{nd} decade. We observe that the highest average for ARH in 5^{th} decade and lowest average in 4th decade while the highest variation for ARH is in 4th decade and lowest in 2^{nd} decade. The decadal average for AMWS is the highest in 4^{th} decade and lowest in 1st decade

while the decadal variation is the highest in 2nd decade and lowest in 4th decade. The decadal average for the variable of ASLP is the highest in 1st decade and lowest in 2nd decade while the decadal variation for the variable of ASLP is the highest in 1st decade and lowest in 3rd decade. The variable of AMXT posses the highest average in 1st decade and lowest average in 4th decade while the highest variation occurs in 3rd decade and lowest variation occurs in 5th decade. The variable of AMNT has the highest average in 2nd decade and lowest average in 4th decade while the highest variation is in 4th decade and lowest variation is in 3rd decade. For the variable of ARNT we obtain the highest average in 1st decade and lowest average in 5th decade while the variation is the highest in 1st decade and lowest in 5th decade. For the variable of ADBT, the highest average is found to be in 4th decade and lowest average is found to be in 5th decade while the highest variation is experienced in 4^{th} decade and lowest variation is experienced in 3rd decade. For the variable of AWBT we observe the highest average in 5th decade and lowest average in 1st decade while the variation is the highest in 4^{th} decade and variation is the lowest in 2nd decade. Table 4.3 presents the decadal position in respect of highest and lowest means and cvs for annual data.

Table 4.3 Decades Containing Highest and Lowest Means and CVS for Annual Climatic Data

	TR	AC	ARH	AMWS	ASLP	AMXT	AMNT	ARNT	ADBT	AWBT
Highest Mean	4th	4th	5th	4th	1st	1st	2nd	1st	4th	5th
Lowest Mean	3rd	1st	4th	1st	2nd	4th	4th	5th	5th	1st
Highest CV	3rd	3rd	4th	2nd	1st	3rd	4th	1st	4th	4th
Lowest CV	1st	1st	2nd	4th	3rd	5th	3rd	5th	3rd	2nd

Table 4.4 Within-Year Variability for Annual Data

Annual	TR	AC	ARH	ARH (0)	ARH (0-12)	ARH (12)	AMXT	AMNT	ARNT	ADBT	AWBT	AST(5)	AT (D-W)	AMWS	AWS	ASLP	AE	ASH
Mean	1636.9	2.87	74.9	90.36	23.03	67.32	30.4	19.71	10.69	24.87	21.64	25.903	3.23	5.81	1.18	1007.5	34.98	6.46
Med	1798	2.78	73.9	89.7	23.16	66.85	30.38	19.81	10.52	24.84	21.63	25.94	3.37	5.42	1.13	1007.6	35.04	6.40
TRM	1650	2.87	74.9	90.35	23.03	67.26	30.39	19.777	10.64	24.86	21.65	25.893	3.24	5.68	1.142	1007.6	35.16	6.45
Min	211	2.13	67.9	85.39	19.98	60.43	28.94	16.59	9.21	23.8	20.01	25.29	2.1	1.75	0.25	1005.4	27.75	5.89
Max	3185	3.58	81.9	95.17	26.81	74.8	31.88	20.69	13.74	26.03	22.63	26.63	4.08	13.08	3.8	1008.8	40.17	7.17
Q1	1289.5	2.53	72.9	88.22	21.99	64.21	29.97	19.54	10.06	24.52	21.33	25.463	2.94	3.58	0.68	1007.2	33.14	6.22
Q3	2141	3.21	77.3	92.83	24.17	70.17	30.79	20.03	11.22	25.08	22.00	26.235	3.56	7.58	1.53	1007.8	37.92	6.69
CV	43.69	13.8	4.53	2.96	6.82	5.52	2.03	3.15	7.82	1.93	2.203	1.579	16.44	45.23	54.28	0.0596	10.16	4.82
QD(Med)	23.7	12.1	2.98	2.57	4.70	4.45	1.35	1.224	5.53	1.117	1.542	1.488	9.27	36.9	37.61	0.0298	6.81	3.71
QD(TRM)	25.80	11.8	2.94	2.55	4.73	4.42	1.34	1.226	5.47	1.116	1.54	1.491	9.62	35.20	37.20	0.0298	6.79	3.68
Range	2974	1.45	14	9.78	6.83	14.37	2.94	4.1	4.53	2.23	2.61	1.34	1.98	11.33	3.55	3.4	12.42	1.28

From the within year variability analysis for annual data of the variables TR, AC, ARH, AWS, AMWS, AMXT, AMNT, ARNT, ADBT and AWBT we get the annual means and variations as shown in Table 4.4 in respect of both robust and nonrobust measurement. The first highest variation is experienced in the variable AWS, 2nd highest variation is experienced in AMWS and third highest variation is experienced in TR in terms of both the robust and nonrobust measurement while the lowest variation is experienced in ASLP. We observe upward trend for the variables of TR, AMNT, AWBT, AWS, AMWS, ARH, ARH(0), ARH(12), AC and AST and downward trend for the variables of FZR, AMXT, ARNT, AT(D-W), ARH(0-12) and AE but the variables of ADBT and ASLP indicated no trend [Figure 4.1 to Figure 4.10]. Indicated trend direction for annual climatic data are shown in Table 4.5 with their residual's stationarity and normality. Trend equations for annual data with forecasted observations of some climatic variables are presented in Appendix Table A.4.1.

Table 4.5 Trend Pattern for Annual Climatic Data with Their Residual's Stationarity and Normality

	Upward trend	Downward trend	No trend
Variables	TR (NS-N), AMNT (S-NN), AWBT (S-NN), AWS (NS-NN), AMWS (NS-N), ARH (N), ARH(0), ARH(12), AC (NS-N) and AST	FZR, AMXT(NS-N), ARNT(S-NN), AT(D-W) and ARH(0-12)	ADBT(S-N) and ASLP(S-NN)

*S-Stationarity, NS-Nonstationarity, N-Normality and NN-Normality

We have shown the detected lower (LO) and higher (HI) outliers for annual climatic data obtained from stem- and- leaf display in Table 4.6 where the respective occurrences year for extreme outliers are shown.

Table 4.6 Detected Outliers and the Respective Year for Extreme Outliers for Annual Climatic Data

	AMNT	ARNT	ADBT	AWBT	ASLP	AMWS	AWS
Detected outliers	(LO: 1659, 1792 and HI: 2069) Leaf Unit = 0.010	(HI: 137) Leaf Unit = 0.10	(HI: 258, 260, 260)Leaf Unit = 0.10	(LO: 200) Leaf Unit = 0.10	(LO: 10054, 10059) Leaf Unit = 0.10	(HI: 130) Leaf Unit = 0.10	(HI: 38) Leaf Unit = 0.10
Year of extreme outlier	LO: 1659 - 1981 HI: 2069 -1999	HI: 137-1957	HI: 260-1985	LO: 200- 1981	LO: 10054-1959	HI: 130-1990	HI: 38-1981

Trend Figures for Some Annual Climatic Data

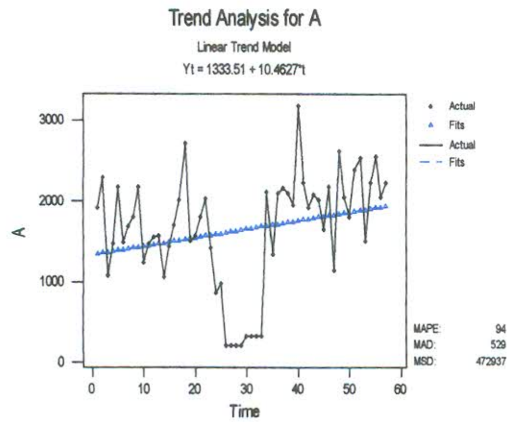


Figure 4.1 Trend for annual TR

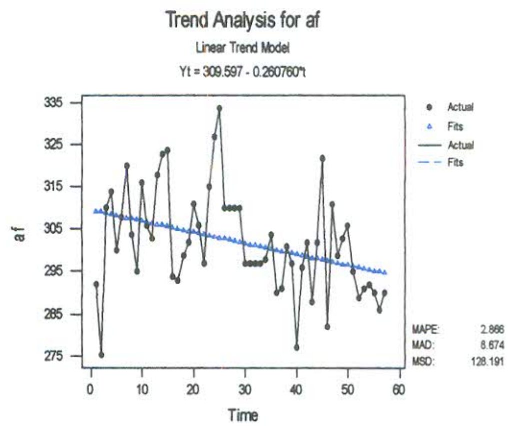


Figure 4.2 Trend for annual FZR

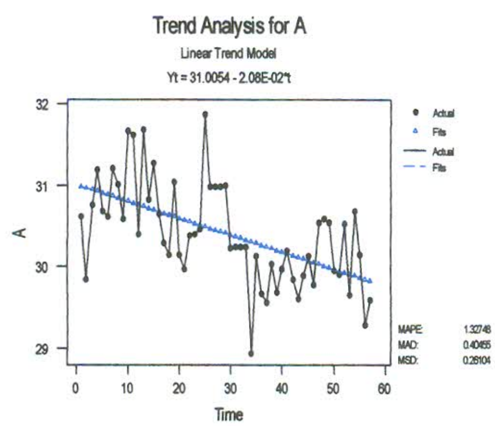


Figure 4.3 Trend for annual AMXT

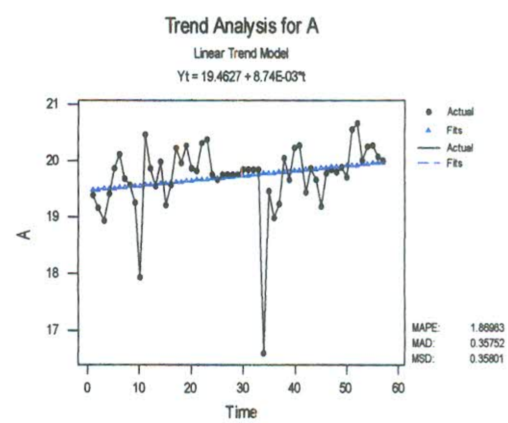


Figure 4.4 Trend for annual AMNT

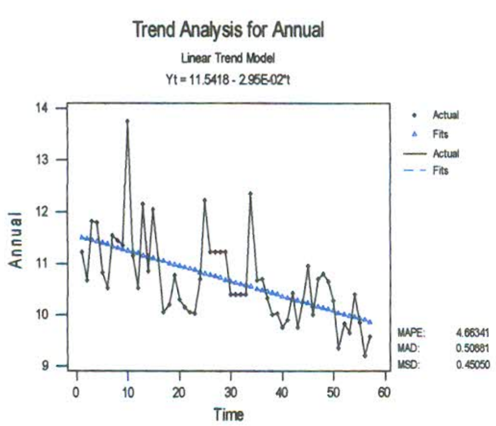


Figure 4.5 Trend for annual ARNT

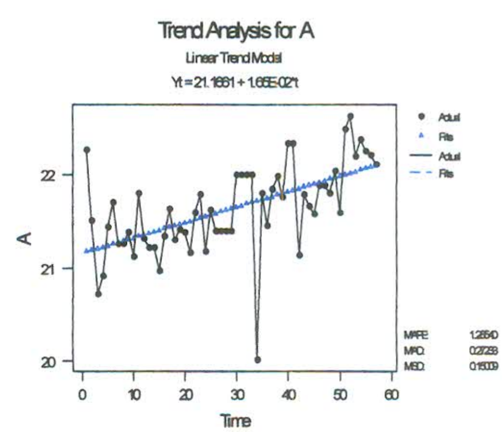


Figure 4.6 Trend for annual AWBT

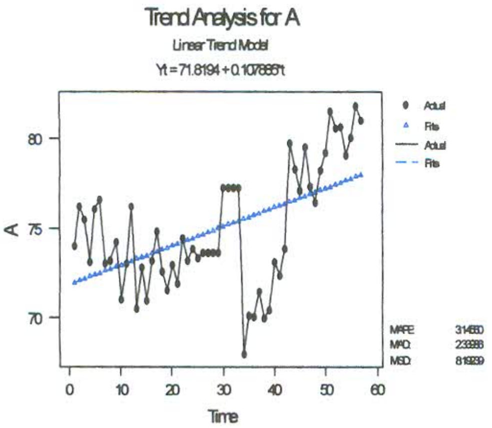


Figure 4.7 Trend for annual ARH

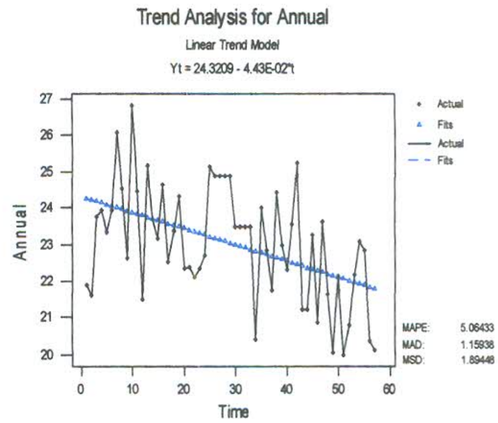


Figure 4.8 Trend for annual ARH(0-12)

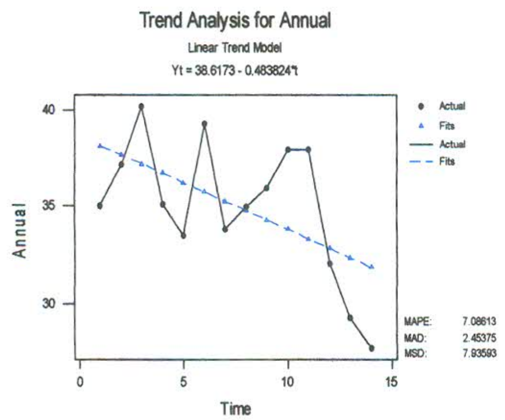


Figure 4.9 Trend for annual AE

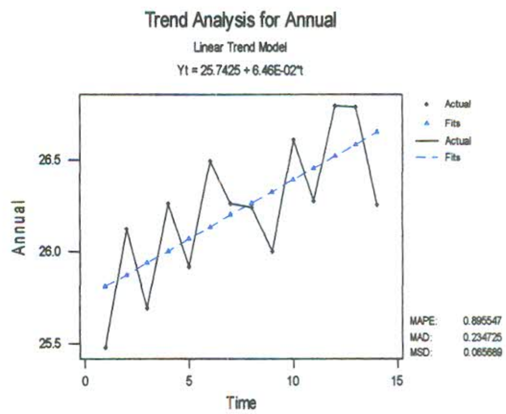


Figure 4.10 Trend for annual AST

4.2.2 Seasonal Data

We have shown the boxplots for seasonal data of some climatic variables [Figure 4.11 to Figure 4.20]. The boxplots for seasonal TR indicate that both the median and variation are highest in Kharif season and lowest in Rabi season. The boxplots of seasonal ARH demonstrate that the highest median and lowest variation are occurred in Kharif season while the lowest median and highest variation are occurred in Prekharif season. The boxplots of seasonal AC indicate that median is the highest in Kharif season and lowest in Rabi season and variation is the highest in Prekharif season and lowest in Kharif season. The boxplots of AMWS demonstrated that both the median and variation are the highest in Prekharif season and lowest in Kharif season. The boxplots of seasonal AMNT indicate highest median and lowest variation in Kharif season and lowest median and highest variation in Rabi season. The boxplots of seasonal AWBT also indicate that the highest median is in Kharif season and lowest median is in Rabi season while the highest variation is in Rabi season and lowest variation is in Kharif season. Boxplots of seasonal AMXT indicated that both median and variation are the highest in Prekharif season and lowest median is in Rabi season and lowest variation is in Kharif season. From boxplots of seasonal ADBT we observe that the median is the highest in Kharif season and lowest in Rabi season and variation is the highest in Prekharif season and lowest in Kharif season. From the boxplot of seasonal ARNT we observe that the highest median is experienced in Rabi season and lowest median is experienced in Kharif season while the highest variation is occurred in Prekharif season and lowest variation occurrs in Kharif season. The boxplot of seasonal ASLP demonstrate that the highest median is in Rabi season and lowest median is in Kharif season while the highest variation is in Prekharif season and lowest variation is in Kharif season. Several outliers are found in both of the positive and negative direction for the seasonal variables as shown in the figures of Boxplots.

Boxplots for Some Seasonal Climatic Data

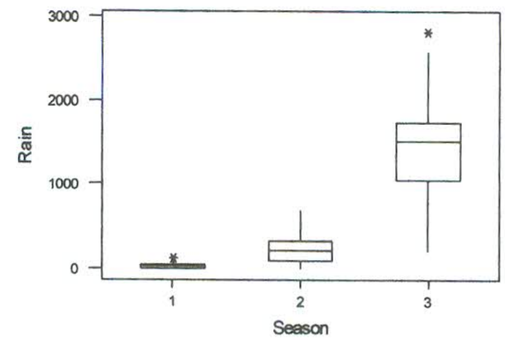


Figure 4.11 Boxplot of seasonal TR

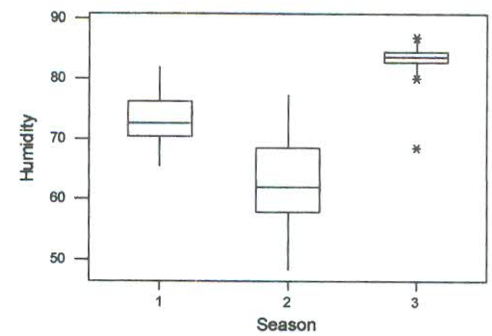


Figure 4.12 Boxplot of seasonal ARH

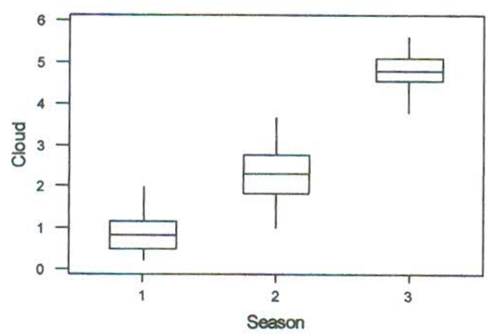


Figure 4.13 Boxplot of seasonal AC

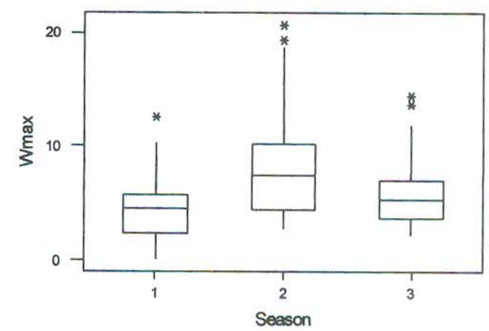


Figure 4.14 Boxplot of seasonal AMWS

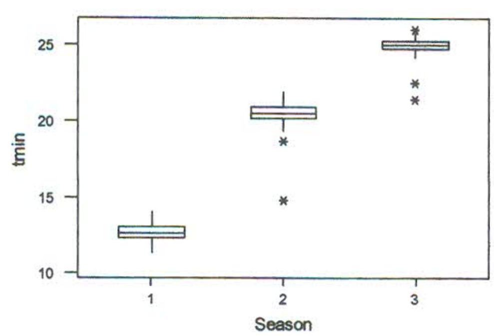


Figure 4.15 Boxplot of seasonal AMNT

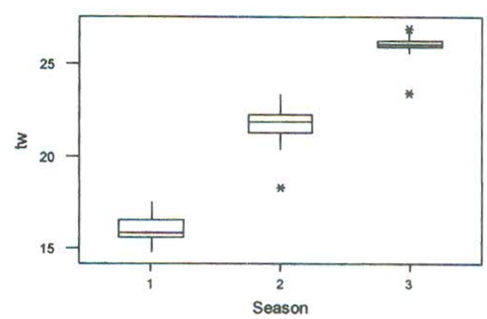


Figure 4.16 Boxplot of seasonal AWBT

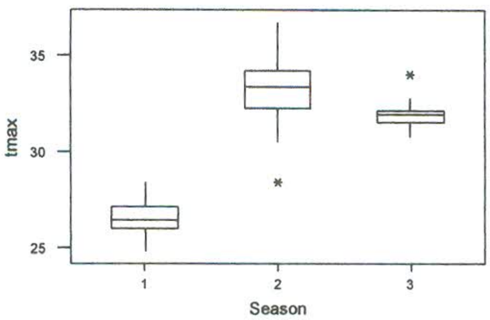


Figure 4.17 Boxplot of seasonal AMXT

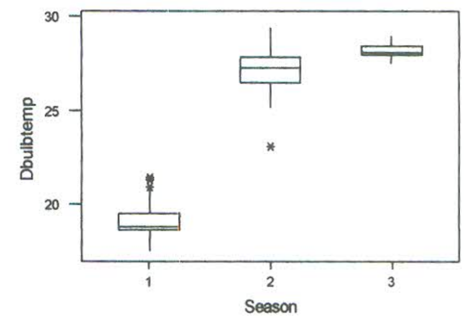


Figure 4.18 Boxplot of seasonal ADBT

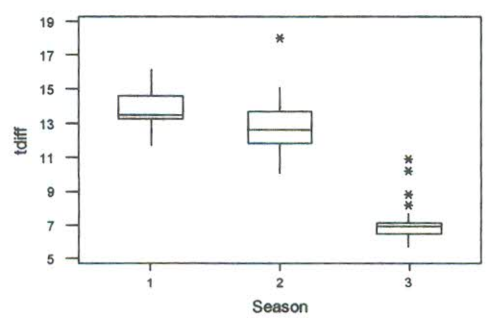


Figure 4.19 Boxplot of seasonal ARNT

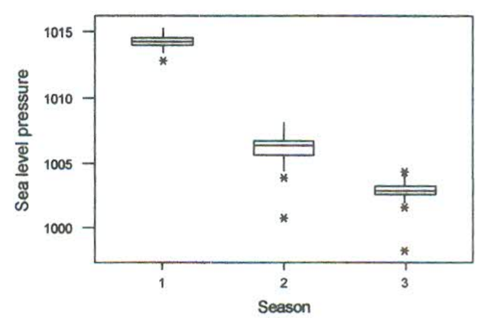


Figure 4.20 Boxplot of seasonal ASLP

Table 4.7 Variability of Seasonal Variables

Variable	Season	Rabi	Prekharif	Kharif	Variable	Season	Rabi	Prekharif	Kharif	Variable	Season	Rabi	Prekharif	Kharif
TR	Mean	27.82	214.3	1395	AT (D-W)	Mean	3.0035	5.366	2.1391	AMWS	Mean	4.268	7.906	5.796
	CV	109.777	77.648	43.35		CV(%)	17.836	24.767	17.498		CV(%)	60.15	52.81	47.91
AC	Mean	0.861	2.325	4.801	ASH	Mean	7.092	7.506	14.525	AWS	Mean	0.712	1.709	1.241
	CV	45.088	26.567	8.289		CV(%)	7.205	7.327	12.344		CV(%)	87.007	50.322	47.667
AMNT	Mean	12.712	20.427	24.89	ARH	Mean	3.0035	5.366	5.346	AMXT	Mean	26.518	33.131	31.872
	CV	5.129	4.807	2.716		CV(%)	17.836	24.767	9.54		CV(%)	2.851	4.558	1.566
ADBT	Mean	19.04	27.12	28.2	ARH(12)	Mean	26.91	32.053	2.1391	AE	Mean	22.607	50.33	35.69
	CV	4.406	4.159	1.163		CV(%)	11.297	12.039	17.498		CV(%)	7.829	14.325	13.113
AWBT	Mean	16.04	21.752	26.06	ARH(0)	Mean	7.092	7.506	14.525	ARNT	Mean	13.806	12.704	6.979
	CV	4.0524	3.8249	1.727		CV(%)	7.205	7.327	12.344		CV	6.939	11.492	12.595
AST(5)	Mean	19.466	27.734	29.95	ARH(0-12)	Mean	26.91	32.053	5.346	ASLP	Mean	1014.3	1006.2	1002.9
	CV	3.524	3.332	1.212		CV(%)	11.297	12.039	9.54		CV	0.0493	0.1193	0.0897

Variability of seasonal climatic variables are presented in respect of nonrobust means and CVs [Table 4.7] and we observe that the variables TR, AC, AMNT, ADBT, AWBT and AST(5) show highest mean in Kharif season and lowest mean in Rabi season while the highest variation in Rabi season and lowest variation in Kharif seasons. The variables AMWS, AWS and ASLP show highest mean in Prekharif season and lowest mean in Rabi season while the highest variation in Rabi season and lowest variation in Kharif season. The variables ARH(0-12) and ASH show highest mean in Prekharif season and lowest mean in Kharif season and highest variation in Kharif season and lowest variation in Rabi season. The variable ARNT shows highest mean in Rabi season and lowest mean in Kharif season and the highest variation in Kharif season and lowest variation in Rabi season. The variable AMXT shows highest mean in Prekharif season and lowest mean in Rabi season and the highest variation in Prekharif season and lowest variation in Kharif season. The variables ARH, ARH (12) and ARH(0) show highest mean in Kharif season and lowest mean in Prekharif season and the highest variation in Prekharif season and lowest variation in Kharif season. The variable AT(D-W) shows highest mean in Prekharif season and lowest mean in Kharif season and the highest variation in Prekharif season and lowest variation in Kharif season. The variable AE shows highest mean in Prekharif season and lowest mean in Rabi season and the highest variation in Prekharif season and lowest variation in Rabi season. The variable ASLP shows highest mean in Rabi season and lowest mean in Kharif season and the highest variation in Prekharif season and lowest variation in Rabi season. Table 4.8 shows at a glance picture for seasonal variables according to their highest and lowest nonrobust means and cvs.

Table 4.8 Highest and Lowest Means and CVs for Seasonal Climatic Variables

CV / Mean	Highest in Rabi and lowest in Kharif	Highest in Kharif and lowest in Rabi	Highest in prekharif and lowest in kharif	Highest in Prekharif and lowest in Rabi
Highest in Kharif and lowest in Rabi	TR, AC, AMNT, ADBT, AWBT and AST(5)	–	–	–
Highest in Prekharif and lowest in Kharif	–	ARH(0-12) and ASH	AT (D-W)	–
Highest in Prekharif and lowest in Rabi	AMWS, AWS and ASLP	–	AMXT	AE
Highest in Kharif and lowest in Prekharif	–	–	ARH, ARH(12) and ARH(0)	–
Highest in Rabi and lowest in Kharif	–	ARNT	–	ASLP

The minimum TR is observed 0 in both the Rabi and Prekharif season and 211 in Kharif season. The maximum TR in Kharif season is observed 2819 while it is 673 in Prekharif season and 123 in Rabi season. The minimum AMXT in Rabi season is 24.75 while it is 28.43 in Parkharif season and 30.75 in Kharif season. The maximum AMXT in Prekharif season is 36.67 while it is 33.94 in Kharif season and 28.4 in Rabi season. Minimum AMNT in Rabi season is 11.34 while it is 14.81 in Parkharif season and 21.38 in Kharif season. The maximum AMNT in Kharif season is 25.94 while it is 21.88 in Prekharif season and 14.08 in Rabi season. Minimum ARNT in Kharif season is 5.73 while it is 10.07 in Parkharif season and 11.75 in Rabi season. The maximum ARNT in Prekharif season is 18.00 while it is 16.14 in Rabi season and 10.91 in Kharif season. Minimum ADBT in Rabi season is 17.49 while in Prekharif season it is 23.11 and in Kharif season it is 27.52. Maximum ADBT in Prekharif season is 29.36 while the maximum ADBT in Kharif season is 28.97 and the maximum ADBT in Rabi season is 21.44. Minimum AWBT is 14.8 in Rabi season while it is 18.33 in Prekharif season and 23.5 in Kharif season. Minimum AT (D-W) in Kharif season is 1.65 while it is 1.88 in Rabi season and 2.72 in Prekharif season. Maximum AT (D-W) in Prekharif season is 8.44 while it is 4.31 in Kharif season and 4.2 in Rabi season. Minimum AWS in Rabi season is 0.00 while it is 0.32 in Kharif season and 0.43 in Prekharif season. Maximum AWS in Prekharif season is 5.93 while it is 3.10 in Kharif season and 3.08 in Rabi season. Minimum AMWS in Rabi season is 0.00 while it is 2.20 in Kharif season and 2.67 in Prekharif season. Maximum AMWS in Prekharif season is 20.67 while it is 14.40 in Kharif season and 12.5 in Rabi season. Minimum AC in Rabi season is 0.200 while it is 1.00 in Prekharif season and 3.8 in Kharif season. Maximum AC in Kharif season is 5.62 while it is 3.67 in Prekharif season and 1.98 in Rabi season. Minimum ARH is 48.22 in Prekharif season while it is 65.42 in Rabi season and 68.43 in Kharif season. Maximum ARH is 86.97 in Kharif season while it is 82.02 in Rabi season and 77.02 in Prekharif season. Minimum ARH(0) is 71.34 in Prekharif season while it is 85.14 in Rabi season and 87.98 in Kharif season. Maximum ARH(0) is 97.28 in Rabi season while it is 95.69 in Kharif season and is 92.81 in Prekharif season. Minimum ARH(12) 33.27 is in Prekharif season while it is 56.35 in Rabi season and 66.9 is in Kharif season. Maximum ARH(12) 82.54 is in Kharif season while it is 75.5 in Rabi season and 69.33 in Prekharif season. Minimum ARH(0-12) is 10.33 in Kharif season while it is 18.22 in Rabi season

we observe the positive seasonal effect in Kharif season and negative seasonal effect in Rabi season for the variables TR, AMNT, ADBT, AWBT and AC. For the variables of ARNT and ASLP we get the positive seasonal effect in Rabi season and negative seasonal effect in Kharif season. We find negative seasonal effect in Rabi season and positive seasonal effect in Prekharif season for the variables AMXT, AMWS and AWS. We determine the negative seasonal effect in Prekharif season and positive seasonal effect in Kharif season for the variable ARH.

and 22.22 in Prekharif season. Maximum ARH(0-12) is 42.41 in Prekharif season while it is 32.61 in Rabi season and 21.07 in Kharif season. Minimum ASLP in Kharif season is 998.10 while it is 1000.7 in Prekharif season and 1012.9 in Rabi season. Maximum ASLP in Rabi season is 1015.40 while it is 1008.20 in Prekharif season and 1004.30 in Kharif season. Minimum AE in Rabi season is 19.25 while it is 35.33 in Parkharif season and 25 in Kharif season. The maximum AE in Prekharif season is 63.67 while it is 40.8 in Kharif season and 25.5 in Rabi season. Minimum ASH in Kharif season is 4.456 while it is 6.341 in Parkharif season and 6.365 in Kharif season. The maximum ASH in Prekharif season is 8.532 while it is 8 in Kharif season and 6.194 in Kharif season. Minimum AST(5cm) in Rabi season is 18.41 while it is 25.86 in Parkharif season and 29.4 in Kharif season. The maximum AST(5cm) in Kharif season is 30.92 while it is 28.93 in Prekharif season and 20.96 in Rabi season. Minimum AST(20cm) in Rabi season is 19.79 while it is 26.16 in Parkharif season and 29.72 in Kharif season. The maximum AST(20cm) in Kharif season is 31.12 while it is 28.87in Prekharif season and 21.71 in Rabi season. Minimum AST(30cm) in Rabi season is 20.05 while it is 25.71 in Parkharif season and 29.1 in Kharif season. The maximum AST(30cm) in Kharif season is 30.74 while it is 28.33 in Prekharif season and 22.02 in Rabi season. Minimum AST (50cm) in Rabi season is 20.16 while it is 25.45 in Prekharif season and 29.23 in Kharif season. The maximum AST (50cm) in Kharif season is 30.39 while it is 27.57 in Prekharif season and 22.47 in Rabi season.

Table 4.9 presents the seasonal effect for the variables TR, AMXT, AMNT, ARNT, ADBT, AWBT, ARH, AC, ASLP, AMWS and AWS from the median polish table and we observe the positive seasonal effect in Kharif season and negative seasonal effect in Rabi season for the variables TR, AMNT, ADBT, AWBT and AC. For the variables of ARNT and ASLP we get the positive seasonal effect in Rabi season and negative seasonal effect in Kharif season. We find negative seasonal effect in Rabi season and positive seasonal effect in Prekharif season for the variables AMXT, AMWS and AWS. We determine the negative seasonal effect in Prekharif season and positive seasonal effect in Kharif season for the variable ARH.

Table 4.9 Seasonal Effect from Median Polish Table for Seasonal Climatic Variables

Season	TR	AMNT	ADBT	AWBT	AC	ARNT	ASLP	AMXT	AMWS	AWS	ARH
Rabi	-153	-7.71	-8.14	-5.78	-1.4	1.23	7.98	-5.08	-0.92	-0.48	0
Prekharif	0	0	0	0	0	0	0	1.26	1.4	0.41	-9.42
Kharif	1226	4.44	0.93	4.293	2.5	-5.53	-3.33	0	0	0	11.08

Table 4.10 presents the trend directions for seasonal variables with their residual's stationarity and normality. The variables of TR, AC, AMWS, AWS, AWBT, AST(5) show upward trend and AE and ASH show downward trend in all the three seasons, while AMXT, ARNT, AT (D-W) demonstrate downward trend and ARH and AMNT demonstrate upward trend in Rabi and Prekharif seasons but no trend is found in Kharif seasons for AMXT, ARNT, AT (D-W) ARH and AMNT. ADBT show upward trend in Rabi and Kharif seasons while show downward trend in Prekharif season and ASLP, ARH(0-12) show downward trend in Rabi seasons and show slight upward trend in Kharif seasons while ASLP show no trend and ARH(0-12) show slight downward trend in Prekharif seasons. The residuals of the trends of seasonal TR, AMXT, ARNT, AMNT and ASLP follow stationary and the residuals of the trends of seasonal AC, AWS, AMWS and ARH follow nonstationary. The residuals of the trend of ADBT and AWBT for Rabi season follow nonstationarity and for Prekharif and Kharif seasons they show stationarity. The detected outliers and the occurrence year for extreme outliers for seasonal climatic variables are presented in Table 4.11. Trend equations for seasonal data with forecasted observations of some climatic variables during 1948-2012 are presented in Appendix [Table A.4.2 and Table A.4.3]. We have also shown the trend equations of ARH (0), ARH (12) and ARH (0-12) in Appendix Table A.4.4.

Table 4.10 Trend Pattern for Seasonal Variables with Their Residual's Stationarity and Normality

Season	TR	AC	AMWS	AWS	AST	AWBT	AE	ASH	AMXT	ARNT	AT (D-W)	ARH	AMNT	ADBT	ASLP	ARH (0-12)
Rabi	U (S-NN)	U (NS-NN)	U (NS-NN)	U (NS-NN)	U	U (NS-N)	D	D	D (S-N)	D (S-N)	D(S)	U (NS-NN)	U (S-N)	U (NS-NN)	D (S-N)	*D
Prekharif	U (S-N)	U (NS-N)	U (NS-NN)	U (NS-NN)	U	U (S-NN)	D	D	D (S-NN)	D (S-NN)	D(NS)	U (S-N)	VVSU (NN)	D (S-NN)	N (NN)	SD
Kharif	U (S-N)	U (NS-N)	U (NS-NN)	U (NS-NN)	U	U (S-NN)	D	D	N (NN)	N (NN)	N	N (S-NN)	N (NN)	U(S-N)	VSU (S-NN)	SU

Note: U-Upward, D-Downward, VVSU-Very Very slight upward S-Stationary, NS-Nonstationary, N-Normal, NN-Nonnormal

Table 4.11 Detected Outliers and the Occurrences Years for Extreme Outliers of Seasonal Variables

	Rabi	Prekharif	Kharif
TR	(HI: 123) Leaf Unit = 1.0 HI: 123 -1981	-	(HI: 28) Leaf Unit = 100 HI: 28 - 1987
AWS	(HI: 308) Leaf Unit = 0.010 HI: 308 - 1981	(HI: 59) Leaf Unit = 0.10 HI: 59 - 1981	(HI: 31) Leaf Unit = 0.10 HI: 31 - 1981
AMWS	(HI: 125) Leaf Unit = 0.10 HI: 125 - 1981	(HI: 186, 193, 206) Leaf Unit = 0.10 HI: 206 - 1992	(HI: 118, 136, 144) Leaf Unit = 0.10 HI: 144 - 1971
ASLP	(LO: 10128)Leaf Unit = 0.10 LO: 10128 - 1985	(LO: 10007, 10039) Leaf Unit = 0.10 LO: 10007 - 1948	(LO: 9981, 10015, 10016 and HI: 10041, 10042, 10043) Leaf Unit = 0.10 LO: 9981 - 1959 and HI: 10043 - 1997
ARH	-	-	(LO: 684, 800, 801, 808, 809, 810, 812, 812 and HI: 866, 869) Leaf Unit = 0.10 LO: 684 - 1981 and HI: 869 - 1999
AWBT	-	(LO: 183) Leaf Unit = 0.10 LO: 183 - 1981	(LO: 2350 and HI: 2690, 2694) Leaf Unit = 0.010 LO: 2350 - 1981 and HI: 2694 - 1998
ADBT	(HI: 208, 209, 213, 214) Leaf Unit = 0.10	(LO: 231) Leaf Unit = 0.10	-
ARNT	-	(HI: 180) Leaf Unit = 0.10 HI: 180 - 1957	(HI: 82, 88, 102, 109) Leaf Unit = 0.10 HI: 109 - 1981
AMNT	(LO: 113, 113, 114 and HI: 140, 140) Leaf Unit = 0.10 LO: 113(2) - 1949, 1950 and HI: 140(2) - 1999	(LO: 148, 186 and HI: 218) Leaf Unit = 0.10 LO: 148 - 1981 and HI: 218 -1970	(LO: 2138, 2252, 2413 and HI: 2594) Leaf Unit = 0.010 LO: 2138 - 1981 and HI: 2594- 1998
AMXT	-	(LO: 284) Leaf Unit = 0.10 LO: 284 - 1981	(HI: 339) Leaf Unit = 0.10 HI: 339- 1972

Some Seasonal Trends for Climatic Variables

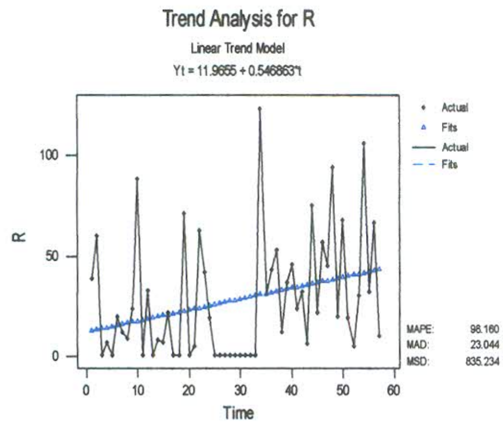


Figure 4.21 Trend of TR for Rabi Season

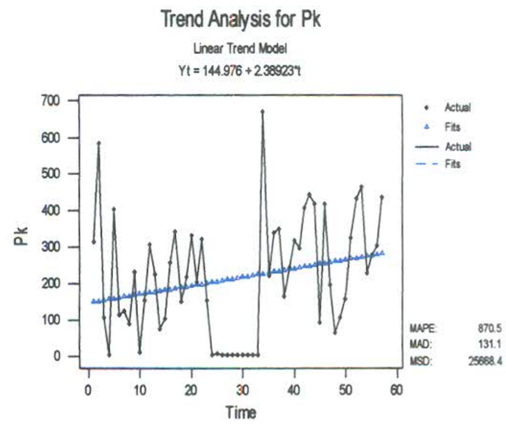


Figure 4.22 Trend of TR for Prekharif Season

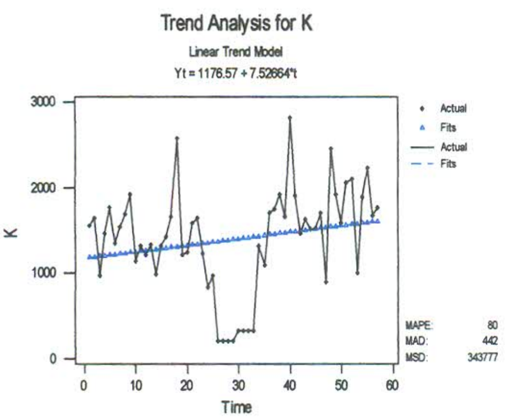


Figure 4.23Trend of TR for Kharif Season

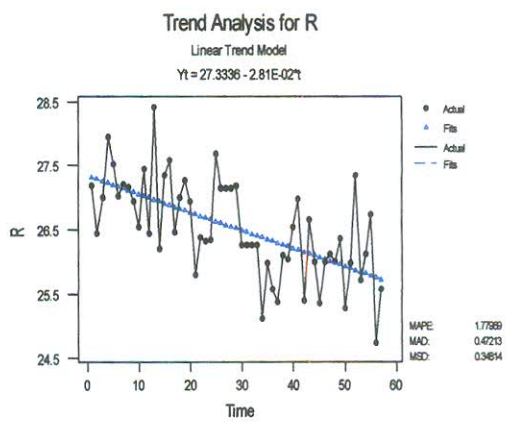


Figure 4.24Trend of AMXT for Rabi season

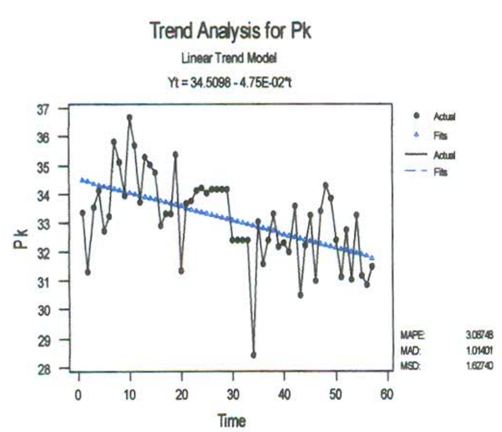


Figure 4.25 Trend of AMXT for Prekharif season

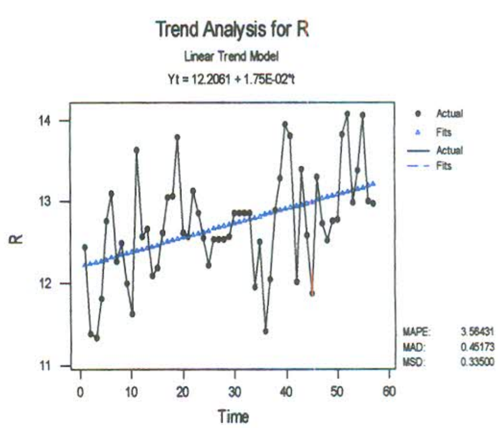


Figure 4.26 Trend of AMNT for Rabi season

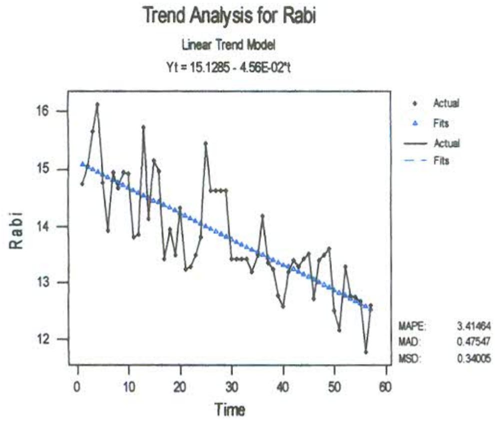


Figure 4.27 Trend of ARNT for Rabi season

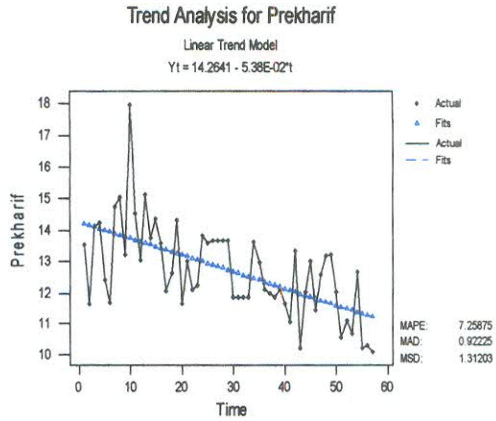


Figure 4.28 Trend of ARNT for Prekharif season

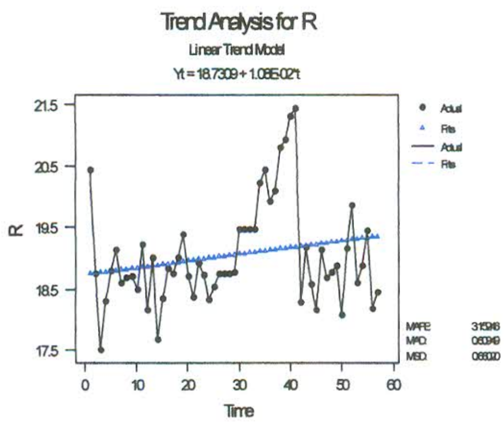


Figure 4.29 Trend of ADBT for Rabi season

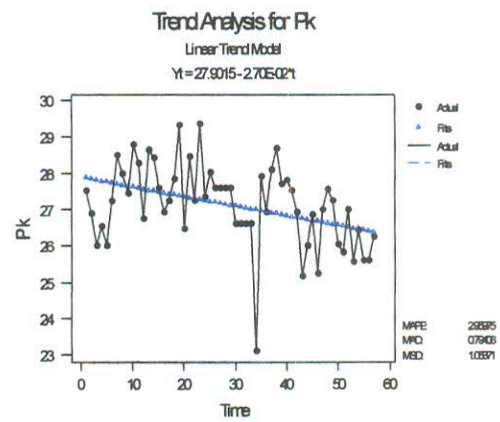


Figure 4.30 Trend of ADBT for Prekharif season

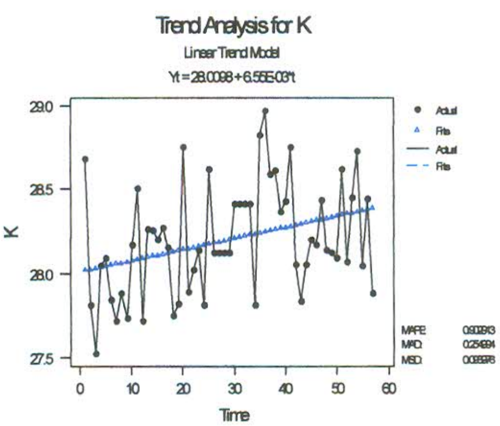


Figure 4.31 Trend of ADBT for Kharif season

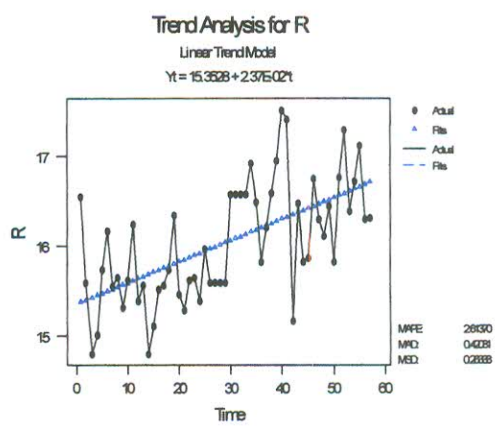


Figure 4.32 Trend of AWBT for Rabi season

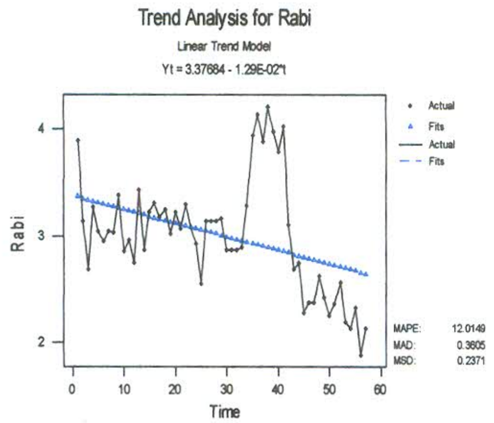


Figure 4.33 Trend of AT (D-W) for Rabi season

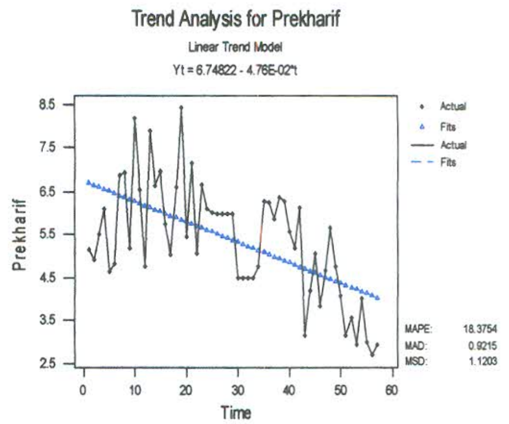


Figure 4.34 Trend of AT(D-W) for Prekharif season

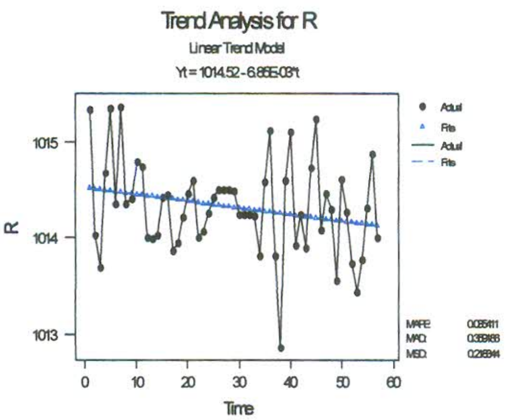


Figure 4.35 Trend of ASLP for Rabi season

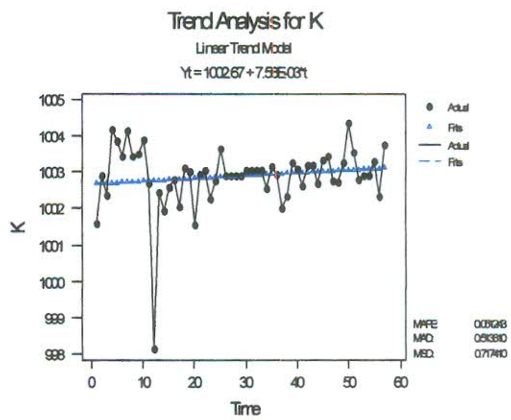


Figure 4.36Trend of ASLP for Kharif season

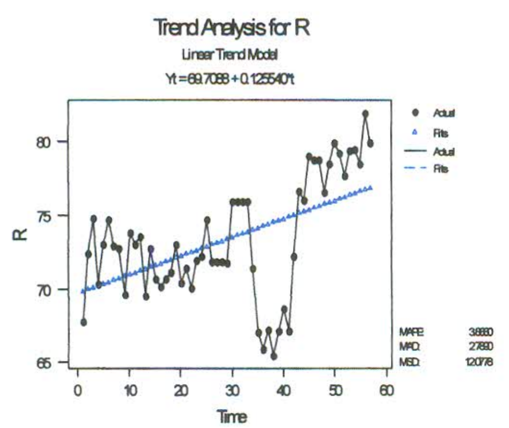


Figure 4.38 Trend of ARH for Rabi season

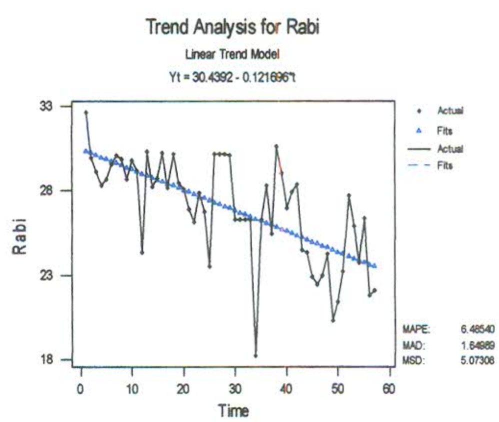


Figure 4.39 Trend of ARH(0-12) for Rabi season

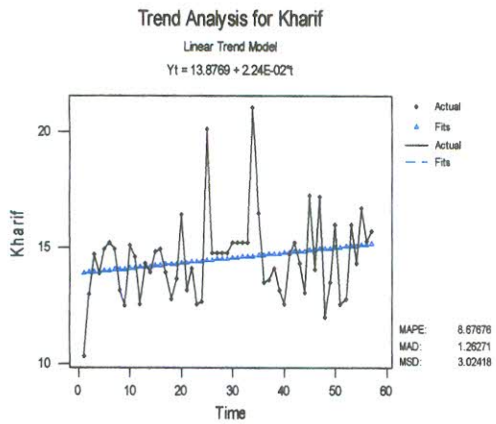


Figure 4.40 Trend of ARH(0-12) in Kharif season

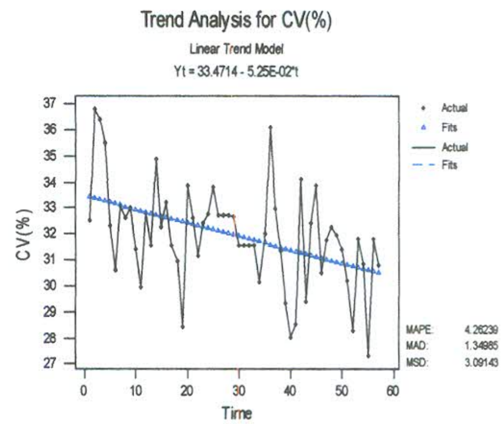


Figure 4. 41 Trend for CV of seasonal AMNT

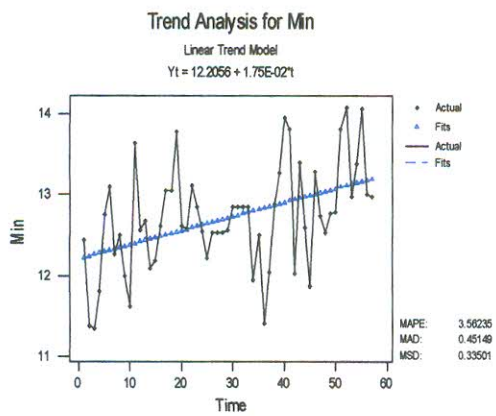


Figure 4.42 Trend for minimum seasonal AMNT

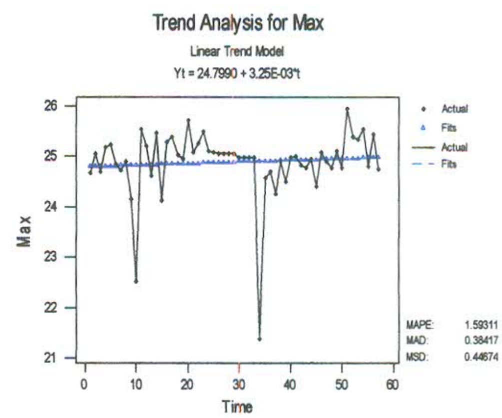


Figure 4.43 Trend for maximum seasonal AMNT

4.2.3 Monthly Data

We have shown month by month (January-December) boxplots for monthly TR, AMXT, ADBT, ARNT, ARH, AC, AMWS and ASLP for the period 1948-2004 in Figure 4.44 to 4.51.These plots clearly indicate annual cycle. Several outliers are detected in boxplots and the stem and leaf plot helps us to get a better idea about the outliers and their time occurrences. All are summarized in the Appendix [Table A.4.5 to Table A.4.7].

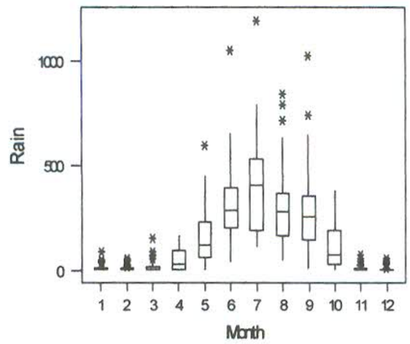


Figure 4.44 Boxplot of monthly TR

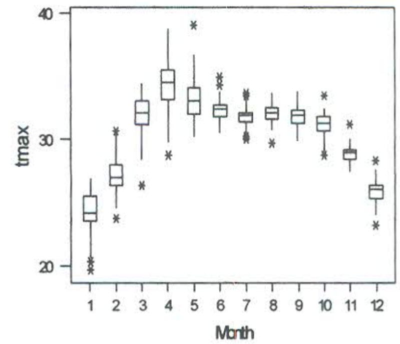


Figure 4.45 Boxplot of monthly AMXT

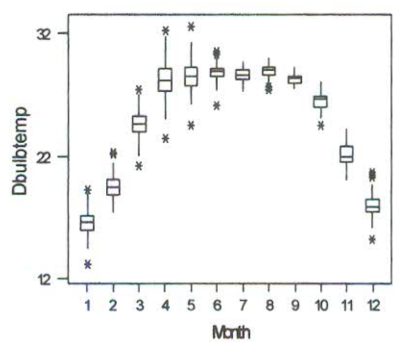


Figure 4.46 Boxplot of monthly ADBT

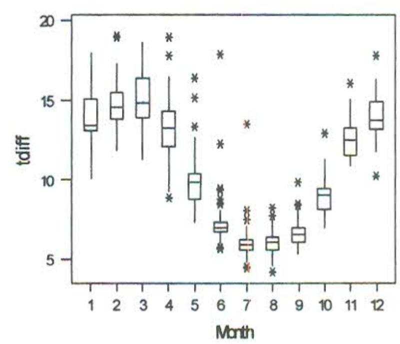


Figure 4.47 Boxplot of monthly ARNT

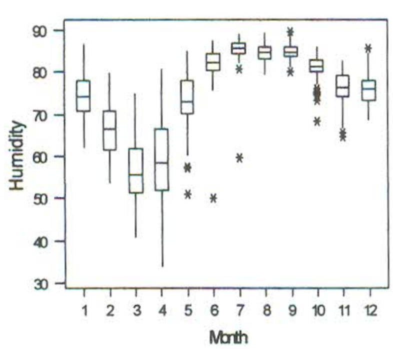


Figure 4.48 Boxplot of monthly ARH

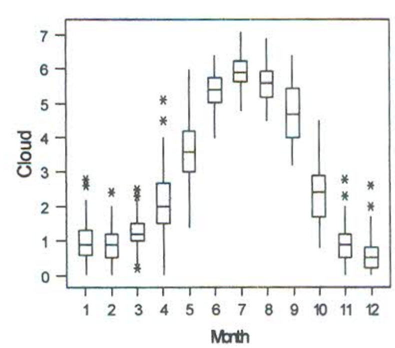


Figure 4.49 Boxplot of monthly AC

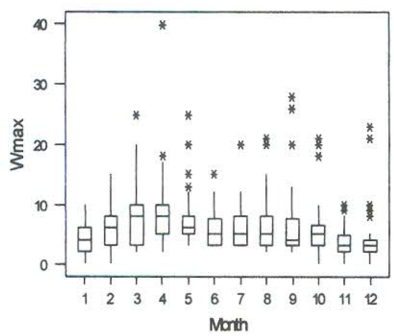


Figure 4.50 Boxplot of monthly AMWS

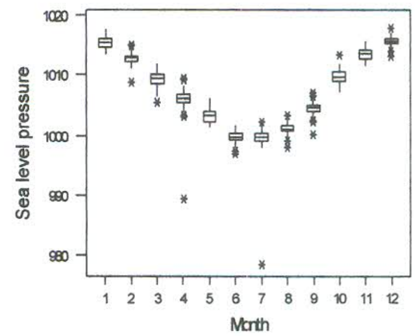


Figure 4.51 Boxplot of monthly ASLP

Table 4.12 Monthly Means for Climatic Variables

Mean	TR	AC	AE	ASH	ASLP	AMXT	AMNT	ARNT	ADBT	AWBT	AT (D-W)	AST (5cm)	AWS	AMWS	ARH	ARH (12)	ARH (0)	ARH (0-12)
Jan	9.09	1.00	17.64	5.74	1015.4	24.20	10.32	13.88	16.60	13.97	2.64	16.62	0.75	3.95	74.94	65.41	92.3	26.9
Feb	6	0.91	28.71	7.56	1012.7	27.19	12.45	14.74	19.48	15.48	3.99	19.29	0.99	5.47	66.11	51.65	88.38	36.7
Mar	14.42	1.26	47.29	8.23	1009.4	31.88	16.94	14.94	24.55	18.55	6.00	24.14	1.52	8.02	56.7	41.64	81.1	39.5
Apr	50.61	2.10	55.71	7.45	1005.9	34.23	20.98	13.25	28.16	21.92	6.24	28.93	1.90	8.83	59.21	47.03	80.5	33.5
May	149.2	3.62	48	6.85	1003.4	33.28	23.36	9.92	28.65	24.79	3.86	30.14	1.70	6.88	72.91	65.17	88.39	23.2
Jun	306.5	5.39	43.79	4.91	999.68	32.43	25.14	7.29	28.76	26.34	2.42	30.74	1.64	5.77	81.73	76.59	91.97	15.4
Jul	391.6	5.95	34.93	4.23	999.37	31.82	25.76	6.05	28.60	26.69	1.92	30.55	1.46	5.86	85.07	80.12	93.41	13.3
Aug	302.3	5.57	35.93	5.32	1001.1	32.07	26.02	6.06	28.84	26.86	1.98	30.67	1.36	5.83	84.60	79.92	93.57	13.7
Sep	280.9	4.72	32.93	5.12	1004.6	31.87	25.25	6.62	28.27	26.32	1.95	29.84	1.06	6.16	84.89	81.12	94.29	13.2
Oct	113.6	2.38	30.86	7.15	1009.7	31.18	22.30	8.88	26.53	24.09	2.43	27.97	0.69	5.37	80.88	76.96	94.11	17.2
Nov	6.95	0.93	25.29	8.00	1013.5	28.89	16.29	12.59	22.14	19.29	2.84	23.24	0.54	3.42	76.18	71.99	93.06	21.1
Dec	5.79	0.59	18.79	7.07	1015.6	25.79	11.79	14.01	17.97	15.42	2.54	18.71	0.55	4.23	76.17	70.27	93.24	23

We again examine within year variability analysis for monthly climatic data of Dinajpur and Table 4.12 presents monthly means for climatic variables and Table 4.13 presents monthly cvs for climatic variables and Table 4.14 also represents the months for highest and lowest means and cvs for climatic data. Within-year variability for monthly total rainfall (TR) during 1948-2004 is presented in Appendix [Table A.4.8] for both robust and nonrobust measurement.

Table 4.13 Monthly CVs for Climatic Variables

CV	TR	AC	AE	AS	ASLP	AMXT	AMNT	ARNT	ADBT	AWBT	AT (D-W)	AST (5cm)	AWS	AMWS	ARH	ARH (12)	ARH (0)	ARH (0-12)
Jan	173.7	56.48	11.25	17.04	0.098	6.47	8.28	10.79	7.23	6.39	25.63	3.95	118.57	66.07	7.09	10.80	4.19	17.1
Feb	196.2	53.75	14.80	12.1	0.098	5.33	8.34	9.81	5.88	6.82	21.66	4.65	89.50	60.70	9.43	15.72	5.26	14.9
Mar	187.3	40.22	10.93	6.82	0.118	5.01	5.98	11.66	4.92	5.60	22.55	3.91	73.078	64.26	13.82	23.82	7.77	15
Apr	105.6	47.19	19.74	13.61	0.248	6.19	6.17	14.89	5.99	5.43	32.88	4.59	50.05	68.39	17.90	26.57	9.60	20.5
May	88.61	25.83	20.29	15.28	0.109	5.17	5.47	16.64	4.73	3.96	34.51	4.23	36.39	60.40	9.69	11.30	4.58	20.2
Jun	62.74	10.7	17.58	24.85	0.093	2.88	5.57	24.36	2.56	4.04	30.84	1.80	44.82	53.76	6.1	6.40	2.44	23.4
Jul	55.9	9.116	20.01	29.28	0.297	2.38	4.36	19.96	1.71	2.86	29.76	2.08	59.45	57.73	4.48	5.18	1.81	23.9
Aug	64.94	9.071	20.26	19.26	0.109	2.29	1.95	12.21	1.99	1.35	17.73	2.22	49.58	67.17	2.75	3.59	1.38	21.2
Sep	68.1	18.22	15.7	21.58	0.109	2.38	1.99	12.57	1.45	1.08	14.82	1.49	54.26	83.20	2.19	3.48	1.48	16.7
Oct	104.1	34.65	8.79	15.54	0.108	2.71	4.11	12.52	2.74	2.58	20.03	1.92	73.68	79.00	4.16	5.71	2.00	20.4
Nov	223.2	65.48	10.33	6.974	0.098	2.15	6.48	9.39	4.32	4.59	19.32	4.11	96.66	68.19	5.16	7.55	2.84	17.9
Dec	232.1	89.6	11.08	9.792	0.078	3.68	8.45	9.05	5.81	5.79	17.88	5.21	85.49	111.76	4.83	9.21	3.15	19.5

Table 4.14 The Months Containing Highest and Lowest Means and CVs during 1948-2004

	TR	AC	AE	AS	ASLP	AMXT	AMNT	ARNT	ADBT	AWBT	AT(D-W)	AST (5cm)	AWS	AMWS	ARH	ARH (12)	ARH (0)	ARH (0-12)
Highest Mean	Jul	Jul	Apr	Mar	Dec	Apr	Aug	Mar	Aug	Aug	Apr	Jun	Apr	Apr	Jul	Sep	Sep	Mar
Lowest Mean	Dec	Dec	Jan	Jul	Jul	Jan	Jan	Jul	Jan	Jan	Jul	Jan	Nov	Nov	Mar	Mar	Apr	Sep
Highest CV	Dec	Dec	May	Jul	Apr	Jan	Dec	Jun	Jan	Feb	May	Dec	Jan	Dec	Apr	Apr	Apr	Jul
Lowest CV	Jul	Aug	Oct	Mar	Dec	Nov	Aug	Dec	Sep	Sep	Sep	Sep	May	Jun	Sep	Sep	Aug	Feb

Table 4.15 presents the monthly effect obtained from median polish and we have the positive effect during May to October and negative effect during November to April for the variables TR, AMNT, AWBT and AC. For ADBT we get the positive effect during April to September and negative effect during October to March and ASLP happens opposite to ADBT. We have the negative effect for AMXT during October to February including July, for ARNT during May to October, for ARH during December to May, for AMWS during October to January and for AWS during September to February.

Table 4.15 Monthly Effects of Monthly Climatic Data from Median Polish Tables

Month	TR	AMNT	AWBT	AC	ADBT	ASLP	AMXT	ARNT	ARH	AMWS	AWS
Jan	-53.38	-11.4	-9	-1.238	-10.7	7.62	-7.756	2.686	-1.38	-1	-0.48
Feb	-57.13	-9.39	-7.7	-1.363	-7.82	4.99	-4.761	3.539	-9.94	0	-0.23
Mar	-55.63	-4.8	-4.5	-1.038	-2.69	1.54	0.214	3.809	-20.8	1.5	0.175
Apr	-12.38	-0.658	-1.03	-0.138	0.683	-1.54	2.551	2.086	-18.4	2	0.675
May	42.88	1.775	1.925	1.438	1.408	-4.49	1.151	-1.51	-2.58	1	0.4
Jun	211.9	3.558	3.425	3.163	1.465	-8.13	0.466	-4.08	5.893	0	0.375
Jul	321.88	4.1625	3.725	3.713	1.29	-8.09	-0.016	-5.26	9.438	0	0.125
Aug	199.9	4.41	3.825	3.438	1.523	-6.68	0.239	-5.03	8.645	0	0.15
Sep	177.38	3.49	3.225	2.463	0.945	-3.04	0.016	-4.63	8.185	0	-0.13
Oct	12.375	0.6575	1.025	0.138	-0.68	1.87	-0.639	-2.5	4.873	-0.5	-0.43
Nov	-57.13	-5.425	-3.73	-1.313	-5.21	5.82	-3.024	1.509	0.008	-1.875	-0.63
Dec	-57.13	-9.91	-7.6	-1.688	-9.37	7.86	-6.079	2.759	-0.01	-2	-0.65

The upward trends are observed for the averages and the downward trends are observed for the variations of the monthly data of TR, AC, ARH, ARH(0), ARH(12), AWBT, AWS, AMWS. The average of AMNT shows slight upward trend and the variation of AMNT show downward trend also. Both the variations and averages follow downward trend for the monthly data of AT(D-W), ARH(0-12), AE and ARNT. The monthly averages of AMXT and ASH indicate downward trend also but their variations indicate upward trend [in respect of nonrobust measurement].

We observe upward trend for the monthly minimum data of the variables of ARH, ARH(12), ARH(0), AWBT, AWS AMWS and ARH(0-12). Very slight upward trends are observed for the minimum values of AMNT and ASLP. Downward trends are found for the minimum AT(D-W), AE and AMXT. The minimum values for monthly ADBT indicate very slight downward trend. But the minimum ARNT and ASH do not indicate any trend.

The 1st quartiles for the monthly data of the variables of TR, AC, ARH, ARH(12), ARH(0), AWBT, AWS, AMWS and AMNT indicate upward trend. Slight upward trend is indicated for the 1st quartiles of monthly ADBT. The 1st quartiles for ARH(0-12), AT(D-W), AE and AMXT indicate downward trend. Slight downward trend is observed for the 1st quartiles of ASH. No trend is observed for the 1st quartiles of ASLP and ARNT.

We observe very slight upward trend for the maximum values of the monthly data of TR, AC, AWBT, AWS, AMWS and AMNT. The maximum ARH does not follow any trend but upward trends are observed in the maximum ARH(12) and ARH(0).The maximum values of monthly AT(D-W), AE, ARH(0-12), AMXT, ARNT and ASH indicate downward trend. The slight downward trends are observed in the maximum values of ADBT and ASLP also.

We observe upward trend for the 3rd quartiles of monthly TR, AC, ARH(12), ARH(0) and AMWS. Slight upward trends are observed for the 3rd quartiles of ARH, AWBT and AWS but the 3rd quartile of AMNT does not show any trend. The 3rd quartiles of AT(D-W), AE, ARH(0-12), ARNT and AMXT show downward trend. ADBT, ASLP and ASH also show very slight downward trend.

Indicated trend directions for monthly means, cvs, minimum values, maximum values, 1st quartiles and 3rd quartiles over the years are shown in Table 4.16. Some trend figures are also shown in Appendix [Figure 4A.1 to Figure 4A.38]. Trend equations for monthly means and cvs of some climatic variables are presented in Appendix Table A.4.9. Trend equations for monthly minimum and maximum values of some climatic variables are presented in Appendix Table A.4.10. Trend equations for 1st and 3rd quartiles of monthly data of some climatic variables are shown in Appendix Table 4.11. We have shown the indicated trend directions for monthly averages, variations [robust], SD and QD for monthly climatic data in Table 4.17 .

Table 4.16 Trend Patterns for Monthly Means, CVs, Minimums, Maximums, 1st and 3rd Quartiles

	TR	AC	ARH	ARH (12)	ARH (0)	AWBT	AWS	AMWS	AMNT	ADBT	ASLP	AT (D-W)	AE	ARH (0-12)	ARNT	AMXT	ASH
Mean	U	U	U	U	U	U	U	U	SU	N	N	D	D	D	D	D	D
CV	D	D	D	D	D	D	D	D	D	SD	D	D	D	SD	D	U	SU
Min	-	-	U	U	U	U	U	U	VVSU	VVSD	SU	D	D	U	N	D	N
Max	VSU	SU	N	U	U	SU	SU	SU	SU	SD	SD	D	D	D	D	D	D
Q1	U	U	U	U	U	U	U	U	U	SU	N	D	D	U	N	D	SD
Q3	U	U	SU	U	U	SU	SU	U	N	VVSD	VSD	D	D	D	D	D	SD

*U-Upward, D-Downward*VSU-Very slight upward, *VSD-Very slight downward *VVSU-Very very slight upward
*VVSD- Very very slight downward

Table 4.17 Trend direction for monthly averages, variations [Robust measures], SD and QD

	TR	AC	ARH	ARH (12)	ARH (0)	AWBT	AWS	AMWS	AMNT	ADBT	ASLP	AT (D-W)	AE	ARH (0-12)	ARNT	AMXT	ASH
Med	U	U	U	U	U	U	U	U	N	SD	SD	D	D	D	D	D	D
TRM	U	U	U	U	U	U	U	U	SU	N	VSD	D	D	D	D	D	D
SD	U	D	D	D	D	D	N	VSU	D	SD	D	D	D	-	D	U	-
QD	U	SD	D	D	D	D	N	N	SD	SD	N	D	D	D	D	SU	SU
CV(Med)	-	D	D	D	D	D	SD	D	D	SD	D	D	D	N	D	U	SU
QD(Med)	-	D	D	D	D	D	SD	D	D	SD	N	D	D	VSD	D	SU	SU
CV(TRM)	D	D	D	D	D	D	D	D	D	SD	D	D	D	D	D	U	SU
QD(TRM)	D	D	D	D	D	D	D	D	D	SD	N	D	D	D	D	SU	-

*U-Upward, D-Downward*VSU-Very slight upward, *VSD-Very slight downward *VVSU-Very very slight upward
*VVSD- Very very slight downward

The AWBT, AWS and AMWS, AC, ARH(0) and AST(5) show upward trend and AE show downward trend in all the twelve months but AWBT show very very slight upward trend in January, May, June, July and September and AMWS show slight upward trend in April, September and October, AC show slight upward trend in June, July ARH(0) slight upward trend in June and AE show slight downward trend in March. The AMXT show downward trend in all the months except June, July and August and it show upward trend in the month of June, July and August. The AMNT shows upward trend in the months of February, March, August, November and December and show no trend in rest of the month. The ARNT show downward trend in all months except June, July and August and it show no trend in June and July and show very slight upward trend in August. The ADBT shows downward trend in January, March, April, May and September while it shows upward trend in the month of February, June, July, August, October, November and December. The AT(D-W) shows downward trend during September to May while it shows slight upward trend in August and no trend in June and July. The TR shows upward trend in February, April, May, September, October and December while it shows no trend in January, March, June, July, August and November. The MXR shows upward trend in February, April, May, September, October and December, no trend in January, July, August and November and slight downward trend in March and June. The FZR shows downward trend in April, May, June, September and December and shows no trend in rest of the month. The ASLP shows downward trend in January, March, May and November while shows very slight upward trend in April, June, August and September and no trend in July, October and December. The ARH and ARH(12) show upward trend during September to May and no trend in June and July and downward trend in August. The ARH(0-12) show downward trend during September to April and upward trend in June, July and August and no trend in May. The downward trend is observed during October-January, March, April and June and upward trend is observed in February, May and September and no trend in July and August for the variable ASH. We have shown the trend direction for the monthly climatic data in Table 4.18 to 4.20. Monthly trend equations for the variables of TR, TFIR, MXR, ADBT, AWBT, AT (D-W), AMXT, AMNT, ARNT, AMWS, AWS, AC, ASLP, ARH, ARH(0), ARH(12) and ARH(0-12) are presented in Appendix [Table A.4.12-Table A.4.17]. We have shown some maps in Appendix [Figure 4A. 39 to Figure 4A. 53] to show the climatic pattern of six divisions of Bangladesh since Dinajpur district is the part of Rajshahi division of Bangladesh.

Chapter 5

Time Series Properties of Climatic and Wheat Production Data in Dinajpur District

5.1 Introduction

Firstly we try to fit ARIMA models for climatic variables TR, MXR, TFIR, ADBT, AMXT, AMNT, ARNT, AWBT, AT(D-W), ARH, ARH(0-12), AWS, AMWS, ASLP and AC for monthly data during 1948-2004. But the data was available for 1948-1972 and 1981-2004 and the data for 8 years (1973-1980) appeared to be missing. We replace the missing data by the forecasted values for the years 1973-1976 and 1977-1980 from the fitted ARIMA models using the data of January 1948 to December 1972 and December 1981 to January 2004 by reversing the year. Then we forecast the values for the variables during January 2005 to December 2008 from the fitted ARIMA models taking the missing replace ready data of 684 monthly observations from January 1948 to December 2004. Similarly we forecast the values from January 2009 to December 2012 from the fitted ARIMA models taking the missing replaced ready data with forecasted values for 780 observations during January 1948 to December 2008. In the cases of the variables ASH and AE we forecast the values during January 2005 to December 2008 for the available observations of January 1989 to December 2004 and January 1987 to December 2000, respectively. Box-Cox power transformation are used when necessary and we select the parsimonious models from 16 models based on minimum root mean square forecasting error (RMSFE) for the last 24 observations for all the variables. Several residual plots such as residuals versus order of the data, residuals versus fitted values, NP plot for residuals, histogram for residuals and the TS plots of point and interval forecasts are checked for selecting an appropriate model and detecting outliers in the models. Secondly we try to analyze the rate of wheat production data [Rate = (Annual wheat production / Annual cultivated area) × 100] for the years 1949 to 2001 and 1948 to 2004 separately where we use some conventional methods like least squares to fit linear trend model and some more important techniques related with diagnostic tools putting an extra emphasis on diagnostics. Lastly we use a 1st order Piecewise autoregressive PAR(1) model to detect structural break and to handle the situation of violation of structural stability in the first order autoregressive scheme as suggested by Imon (2007).

5.2 Analysis and Results

5.2.1 Climatic Variables

The observations for the year 1981 are detected as outliers in the variables AMNT, ARNT, ARH, AWS, AWBT and ARH (0-12). We forecast the outliers for the year of 1981 from the fitted ARIMA models for the data of January 1982 to December 2004 by reversing the years. We observe two drops examining the TS plot of monthly ASLP for January1948 to December 1972 and the 4th observation for April 1948 (989.48) and 139th observation for September 1960 (978.51) is detected as outliers. We replace one outlier for September 1960 of monthly ASLP by the forecasted values of 1006.523 (139th) from the well fitted ARIMA models for the data of January 1960 to December 1972 by reversing the years. Then we replace another outlier for April 1948 (4th) from the fitted models during the data of January 1949 to December 1972 by reversing the years where the forecasted values of 1000.13 are replaced in September 1960. Some relative residual figures such as residuals versus order of the data, residuals versus fitted values, NP plot for residuals, histogram for residuals for some variables are shown where we use those diagnostics for detecting outliers and checking and selecting the appropriate models. The ACF displays for residual autocorrelations for the estimated models are fairly small relative to their standard errors for all the variables. The histograms of the residuals are symmetrical suggesting that the shocks may be normally or approximately normally distributed. The normal probability plots of the residuals do not deviate badly from straight lines (is fairly close to a straight line), again suggesting that the shocks are normal. Some TS plots of point and interval forecasts for the models of the climatic variables TR, TFIR, MXR, ADBT, AMNT, AMXT, ARH, ARH(0-12), AMWS, AWS and ASLP and some residual plots are shown in Figure 5.1 to Figure 5.52. We have presented the estimated ARIMA models including their RMSFE for the 24 forecasts for all the climatic variables in Table 5.1 to 5.16. Table 5.19 presents the forecasted values (Point forecasts) for monthly TR during 2005-2012. Estimated missing values for the monthly climatic variables during 1973-1980 are presented in Appendix [Table A.5.1-A.5.12] and the point forecasts for the monthly climatic variables except TR during 2005-2012 are presented in Appendix [Table A.5.13- Table A.5.23]. The obtained interval forecasts for the variables are not shown in the thesis.

Table 5.1 Models for TR and Their Results

Variable	Model	Equation of Model	FE	MS
SQ R T of TR(1948-1972)	ARIMA(101)(011)	$(1-0.8739B)\ \nabla^{12}y_t = -\ 0.00555+(1-0.7768B)(1-0.9217B^{12})\ \varepsilon_t$	5.2150284	15.06
SQ R T of TR(1981-2004)	ARIMA (100)(111)	$(1-0.0324B)\ (1+0.0449\ B^{12})\ \nabla_{12}\ y_t = -0.02654+(1-0.9295\ B^{12}))\ \varepsilon_t$	4.857836	15.94
S QRT of TR(1948-2004)	ARIMA(100)(111)	$(1-0.089B)(1-0.0131B^{12}))\ \nabla_{12}\ y_t = (1-0.9616B^{12})\ \varepsilon_t$	3.894325	13.66
SQ R T of TR(1948-2008)	ARIMA(200)(111)	$(1-0.0774B-0.0777B^2)(1-0.0287\ B^{12})\ \nabla_{12}\ y_t = 0.035531+(1-0.9996\ B^{12})\ \varepsilon_t$	0.013269	12.43

*FE-Forecasting error, MS-Mean sum of square

Table 5.2 Models for TFIR and Their Results

Variable	Model	Equation of Model	FE	MS
TFIR (1948-1972)	ARIMA (100)(011)	$(1-0.1692B)\ \nabla_{12}\ y_t = .05077+(1-0.9348)\ \varepsilon_t$	2.64274	6.53
TFIR(1981-2004)	ARIMA (100)(111)	$(1-0.0521B)\ (1+0.0654B^{12})\ \nabla_{12}\ y_t = 0.01848+(1-0.9327B^{12})\ \varepsilon_t$	2.470729	6.14
TFIR(1948-2004)	ARIMA (111)(011)	$(1-0.0758\ B)\ (1-0.9528\ B^{12})\ \nabla_{12}\ \nabla\ y_t = -0.00031(1-0.9562B)(1-0.9528B^{12})\ \varepsilon_t$	2.326303	5.70
TFIR(1948-2008)	ARIMA(011)(111)	$(1-0.0303\ B)\ \nabla_{12}\ \nabla\ y_t = -0.0003176+(1-.9492B)\ (1-0.9925B^{12})\ \varepsilon_t$	0.175539	5.29

Table 5.3 Models for MXR and Their Results

Variable	Model	Equation of Model	FE	MS
SQRT of MXR(1948-1972)	ARIMA (101)(101)	$(1-0.7381B)(1-0.9984B^{12})\ y_t = -0.003462+(1-0.6737B)(1-0.9328\ B^{12})\ \varepsilon_t$	2.949472	6.16
SQRT of MXR(1981-2004)	ARIMA (111)(101)	$(1+0.0168B)(1-0.9986B^{12})\ \nabla\ y_t = -0.000099+(1-0.8923\ B^{12})\ \varepsilon_t$	3.841936	7.33
SQRT of MXR(1948-2004)	ARIMA(100)(111)	$(1-0.0227B)(1-0.0109\ B^{12})\ \nabla_{12}\ y_t = 0.024318+(1-0.9588\ B^{12})\ \varepsilon_t$	2.884636	5.74
SQRT of MXR(1948-2008)	ARIMA (100)(111)	$(1-0.0197B)(1-0.0354\ B^{12})\ \nabla_{12}\ y_t = 0.023802+(1-0.9989\ B^{12})\ \varepsilon_t$	0.024763	5.23

Table 5.4 Models for ARH and Their Results

Variable	Model	Equation of Model	FE	MS
ARH(1948-1972),(λ=3)	(100)(011)	$(1-0.3606B)\ \nabla\ _{12}y_t = -248.19+(1-0.9658B^{12})\ \varepsilon_t$	13987.52	288869809
ARH (1982-2004),(λ=3)	(011)(111)	$(1-0.0854\ B^{12})\ \nabla\nabla\ _{12}y_t = -30.13+(1-0.6956\ B)(1-0.8266\ B^{12})\ \varepsilon_t$	18290.84	423950172
ARH (1981-2004),(λ=3)	(111)(011)	$(1-0.3959\ B)\ \nabla\nabla\ _{12}y_t = -9.650+(1-0.9771\ B)(1-0.8247\ B^{12})\ \varepsilon_t$	16825.02	365751625
ARH (1948-2004),(λ=3)	(111)(011)	$(1-0.3956B)\ \nabla\nabla\ _{12}yt = -2.053+(1-0.9415\ B)(1-0.8642\ B^{12})\ \varepsilon_t$	25268.87	315734934

Table 5.5 Models for AMXT and Their Results

Variable	Model	Equation of Model	FE	MS
Ln of AMXT(1948-1972)	ARIMA (011)(111)	$(1+0.0269B^{12})\ \nabla\nabla^{12}y_t = 0.00004830+(1-0.776\ B)\ (1-0.9474B^{12})\ \varepsilon_t$	0.0463832	0.001292
Ln of AMXT (1981-2004)	ARIMA (011)(011)	$\nabla\nabla^{12}y_t = -5.370E-05+(1-0.8682\ B)\ (1-0.9177\ B^{12})\ \varepsilon_t$	1.890776	0.001827
SQRT of AMXT (1948-2004)	ARIMA (100)(011)	$(1-0.628B)\ \nabla_{12}y_t = -0.0007+(1-0.9084B^{12})\ \varepsilon_t$	0.13307	0.01203
SQRT of AMXT (1948-2008)	ARIMA (100)(011)	$(1-0.6281B)\ \nabla_{12}y_t = -0.0007+(1-0.9085\ B^{12})\ \varepsilon_t$	3.28E-05	0.01123

Table 5.6 Models for AMNT and Their Results

Variable	Model	Equation of Model	FE	MS
AMNT(1948-1972)	ARIMA(101)(011)	$(1-0.8234B)\nabla_{12}y_t = 0.004446+(1-0.5666B)(1-0.9606B^{12})\varepsilon_t$	0.453919	0.728
AMNT (1982-2004)	ARIMA (111)(011)	$(1-0.2559B)\nabla\nabla_{12}y_t = -0.0004017+(1-0.9088B)(1-0.9129B^{12})\varepsilon_t$	0.690203	0.560
AMNT (1981-2004)	ARIMA(100)(011)	$(1-0.3414B)\nabla_{12}y_t = -0.025249+(1-0.9388B^{12})\varepsilon_t$	0.350184	0.512
AMNT (1948-2004)	ARIMA (101)(111)	$(1-0.85B)(1+0.0646B^{12})\nabla_{12}y_t = 0.001553+(1-0.5812B)(1-0.948)\varepsilon_t$	0.888943	0.550
AMNT (1948-2008)	ARIMA (111)(111)	$(1-0.1925B)(1+0.0849B^{12})\nabla\nabla_{12}y_t = 2.3E\text{-}06+(1-0.864B)(1-0.9686B^{12})\varepsilon_t$	0.059253	0.529

Table 5.7 Models for ARNT and Their Results

Variable	Model	Equation of Model	FE	MS
ARNT(1948-1972)	ARIMA (011)(111)	$(1+0.0874B)\nabla\nabla_{12}y_t = 0.0024+(1-.5504B)(1-0.9459B^{12})\varepsilon_t$	2.211549	1.302
ARNT(1982-2004)	ARIMA (011)(011)	$\nabla\nabla_{12}y_t = 0.00099+(1-0.7659B)(1-0.9193B^{12})\varepsilon_t$	0.94313	1.034
ARNT(1981-2004)	ARIMA (011)(111)	$(1+0.1437B^{12})\nabla\nabla_{12}y_t = 0.000665+(1-0.8157B)(1-0.9023B^{12})\varepsilon_t$	0.797912	0.980
ARNT(1948-2004)	ARIMA (100)(011)	$(1-0.6911B)\nabla_{12}y_t = -0.00065+(1-0.8594B^{12})\varepsilon_t$	0.106275	0.01018
ARNT(1948-2008)	ARIMA (100)(011)	$(1-0.6939B)\nabla_{12}y_t = (1-0.8598)\varepsilon_t$	0.000243969	0.00950

Table 5.8 Models for AWS and Their Results

Variable	Model	Equation of Model	FE	MS
SQRT of AWS(1948-1972)	ARIMA (200)(101)	$(1-0.4642B-.1508B^2)(1-0.9864B^{12})y_t = 0.004999+(1-0.7602B^{12})\varepsilon_t$	0.220044	0.0553
SQRT of AWS(1982-2004)	ARIMA (011)(011)	$\nabla\nabla_{12}y_t = -0.0001468+(1-0.6871B)(1-0.8781B^{12})\varepsilon_t$	0.225118	.01910
SQRT of AWS(1981-2004)	ARIMA (101)(111)	$(1-0.9389B)(1-0.0082B^{12})\nabla_{12}y_t = 0.000793+(1-0.6122B)(1-0.8805B^{12})\varepsilon_t$	0.13206	0.01786
SQRT of AWS(1948-2004)	ARIMA (111)(011)	$(1-0.2864B)\nabla\nabla_{12}y_t = 0.0000654+(1-0.8755B)(1-0.8255B^{12})\varepsilon_t$	0.076528	0.0311
SQRT of AWS(1948-2008)	ARIMA (011)(011)	$\nabla\nabla_{12}y_t = 0.000076+(1-0.7376B)(1-0.8359B^{12})\varepsilon_t$	0.00189	0.0306

Table 5.9 Models for AMWS and Their Results

Variable	Model	Equation of Model	FE	MS
SQRT of AMWS (1948-1972)	ARIMA (100)(111)	$(1-0.437B)(1-.0481B^{12})\nabla_{12}y_t = 0.003916+(1-0.9009B^{12})\varepsilon_t$	1.013	0.541
Ln of AMWS (1981-2004)	ARIMA (200)(111)	$(1-0.0452B-.26B^2)(1+0.0189B^{12})\nabla_{12}y_t = 0.0211+(1-0.9107B^{12})\varepsilon_t$	.493726	0.1615
SQRT of AMWS (1948-2004)	ARIMA(011)(101)	$(1-0.9938B^{12})\nabla y_t = -1E\text{-}06+(1-0.8649B)(1-0.9317B^{12})\varepsilon_t$	0.338875	0.424
SQRT of AMWS(1948-2008)	ARIMA(011)(101)	$(1-0.994B^{12})\nabla y_t = -8E\text{-}07+(1-0.8645B)(1-0.9334B^{12})\varepsilon_t$	0.002889	0.396

Table 5.10 Models for AC and Their Results

Variable	Model	Equation of Model	FE	MS
AC(1948-1972)	ARIMA (100)(011)	$(1-0.026B)\nabla_{12}y_t = -0.0194+(1-0.9417B^{12})\varepsilon_t$	0.427023	0.3400
AC(1981-2004)	ARIMA (011)(111)	$(1+0.1167B^{12})\nabla\nabla_{12}y_t = 0.000543+(1-0.9633B)(1-0.8713B^{12})\varepsilon_t$	0.945277	0.447
AC(1948-2004)	ARIMA (011)(111)	$(1+0.0548B^{12})\nabla\nabla_{12}y_t = 0.000183+(1-0.9047B)(1-0.9163B^{12})\varepsilon_t$	0.78444	0.375
AC(1948-2008)	ARIMA (011)(111)	$(1+0.0532B^{12})\nabla\nabla_{12}y_t = .00018+(1-0.9047B)(1-0.9176B^{12})\varepsilon_t$	0.002441	0.350

Table 5.11 Models for ADBT and Their Results

Variable	Model	Equation of Model	FE	MS
ADBT(1948-1972)	ARIMA (101)(011)	$(1-0.4814B)\ y_t = 0.004596 + (1-0.2037\ B)\ (1-0.9529\ B^{12})\ \varepsilon_t$	0.631275	0.761
ADBT(1981-2004)	ARIMA (011)(111)	$(1-.0.038B^{12})\ \nabla\nabla_{12}y_t = -0.00148 + (1-0.694\ B)\ (1-0.8926\ B^{12})\ \varepsilon_t$	1.814771	1.062
ADBT(1948-2004)	ARIMA (011)(101)	$(1-0.9997B^{12})\ \nabla y_t = 0.000181 + (1-0.7266\ B)\ (1-0.8189\ B^{12})\ \varepsilon_t$	2.89E-05	0.899
ADBT(1948-2008)	ARIMA (011)(101)	$(1-0.9997B^{12})\ \nabla y_t = 0.000181 + (1-0.7266\ B)\ (1-0.8189\ B^{12})\ \varepsilon_t$	2.89E-05	0.840

Table 5.12 Models for AWBT and Their Results

Variable	Model	Equation of Model	FE	MS
AWBT(1948-1972)	ARIMA (200)(111)	$(1-0.1809B-.1303B^2)(1+0.0974\ B^{12})\ \nabla_{12}y_t = 0.000398 + (1-0.9482\ B^{12})\ \varepsilon_t$	0.542282	0.543
AWBT(1982-2004)	ARIMA (101)(111)	$(1-0.6488B)(1+0.0676\ \nabla_{12}y_t = -0.00925 + (1-0.349B)(1-0.8822\ B^{12})\ \varepsilon_t$	0.7175155	0.440
AWBT(1981-2004)	ARIMA (100)(011)	$(1-0.3423B)\ \nabla_{12}y_t = -0.01649 + (1-0.9206\ B^{12})\ \varepsilon_t$	0.365311	0.422
AWBT(1948-2004)	ARIMA (101)(111)	$(1-0.7958B)\ (1+0.0443\ B^{12})\ \nabla_{12}y_t = 0.003359 + (1-0.5849B)(1-0.9164\ B^{12})\ \varepsilon_t$	0.84643619	0.428
AWBT(1948-2008)	ARIMA(101)(111)	$(1-0.7958B)(1+0.0439B^{12})\ \nabla_{12}y_t = 0.003359 + (1-0.5849B)(1-0.9165\ B^{12})\ \varepsilon_t$	0.000188193	.400

Table 5.13 Models for AT (D-W) and Their Results

Variable	Model	Equation of Model	FE	MS
Ln of AT(D-W)(1948-1972)	ARIMA (200)(101)	$(1-0.4213B+0.0817B^2)(1-1.0007\ B^{12})\ y_t = -0.0004+(1-0.9291\ B^{12})\ \varepsilon_t$	0.163075	0.02841
Ln of AT(D-W)(1981-2004)	ARIMA (101)(011)	$(1-0.2865B)\ \nabla_{12}y_t = 0.019375+(1+0.1822B)(1-0.9075\ B^{12})\ \varepsilon_t$	0.366006	0.0387
Ln of AT(D-W)(1948-2004)	ARIMA (101)(101)	$(1-0.4744B)(1-0.9925\ B^{12})\ y_t = 0.002626+(1+0.0287B)(1-0.7837\ B^{12})\ \varepsilon_t$	0.232645	0.0327
Ln of AT(D-W)(1948-2008)	ARIMA (101)(101)	$(1-0.4855B)(1-0.9927\ B^{12})\ y_t = 0.002492+(1+0.0209B)(1-0.7885\ B^{12})\ \varepsilon_t$	0.001828	0.0305

Table 5.14 Models for ASLP and Their Results

Variable	Model	Equation of Model	FE	MS
ASLP (1960-1972)	ARIMA (100)(111)	$(1-0.1482\ B)(1+0.1299\ B^{12})\ \nabla_{12}y_t = -0.03685(1-0.8997\ B^{12})\ \varepsilon_t$	0.809537	0.912
ASLP(1949-1972)	ARIMA (100)(011)	$(1-0.2325\ B)\ \nabla_{12}y_t = 0.023107+(1-0.9253\ B^{12})\ \varepsilon_t$	1.019017	1.024
ASLP(1948-1972)	ARIMA (100)(011)	$(1-0.2615B)\ \nabla_{12}y_t = -0.019005+(1-0.9382\ B^{12})\ \varepsilon_t$	0.988437	1.033
ASLP (1981-2004)	ARIMA (101)(111)	$(1-0.8405B)(1+0.0344\ B^{12}) = -0.000162+(1-0.6583B)(1-0.9199\ B^{12})\ \varepsilon_t$	1.12417	1.328
ASLP(1948-2004)	ARIMA(011)(101)	$(1-0.9999\ B^{12}) = -0.0000467+(1-0.8297B)(1-0.9620\ B^{12})\ \varepsilon_t$	1.354891	1.033

Table 5.15 Models for ARH (0-12) and Their Results

Variable	Model	Equation of Model	FE	MS
Ln of ARH(0-12)(1948-1972)	ARIMA (100)(111)	$(1-.287B)(1+.0713\ B^{12})\ \nabla_{12}\ y_t = .00028+(1-.9404\ B^{12})\ \varepsilon_t$	0.2308	0.0294
ARH(0-12)(1982-2004)	ARIMA (100)(011)	$(1-.3191B)\ \nabla_{12}\ y_t = .07771+(1-.913\ B^{12})\ \varepsilon_t$	3.1082	13.62
ARH(0-12)(1981-2004)	ARIMA(011)(101)	$(1-1.0005\ B^{12})\ \nabla\ y_t = .5.4081E-04+(1-.8686\ B)(1-.9514\ B^{12})\ \varepsilon_t$	2.4036	14.89
Ln of ARH(0-12)(1948-2004)	ARIMA (200)(101)	$(1-.2929B-.0306B^2)(1-.9973B^{12})\ y_t = .005229+(1-.9006\ B^{12})\ \varepsilon_t$	0.2002	0.0284
Ln of ARH(0-12)(1948-2008)	ARIMA (101)(101)	$(1-.4175\ B)(1-.9973\ B^{12})\ y_t = 0.0045025 + (1-0.1276\ B)(\ 1-0.9008\ B^{12}) + \varepsilon_t$	7.3E-05	0.0265

Table 5.16 Models for ASH and AE and Their Results

Variable	Model	Equation of Model	FE	MS
ASH(1989-2004)	ARIMA (111)(111)	$(1-0.1007B)(1+0.2393\ B^{12}) = -.0015+(1-0.9487\ B)(1-0.8494\ B^{12})\ \varepsilon_t$	1.0670	1.044
AE(1987-2000)	ARIMA (112)(111)	$(1-0.2759\ B)(1-0.0111\ B^{12})\ \nabla\ \nabla_{12}y_t = -0.0105+(1-.774\ B-0.2304B^2)(1-0.882B^{12})\varepsilon_t$	7.6465	27.66

5.2.2 Wheat Production

The linear trend (LT) model using least squares method and the time series (TS) plot of the data on wheat yield rate together with the fitted trend line follow upward trend over the years 1949 to 2001, where we observe an unusual drop in the year 1982 [Figure 5.53]. The TS plots of residuals and deleted Studentized residuals (DSR) for these data clearly identify the observation for the year 1982 as an outlier [Figure 5.54]. The normal probability (NP) plot for the residuals follows a marked departure from normality and RM normality test supports that. [Figure 5.55 and Table1]. We observe a clear non-autocorrelated structure for the residuals from ACF display and Ljung-Box Q test which is highly unlikely for any kind of production data. So we try to reinvestigate before going further analysis what really happened in the year 1982 and after checking we confirm that there is a recording error in wheat production for that year. The data is 13,913 metric ton in 1982 sources from [Hamid (1991)] but it is recorded 1,28,845 metric ton in the Statistical Year Book of Bangladesh, Bangladesh Bureau of Statistics (BBS) and which is more than 9 times bigger than the value what we use earlier.

After being convinced about the recording error we correct the data set and do the same kind of analysis as we do with the uncorrected data and obtain almost opposite conclusions for corrected data. We observe an upward linear trend as before but the NP plot of residuals show normality pattern and the normality is also accepted by the RM test. The TS plot of the deletion Studentized residuals indicate no further outlier in the data and the ACF and PACF display and the LBQ statistic demonstrate the auto correlated pattern of residuals [Figure 5.56].

Again the data indicate a clear structural change from the year 1976 [Figure 5.57]. We also observe that the coefficient associated with the structural change is highly significant which confirm that a significant change is occurred from the year 1976 in the production data and we divide the data into two groups from 1949 to 1975 and 1976 to 2001and both groups of data follow upward linear trend with normal and first order autoregressive residuals where we also use the diagnostics like NP plot, the RM test, ACF and PACF displays, LBQ test for each of the groups separately. We get similar kind of result from RM and LBQ test. So we confirm that wheat production of Dinajpur district for the years 1949 to 1975 and for the years 1976 to 2001 follow AR(1) model separately but not overall.

From the above results we realize that the data may be fitted by the PAR(1) model suggested by Imon (2007) and try to fit the PAR(1) model by the data as defined in Chapter 3. But the TS plot of deleted Studentized residuals indicated the year as outlier which is declared as the structural change and we achieve the normality and stationarity for residuals which confirm about the adequacy of the fitted PAR(1) Model for the data after omission of the outlier. But some different results are observed when we analyze the data for the years 1948 to 2004 as the results shown in Table 5.18 and Figure 5.58 to Figure 5.62.

Table 5.17 RM Test for Normality for Different Models (1949-2001)

Model	No of Observation	Degrees of Freedom	Value of the Statistic	*p*-value	Decision
LT with Outlier	53	2	76.59	0.000	Reject *N*
LT without Outlier	53	2	1.04	0.595	Accept *N*
AR(1) for 1949-1975	27	2	2.51	0.285	Accept *N*
AR(1) for 1976-2001	26	2	0.10	0.951	Accept *N*
PAR(1) with the SCP	52	2	126.96	0.000	Reject *N*
PAR(1) without the SCP	51	2	0.31	0.856	Accept *N*

Table 5.18 RM Test for Normality for Different Models (1948-2004)

Model	No of Observation	Degrees of Freedom	Value of the Statistic	*p*-value	Decision
LT with Outlier	57	2	78.90447	0.049	Reject *N*
LT without Outlier	56	2	0.275485	0.894	Accept *N*
AR(1)	28	2	6.572447	0.094	Reject *N*
AR(2)	29	2	5.977012	0.481	Accept *N*
PAR(1) with SCP	56	2	146.3781	0	Reject *N*
PAR(1) without SCP	55	2	46.81022	0.02	Reject *N*

5.3 Conclusion

We fit the ARIMA models for the monthly climatic data and forecasted the values for 2005 to 2008 and 2009 to 2012. Missing values during 1973-1976 and 1977-1980 are replaced by the forecasted values for 1948-1972 and 1981-2004 respectively. The observations for the year 1981are found to be outlier for the variables AMNT, AWBT, AWS, ARH and ARH(0-12) but after replacing the outliers by forecasted observations for 1982 to 2004, residuals follow stationarity and normality. For the production of wheat we have found structural change in 1976 and the data 1949 to 1975 and 1976 to 2001 separately follow AR (1) model but not for the overall period. The data during 1949-2001 adequately fits the 1st order Piecewise Autoregressive Model PAR(1) also. But the wheat production during 1948-2004 do not adequately fit PAR(1) model.

Some Residual (Resid.) and TS Plots with Forecasts (Fore.) for Climatic Variables

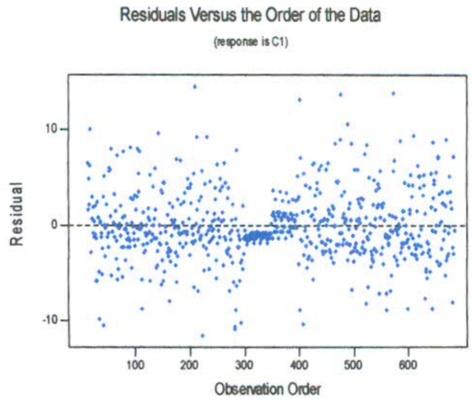


Figure 5.1 Resid. vs order of the data for SQRT of TR(1948-2004)

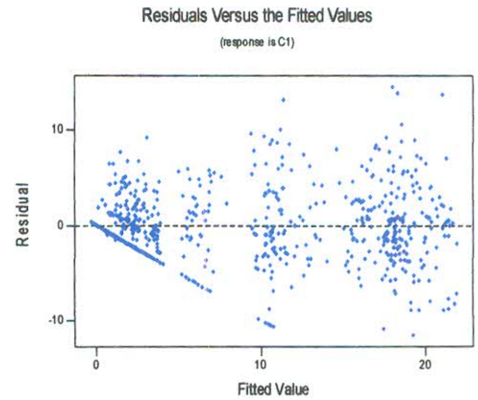


Figure 5.2 Resid. vs the fitted values for SQRT of TR(1948-2004)

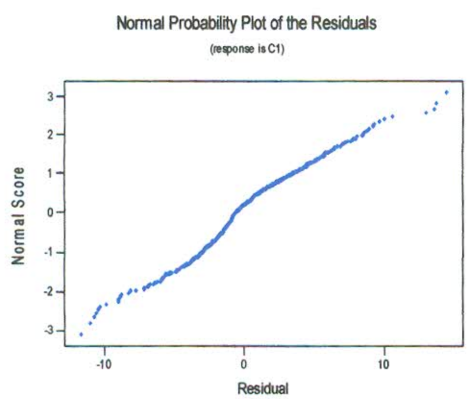
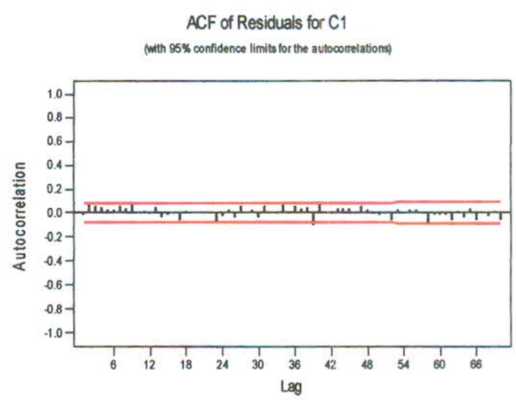


Figure 5.3 Np plot of resid. for SQRT of TR(1948-2004)



Figre 5.4 ACF plot of resid. for SQRT of TR(1948-2004)

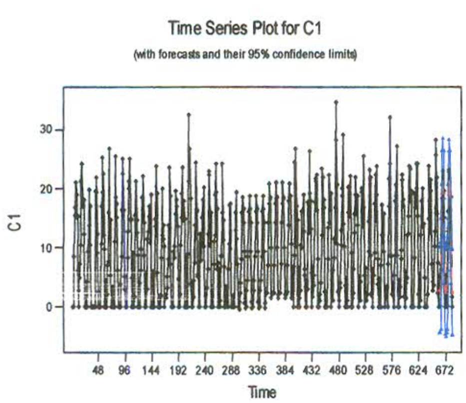


Figure 5.5TS plot for SQRT of TR (1948-2004) with 24 fore.

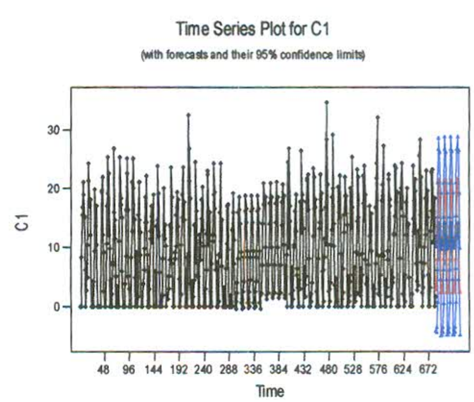


Figure 5.6 TS plot for SQRT of TR (1948-2004) with 48 fore.

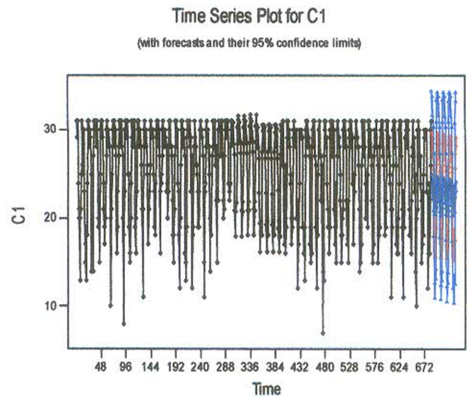


Figure 5.7 TS plot for TFIR(1948-2004) for 48 fore.

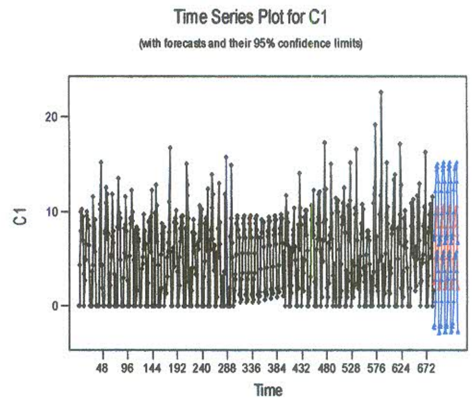


Figure 5.8 Fore. for MXR (1948-2004)

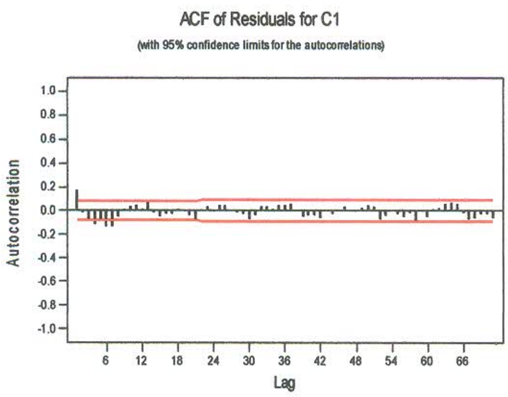


Figure 5.9 ACF plot of resid for ADBT(1948-2004)

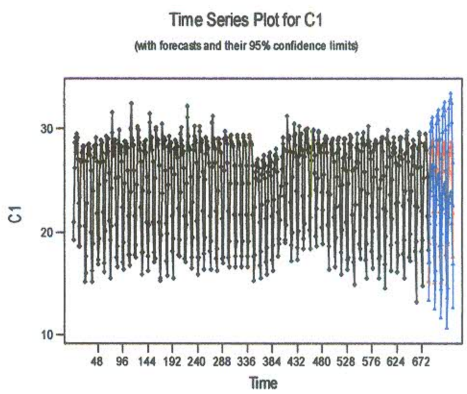


Figure 5.10 48 fore. for ADBT(1948-2004)

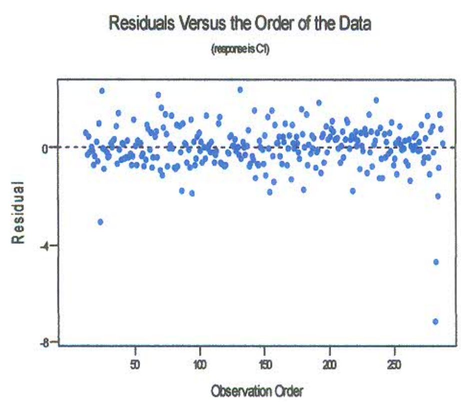


Figure 5.11 Resid. vs order of the data for AMNT (1981-2004)

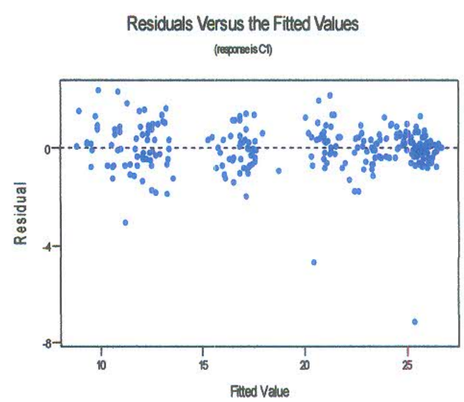


Figure5.12 Resid. vs the fitted values for AMNT(1981-2004)

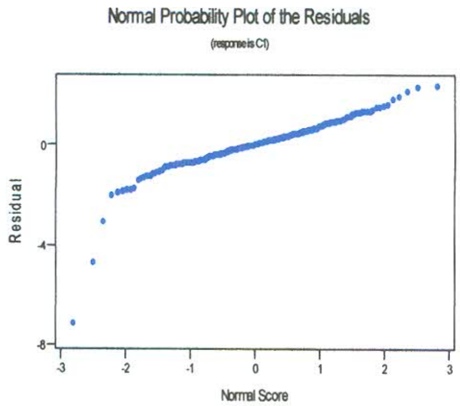


Figure 5.13 Np plot of resid. for AMNT (1981-2004)

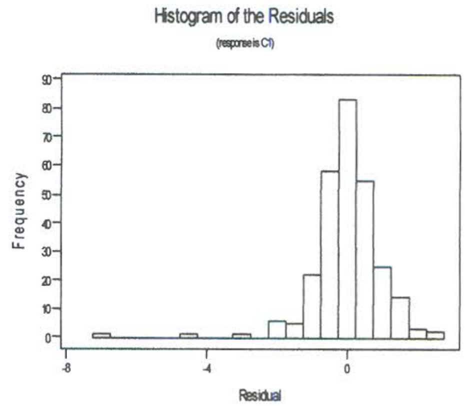


Figure 5.14 Hist. of resid. for AMNT(1981-2004)

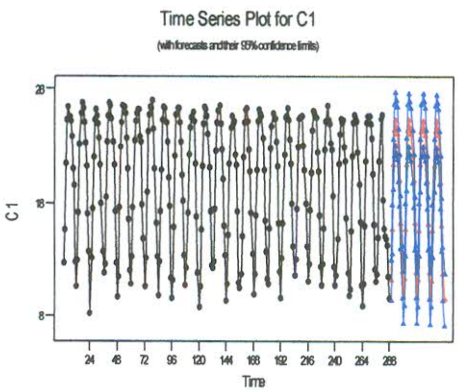


Figure 5.15 48 fore. for AMNT(1981-2004)

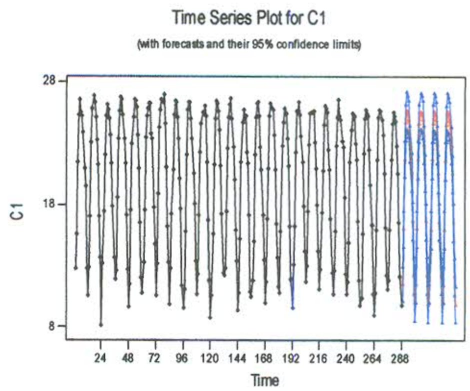


Figure 5.16 48 fore. for ORAMNT(1981-2004)

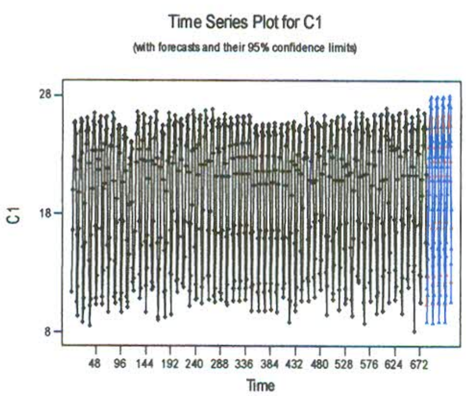


Figure 5.17 48 fore. for ORAMNT(1948-2004)

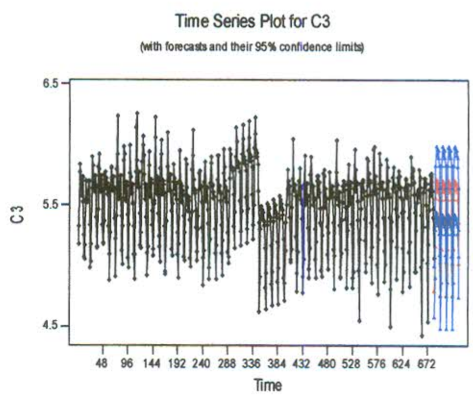


Figure 5.18 48 fore. for SQRT of AMXT(1948-2004).

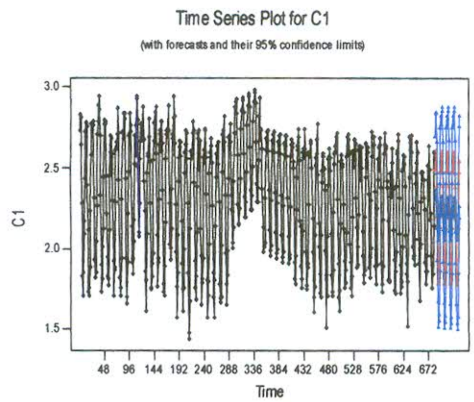


Figure 5.19 48 fore. for ORARNT(1948-2004)

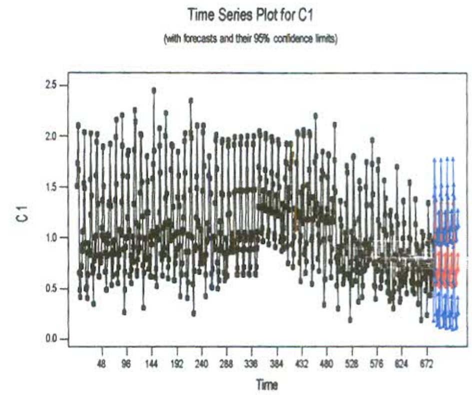


Figure 5.20 48 fore for AT(D-W)(1948-2004)

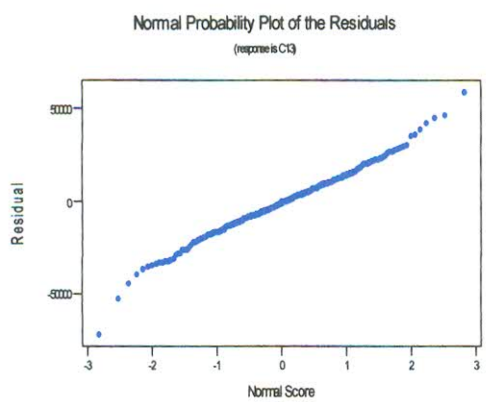


Figure 5.21 Np plot of resid. for ARH (1948-1972)

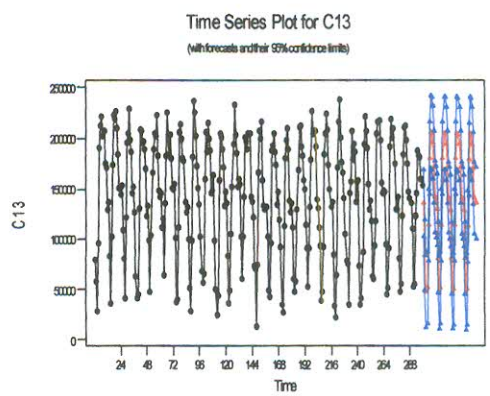


Figure 5.22 48 fore for ARH(1948-1972)

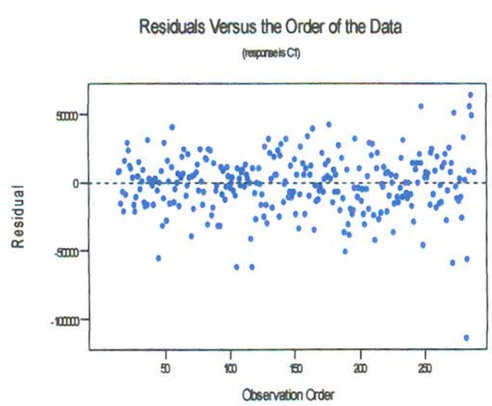


Figure 5.23 Resid. vs order of the data for ARH (1981-2004)

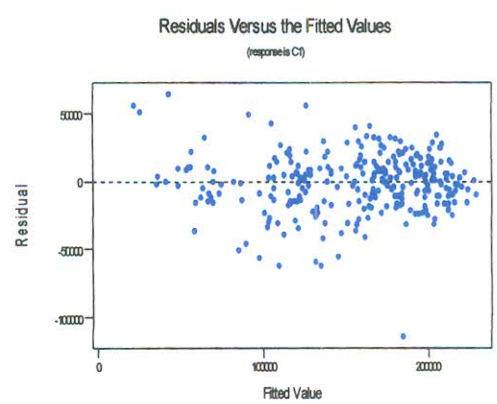


Figure 5.24 Resid vs the fitted values for ARH(1981-2004)

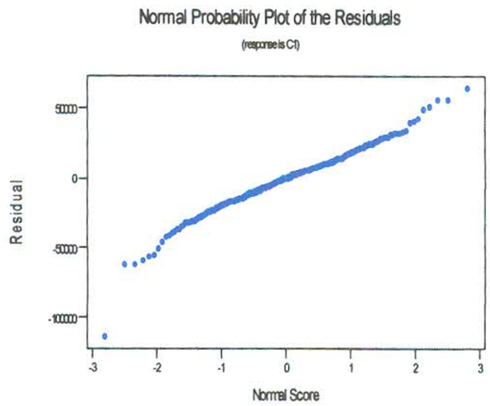


Figure 5.25 Np plot of resid. for ARH (1981-2004)

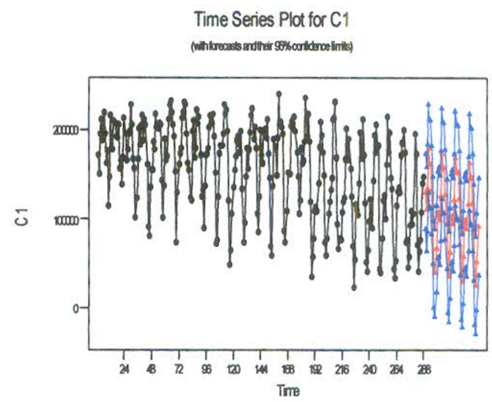


Figure 5.26 48 fore. for ARH(1981-2004).

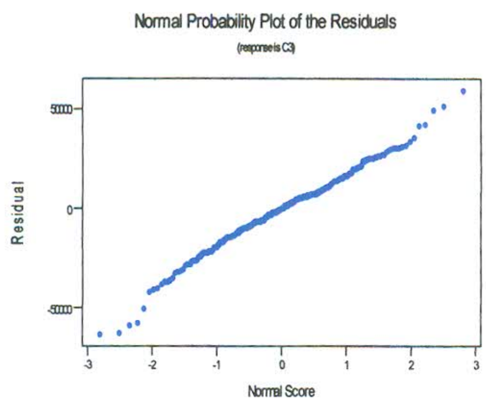


Figure 5.27 Np plot of resid. for ORARH (1981-2004)

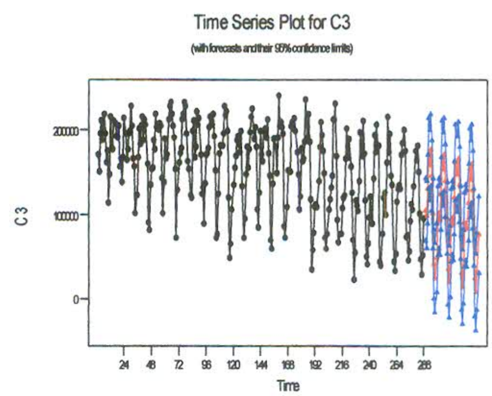


Figure 5.28 48 fore . for ORARH(1981-2004)

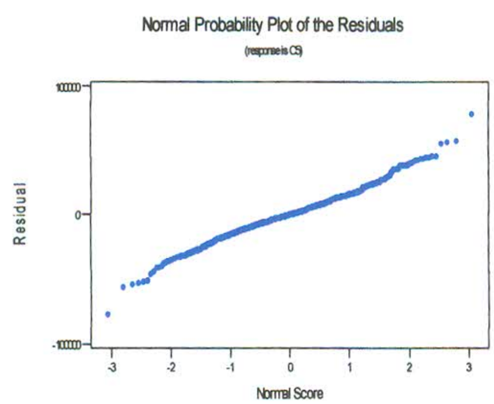


Figure 5.29 Np plot of resid. for ORARH (1948-2004)

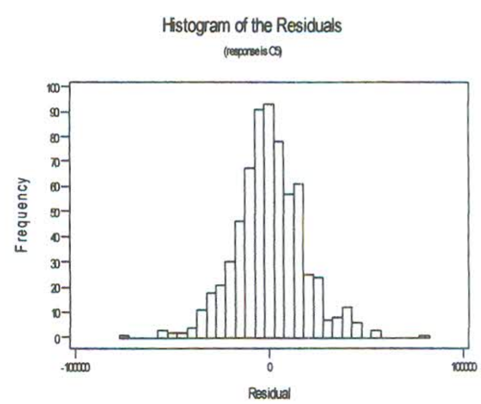


Figure 5.30 Hist.of resid. for ORARH(1948- 2004)

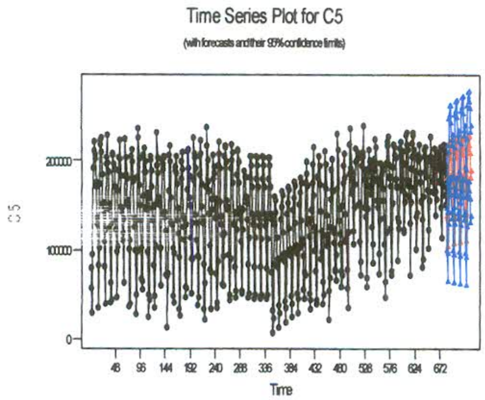


Figure 5.31 48 fore. for ORARH(1948-2004)

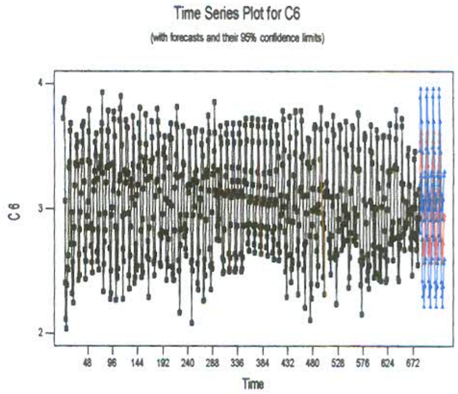


Figure 5.32 48 fore for ARH(0-12)(1948-2004)

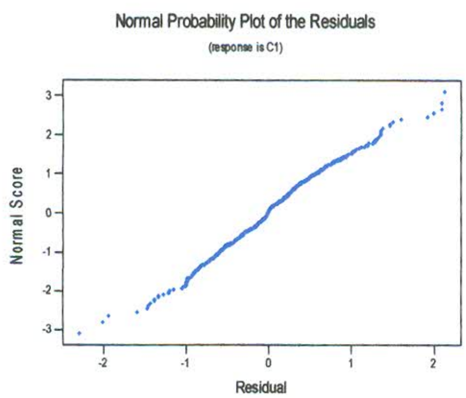


Figure 5.33 Np plot of resid. for AC (1948-2004)

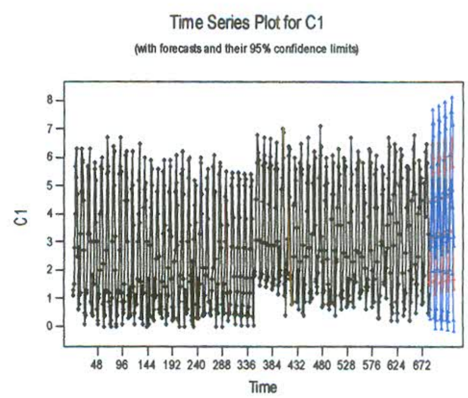


Figure 5.34 48 fore. for AC(1948-2004)

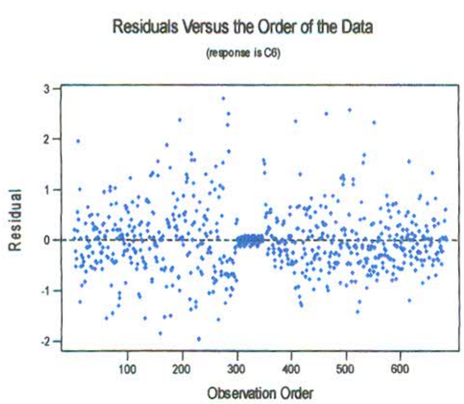


Figure 5.35 Resid. vs order of the data for AMWS (1948-2004)

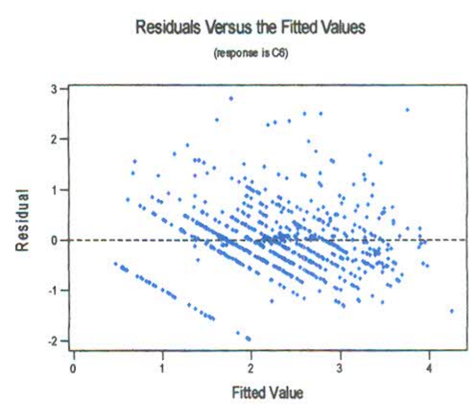


Figure 5.36 Resid. vs the fitted values for AMWS(1948-2004)

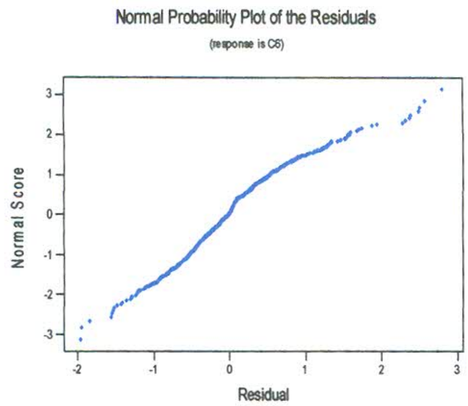


Figure 5.37 Np plot of resid. for AMWS (1948-2004)

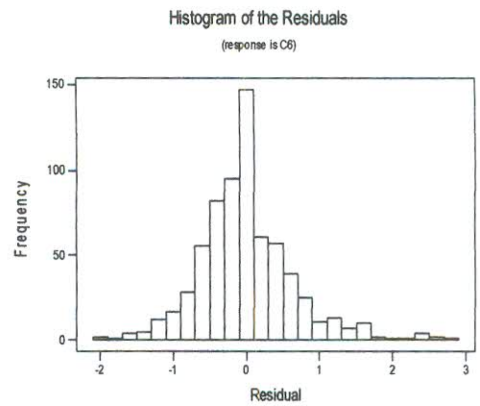


Figure5.38 Hist. of resid. for AMWS(1948- 2004)

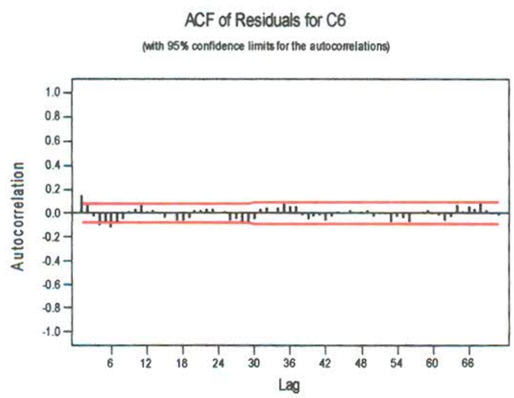


Figure 5.39 ACF plot of resid. for AMWS(1948-2004)

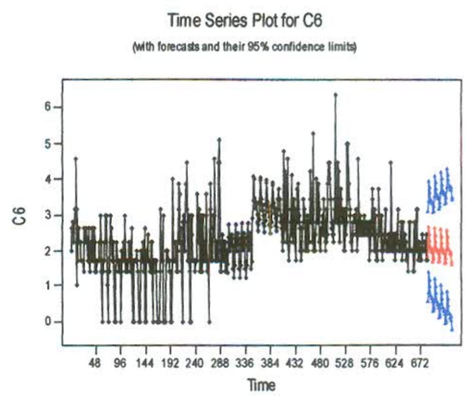


Figure 5.40 48 fore. for AMWS(1948-2004)

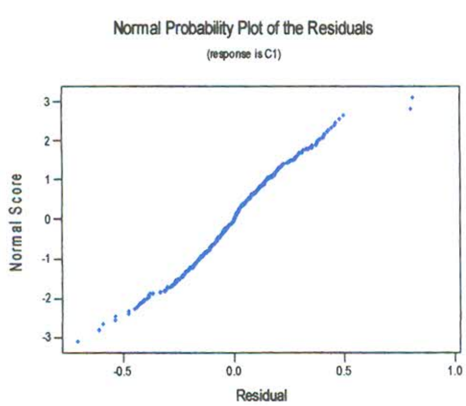


Figure 5.41 Np plot of resid. for AWS(1948-2004)

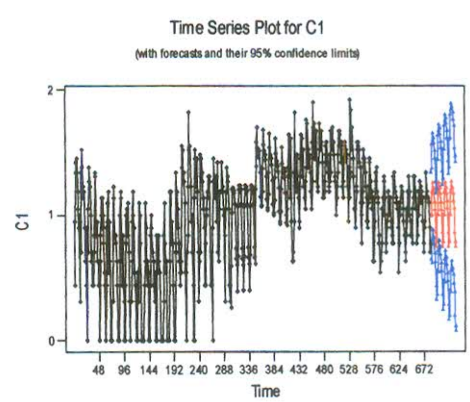


Figure 5.42 48 fore for AWS (1948-2004)

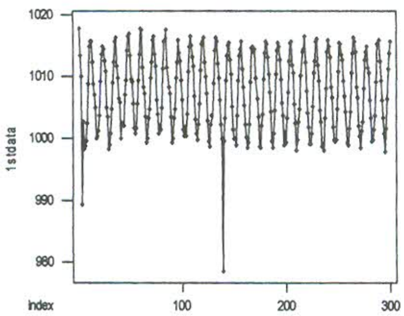


Figure 5.43 TS plot of ASLP (1948-1972)

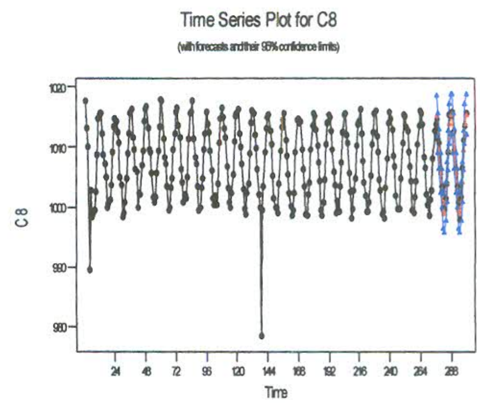


Figure 5.44 24 fore. of ASLP(1948-1972)

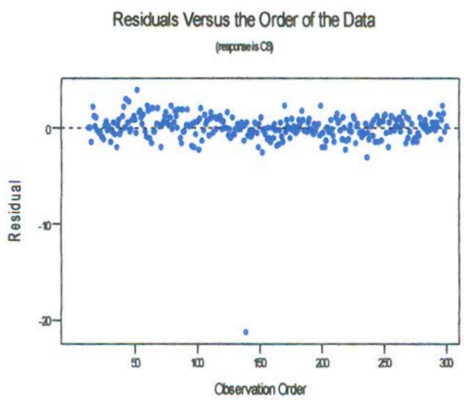


Figure 5.45 Resid. vs order of the data for ASLP (1948-1972)

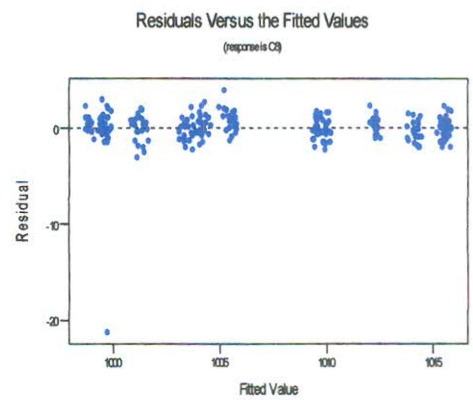


Figure 5.46 Resid.vs the fitted values for ASLP(1948-1972)

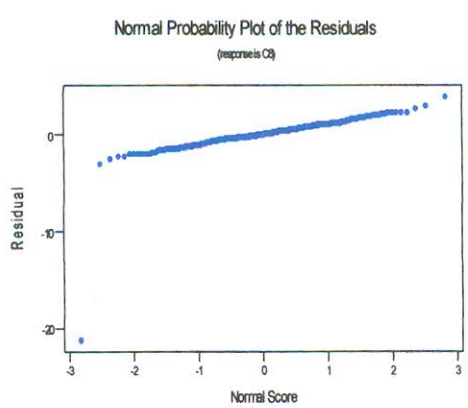


Figure 5.47 Np plot of resid. for ASLP (1948-1972)

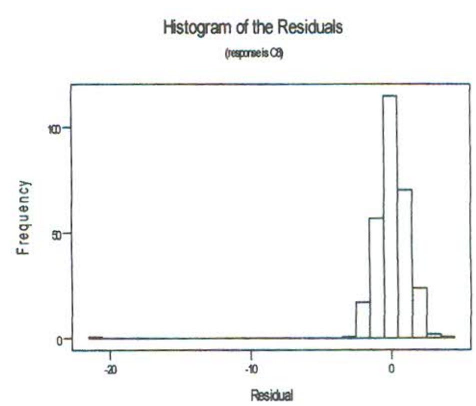


Figure 5.48 Hist. of resid. for ASLP (1948-1972)

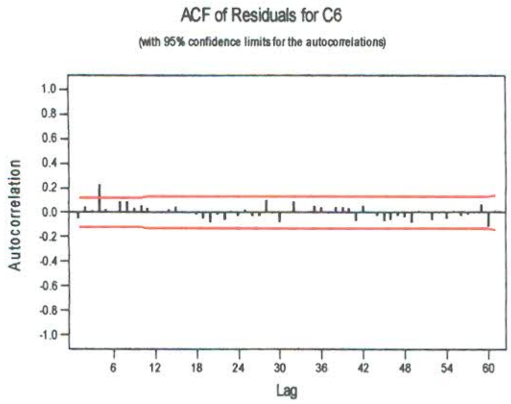


Figure 5.49 ACF plot of resid. for ORASLP (1948-1972)

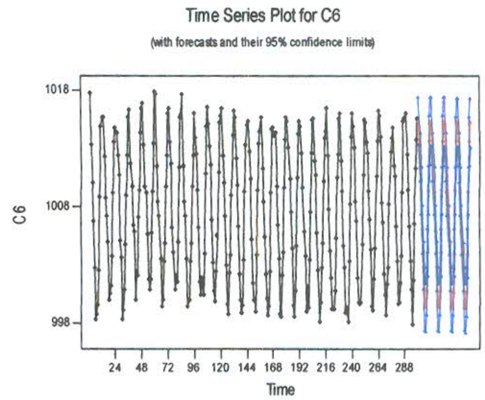


Figure 5.50 48 fore for ORASLP (1948-1972).

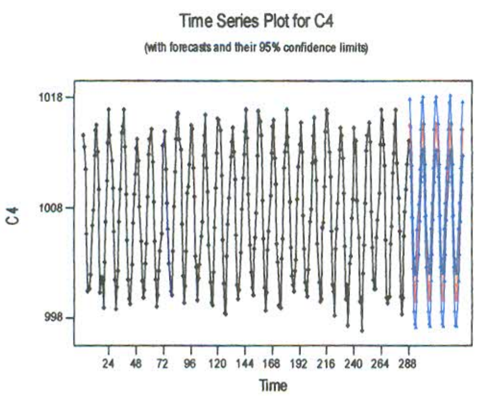


Figure 5.51 48 fore. for ORASLP(1981-2004)

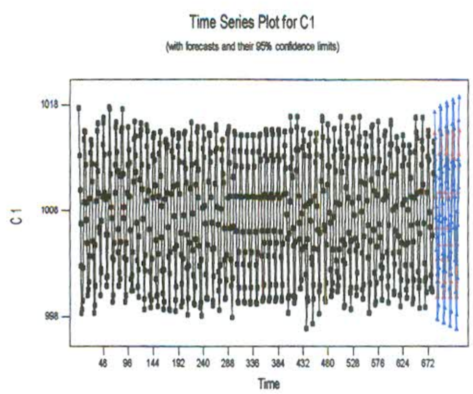


Figure 5.52 48 fore. for ORASLP(1948-2004)

Figures for Wheat Production

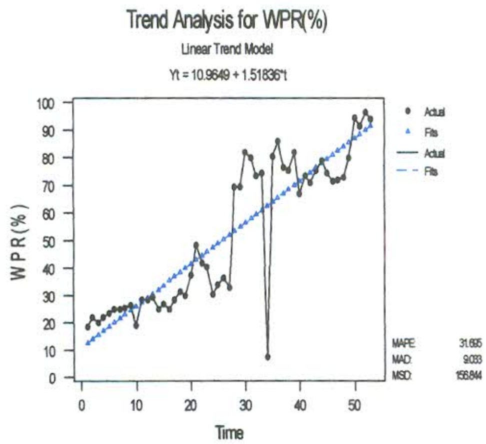


Figure 5.53. LT model for wheat production rate (1949-2001)

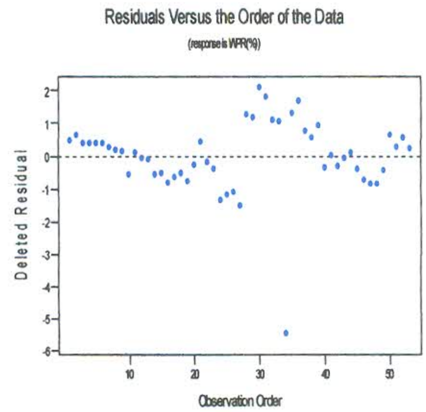


Figure 5.54 TS plot of DS residuals

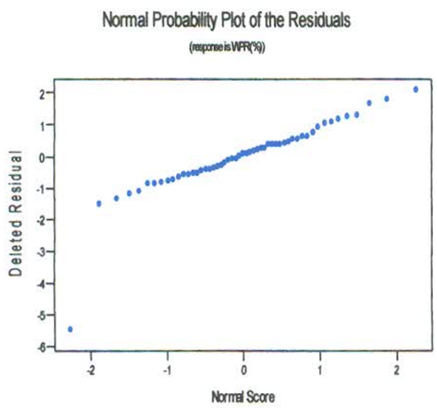
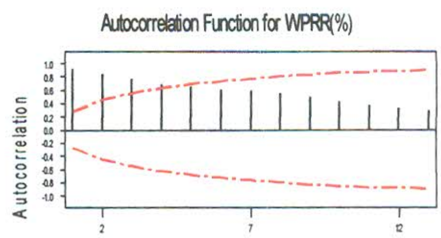


Figure 5.55 NP plot for resid. of LT model



Lag	Corr	T	LBQ	Lag	Corr	T	LBQ
1	0.92	6.67	47.02	8	0.56	1.39	241.14
2	0.85	3.76	87.84	9	0.50	1.21	257.79
3	0.77	2.75	121.98	10	0.43	1.02	270.59
4	0.68	2.17	149.82	11	0.38	0.88	280.83
5	0.65	1.89	175.29	12	0.33	0.75	288.71
6	0.62	1.69	198.76	13	0.31	0.69	295.52
7	0.59	1.54	221.02				

Figure 5.56. ACF for corrected data (1949-2001)

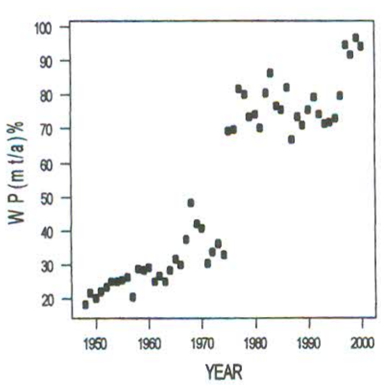


Figure 5.57 Scatter plot of corrected data (1949-2001)

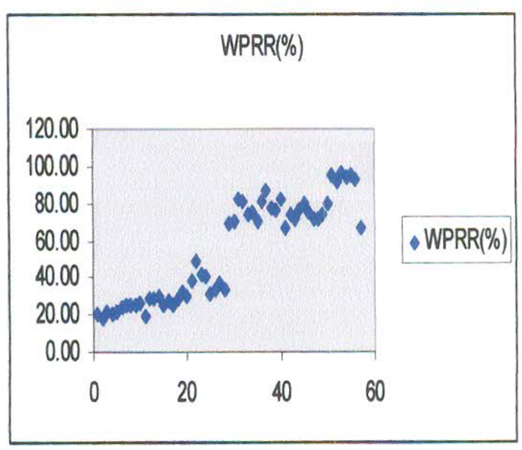


Figure 5.58 Scatter plot of corrected data (1948-2004)

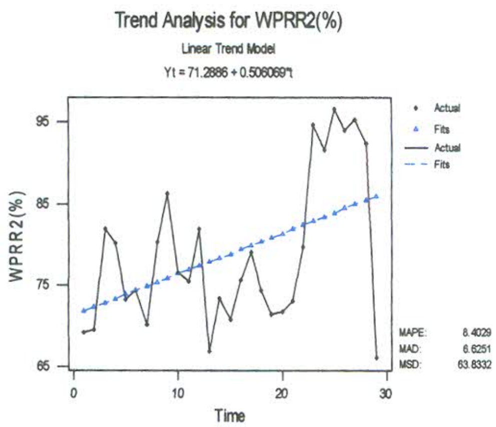


Figure 5.59 LT of wheat production rate (1976-2004)

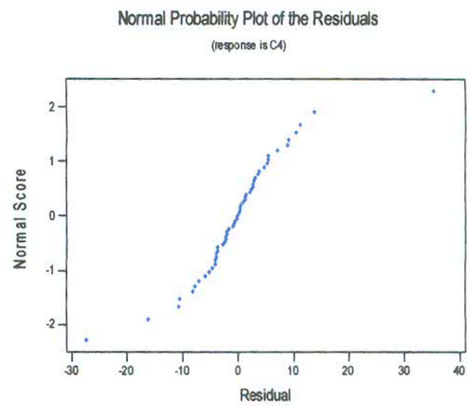


Figure 5.60 PAR(1) stage 2(1948-2004)

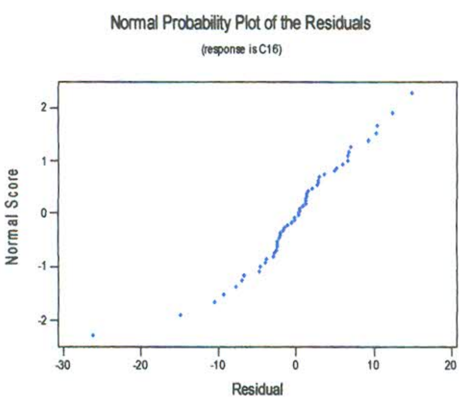


Figure 5.61 NP plot for resid.of LT model (1976-2004)

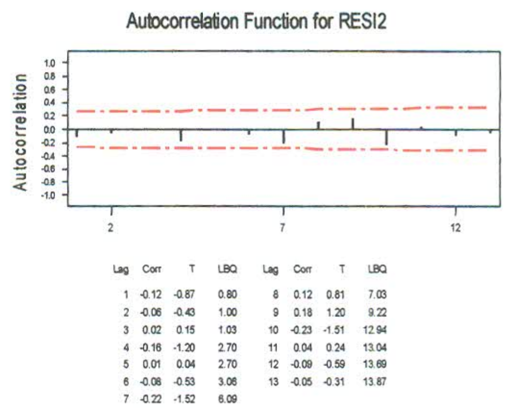


Figure 5.62 PAR(1) stage 2(1948-2004)

Table 5.19 Point Forecasts for Monthly Climatic TR during 2005-2012

TR	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
2005	9.51	8.14	13.82	62.72	184.60	370.51	455.30	346.83	357.96	140.59	5.66	6.14
2006	10.22	8.63	14.18	62.38	184.79	370.35	455.99	352.14	361.04	139.54	6.01	6.39
2007	10.50	8.88	14.50	63.03	185.92	371.95	457.78	353.78	362.66	140.51	6.22	6.61
2008	10.77	9.13	14.82	63.70	187.07	373.58	459.58	355.36	364.26	141.51	6.44	6.83
2009	11.13	9.38	15.28	64.22	187.99	375.26	461.83	357.75	365.04	142.24	6.74	7.07
2010	11.43	9.64	15.63	64.92	189.17	376.94	463.71	359.42	366.67	143.26	6.97	7.30
2011	11.73	9.91	15.97	65.61	190.37	378.62	465.58	361.06	368.33	144.30	7.20	7.54
2012	12.02	10.19	16.32	66.32	191.56	380.31	467.45	362.71	370.00	145.34	7.44	7.78

Chapter 6

Chapter 6

Assessment for Impact of Climate Change on Wheat Production in Dinajpur District: A Regression Analysis Approach

6.1 Introduction

In this chapter we try to fit regression model for the rate of wheat production data on climatic variables over the years 1948-2004 and we use three sets of historical climatic data with one dummy variable in each case as the structural change are viewed in response variable from 1976. The three sets of predictors are mentioned below and the descriptions of both the predictors and response variables are given in Table 6.10. The predictor set 1 includes 15 variables such as dm, tmn, tw, ftd, ttr, td, hu, mxr, tmx, slp, ac, wmx, wv, hu(0-12) and rf. The predictor set 2 includes 11 variables such as dm, tmn, tw, ttr, td, hu, tmx, slp, ac, wmx and wv. The predictor set 3 contains 10 variables such as dm, tmn, tw, ftd, ttr, td, hu, tmx, slp and ac. At first we check multicollinearity for the regression models through investigating the range of variance inflation factors and select the variables by using backward elimination procedure starts with full equation and dropped one variable at a time against the smallest insignificant t values where we stop the backward elimination procedure for the minimum absolute t- test become greater than 1. We check the normality and stationarity for residuals of regression models to select variables and get normality and to have first order autocorrelated structure for residuals. Then we refit and reexamine the new regression coefficients taking the autocorrelation into account where we estimate the new regression models by Cochrane and Orcutt(1949) iterative procedure which satisfy the assumption of uncorrelated errors with the same procedure. To obtain robust models we identify unusual observations such as outliers, hi-leverage points and influential observations applying some modern diagnostics tools like deleted Studentized residuals, PRESS residuals, Cook distance, Diffits and other residual based techniques and finally get the three appropriate models. We select a model among three models having the highest F and R^2 values.

6.2 Analysis and Results

We estimate the first regression models for the three predictor sets 1, 2 and 3 and the estimated models are as follows:

(1) wprr = 749 + 49.2 dm + 5.36 tmn + 0.79 tw - 0.35 ftd + 0.0206 ttr - 1.17 td + 0.129 hu - 2.66 tmx - 0.76 slp - 8.23 ac - 0.025 wmx + 0.94 wv + 0.289 hu(0-12) + 0.351 mxr + 1.75 rf (6.1)

(2)wprr = 1084+48.9dm+5.07tmn-0.29tw+0.0441ttr-1.15td+0.133hu-2.35tmx-1.02slp-8.47ac+0.173wmx (6.2)

(3) wprr = 883+49.322dm+5.424tmn+0.249tw-0.5531ftd+0.04341ttr-0.324td+0.0406hu-2.4tmx-0.837slp-8.195ac-0.0107wmx +0.908wv (6.3)

The ranges of VIFs are 1.4 to 9.5 for set 1, 1.4 to 7.1 for set 2 and 1.4 to 7.5 for set 3 in the models where no strong evidence of multicollinearity are observed. We observe the significant t value for only the coefficient of dummy variables (dm) where the t values for the coefficients of climatic variables are less than 2 for each regression. But we get the t values 1.69 and -1.37 for the coefficients of climatic variables tmn and tmx, in the regression of the data set 1, 1.76, 1.34, -1.43 and -1.57 for the coefficients of climatic variables tmn, ttr, tmx and ac in the regression model of the data set 2 and 1.78, 1.29, and -1.49 for the coefficients of climatic variables tmn, ttr, and ac in the regression model of the data set 3, where the rest of the climatic predictors for the data set 1, 2 and 3 contain the absolute t values 0.50, 0.52 and 0.57, respectively. The normal probability plots for these residuals do not indicate violation of normality but the ACF displays of residuals indicate first order autoregressive structure. The Durbin d value for set 1, 2 and 3 are 0.92, 0.96 and 0.97 and evidence of autocorrelations is also indicated by their deviation of Durbin-Watson statistic d from 2.

We select 6 variables such as dm ,tmn, ftd, tmx, ac, mxr for set 1 eliminating the 9 variables wmx, tw, wv, ttr, td, rf, hu, hu(0-12) and slp; the six variables such as dm, tmn, ttr, td, tmx and ac for set 2 eliminating the 4 climatic variables tw, hu, slp and wmx and the six variables dm, tmn, ftd, ttr, tmx and ac eliminating tw, hu, td, slp, wmx and wv variables for the data set 3 for fitting the regression model by the described backward elimination procedure. The regression results for the selection procedure of the data sets 1, 2 and 3 are presented in Table 6.1, 6.2 and 6.3 respectively.

Table 6.1 Summery Table for Variable Selection from the Regression Models of Predictor Set 1

Regression	RMS	EMS	F	P	R-Sq(adj)	DW	Minimum Absolute t
1	2458.7	68.8	35.75	0	90.3	0.92	0.03(wmx)
2	2634.3	67.1	39.24	0	90.5	0.92	0.16(tw)
3	2836.9	65.6	43.24	0	90.7	0.91	0.21(wv)
4	3073	64.2	47.88	0	90.9	0.92	0.28(ttr,td)
5	3686.6	61.6	59.84	0	91.3	0.93	0.18(rf)
6	4096.1	60.3	67.89	0	91.5	0.93	0.28(hu)
7	4607.5	59.2	77.85	0	91.7	0.95	0.18 h(0-12)
8	5265.4	58	90.76	0	91.8	0.95	0.31(slp)
9	6141.8	57	107.78	0	92	0.92	1.31 ftd)

Table 6.2 Summery Table for Variable Selection from the Regression Models of Predictor Set 2

Regression	RMS	EMS	F	P	S	R-Sq(adj)	DW	Minimum Absolute t
1	3681.9	62.6	58.77	0	7.915	91.20%	0.96	-0.06(tw)
2	4090.9	61.3	66.72	0	7.831	91.40%	0.97	0.28 (wmx)
3	4601.7	60.1	76.52	0	7.755	91.50%	0.97	0.48 (hum)
4	5257.1	59.2	88.81	0	7.694	91.70%	0.98	0.42(slp)
5	6131.2	58.3	105.23	0	7.633	91.80%	0.93	

Table 6.3 Summery Table for Variable Selection from the Regression Models of Predictor Set 3

Regression	RMS	EMS	F	P	S	R-Sq(adj)	DW	Minimum Absolute t
1	3070.1	65	47.26	0	8.06	90.80%	0.97	0.01(wmx)
2	3349.2	63.5	52.72	0	7.97	91.00%	0.97	0.05(tw)
3	3684.2	62.1	59.28	0	7.883	91.20%	0.97	0.1(td)
4	4093.4	60.8	67.28	0	7.8	91.40%	0.97	0.16(hu)
5	4604.9	59.6	77.26	0	7.72	91.60%	0.98	0.19(wv)
6	5262.5	58.4	90.06	0	7.644	91.80%	0.99	0.39(slp)
7	6138.1	57.4	106.86	0	7.579	91.90%	0.95	

The estimated regression coefficients for the selected (original) variables after eliminating the insignificant variables are presented in Table 6.4 for the three data sets 1, 2 and 3. Furthermore Table 6.5 presents regression coefficients of the models for the transformed variables. Table 6.6 presents the identified outliers and hi-leverage points for the regression models. 2 outliers (the 50^{th} and 56^{th} observations) and 2 hi-leverage points (28^{th} and 29^{th} observations) are detected for all the models of the transformed variables and we omit those unusual observations to obtain the appropriate regression models by deleting the observations such as 56^{th}, 50^{th}, 29^{th} and then 28^{th} one after another.

Table 6.4 Regression Coefficients for the Selected Variables of the Three Data Sets 1, 2 and 3

Set 1					Set 2					Set 3				
Pred	coef	sd	t	p	Pred	Coef	StDev	T	P	Pred	coef	sd	t	p
const	34.72	41.35	0.84	0.405	const	55.69	40.9	1.36	0.179	const	34.62	41.55	0.83	0.409
dm	50.231	3.083	16.29	0	dm	50.267	3.128	16.07	0	dm	50.469	3.113	16.21	0
tmn	5.965	1.87	3.19	0.002	tmn	5.551	1.854	2.99	0.004	tmn	5.881	1.882	3.12	0.003
ftd	-0.6013	0.4596	-1.31	0.197	ttr	0.04692	0.02918	1.61	0.114	ftd	-0.6301	0.4605	-1.37	0.177
tmx	-2.621	1.363	-1.92	0.06	td	-1.55	1.453	-1.07	0.291	ttr	0.0415	0.02875	1.44	0.155
ac	-8.49	4.674	-1.82	0.075	tmx	-2.332	1.462	-1.6	0.117	tmx	-2.553	1.375	-1.86	0.069
mxr	0.3566	0.2257	1.58	0.12	ac	-9.342	4.649	-2.01	0.05	ac	-8.543	4.708	-1.81	0.076

Table 6.5 Regression Coefficients for the Transformed Variables of Three Data Sets 1, 2 and 3

Set 1					Set 2					Set 3				
Pred	coef	sd	t	p	Pred	coef	sd	t	p	Pred	coef	sd	t	p
const	25.75	16.87	1.53	0.133	const	37.93	17.24	2.2	0.033	const	25.96	17.67	1.47	0.148
dm*	46.876	3.619	12.95	0	dm*	47.163	3.725	12.66	0	dm*	47.111	3.637	12.95	0
tmn*	2.805	1.904	1.47	0.147	tmn*	2.675	2.04	1.31	0.196	tmn*	2.639	1.915	1.38	0.174
ftd *	-0.4907	0.4457	-1.1	0.276	ttr*	0.04336	0.02131	2.03	0.047	ftd *	-0.5244	0.4522	-1.16	0.252
tmx*	-1.875	1.277	-1.47	0.148	td*	-1.81	1.859	-0.97	0.335	ttr*	0.04087	0.02116	1.93	0.059
ac*	-3.291	4.084	-0.81	0.424	tmx*	-1.57	1.344	-1.17	0.248	tmx*	-1.738	1.294	-1.34	0.185
mxr*	0.3786	0.1681	2.25	0.029	ac*	-3.856	4.134	-0.93	0.356	ac*	-2.998	4.153	-0.72	0.474

Table 6.6 Identification of Outlier and Hi-Leverage Points in the Transformed Regression Models

	n =56, k=3,(3k/n)=0.375,			n=55 k=3,(3k/n)=0.382			n=54 k=3,(3k/n)=0.389			n=53 k=3,(3k/n)=0.396,		
	Set 1	Set 2	Set 3	Set 1	Set 2	Set 3	Set 1	Set 2	Set 3	Set 1	Set 2	Set 3
Obs. no	56	56	56	50	50	50	29	29	29	28	28	28
SRES1	-2.687	-2.722	-2.630	2.694	2.576	2.617	-1.222	-1.655	-1.363	-1.446	-1.512	-1.374
TRES1	-2.880	-2.924	-2.809	2.893	2.746	2.797	-1.229	-1.687	-1.376	-1.464	-1.534	-1.388
HI1	0.074	0.085	0.084	0.065	0.072	0.068	0.489	0.425	0.469	0.457	0.449	0.453

Table 6.7 Regression Coefficients for the Three Fitted Models Deleting Unusual Observations

Set 1					Set 2					Set 3				
Pred	coef	sd	t	p	Pred	coef	sd	t	p	Pred	coef	sd	t	P
const	23.4	18.85	1.24	0.221	const	40.88	16.71	2.45	0.018	const	25.5	19.69	1.3	0.202
dm*	50.035	4.084	12.25	0	dm*	50.582	4.081	12.39	0	dm*	49.912	4.116	12.13	0
tmn*	2.183	1.647	1.33	0.192	tmn*	2.62	1.745	1.5	0.14	tmn*	2.028	1.665	1.22	0.229
ftd *	-0.4759	0.4231	-1.12	0.267	ttr*	0.03127	0.01912	1.63	0.109	ftd *	-0.482	0.4313	-1.12	0.27
tmx*	-1.427	1.397	-1.02	0.313	td*	-2.583	1.667	-1.55	0.128	ttr*	0.03021	0.01942	1.56	0.127
ac*	-3.316	3.568	-0.93	0.358	tmx*	-1.22	1.404	-0.87	0.389	tmx*	-1.443	1.428	-1.01	0.317
mxr*	0.3056	0.1539	1.99	0.053	ac*	-3.581	3.605	-0.99	0.326	ac*	-2.924	3.649	-0.8	0.427

TS plots of the deleted Studentized residuals for the regressions of the transformed variables of data sets 1, 2 and 3 indicate unusual point along the X-axis and the figures show only one unusual point at a time in each case. NP plots for residuals follow normality and ACF displays for residuals show nonautocorrelated structure (approximately) for the fitted models after deleting the 4 unusual points. We have presented some residual figures for the data set 2 [Figure 6.1 to Figure 6.12]. Table 6.7 presents the finally fitted regression coefficient deleting the unusual observations and Table 6.8 shows the ANOVA results for the obtained regression models where the detected outliers and hi-leverage points have been deleted one by one. But from the regression results for all sets of data we observe no significant regression coefficient of climatic variables at 5% level of significance. ANOVA results for the models such as fitted models for all the original variables, fitted models for selected original variables, fitted models for transformed variables and fitted models for finally selected variables and observations are presented in Table 6.9.

Table 6.8 ANOVA Results for the Regression Models of Data Sets 1, 2 and 3 Deleting UO

		DF	TSS	RSS	RMS	ESS	EMS	DF	F	P	S	R-Sq	R-Sq(adj)	DW
1	56 O del	54	11028.9	9441.9	1573.6	1587	33.1	48	47.6	0	5.75	85.60%	83.80%	1.38
	50 O del	53	10304.8	8957.7	1493	1347	28.7	47	52.09	0	5.354	86.90%	85.30%	1.4
	29 HL del	52	10248	8943.8	1490.6	1304.2	28.4	46	52.58	0	5.325	87.30%	85.60%	1.41
	28 HL del	51	9578.8	8333.9	1389	1244.9	27.7	45	50.21	0	5.26	87.00%	85.30%	1.32
2	56 O del	54	11316.2	9676.6	1612.8	1639.6	34.2	48	47.21	0	5.845	85.50%	83.70%	1.4
	50 O del	53	10580.4	9167.5	1527.9	1412.9	30.1	47	50.83	0	5.483	86.60%	84.90%	1.42
	29 HL del	52	10521.7	9191.1	1531.8	1330.6	28.9	46	52.96	0	5.378	87.40%	85.70%	1.4
	28 HL del	51	9860.8	8596.3	1432.7	1264.5	28.1	45	50.99	0	5.301	87.20%	85.50%	1.29
3	56 O del	54	11498.9	9847.9	1641.3	1650.9	34.4	48	47.72	0	5.865	85.60%	83.80%	1.42
	50 O del	53	10755.7	9340.3	1556.7	1415.4	30.1	47	51.69	0	5.488	86.80%	85.20%	1.45
	29 HL del	52	10695.6	9336.2	1556	1359.4	29.6	46	52.65	0	5.436	87.30%	85.60%	1.44
	28 HL del	51	10039.9	8736.2	1456	1303.7	29	45	50.26	0	5.382	87.00%	85.30%	1.37

*UO-Unusual Observations

Table 6.9 ANOVA Results for the Models of Data Sets 1, 2 and 3

	Set 1				Set 2				Set 3			
Source	AV	SV	TV	FVO	AV	SV	TV	FVO	AV	SV	TV	FVO
TSS	39700.4 (56)	39700.4 (56)	11094.8 (55)	9578.8 (51)	39700.4 (56)	39700.4 (56)	11377.2 (55)	9860.8 (51)	39700.4 (56)	39700.4 (56)	11556.8 (55)	10039.9 (51)
RSS	36880.9	36851	9233.7	8333.9	36818.6	36787.2	9445.6	8596.3	36841.7	36828.4	9634.5	8736.2
RMS	2458.7	6141.8	1538.9	1389	3681.9	6131.2	1574.3	1432.7	3070.1	6138.1	1605.8	1456
ESS	2819.5	2849.4	1861.1	1244.9	2881.8	2913.2	1931.6	1264.5	2858.6	2871.9	1922.3	1303.7
EMS	68.8(41)	57(50)	38(49)	27.7(45)	62.6(46)	58.3(50)	39.4(49)	28.1(45)	65(44)	57.4(50)	39.2(49)	29(45)
F	35.75	107.78	40.52	50.21	58.77	105.23	39.94	50.99	47.26	106.86	40.93	50.26
P	0	0	0	0	0	0	0	0	0	0	0	0
S	8.293	7.549	6.163	5.26	7.915	7.633	6.279	5.301	8.06	0.59	6.263	5.382
R-Sq	0.929	0.928	0.832	0.87	0.927	0.927	0.83	0.872	92.80%	92.80%	83.40%	0.87
R-Sq(adj)	0.903	0.92	0.812	0.853	0.912	0.918	0.809	0.855	90.80%	91.90%	81.30%	0.853
DW	0.92	0.92	1.28	1.32	0.96	0.93	1.32	1.29	0.97	0.95	1.33	1.37

Notes: 1.AV-All Variables, SV-Selected Variables, TV-Transformed Variables and FVO-Finally Selected Variables and Observations
2.Figures in the parenthesis is the corresponding degrees of freedom

6.3 Conclusion

In order to quantify the impact of climatic change on wheat production in Dinajpur district of Bangladesh we have built up three multiple regression models taking several climatic variables during wheat growing period (Nov-Mar) including a dummy variable. Dummy variable is taken for the structural change of wheat production data in 1976. We have selected one model among the three models based on the highest F and R^2. We have found significant t values only for the coefficient of dummy (dm*) variable. The coefficients of dm*, tmn*, td*, ttr* tmx* ac* are 50.58, 2.62, -2.58, 0.0312, -1.22 and -3.58 respectively and the corresponding t values are 12.39, 1.5, 1.55, 1.63, 0.87 and 0.99 in absolute term. The t values are less than one for the coefficient of tmx* and ac*. So, according to the results of the model, it may be reported that one percent increase in tmn increases the yield rate by about 2.62%, one percent increase in td decreases the yield rate by about 2.58%, one percent increase in ttr increases the yield rate by about 0.03%, one percent increase in tmx reduces the yield rate by about 1.22% and one percent increase in dm increases the yield rate by about 50%. Though we did not get any significant effect of climatic variables on wheat production in Dinajpur district at the 5% level of significance, the improved technology such as high yielding variety, irrigation system and other physical inputs may contribute positively to the wheat production and yield rate.

Residual Plots for Data Set 2

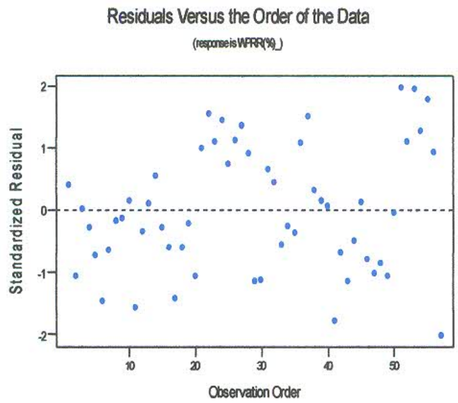


Figure 6.1 SR vs order of the data for original data

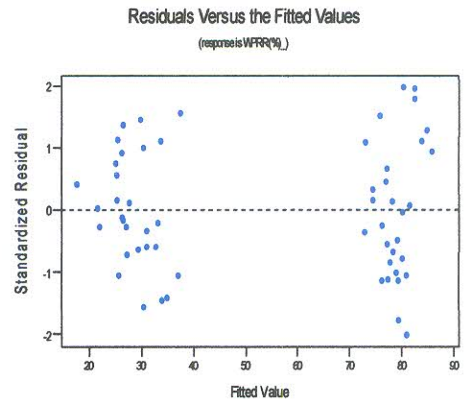


Figure 6.2 SR vs fitted value for original data

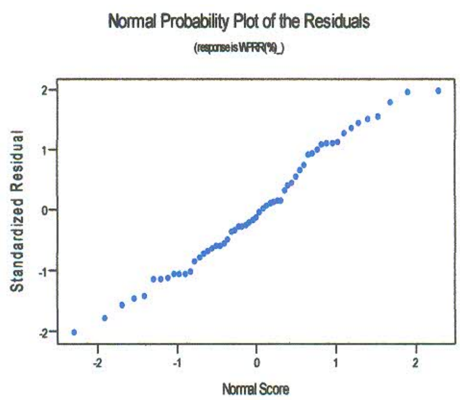
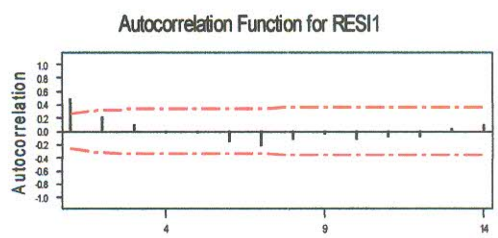


Figure 6.3 Np plot of SR for original data



Lag	Corr	T	LBQ	Lag	Corr	T	LBQ
1	0.50	3.74	14.75	8	-0.13	-0.76	25.40
2	0.23	1.43	18.04	9	-0.04	-0.23	25.51
3	0.11	0.65	18.77	10	-0.13	-0.72	26.69
4	-0.03	-0.18	18.83	11	-0.08	-0.45	27.18
5	-0.03	-0.17	18.89	12	-0.08	-0.45	27.67
6	-0.17	-0.99	20.73	13	0.04	0.23	27.81
7	-0.23	-1.31	24.15	14	0.10	0.56	28.61

Figure 6.4 ACF plot of SR for original data

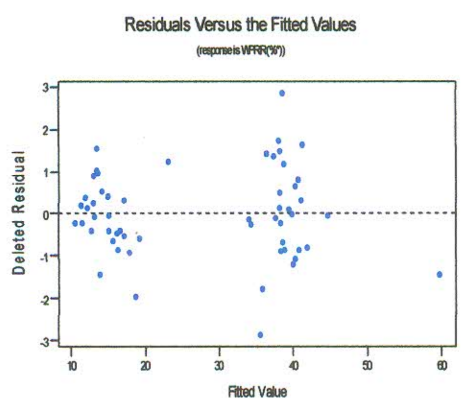


Figure 6.5 DR vs fitted value for transformed data

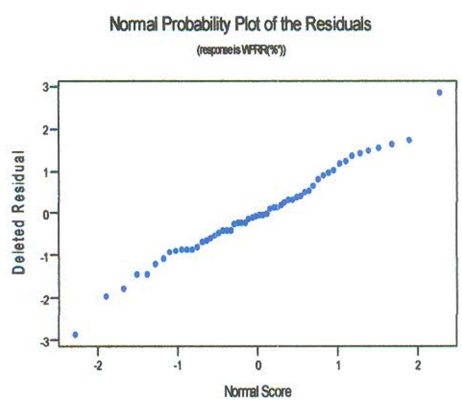


Figure 6.6 Np plot of DR for transformed data

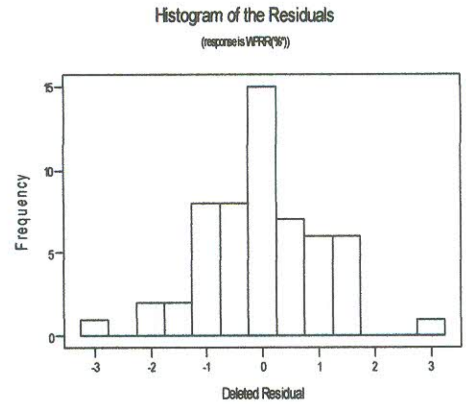
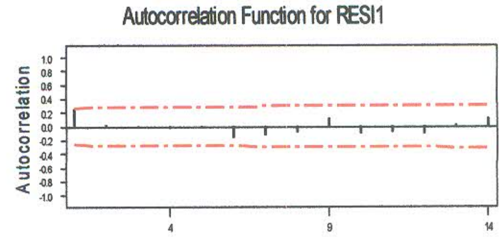


Figure 6.7 Histogram of DR for transformed data



Lag	Corr	T	LBQ	Lag	Corr	T	LBQ
1	0.26	1.97	4.08	8	-0.09	-0.60	7.75
2	0.03	0.24	4.16	9	0.12	0.78	8.70
3	-0.01	-0.08	4.16	10	-0.11	-0.70	9.49
4	-0.04	-0.27	4.26	11	-0.09	-0.58	10.05
5	-0.01	-0.08	4.27	12	-0.10	-0.65	10.79
6	-0.17	-1.20	6.18	13	0.03	0.16	10.84
7	-0.12	-0.85	7.21	14	0.13	0.86	12.19

Figure 6.8 ACF plot of DR for transformed data

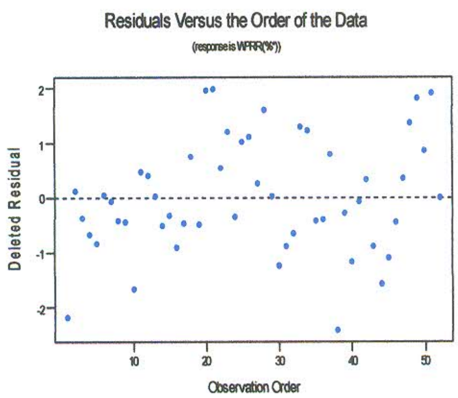


Figure 6.9 DR vs fitted value deleting 28^{th} obs.

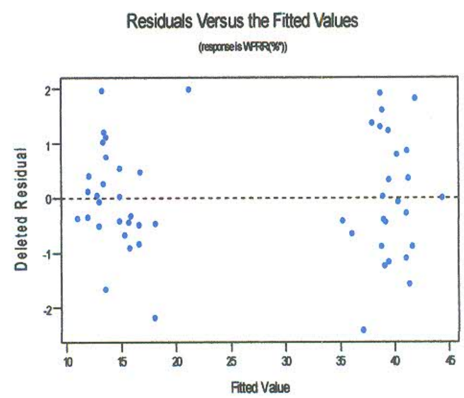


Figure 6.10 Np plot of DR deleting 28^{th} obs.

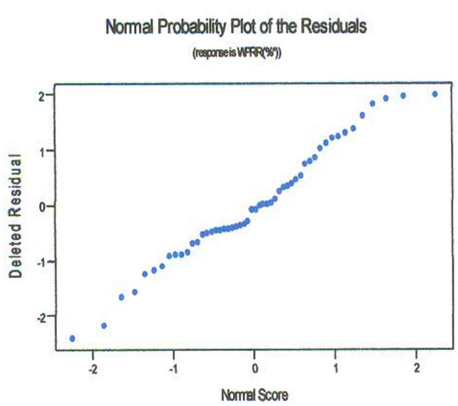
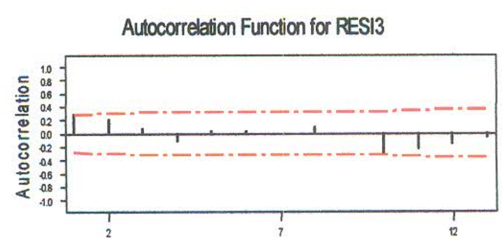


Figure 6.11 Hist. of DR deleting 28^{th} obs.



Lag	Corr	T	LBQ	Lag	Corr	T	LBQ
1	0.30	2.16	4.93	8	0.12	0.73	10.25
2	0.22	1.43	7.53	9	0.00	0.02	10.25
3	0.09	0.57	8.00	10	-0.29	-1.81	16.01
4	-0.13	-0.84	9.02	11	-0.25	-1.44	20.18
5	0.06	0.35	9.21	12	-0.17	-0.93	22.12
6	0.05	0.32	9.37	13	-0.07	-0.41	22.52
7	0.02	0.10	9.38				

Figure 6.12 ACF plot of DR deleting 28^{th} obs.

Table 6.10 Studied Variables during Nov-Mar over the Years 1948-2004

Variable's name	Variable's description	Variable's stationarity (Box-Peirce test)
wprr	Wheat Production Rate in percentage	
dm	Dummy variable that was taken for structural change in wheat production rate data in 1976 where dm= 0 for t<1976 and dm= 1 for t>=1976	
tmn	Average of the Nov-Mar monthly average minimum temperatures(in celcius degrees)	S
tw	Average of the Nov-Mar monthly average maximum wet bulb temperatures(in celcius degrees)	NS
ftd	Average frequency of the Nov-Mar monthly average dry bulb temperature which is greater than 20 ^{0}C	NS
ttr	Total of the Nov-Mar monthly total rainfall(in millimeter)	S
td	Average of the Nov-Mar monthly average dry bulb temperature (in celcius degrees)	NS
hu	Average of the Nov-Mar monthly average relative humidity (in percentage)	NS
mxr	Average of the Nov-Mar monthly average maximum rainfall (in millimeter)	NS
tmx	Average of the Nov-Mar monthly average maximum temperatures (in celcius degrees)	NS
slp	Average of the Nov-Mar monthly average sea level pressure (in milibar)	S
ac	Average of the Nov-Mar monthly average cloud(in octas)	NS
wmx	Average of the Nov-Mar monthly average maximum wind speed (in knot)	NS
wv	Average of the Nov-Mar monthly average wind speed(in knot)	NS
hu(0-12)	Average of the Nov-Mar monthly average difference of morning and afternoon humidity	NS
rf	Average of the Nov-Mar monthly average frequency of insignificant rain	S

Chapter 7

Chapter 7

People's Perception about Climate Change and Wheat Production in Dinajpur District

7.1 Introduction

We conduct an opinion survey among 50 and above aging farmers and agriculture workers in selected Mauzas of Dinajpur district. The main objective of this survey is to know the valuable experience of farmers and what they feel in practical field about climate change and wheat production of Dinajpur region and the total number of persons interviewed are 313. In the survey all respondents opine that there is a change in climate than previous time and inform that crop land, crop cultivation and crop production have been affected due of climatic change. So, some specific questions are put to them about the change of climatic behavior in Rainy season, Winter season, Summer, Autumn and Spring Seasons. They report about the effect of climate change on rainfall in Rainy season, the effect of climate change on Summer temperature and Summer season etc. We try to compare this information with our results obtained from secondary sources. In some cases we fail to collect secondary data such as fog in Winter season, dew in Autumn etc. and we collect these informations through the sample survey.

7.2 Results and Discussion

7.2.1 Socio-Economic Background of the Respondentsr

Distibution of respondent by Upazila is shown in Table 7.1

Table 7.1 Distribution of respondents by Upazila

Upazila	Frequency	Percent
Hakimpur	70	22.4
Ranisankail	48	15.3
Atwari	195	62.3
Total	313	100

Of the total 313 respondents, 22.4% (70) are from in the Hakimpur Upazila, 15.3% (48) from Ranisankail and 62.3% (195) from Atwari Upazila in Dinajpur [Table 7.1, Figure 7.1]. Of the total respondents, 99.4% are male and the rest of 0.6% is female.

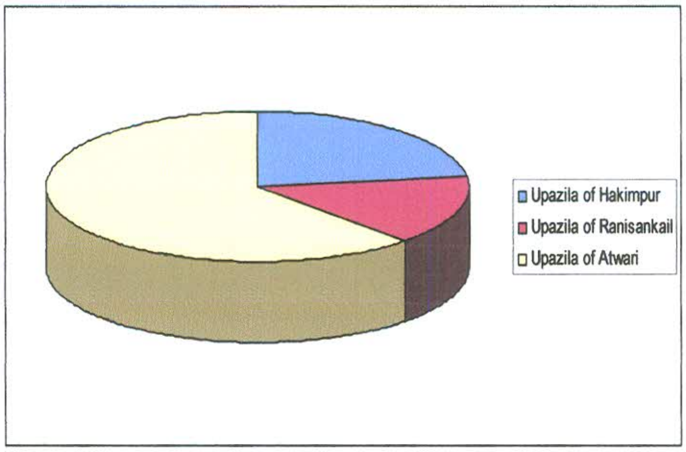


Figure 7.1 Pie Chart of respondent's distribution by Upazila

We have shown the cross classification of sample respondents by Age and Upazila and the frequency distribution of land by Upazila in Table 7.2. For testing an association between the two criteria such as Age and Upazila we set up the null hypothesis Ho: there is no association between Upazila and Age and the estimated value of χ^2 =0.824 falls in the critical region [$\chi^2 > \chi^2$ 0.05(2) = 5.99] and we have reasonable evidence to conclude that the two criteria are not independent. For testing an association between the two criteria such as Land and Upazila we set up the null hypothesis Ho: there is no association between Upazila and Land size and the estimated value of χ^2 =59.353 falls in the critical region [$\chi^2 > \chi^2$ 0.05(6) = 12.59] and thus we can conclude that the two criteria are not independent.

Table 7.2 Cross Classification of Sample Respondents by Age and Upazila and by Land and Upazila

Distribution of respondent's Age by Upazila				Distribution of respondent's land by Upazila					
Age / Upazila	50-59yrs	60 or 60yrs above	All	Land / Upazila	No Land	.01-249dl	250-749dl	750-10000dl	Total
Hakimpur	47	23	70	Hakimpur	13	42	13	2	70
Ranisankail	30	18	48	Ranisankail	0	24	21	3	48
Atwari	119	76	195	Atwari	1	81	89	24	195
Total	196	117	313	Total	14	147	123	29	313
	Chi-Square = 0.824	DF = 2	P-Value = 0.662		Chi-Square = 59.35	DF = 6	P-Value = 0.000		

Boxplot for respondent's age in Figure 7.2 shows 5 outliers where larger variation is indicated in 3rd quartile and boxplot of respondent's land also shows 4 outliers indicating larger variation in 3rd quartile. But stem-and-leaf Display for respondent's age shows the age distribution with 12 high outliers where 54 is the median age and stem- and- leaf display of respondent's land shows 16 high outliers where 40 decimal is median land. Besides these we have shown boxplot of respondent's age by upazila and boxplot of respondent's land by upazila [Figures 7.6 and Figure 7.7].

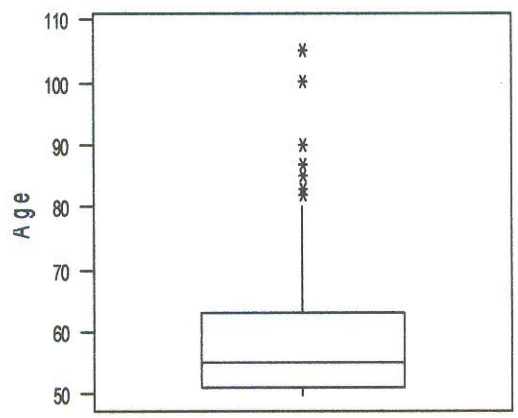


Figure 7.2 Boxplot for distribution of Age

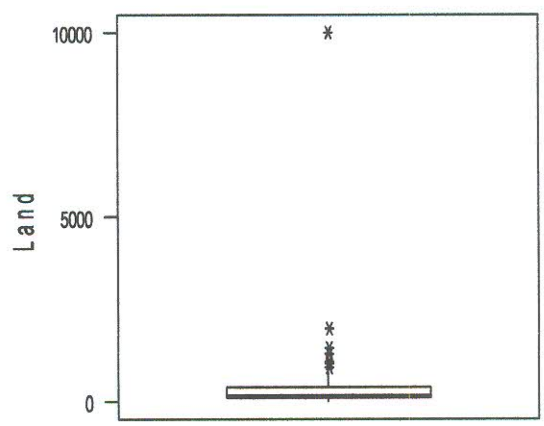


Figure 7.3 Boxplot for distribution of Land

```
Stem-and-leaf of Age       N  = 313
Leaf Unit = 1.0

  79     5 000000000000000000000000000000000000000000000000000000000000000000+
 118     5 222222222222222222222222222223333333333
 (54)    5 444444455555555555555555555555555555555555555555555555
 141     5 667777777
 132     5 888888888888999
 117     6 0000000000000000000000000000000011
  83     6 222333
  77     6 4455555555555555
  61     6 7777
  57     6 88888
  52     7 00000000000000000
  35     7 22333
  30     7 5555555555
  20     7 6
  19     7 88
  17     8 00000

         HI   82, 82,  83,  85,  85,  85,  87,  90, 100, 100, 100, 105,
```

Figure 7.4 Stem-and-Leaf Display of age for respondents

```
                Stem-and-leaf of Land      N  = 313 Leaf Unit = 10

  33     0 000000000000000111333333333334444
  54     0 555555555555666667778
  96     1 000000000000000000000000011222222223333344
 121     1 5555555555555555555666778
(40)     2 0000000000000000000000000000000000002223
 152     2 55555555555555555555667
 129     3 0000000000000000000002333
 104     3 555555555555556
  89     4 00000000000000000
  72     4 55555
  67     5 0000000000000000000000
  45     5
  45     6 000000000000
  33     6 67
  31     7 00
  29     7 555555
  23     8 000000
  17     8 5

      HI    90,  100,  100,  100,  100,  110,  130,  145,  200, 1000,
          1000, 1000, 1000, 1000, 1000, 1000,
```

Figure 7.5 Stem-and-Leaf Display for respondent's land

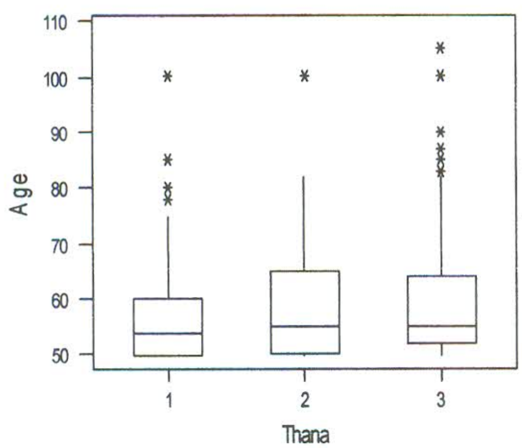


Figure 7.6 Boxplot for respondent's age by upazila

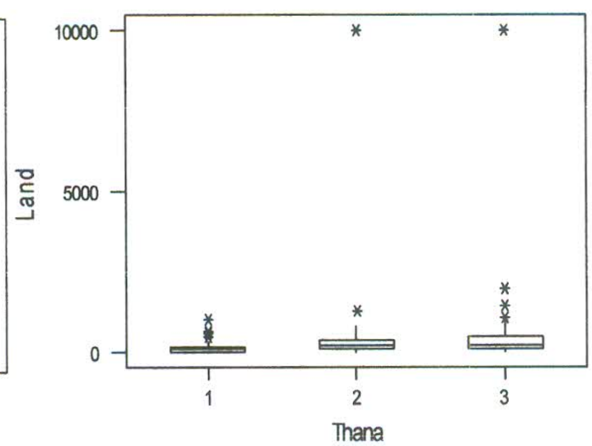


Figure 7.7 Boxplot of respondent's land by upazila

The Distribution of respondent's by education level and upazila shown in Table 7.3 shows an association between the two criteria. We set up the null hypothesis Ho: there is no association between upazila and education for testing an association between these two criteria. We observe that the estimated value of $\chi^2 = 28.183$ falls in the critical region [$\chi^2 > \chi^2$ 0.05(8) = 15.5073], so reasonable evidence is observed to conclude that the Upazila and education are not independent. Bar diagram for respondent's education shown in Figure 7.8 shows that about 20% of total respondents are illiterate, about 38% have primary level education, 33% have secondary level, 6% have higher secondary level and only 2% have graduation and above level education.

Table 7.3 Distribution of Respondent's Education by Upazila

Upazila \ Education	Illiterate	Primary	Secondary	Higher Secondary	Graduate and above	Total
Hakimpur	26	24	15	3	2	70
Ranisankail	1	26	17	2	2	48
Atwari	36	70	71	15	3	195
Total	63	120	103	20	7	313
	Chi-Square = 28.183	DF = 8	P-Value = 0.000			

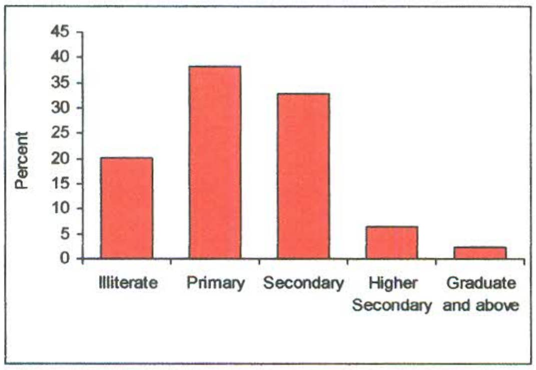


Figure 7.8 Bar diagram for distribution of respondent's education

7.2.2 Descriptive Results of Survey

The respondents are asked to state whether there is any change in climatic condition in Dinajpur District from their boyhood. Hundred percent (100%) of the respondents reply in the affirmative "Yes". The respondents are also asked to state whether there is any change in climatic characteristics since 1970-1975 and 100% of them reply "Yes".

Table 7.4 Different Changes for AR, DR, BR, CA and CS in Rainy Season Due to Climate Change

Amount of rain(AR)			Duration of Rainy season(DR)			Beginning of Rainy season(BR)			Characteristics of Ashar(CA)			Characteristics of Srabon(CS)		
	F	P		F	P		F	P		F	P		F	P
Reduced	281	89.8	Shorter	274	87.5	Happen early	61	19.5	Drier than previous	276	88.2	Rainfall like previous	14	4.5
Increase	15	4.8	Longer	15	4.8	Happen later	76	24.3	Rainy like previous	11	3.5	Not rain like previous	285	91.1
Unchanged	3	1.0	Irregular	15	4.8	Unchanged	18	5.8	No pattern	22	7.0	Irregular	10	3.2
No pattern	13	4.2	Same	9	2.9	Irregular	151	48.2	Others	4	1.3	Others	3	1.0
Others	1	.3	Total	313	100.0	Others	6	1.9	Total	313	100.0	Don't know (9)	1	.3
Total	313	100.0	-	-	-	Don't know (9)	1	.3	-	-	-	Total	313	100.0
-	-	-	-	-	-	Total	313	100.0	-	-	-	-	-	-

Table 7.4 presents the respondent's opinion about the changes of Rainy season due climate change. When the respondents are questioned about the quantity of rain in Rainy season, 90% of the total respondents mention that quantity of rainfall has decreased than before. About 5% mention that it has increased than before, only 1% state that it is same as it was before, while 4% mention that rainfall is irregular and it does not follow any regular trend. When the respondents are questioned about the duration of rainfall, 88% of the total respondents affirm that duration of rainfall has become shorter, about 5% say that it has become longer, about 5% say that duration is irregular and about 3% report that duration of Rainy season has not changed and remain as it was before. When the respondents are asked about the beginning period of Rainy season due to climate change, about 20% of the respondents mention that Rainy season starts early than the before, 24% point out that it starts lately than before. Almost half (48%) of the respondents opine that the starting period of Rainy season is not regular and sometimes it starts early and some times it starts lately, while about 6%, however, mention that there is no change in occurrence period of rainfall. When the respondents are asked to state their opinion regarding the condition in the month of Ashar, 88% of them say that the month of Ashar has become drier than before, about 4% of them express that it is same as before. However, 7% of the respondents state that the situation of dryness does not remain constant in all the years. When the respondents are requested to state the intensity of rainfall in the month of Srabon, about 91% mention that the intensity of rainfall is not like as before, while only 5% mention that the intensity of rainfall is like before. About 3% opine that the trend of intensity of rainfall in the month of Srabon is not regular. Figure 7.9 to Figure 7.13 shows the respondent's opinion about the changes in Rainy season due to climate change.

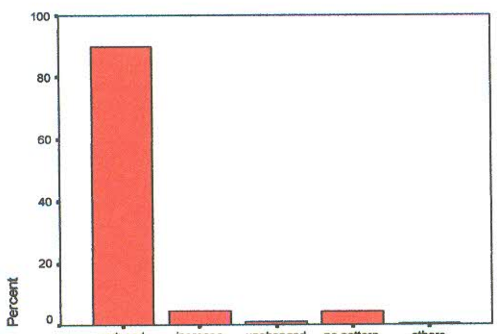


Figure 7.9 Changes about amount of rain in Rainy season

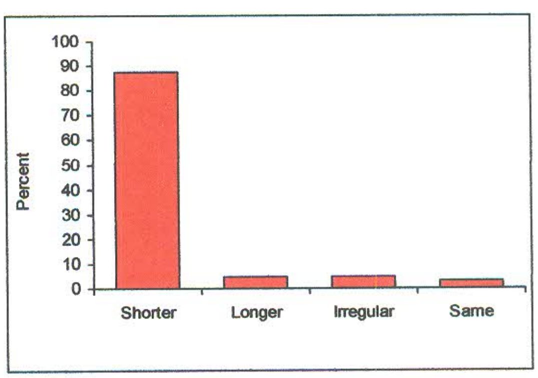


Figure 7.10 Changes about duration of Rainy season

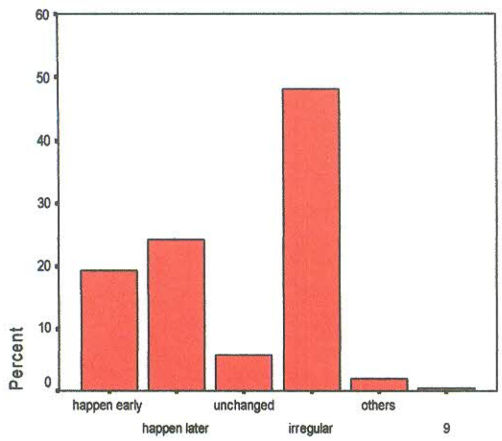


Figure 7.11 Changes about starting of Rainy season

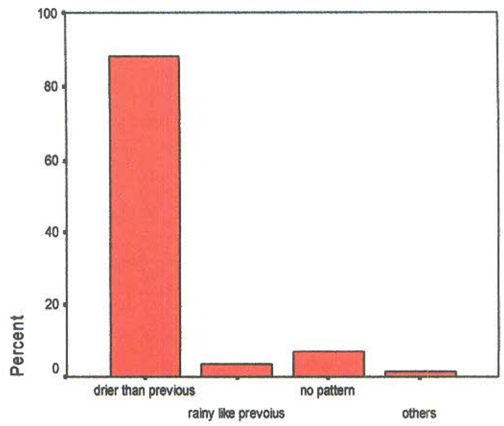


Figure 7.12 Changes in characteristics of Ashar

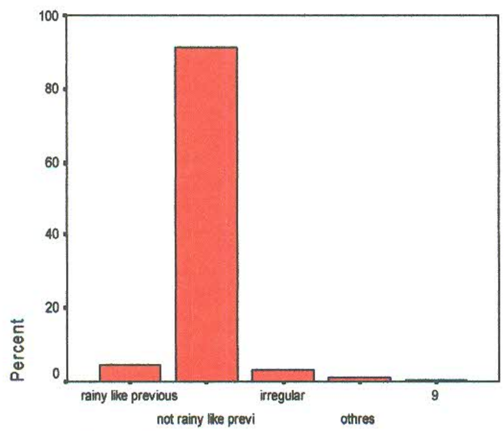


Figure 7.13 Changes in characteristics of Srabon

The distribution of respondent's opinion regarding about amount of rainfall in Rainy season by upazila shown in Appendix [Table A.7.1] shows an association between the two criteria. We set up the null hypothesis Ho: there is no association between amount of rainfall and upazila. The estimated value of χ^2 = 36.797 falls in the critical region [$\chi^2 > \chi^2$ 0.05(2) = 5.99] and we have found no reasonable evidence to conclude that the two criteria are independent. The cross classification of opinion of sample respondents regarding the duration period of Rainy season and upazila shown in Appendix [Table A.7.1] shows an association between the two criteria. We set up the null hypothesis Ho: There is no association between duration of Rainy season and upazila. The estimated value of χ^2 =21.724 falls in the critical region [$\chi^2 > \chi^2$ 0.05(2) = 5.99] and thus we have reasonable evidence to conclude that the two criteria are not independent. The cross classification of sample respondents by duration of Rainy season and amount of rain in

Table 7.5 shows an association between the two criteria. For the null hypothesis Ho: there is no association between amount of rain and the duration period of Rainy season we have the estimated value of $\chi^2 = 62.663$ falls in the critical region [$\chi^2 > \chi^2$ 0.05(1) = 3.84] and thus we conclude that the two criteria are not independent. Similarly the cross classification of sample respondent's opinion regarding beginning period of Rainy season by upazila shown in Appendix [Table A.7.2] shows an association between the two criteria and for testing the null hypothesis Ho: there is no association between Upazila and beginning period of Rainy season where we find that the computed $\chi^2 = 95.152$ falls in the critical region [$\chi^2 > \chi^2$ 0.05(8) = 15.5073] and it may be concluded that the two criteria are not independent. The cross classification of sample respondent's opinion regarding changes in characteristics of Ashar by Upazila shown in Appendix[Table A.7.3] shows an association between the two criteria and for the null hypothesis Ho: there is no association between changes in characteristics of Ashar and Upazila. The estimated value of $\chi^2 = 100.395$ falls in the critical region [$\chi^2 > \chi^2$ 0.05(2) = 5.99] so we have reasonable evidence to conclude that the two criteria are not independent. Opinion distribution of respondents about changes in characteristics of Srabon by upazila shown in Appendix[Table A.7.3] shows an association between the two criteria. We set up the null hypothesis Ho: there is no association between Upazila and changes in characteristics of Srabon. The estimated value of $\chi^2 = 18.306$ falls in the critical region [$\chi^2 > \chi^2$ 0.05(2) = 5.99] and thus we have reasonable evidence to conclude that the two criteria are not independent.

Table 7.5 Distribution of CCS by CCA and DPRS by ARRS

CCS / CCA	Responses other than rainless condition	Not rain like previous	Total	DPRS / AR	Others	Rainy Season Shorter	Total
Responses other than drier condition	13	24	37	rain reduced	18	14	32
Drier than previous	15	261	276	others	21	260	281
Total	28	285	313	Total	39	274	313
	Chi-Square = 35.333	DF=1	P-Value = 0		Chi-Square =62.66	DF = 1	P-Value = 0.000

*DPR-Duration period of Rainy season *ARRS-Amount of rain in Rainy season

*CCS-Changes of characteristics in Srabon *CCA-Changes of characteristics in Ashar

The cross classification of opinion of sample respondents regarding changes in characteristics of Ashar and Srabon shown in Table 7.5 shows an association between the two criteria. We set up the null hypothesis Ho: there is no association between changes in characteristics of Ashar and Srabon. The estimated value of χ^2 =35.333 falls in the critical region [$\chi^2 > \chi^2$ 0.05(1) = 3.84] and thus we have reasonable evidence to conclude that the two criteria are not independent.

Table 7.6 Different Changes for TS, IN, SJ and FHBJ in Summer Due to Climate Change

Temperature in Summer(TS)			Intensity of Norwester(IN)			Soil condition in Jaistha(SJ)			Feeling of heat in Boishakh and Jaistha(FHBJ)		
	F	P		F	P		F	P		F	P
Decrease	215	68.7	Lower	280	89.5	Soil becomes craked	22	7.0	Lower	224	71.6
Increase	72	23.0	Higher	24	7.7	Not craked like previous	288	92.0	Higher	59	18.8
Unchanged	10	3.2	Same	4	1.3	Irreguar	-	-	Same	18	5.8
Irregular	12	3.8	Irregular	5	1.6	Others	3	1.0	Irregular	11	3.5
Others	3	1.0	Total	313	100.0	Total	313	100.0	Others	1	.3
Don't know (9)	1	.3							Total	313	100.0
Total	313	100.0									

We have presented the opinions about the changes of temperature in Summer due to climate change in Table 7.6. The respondents are questioned about the change of temperature in Summer due to climate change. About 69% of them ention that the level of temperature has decreased in Summer, while about 23% give opposite views and mention that the level of temperature has increased. On the other hand, 3% report that there is no variation in the level of temperature due to climate change but 4% of the respondents mention that the change in temperature does not follow any regular pattern. The respondents are again questioned about the intensity of Norwester hit due to climate change and about 90% state that they feel lower intensity of Norwester hit, while about 8% opine that they feel higher intensity of Norwester hit and very few of them express other views. The respondents are asked to state about the changed condition of soil for the Sunshine of Joistha and about 92% of total respondent have responded in favor of not cracking of soil, 7% respond in favor of cracking of soil and 1% mention other things. The respondents are questioned regarding the feeling of heat in Boishakh and Joistha due to climate change. About 72% respondents inform that they experience less heat in Boishakh and Joistha than the before. About 19% experience more heat after climate change. About 6% felt the same as before and 3.5% felt no regular pattern. Opinions about the changes of Summer are shown in Figures 7.14 to 7.18.

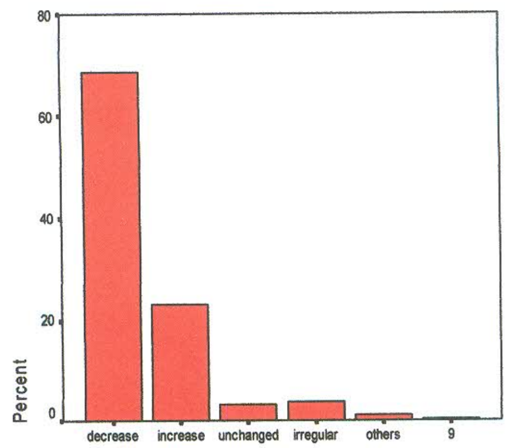


Figure 7.14 Changes in Temperature of Summer

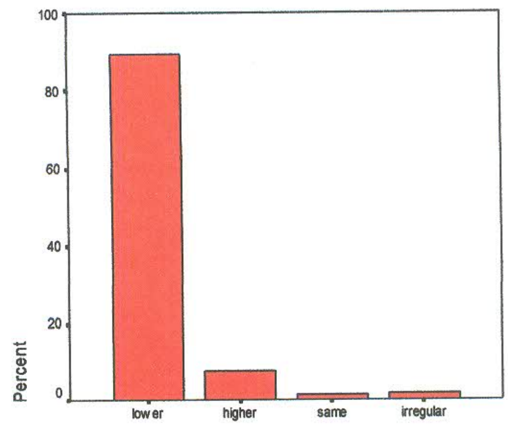


Figure 7.16 Changes in intensity of Norwester hit

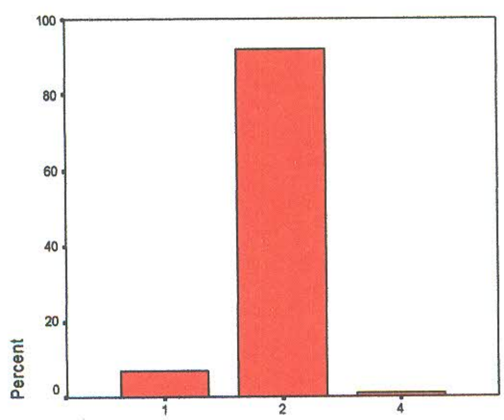


Figure 7.17 Changes in climatic characteristics of Jaistha

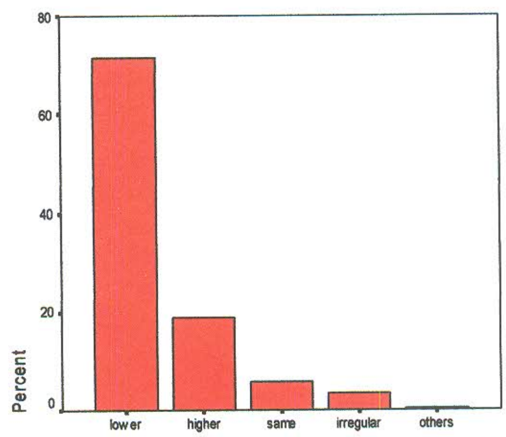


Figure 7.18 Changes in hot feeling of Boishakh -Joistha

The cross classification of sample respondents by level of Summer temperature and Upazila shows an association between the two criteria in Appendix [Table A.7.4]. We set up the null hypothesis Ho: There is no association between Summer temperature and Upazila. The estimated value of χ^2 =43.243 falls in the critical region [$\chi^2 > \chi^2$ 0.05(2) = 5.99] and thus we have reasonable evidence to conclude that the two criteria are not independent. The cross classification of opinion of sample respondents regarding intensity of norwester by Upazila shown in Appendix [Table A.7.4] indicates an association between the two criteria. We set up the null hypothesis Ho: there is no association between Upazila and Intensity of Norwester. The estimated value of χ^2 =61.397 falls in the critical region [$\chi^2 > \chi^2$ 0.05(2) = 5.99] and thus we have reasonable evidence to conclude that the two criteria are not independent.

Table 7.7 Respondet's Opinion about Intensity of Norwester by Summer Temperature

Temperature in Summer \ Intensity of Norwester hit	Lower	Comments other than lower intensity	Total
Decrease	203	12	215
Commentsotherthan decrease	77	21	98
Total	280	33	313
	Chi-Square = 17.924	DF=1	P-Value = 0

The cross classification of opinion of sample respondents regarding Summer temperature and Intensity of Norwester shown in Table 7.7 shows an association between the two criteria. We set up the null hypothesis Ho: there is no association between temperature in Summer and Intensity of Norwester. The estimated value of χ^2 =17.924 falls in the critical region [$\chi^2 > \chi^2$ 0.05(1) = 3.84] and thus we have reasonable evidence to conclude that the two criteria are not independent.

Table 7.8 Different Changes for IC, LD, SP, IF and CC in Winter Due to Climate Change

Intensity of coldness(IC)			Length of duration(LD)			Starting period (SP)			Intensity of fog (IF)			Changes of characteristics(CC)		
	F	P		F	P		F	P	719	F	P		F	P
Lower	227	72.5	Shorter	116	37.1	Come early	34	10.9	Same	19	6.1	Few rain	76	24.28
Higher	66	21.1	Longer	157	50.2	Come later	83	26.5	More	108	34.5	Few storm	8	2.55
Unchanged	17	5.4	Same	29	9.3	Just time	136	43.5	Less	169	54.0	Extreme cold	103	32.90
Irregular	3	1.0	Irregular	10	3.2	Irregular	56	17.9	Irregular	13	4.2	Light hot	114	36.42
Total	313	100.0	Others	1	.3	Others	4	1.3	Others	4	1.3	Nothing happen	20	6.38
-	-	-	Total	313	100.0	Total	313	100.0	Total	313	100.0	Other comments	26	8.30

Table 7.8 presents the different changes in Winter due to climate change. The respondents are questioned about the Intensity of coldness in Winter due to climate change .About 74% of total respondents inform that the intensity of coldness in Winter is lesser than before, 21% confirm that it has increased, 5% reply that the intensity is same as before and only 1% say that it is irregular that means that the intensity of coldness in Winter Season does not follow any regular pattern. The respondents were asked to say about the length of Winter duration due to climate change. About 50% of total respondents affirm that the length of Winter duration has become longer, 37% confirm that the length of Winter duration has become shorter, I% mention that it is same as it was before and 3% reply that the change of duration in Winter is not regular.

The respondents are also asked regarding the starting period of Winter season, about 11% respondents report that Winter season starts early, 27% mention that it starts lately, 44% respondents confirm that the Winter season starts in due time and 18% confirm that the starting period of Winter season is not regular. The respondents are questioned about the change of fog in Winter, 54% of the respondents confirm that the intensity of fog in Winter is lesser than before, 35% mention that the intensity of fog in Winter is more than previous, 6% confirm that the fog in Winter is same as before and 4% mention that it is irregular that means the fog in Winter is lesser than before some times and sometimes it is more than before which means intensity of fog is not regular. When the respondents are questioned about the different changed condition in Winter, 36% of total respondents mention that sometimes they feel slight hot in Winter, 32% of total respondents mention that they feel extreme cold in Winter, 24% of total respondents experience few rain in Winter, 6% say that they experience no remarkable change in Winter and 8% report that they experience other things. Figure 7.19 to Figure 7.22 show changes on different aspects in Winter graphically.

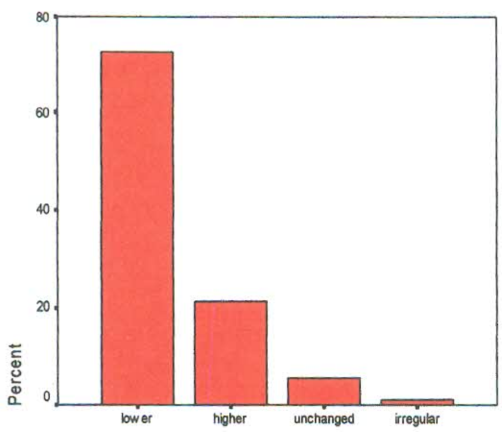


Figure 7.19 Changes in coldness of Winter

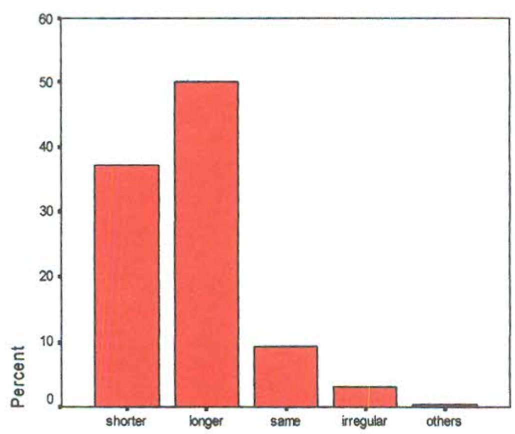


Figure 7.20 Changes in duration of Winter

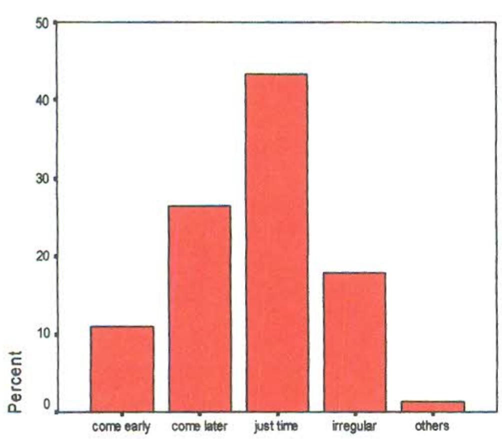


Figure 7.21 Changes in starting period of Winter

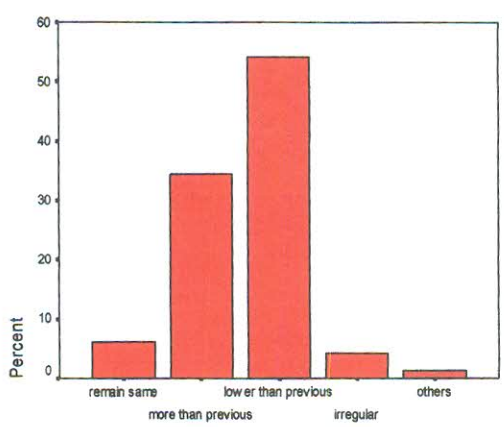


Figure 7.22 Changes in fog intensity of Winter

Table 7.9 Respondent's Opinion about the Intensity Of Winter Fog by Upazila

Fog in Winter / Upazila	Irregular and others	Remain same	More than before	Less than before	Total
Hakimpur	0	3	59	8	70
Ranisankail	7	3	22	16	48
Atwari	10	13	27	145	195
Total	17	19	108	169	313
	Chi-Square = 130.162	DF = 6	P-Value = 0.000		

The respondent's opinion about the intensity of fog in Winter by Upazila shown in Table 7.9 shows an association between the two criteria. We set up the null hypothesis Ho: there is no association between Upazila and fog intensity in Winter. The estimated value of χ^2 =130.162 falls in the critical region [$\chi^2 > \chi^2$ 0.05(6) = 12.59] and thus we have reasonable evidence to conclude that the two criteria are not independent.

Table 7.10 Changes in Dew Intensity of Autumn

	Frequency	Percent
Decrease	234	74.8
Increase	34	10.9
Same	34	10.9
Irregular	5	1.6
Not happen	1	.3
Others	4	1.3
Don't know (9)	1	.3
Total	313	100.0

The respondents are questioned about the change in dew fallen in Autumn season, about 75 % respondents say that dew has decreased, 1% express that dew has increased, 11% inform that the dew is unchanged, 2% report that it is irregular that means some times it has increased and some times it has decreased and 0.3% mention that it does not occur at all. [Table 7.10, Figure 7.23]

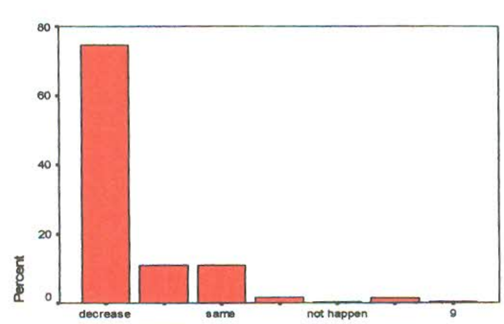


Figure 7.23 Changes in Intensity of Autumn dew

Table 7.11 Respondent's Opinion about Dew in Autumn by Upazila

Dew in Autumn / Upazila	Not reduced	Reduced	Total
Hakimpur	36	34	70
Ranisankail	27	21	48
Atwari	16	179	195
Total	79	234	313
	Chi-Square = 79.894	DF = 2	P-Value = 0.000

The cross classification of sample respondents of dew intensity in Autumn by Upazila and in Table 7.11 shows an association between the two criteria. We set up the null hypothesis Ho: there is no association between Upazila and dew in Autumn. The estimated value of χ^2 =79.894 falls in the critical region [$\chi^2 > \chi^2$ 0.05(2) = 5.99] and thus we have reasonable evidence to conclude that the two criteria are not independent.

Table 7.12 Respondent's Opinion about Intensity of Dew in Autumn and Fog in Winter

Dew in Autumn / Fog in Winter	Not reduced	Reduced	Total
others and irregular	5	12	17
Remain same	6	13	19
More than previous	55	53	108
Less than previous	13	156	169
Total	79	234	313
	Chi-Square = 65.902	DF = 3	P-Value = 0.000

The distribution of sample respondent's opinion regarding dew in Autumn and fog in Winter shown in Table 7.12 shows an association between the two criteria. We set up the null hypothesis Ho: there is no association between fog intensity in Winter and dew intensity in Autumn. The estimated value of χ^2 =65.902 falls in the critical region [$\chi^2 > \chi^2$ 0.05(3) = 7.81] and thus we have reasonable evidence to conclude that the two criteria are not independent.

Table 7.13 Changes in Characteristics of Autumn Due to Climate Change

	Frequency	Percent
Rain like rainy season	19	6.1
Moon light	52	16.6
Same as before	21	6.7
White cloud in sky	160	51.1
Others	22	7.0

When the respondents are questioned regarding the different changes in Autumn due to climate change, 51% respondents express that white cloud is seen in the sky, 16.6% support that moonlight is seen in the sky, 6% confirm that rain occur in Autumn season like the Rainy season, 7% say that it is same as before and 7% mention other comments. [Table 7.13]

Table 7.14 Changes in Spring Due to Climate Change

	Frequency	Percent
Feel cold at night	288	92
No existence of wind wave	304	97.1
Lower chirping of Cuckoo	262	83.7
Same as before	2	.6
Others	13	4.2

When the respondents are asked to state about the change of Spring season due to climate change, about 97% respondents confirm that strong wind speed of Choitra in Spring season is not observed like before, 92% respondents report that they feel cold at night of Choitra, about 84% say that the chirping of Cuckoo is very rare in the Spring, 0.6 % report that the Spring is same as before and about 4% express other comments about the Spring. [Table 7.14]

Table 7.15 Impact of Climate Change on Environment

	F for Yes	P for Yes
Pond/ canal dry due to climate change	281	89.8
Season become different due to climate change	291	93.0
More drought	259	82.7
More flood	166	53.0
More storm		14.1
Agricultural production hampers	107	34.2
Other impacts	14	4.5

F=frequency, P=Percent

The respondents are asked to express their opinion regarding the effect of climate change on environment and about 90% of the respondents mention that pond/Canal/Bill has become dried due to climate change, about 93% report that seasons play different role than before, about 83% report that the incidence of drought is more than previous, about 53% report that the flood is more than before, about 14% mention that the storm is also more than before. On the other hand 86% of the respondents report that the intensity of storm is less than it was before. About 34% mention that agricultural production is being hampered due to climate change and 5% said about other impacts. [Table 7.15]

When the respondents are asked whether the cropland, crop cultivation and crop production are affected by the climate change about 100% respondents reply in the affirmative.

Table 7.16 Nature of Impact on Crop Land, Cultivation and Production

	F for Yes	P for Yes
Not enough water for cultivation	309	98.7
Extra irrigation for cultivation	304	97.1
Wetness of crop land decreasing	279	89.1
Use of crop land changing	297	94.9
Productivity of crop land decreasing	101	32.3
No cultivation as per its calendar	75	24.0
No dense cultivation	78	24.9
No those kinds of crops grow as before	297	94.9
Per acre yield decreases	76	24.3
Other comments on crop land & production	18	5.8

*F=frequency, P=Percentage

When the respondents are asked about the type of impact occur due to change in climate about 99% of total respondents inform that water shortage has become problem for cultivation and it does not get properly in time. Ninety seven percent (97%) of total respondents report that irrigation is required more for crop cultivation, 89% report that wetness of cropland has decreased, 95% mention that the utilization of crop land has changed, 32% mention that the fertility of crop land has reduced, 24% mention that crop cultivation is not possible according to crop calendar, 25% report that dense cultivation of crop is not possible, 95% report that types of crop has changed at present, 24% opine that per acre yield has decreased and 6% of respondents opine the other views. [Table 7.16]

Table 7.17 Deeper Impact of Climate Change on Some Crops

	Aus	Amon	IRRI	Boro	Wheat	Sugarcane	Potato	Maize	Spring Harvest	Other crops
F	202	42	200	85	103	8	275	11	70	6
P	64.5	13.4	63.9	27.2	32.9	2.6	87.9	3.5	22.4	1.9

*F=Frequency, P=Percentage

When the respondents are questioned to express their views regarding the deeper impact on different crops due to climate change, about 65% of total respondents report about Aus, about 13% of total respondents report about Aman, 64% of total respondents about IRRI, 27% report about wheat, about 3% report about sugarcane, about 88% report about potato, 4% report about Maize, 12% report about Rabi crop and about 2% report about other crops [Table 7.17].

Table 7.18 Impact of Climate Change on Wheat Cultivation and Production

Production	F	P	Pest	F	P	Irrigation	F	P	Sowing time	F	P	Land	F	Percent
Decreased	264	84.3	Decreased	14	4.5	More	237	75.7	Changing	90	28.8	Decreased	292	93.3
Increased	37	11.8	Increased	278	88.8	Less	29	9.3	Unchanged	212	67.7	Increased	9	2.9
Unchanged	3	1.0	Unchanged	3	1.0	Same	38	12.1	Others	10	3.2	Unchanged	5	1.6
Others	9	2.9	Others	18	5.8	Others	9	2.9	Don't know	1	.3	Irrigular	6	1.9
Total	313	100.0	Total	313	100.0	Total	313	100.0	Total	313	100.0	Don't know	1	.3
												Total	313	100.0

*F=Frequency, P=Percent

Table 7.18 represents the impact of climate change on wheat cultivation and production. When the respondents are asked about the impact of climate change on wheat production in Dinajpur district, 84% respondents report that the wheat production has decreased, 11.8% report that it has increased and 1% report that it is unchanged. The respondents are asked about the pest on wheat field due to climate change, about 89% respondent report that it has increased, 5% said that it has decreased, 1% say that it is unchanged and 6% express other views. When the respondents are questioned about the change of irrigation requirement for wheat field due to climate change, 76% of total respondents report that irrigation requirement has increased on wheat field, 9% confirm that irrigation requirement has decreased, 12% say that irrigation requirement is unchanged and about 3% express other comments. When the respondents are asked about the effect of climate change on sowing time of wheat seed, 68 % or total respondents say that the sowing time of wheat seed has unchanged, 29% say that it has changed and 3% express other comments. When the respondents are asked about the change of land under wheat production due to climate change, about 94% of total respondents express that the land under wheat production has decreased, about 3% say that it has increased, about 2% express other comments about the land under wheat cultivation.

Table 7.19 Adverse Impact on Wheat Production Due to Climate Change

	F for Yes	P for Yes
Reaping and sowing of wheat delayed due to change of Rainy season	296	94.6
Disease increase in wheat field due to thick fog and lack of sunlight	126	40.3
Wheat loss due to wetness of soil, downing of water layer, change in temperature	156	49.8
Problem due to excessive rain after threshing of wheat	265	84.7
Other comments on damage in wheat production	15	4.8

*F=Frequency, P=Percent

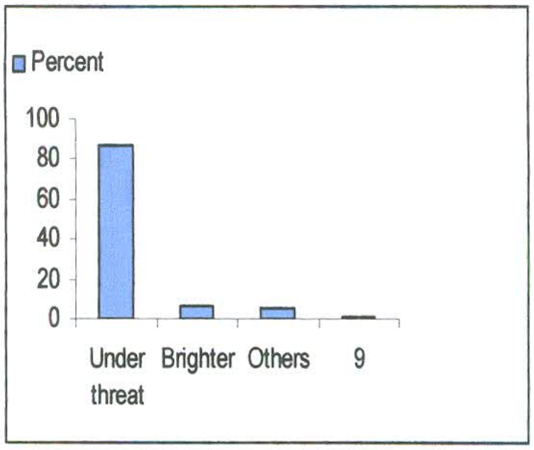


Figure 7.24 Future of wheat production due to climate change

The cross classification of sample respondents by future prospect of wheat and Upazila is shown in Appendix [Table A.7.5] shows an association between the two criteria. We set up the null hypothesis Ho: There is no association between future prospect of wheat and upazila. Since the calculated value of χ^2 =26.979 is greater than the tabulated value of χ^2 0.05(4) = 9.49 and it is significant, we can reject the null hypothesis and conclude that Upazila is related to future wheat production.

7.2.3 Casc Study

Case 1

Md Akram Khan, age 100+, inhabitant of the Mauza Chotachenggram of Hakimpur Upazila observes no drops of rainfall in the month of Choitra in the previous day and he also mention that the month of Choitra of that time was as like as the firing Ulka. The very hot and strongest windy days were experienced in that Choitra when a lot of green mangos in the trees and Cuckoo birds were also found by him. Moreover, he mention that even the green leaves of trees have broken down with the shocking and pressure of wind flaw and the cattle ate that broken leaves. Recalling his early age, he utters a proverb about Mango "*Maghe Mul, Falgune guti, Chotre katikuti, Boishakhe Ati, joishthe Chusi'*. Then soil is cracked creating a big gap in field in the month of Joistha and a big portion of cracked soil is found on the spade at a time in his boyhood. In previous Rainy season, immense black and dark cloud were gathered on the North-West

Corner and hearing the sound 'gur gur' of this cloud. People were feared and a very big ear bursting drops of rain and a very high speed man turning wind flaw they are experienced. Some times, that type of rain scattered everything and man turned himself in the field and people took shelter into the Mosque for safety leaving their house to escape from that excessive disrupting rain and flood. In the month Bhadro and Aswin immense dew were observed by Akram Khan and in the month of Aswin and Kartik he experienced rain with wind called "Satah" and about this he auttured a proverb" Sonir satah sat din, Budher satah tin din, r joto satah hobe din ka din." He never experienced Winter rain and fog in the early age and opposite scenario is observing at present according to him.

Case 2

Mr. Ummedul Islam, Durra, Upazilla of Hakimpur, Dinajpur said that cultivation of Boro is most responsible factor for decreased wheat cultivation in Dinajpur district where drainage system for irrigation badly affect the wheat lands by their water. Besides this electricity shortage for irrigation, necessity of excessive insecticide, requirement of excessive money for herbicide, requirement of excess labor are also responsible for wheat cultivation. He mentioned that per acre yield for Hybrid Boro is 50-60maund while wheat grows 12-21maund. Further he mentions that planting of Boro continues from 15 Poush or end of Poush to 15 Magh. He also comment that if we complete every process from all sides and sowing is done in proper time in plain fallow land yet wheat is not possible as the previous time (20 years ago). In the previous time 15 Kartik experienced Winter and it continued upto 15 Falgun while at present time it starts from 15 Agrahayan and continues till the end of Choitra and this was not possible in the previous period, according to Mr. Ummedul.

"Jodi Magher mogore hoy ban, tahole ale tikore hoy dhan" that is, the rain on the 1st week of Magh was very fruitful for growing rice crop and that rain is absent in present days. Fruits get damaged if the rain comes at the first stage or middle stage or last stage of Falgun. When the rain comes late it causes damage to buds of mango, Sajinas, Lichis, Jackfruits etc. Wet soil, the outcome of cultivation of Boro, causes harm to the production of wheat because wheat needs dry soil. Cultivation of Boro crop is done through artificial irrigation system and water from the drains has a tendency to flow towards the lands where wheat is cultivated. This flow of water causes death to the young plants of wheat. So cultivation of wheat in those areas has been completely impossible. That rain is shifted in the first, middle or in the last Falgun that causes the fruit damage. As for example he further mentioned about the fallen and damaged buds of mango, damaged Sajinas, Litchis, Jackfruits etc. He thinks drought-less situation is an artificial problem and it occurs due to cultivation of the Boro crop in the whole Bangladesh. According to him Norwester comes from the corner of Isan but at present it is not found regularly and its presence is very scanty. Katari (continuous rainfall for some days) was observed in the later period of Kartik to first period of Agrahayan but it is not regular now.

Case 3

Wheat cultivator Md. Insan Ali, said that the acreage under wheat cultivation have been decreasing due to climate change. Wheat cultivators opined that they are not getting enough cold in Spacial analysis what is necessary for wheat sowing. They also opine that Winter comes late at present. Now-a-days it starts in the month of Magh but it was started in the month of Agrahayan in the previous days.

7.3 Conclusion

Hundred percent (100%) respondents have opined in favor of climate change in Dinajpur District and 90% people mention that amount of rainfall in Rainy season has become insufficient than it was before. Coldness in Winter has become lesser than before what is opined by 73% people and Temperature in Summer has fallen than before that is experienced by 69% people. In Autumn, dew is not seen as it was seen before which is the opinion of 75% people. Spring does not behave as it behaved earlier. Cold affects people at night in the month of Choitra and 92% people feel like that. Stormy and dusty wind does not blow as it blew before and 97% people say it expressing their views. Cuckoo is not found and some times keeps silent and it is the opinion of 84% respondents. The changing behavior of climate has severely affected the crops, productive land and total process of production as a whole and it is about 100% people to speak. Sometimes, Winter brings unusual warmness for people and it is the opinion of 36% people. Due to the cruel behavior of climate wheat production has suffered a lot and it is 84% of people to speak. Change of temperature is affecting the production of wheat greatly-it was the opinion of 65% of people. They held it to be the most potential reason. Changing of climate may pose a big and devastating threat to the production of wheat. 88% people are in fear, lest the cultivation of wheat in future may be threatened.

Chapter 8

Chapter 8

Summary Results and Scope of Further Research

8.1 Summary Results

This thesis is designed to study the climatic change and its impact on wheat production in Dinajpur district. Historical climatic and wheat acreage and production data from 1948 to 2004 have been taken into consideration for the study. Because, wheat is the 2nd staple food of Bangladesh and Dinajpur is the highest wheat growing area in Bangladesh. A lot of studies have been made by taking the variables of rainfall and temperature in global and local levels but few studies are found in the literature by taking into consideration the other climatic variables directly. We have already studied twenty (20) climatic variables such as TR, TFIR, MXR, AMXT, AMNT, ARNT, ADBT, AWBT, AT (D-W), AC, ARH, ARH(0), ARH(12), ARH(0-12), AMWS, AWS and ASLP during the period 1948-2004 and the ASH (1989-2004), AE (1987-2000) and AST (1987-2000). Both the secondary and primary data are used in this research to draw a valid and complete conclusion. We have got a great missing in the climatic data for the years 1973-1980 and the missing values are replaced by medians estimated in chapter 4 and by forecasted values obtained from the well fitted ARIMA models shown in chapter 5. We have conducted exploratory analysis to investigate the trend and variability pattern for decadal, annual, seasonal and monthly aspects. To check the stationarity for the residuals of the climatic trends we use Box-Pierce test statistic and use RM (Rescaled moment) normality test statistic for checking their normality. The time series properties for the monthly climatic data are also investigated by using univariate Box-Jenkins modeling techniques. We have developed a new piecewise autoregressive model PAR (1) for the wheat production data during 1949-2001, as suggested by Imon (2007). For measuring the impact of climatic change on wheat production, we have tried to fit the multiple regression model of the wheat production data on the climatic variables. An opinion survey has been conducted to understand the people's perception about the climatic change and its impact on wheat production.

Exploratory Analysis for Climatic Variables

The climate data for average soil temperature (AST), average sunshine hour (ASH) and average evaporation (AE) are collected for the period of 1987-2004, 1987-2004 and 1989-2000, respectively. We observe that the mean of total rainfall (TR) is 1636.9mm and its coefficient of variation (cv) is 43.69%, mean of average cloud(AC) is 2.87octas and its cv is 13.8%, mean of average wind speed (AWS) is 1.18knots and its cv is 54.28%, mean of average maximum wind speed (AMWS) is 5.81knots and its cv is 45.23%, mean of average relative humidity (ARH) is 74.9% and its cv is 4.53%, mean of average relative humidity for morning (ARH(0)) is 90.36% and its cv is 2.96%, mean of average relative humidity for evening (ARH(12)) is 67.32% and its cv is 5.52%, mean of average difference of relative humidity for morning and evening (ARH(0-12) is 23.03% and its cv is 6.82%, mean of average evaporation(AE) is 34.98% and its cv is 10.16%, mean of average dry bulb temperature (ADBT) is 24.87^{0}C and its cv is 1.93%, mean of average minimum temperature (AMNT) is 19.71^{0}C and its cv is 3.15%, mean of average maximum temperature (AMXT) is 30.4^{0}C and its cv is 2.03%, mean of average range temperature (ARNT) is 10.69^{0}C and its cv is 7.82%, mean of average difference of dry bulb and wet bulb temperature (AT(D-W)) is 3.23^{0}C and its cv is 16.44%, mean of average wet bulb temperature (AWBT) is 21.64^{0}c and its cv is 2.203%, mean of average soil temperature at the depth of 5 cm (AST(5)) is 25.90^{0}C and its cv is 1.57% and mean of average sunshine hour (ASH) is 6.46 and its cv is 4.82% mean of average sea level pressure (ASLP) is 1007.5mb and its cv is 0.0596%.

During the wheat growing period (Nov-Mar), the mean for the climatic variables of TR, AC, AMXT, AMNT, ARNT, ADBT, AWBT, AT (D-W), AST(5), ARH, ARH(12), ARH(0), ARH(0-12), AMWS, AWS, ASLP, AE and ASH are 42.25mm, 0.938octas, 27.6^{0}C, 13.6^{0}C, 14^{0}C, 20.1^{0}C, 16.5^{0}C, 3.6^{0}C, 20.4^{0}C, 70.02%, 60.19%, 89.62%, 29.42%, 5.018knots, 0.872 knots, 1013mb, 27.54% and 7.319 respectively. The coefficient of variations of those variables are 94.49%, 38.7%, 2.94%, 4.71%, 7.37%, 3.9%, 3.89%, 17.8%, 3%, 6.458%, 9.903%, 4.038%, 10.65%, 56.16%, 80.37%, 0.049%, 0.049% and 6.79% respectively.

Annual TR, AMNT, AWBT, AWS, AMWS, ARH, ARH(0), ARH(12), AC and AST show upward trend. Annual FZR, TFIR, AMXT, ARNT, AT(D-W), ARH(0-12), AE and ASH follow downward trend. Annual ADBT and ASLP do not show any trend. CV of annual AMXT and FZR demonstrate upward trend but CV of annual TR, ARH, AC, AWS, AMWS, AWBT, ARNT, AMNT, AE, ARH(12), ARH(0), AT(D-W) indicate downward trend. Slight upward trend is observed in CV of annual ASH and slight downward trend is found in CV of annual ADBT and AST(5cm). Very very slight downward trend is identified in CV of annual ASLP and ARH(0-12). CV of annual TR, AWS and AMWS are not computable.

In Kharif season, TR, AC, AMWS, AWS, AST, AWBT, ADBT and ARH(0-12) demonstrate upward trend. Downward trend is observed in Kharif AMXT, ARNT, AT(D-W), ARH, AE and ASH. Kharif ASLP show very slight upward trend but Kharif AMNT does not show any trend. CV of Kharif ADBT and FZR show upward trend. CV of Kharif AMXT and AST follow slight upward trend. Very very slight upward trend is observed in CV of Kharif AMNT and AWBT. CV of Kharif AC, AWS and AMWS indicate downward trend. Slight downward trend is indicated in CV of Kharif AE. CV of Kharif ARNT and ARH(0-12) show very very slight downward trend but CV of Kharif ARH, ASLP, ASH, ARH(0), ARH(12) and AT(D-W) do not show any trend.

In Prekharif season, TR, AC, AMWS, AWS, AST, AWBT and ARH show upward trend. Prekharif AE, ASH, AMXT, ARNT, AT(D-W), ADBT and ARH(0-12) show downward trend. Prekharif AMNT shows very slight upward trend but Prekharif ASLP does not show any trend. CV of Prekharif AMWS and FZR follow upward trend. CV of Prekharif AMXT and AST show slight upward trend. CV of Prekharif ARH, AC, AWS, AWBT, AMNT, AE, ARH(0), ARH(12) show downward trend. CV of ARNT and AT(D-W) indicate slight downward trend. CV of Prekharif ADBT, ASH and ARH(0-12) do not show any trend. Very slight downward trend is observed in Prekharif CV of ASLP.

In Rabi season, TR, AC, AMWS, AWS, AST, AWBT, ARH, AMNT and ADBT show upward trend and AE, ASH, AMXT, ARNT, AT(D-W), ASLP, ARH(0-12) show downward trend. CV of ADBT, AWBT, AMXT, FZR, ASH, AST and ARH(0-12) show upward trend in Rabi season. CV of Rabi AE show slight upward trend and CV of Rabi AMNT show very very slight upward trend. During Rabi season, CV of ARH, ARH(0) and AC show downward trend, CV of ASLP show very slight downward trend (VSD) and very very slight downward trend is indicated in CV of ARNT, ARH(12) and AT(D-W). CV of Rabi TR, AWS and AMWS are not computable.

In wheat growing period(Nov-Mar), TR, MXR, ADBT, FADBTT, AMNT, AWBT and ARH show upward trend. AMXT, ARNT, AFIR, AT(D-W), ARH(0-12), ASLP and AMWS show downward trend. CV of ASLP, AWBT, AMXT, ASH, AST, AE, FZR and ARH(0-12) show upward trend. CV of ARH, AC, AWS, AMWS, ARNT, ARH(0) and AT(D-W) show downward trend. CV of ARH(12) show slight downward trend but CV of ADBT, AMNT do not show any trend.

The upward trends are observed for the averages and downward trends are observed for variations of the monthly data of TR, AC, ARH, ARH(0), ARH(12), AWBT, AWS, AMWS. The average of AMNT shows slight upward trend and the variation of AMNT show downward trend also. Both the variations and averages follow downward trend for the monthly data of AT(D-W), ARH(0-12), AE and ARNT. The monthly averages of AMXT and ASH indicate downward trend but their variations indicate upward trend [in respect of nonrobust measurement].

We observe upward trend for the monthly minimum data of the variables of ARH, ARH(12), ARH(0), AWBT, AWS AMWS and ARH(0-12). Very slight upward trends are observed for the minimum values of AMNT and ASLP. Downward trends are found for the minimum AT(D-W), AE and AMXT. The minimum values for monthly ADBT indicate very slight downward trend. But the minimum ARNT and ASH do not indicate any trend.

The 1st quartiles for the monthly data of the variables of TR, AC, ARH, ARH(12), ARH(0), AWBT, AWS, AMWS and AMNT indicate upward trend. Slight upward trend is also indicated for the 1st quartiles of monthly ADBT. The 1st quartiles for ARH(0-12), AT(D-W), AE and AMXT indicate downward trend. Slight downward trend is observed for the 1st quartiles of ASH. No trend is observed for the 1st quartiles of ASLP and ARNT.

Very slight upward trends are observed for the maximum values of the monthly data of TR, AC, AWBT, AWS, AMWS and AMNT. The maximum ARH does not follow any trend but upward trends are observed in the maximum ARH(12) and ARH(0).The maximum values of monthly AT(D-W), AE, ARH(0-12), AMXT, ARNT and ASH indicate downward trend. The slight downward trends are observed in the maximum values of ADBT and ASLP also.

We observe upward trend for the 3rd quartiles of monthly TR, AC, ARH(12), ARH(0) and AMWS. Slight upward trends are observed for the 3rd quartiles of ARH, AWBT and AWS but the 3rd quartile of AMNT does not show any trend. The 3rd quartiles of AT(D-W), AE, ARH(0-12), ARNT and AMXT show downward trend. ADBT, ASLP and ASH also show very slight downward trend.

During wheat growing period the variables TR, MXR, ADBT, FADBTT (average frequency for greater than 20^{0}c average dry bulb temperature), AMNT, AWBT and ARH show upward trend. The variables AMXT, ARNT, AFIR (average frequency for less than 5mm rain which is insignificant from agricultural viewpoint), AT(D-W), ARH(0-12), ASLP and AMWS show downward trend.

Annual TR of Dinajpur shows upward trend but it's CV shows downward trend. Annual TR of Dhaka, Khulna and Sylhet(slight) shows upward trend but no trend is found in Rajshahi, Barisal and Chittagong. Downward trend is observed in CV of annual TR in Dhaka, Khulna(slight) and Sylhet(very slight) but very slight upward trend is observed in Rajshahi and no trend is found in Barisal and Chittagong.

Annual average AMNT of Dinajpur shows slight upward trend and it's cv shows downward trend. Annual average AMNT shows upward trend in Dhaka, Rajshahi(very very slight), Sylhet and Chittagong but it shows downward trend in Khulna and Barisal. CV of Annual average AMNT shows downward trend in Dhaka, Sylhet and Chittagong(slight) and upward trend in Rajshahi, Khulna and Barisal.

Annual average AMXT of Dinajpur shows downward trend and it's cv shows upward trend. Annual average AMXT shows downward trend in Rajshahi and upward trend is in Dhaka, Khulna(slight), Barisal, Sylhet and Chittagong. CV of annual average AMXT shows upward trend in Khulna and downward trend in Dhaka, Rajshahi, Barisal, Sylhet and Chittagong(very slight).

Annual ARNT and its cv of Dinajpur shows downward trend. Annual ARNT show downward trend in Dhaka and Rajshahi but it shows upward trend in Khulna, Barisal, Sylhet and Chittagong. CV of annual ARNT shows downward trend in all the six divisional stations.

Annual average ARH of Dinajpur shows upward trend and it's cv shows downward trend Annual average ARH also show upward trend in Rajshahi, Khulna, Barisal and Sylhet and downward trend in Dhaka and Chittagong. CV of annual average ARH show downward trend in six divisional stations.

Annual Average ASH of Dinajpur shows downward trend and it's cv shows upward trend. Annual Average ASH show downward trend in six divisional stations and it's cv show upward trend in Dhaka and Barisal, slight downward trend in Rajshahi and Khulna but it does not show any trend in Sylhet and Chittagong.

Time Series Properties of Climatic and Wheat Production Data

ARIMA models are fitted for the monthly data (1948-2004) of 17 climatic variables and forecasted the data for the period of 2005-2008. Again we have fitted the ARIMA models taking the monthly data for the period of 1948-2008 and forecasted the values of the variables during the years 2009-2012. The monthly missing data are forecasted for the years 1973-1976 and 1977-1980 from the well fitted ARIMA models with the data during 1948-1972 and 1981-2004 respectively. The observations for the years 1981 are detected as outliers for the variables ARH, AMNT, ARNT and AWS. The fitted models for the period of 1948-2004 (including the required transformations) are given below:

SQRT of TR (1948-2004) – ARIMA (100) (111)
TFIR (1948-2004) -ARIMA (111) (011)
SQRT of MXR (1948-2004) –ARIMA (100) (111)
ARH (1948-2004) [Box-Cox transformation of power 3] -ARIMA (111) (011)
AC (1948-2004) -ARIMA (011) (111)
SQRT of AWS (1948-2004) -ARIMA (111) (011)
SQRT of AMWS (1948-2004) – ARIMA (011) (101)
Ln of ARH (0-12) (1948-2004) - ARIMA (200) (101)
AE (1987-2000) -ARIMA (112) (111)
SQRT of AMXT (1948-2004) -ARIMA (100) (011)
AMNT (1948-2004) -ARIMA (101) (111)
ARNT (1948-2004) -ARIMA (100) (011)
ADBT (1948-2004) - ARIMA (011) (101)
AWBT (1948-2004) -ARIMA (101) (111)
Ln of AT (D-W) (1948-2004) -ARIMA (101) (101)
ASH (1989-2004) -ARIMA (111) (111)
ASLP (1948-2004) –ARIMA (011) (101)

The production of wheat during 1949-2001 in the Dinajpur district primarily follow upward linear trend whose residuals are departed from normality but support non-autocorrelated structure and one outlier is identified in 1982. We have got an opposite conclusions for outlier corrected data obtained from BBS. Structural change is found in 1976 and the data during 1949 to 1975 and 1976 to 2001 separately follow AR (1) models but the autoregressive structure is lost when they are combined together. The corrected data set during 1949-2001 adequately fits the 1^{st} order Piecewise Autoregressive Model PAR(1) but the data during 1948-2004 do not adequately fit PAR(1) model.

Impact of Climate Change on Wheat Production

In order to quantify the impact of climatic change on wheat production in Dinajpur district we have built up three multiple regression models taking several climatic variables during wheat growing period (Nov-Mar) including a dummy variable. Dummy variable is taken for the structural change of wheat production data in 1976. One model among the three models is selected based on the highest F and R^2. Significant t values only are observed for the coefficient of dummy (dm*) variable. The coefficients of dm*, tmn*, td*, ttr* tmx* ac* are 50.58, 2.62, -2.58, 0.0312, -1.22 and -3.58 respectively and the corresponding t values are 12.39, 1.5, 1.55, 1.63, 0.87 and 0.99 in absolute term. The t values are less than one for the coefficient of tmx* and ac*. So, according to the results of the model, it may be reported that one percent increase in tmn increases the yield rate by about 2.62%, one percent increase in td decreases the yield rate by about 2.58%, one percent increase in ttr increases the yield rate by about 0.03%, one percent increase in tmx reduces the yield rate by about 1.22% and one percent increase in dm increases the yield rate by about 50%. Though we did not get any significant effect of climatic variables on wheat production in Dinajpur district at the 5% level of significance, the improved technology such as high yielding variety, irrigation system and other physical inputs may contribute positively to the wheat production and yield rate.

People's Perception about Climate Change and Wheat Production in Dinajpur District

People's perception is that the amount of rainfall in Rainy season has become insufficient (opinion of 90% respondents), coldness in winter has become lesser (73%), that temperature has fallen (69%) in summer, dew is not seen in Autumn as before (75%), Spring does not behave as it behaved earlier, cold affects people at night in the month of Choitra (92%), stormy and dusty wind does not blow as it blew before (97%) and Cuckoo is not found and some times keeps silent (84%). Sometimes, winter brings warmness for people which is unusual (36%).100% people express that the changing behavior of climate has severely affected the crops, productivity of land and total process of production as a whole. Due to the unusual behavior of climate wheat production has suffered a lot (84%). Change of temperature is affecting the production of wheat greatly (65%) and it is the most potential reason by their opinion. Changing of climate may pose a big and devastating threat to the production of wheat. 88% people are in fear, lest the cultivation of wheat in future should get stopped.

8.2 Scope of Further Research

Countrywide study is needed for the climatic and crop production variables, particularly in developing countries like Bangladesh where food insecurity is acute and where climate change may affect adversely on crop productivity. Long term control experiment is essential to understand the impact of climate change on production.

Appendix

Appendix

Table A.4.1 Trend for Annual Climatic Data during 1948-2012 (IFP)

Variable	Trend Equation	Variable	Trend Equation
TR	Yt = 1531.70 + 9.27451*t (u)	ADBT	Yt = 24.9665 - 8.71E-03*t (d)
AMWS	Yt = 58.8516 + 0.359717*t (u)	AMXT	Yt = 31.0413 - 2.22E-02*t (d)
TMXR	Yt = 458.458 + 3.02527*t (u)	AMNT	Yt = 19.4657 + 9.54E-03*t (u)
TFIR	Yt = 312.900 - 0.383769*t (d)	ARNT	Yt = 11.8889 - 3.31E-02*t (d)
AC	Yt = 2.34870 + 1.93E-02*t (u)	AWBT	Yt = 21.1552 + 1.70E-02*t (u)
AWS	Yt = 0.772019 + 1.22E-02*t (u)	ARH	Yt = 70.0670 + 0.148212*t (u)

IFP-Including forecasted period

Table A.4.2 Trend for Seasonal TR, AMWS, MXR, TFIR, AC and AWS during 1948-2012 (IFP)

Variable	Trend Equation for Kharif Season	Trend Equation for Prekharif Season	Trend Equation for Rabi Season
TR	Yt = 1339.01 + 6.87214*t (u)	Yt = 176.911 + 1.97968*t (u)	Yt = 15.7833 + 0.422682*t (u)
AMWS	Yt = 28.5639 + 2.51E-02*t (n)	Yt = 19.0476 + 0.155564*t (u)	Yt = 11.2400 + 0.179062*t (u)
MXR	Yt = 373.076 + 2.37126*t (u)	Yt = 73.8230 + 0.377504*t (u)	Yt = 11.5580 + 0.276533*t (u)
TFIR	Yt = 106.907 - 0.167317*t (d)	Yt = 85.3018 - 0.131314*t (d)	Yt = 120.691 - 8.51E-02*t (d)
AC	Yt = 4.35138 + 1.68E-02*t (u)	Yt = 1.58032 + 2.65E-02*t (u)	Yt = 0.415952 + 1.71E-02*t (u)
AWS	Yt = 0.895918 + 1.09E-02*t (u)	Yt = 1.32090 + 1.00E-02*t (u)	Yt = 0.206822 + 1.54E-02*t (u)

IFP-Including forecasted period

Table A.4.3 Trend for Seasonal ADBT, AMXT, AMNT, ARNT, AWBT and ARH during 1948-2012 (IFP)

Variable	Trend equation for Kharif Season	Trend equation for Prekharif Season	Trend equation for Rabi Season
ADBT	Yt = 28.0537 - 6.68E-04*t (n)	Yt = 27.9381 - 3.33E-02*t (d)	Yt = 18.8772 - 2.28E-04*t (n)
AMXT	Yt = 31.9341 - 3.24E-03*t (n)	Yt = 34.4963 - 4.60E-02*t (d)	Yt = 27.3323 - 2.79E-02*t (d)
AMNT	Yt = 24.7724 + 5.45E-03*t (u)	Yt = 20.2657 + 8.09E-03*t (u)	Yt = 12.2373 + 1.56E-02*t (u)
ARNT	Yt = 7.38669 - 7.37E-03*t (sd)	Yt = 14.6304 - 5.70E-02*t (d)	Yt = 15.4611 - 4.72E-02*t (d)
AWBT	Yt = 25.7999 + 1.02E-02*t (u)	Yt = 21.1421 + 2.18E-02*t (u)	Yt = 15.3535 + 2.20E-02*t (u)
ARH	Yt = 82.0799 + 4.36E-02*t (u)	Yt = 53.1551 + 0.299017*t (u)	Yt = 67.7358 + 0.165815*t (u)

IFP-Including forecasted period

Table A.4.4 Trend for Annual and Seasonal ARH (0), ARH (12) and ARH (0-12) during 1948-2004

Period	Trend of ARH(0)	RS	RN	Trend of ARH(12)	RS	RN	Trend of ARH(0-12)	RS	RN
Annual	Yt = 86.5598 + 0.131049*t	NS	N	Yt = 62.2395 + 0.175336*t	S	N	Yt = 24.3209 - 4.43E-02*t	S	N
Prekharif	Yt = 76.9852 + 0.218870*t	S	N	Yt = 43.4218 + 0.270990*t	S	N	Yt = 33.5650 - 5.21E-02*t	S	N
Kharif	Yt = 91.8698 + 5.52E-02*t	S	NN	Yt = 77.9915 + 3.29E-02*t	S	NN	Yt = 13.8769 + 2.24E-02*t	S	NN
Rabi	Yt = 87.1017 + 0.159997*t	NS	N	Yt = 56.6645 + 0.281642*t	S	N	Yt = 30.4392 - 0.121696*t	NS	N
Wp	Yt = 84.5412 + 0.174949*t	NS	N	Yt = 52.0366 + 0.281304*t	S	NN	Yt = 32.5047 - 0.106345*t	NS	NN

RN-Residual's Normality RS-Residual's Stationarity S-Stationary NS –Nonstationary NN-Nonnormal, N-Normal

Table A.4.5 Detected Outliers and the Respective Year for Extreme Outliers in Monthly TR, AC, AMWS and AWS

Month	TR		AC		AMWS		AWS	
	DO	RYEO	DO	RYEO	DO	RYEO	DO	RYEO
Jan	(HI: 33, 42, 42, 46, 85) Leaf Unit = 1.0	HI: 85 -1957	(HI: 26, 28) Leaf Unit = 0.10	HI: 28 - 1981	-	-	(HI: 54) Leaf Unit = 0.10	HI: 54 - 1981
Feb	(HI: 170, 180, 220, 270, 300, 380, 470, 520) Leaf Unit =0.10	HI: 520 - 1949	(HI: 24) Leaf Unit = 0.10	HI: 24 -1990	-	-	(HI: 49) Leaf Unit = 0.10	HI: 49 -1981
Mar	(HI: 41, 52, 53, 69, 70, 86, 151) Leaf Unit = 1.0	HI: 151 - 1967	(LO: 2 and HI: 23, 23, 25) Leaf Unit = 0.10	LO: 2 - 1954 HI: 25 - 2003	(HI: 25) Leaf Unit = 1.0	HI: 25 - 1992	(HI: 69 Leaf Unit = 0.10	HI: 49 - 1981
Apr	-	-	(HI: 45, 51) Leaf Unit = 0.10	HI: 51 - 2004	(HI: 180, 400) Leaf Unit = 0.10	HI: 400 - 1990	(HI: 62) Leaf Unit = 0.10	HI: 62 - 1981
May	(HI: 59) Leaf Unit = 10	HI: 59 - 1981	-	-	(HI: 130, 150, 150, 200, 250) Leaf Unit = 0.10	HI: 250 - 1992	(HI: 47) Leaf Unit = 0.10	HI: 47 - 1981
Jun	(HI: 105) Leaf Unit = 10	HI: 105 - 1965	(LO: 40, 41) Leaf Unit = 0.10	LO: 40 - 1958	(HI: 150, 150) Leaf Unit = 0.10	HI: 150 (2) - 1982, 1992	(HI: 30, 50) Leaf Unit = 0.10	HI: 50 -1981
Jul	(HI: 119) Leaf Unit = 10	HI: 119 - 1987	(LO: 48, 49, 49, 49 and HI: 70, 71) Leaf Unit = 0.10	LO: 48 - 1961 HI: 71 - 1987	(HI: 200) Leaf Unit = 0.10	HI: 200 - 1966	(HI: 58) Leaf Unit = 0.10	HI: 58 - 1981
Aug	(HI: 71, 79, 84) Leaf Unit = 10	HI: 84 - 1988	-	-	(HI: 200, 210) Leaf Unit = 0.10	HI: 210 - 1982	(HI: 30) Leaf Unit = 0.10	HI: 30 - 1981
Sep	(HI: 74, 102) Leaf Unit = 10	HI: 102 - 1995	-	-	(HI: 200, 260, 280) Leaf Unit = 0.10	HI: 280 - 1986	(HI: 28) Leaf Unit = 0.10	HI: 28 - 1986
Oct	-	-	-	-	(HI: 180, 200, 210) Leaf Unit = 0.10	HI: 210 - 1948	(HI: 250) Leaf Unit = 0.010	HI: 250 - 1990
Nov	(HI: 220, 240, 260, 290, 390, 530, 560, 740) Leaf Unit =0.10	HI: 740 - 1995	(HI: 23, 28) Leaf Unit = 0.10	HI: 28 -1948	(HI: 90, 100) Leaf Unit = 0.10	HI: 100 -1988	(HI: 200, 220) Leaf Unit = 0.010	HI: 220 - 1988
Dec	(HI: 70, 260, 290, 320, 360, 370, 440, 440, 530) Leaf Unit = 0.10	HI: 530 - 2001	(HI: 200, 260) Leaf Unit = 0.010	HI: 260 - 1997	(HI: 80, 90, 100, 100, 210, 210, 230) Leaf Unit = 0.10	HI: 230 - 1981	(HI: 190) Leaf Unit = 0.010	HI: 190 - 1991

DO-Detected outliers *RYEO-Respective years for extreme outliers

Table A.4.6 Detected Outliers and the Respective Year for Extreme Outliers in Monthly ARH, AWBT, ADBT and ASLP

Month	ARH		AWBT		ADBT		ASLP	
	DO	RYEO	DO	RYEO	DO	RYEO	DO	RYEO
Jan	-	-	(HI: 165) Leaf Unit = 0.10	HI: 165 - 1981	(LO: 132 and HI: 189, 189, 192, 192) Leaf Unit = 0.10	LO: 132 - 2003, HI: 192(2) - 1948, 1982	-	-
Feb	-	-	-	-	(HI: 222, 223) Leaf Unit = 0.10	HI: 223- 1987	(HI: 10148, 10150) Leaf Unit = 0.10	HI: 10150 - 1987
Mar	-	-	(HI: 214) Leaf Unit = 0.10	HI: 214 - 2004	(LO: 212 and HI: 273) Leaf Unit = 0.10	LO: 212 – 1981, HI: 273 - 1985	(LO: 10055, 10067 and HI: 10117) Leaf Unit = 0.10	LO: 10055 – 1999, HI: 10117 - 1954
Apr	-	-	(LO: 186, 192, 195, 197, 198, 198, 201, 203 and HI: 251) Leaf Unit = 0.10	LO: 186 - 1981, HI: 251 - 1999	(LO: 235 and HI: 321) Leaf Unit = 0.10	LO: 235 – 1981, HI: 321 - 1966	(LO: 9894, 10032, 10035, 10040 and HI: 10091, 10094) Leaf Unit = 0.10	LO: 9894 – 1948, HI: 10094 - 1997
May	(LO: 50, 57, 57) Leaf Unit = 1.0	LO: 50 - 1957	(LO: 188) Leaf Unit = 0.10	LO: 188 - 1981	(LO: 245 and HI: 311, 311, 324) Leaf Unit = 0.10	LO: 245 – 1981, HI: 324- 1957	(HI: 10061) Leaf Unit = 0.10	HI: 10061- 1987
Jun	(LO: 500) Leaf Unit = 0.10	LO: 500 - 1981	(LO: 1920, 2550, 2550, 2570, 2580, 2580, 2580 and HI: 2710, 2710, 2720, 2720, 2730, 2730, 2750, 2770) Leaf Unit = 0.010	LO: 1920 – 1981, HI: 2770 - 1998	(LO: 260 and HI: 302, 304) Leaf Unit = 0.10	LO: 260- 1981, HI: 304 - 1983	(LO: 9968, 9972) Leaf Unit = 0.10	LO: 9968 - 1984
Jul	(LO: 596, 805) Leaf Unit = 0.10	LO: 596 - 1981	(LO: 2160) Leaf Unit = 0.010	LO: 2160 - 1981	-	-	(LO: 9785 and HI: 10024) Leaf Unit = 0.10	LO: 9785 - 1959, HI: 10024- 1951
Aug	-	-	(LO: 2600, 2600) Leaf Unit = 0.010	LO: 2600 (2) - 1950, 1971	(LO: 274, 275) Leaf Unit = 0.10	LO: 274 - 1950	(LO: 9981, 9989 and HI: 10033, 10033) Leaf Unit = 0.10	LO: 9981 - 1967 and HI: 10033 (2) - 1953, 1955
Sep	(LO: 801 and HI: 891, 895) Leaf Unit = 0.10	LO: 801 - 1982 , HI: 895 - 1991	(LO: 2550 and HI: 2710) Leaf Unit = 0.010	LO: 2550 - 1986, HI: 2710 - 1948	-	-	(LO: 10002, 10024, 10025, 10027 and HI: 10065, 10065, 10070) Leaf Unit = 0.10	LO: 10002 – 2003, HI: 10070 - 1951
Oct	(LO: 683, 731, 746, 749, 750, 755, 760) Leaf Unit = 0.10	LO: 683 - 1981	(LO: 226 and HI: 256) Leaf Unit = 0.10	LO: 226 - 1990 , HI: 256 - 1998	(LO: 245) Leaf Unit = 0.10	LO: 245 - 1990	(HI: 10133) Leaf Unit = 0.10	HI: 10133 - 1997
Nov	(LO: 647, 655, 669) Leaf Unit = 0.10	LO: 647 - 1984	(HI: 214) Leaf Unit = 0.10	HI: 214 - 1998	-	-	-	-
Dec	(HI: 857) Leaf Unit = 0.10	HI: 857 - 1997	(LO: 128, 129) Leaf Unit = 0.10	LO: 128 - 1949	(LO: 151, 152 and HI: 202, 204, 207) Leaf Unit = 0.10	LO: 151 - 1949 , HI: 207 - 1988	(LO: 10131, 10138 and HI: 10177) Leaf Unit = 0.10	LO: 10131 - 1984 , HI: 10177 - 1952

*DO-Detected outliers *RYEO-Respective years for extreme outliers

Table A.4.7 Detected Outliers for Monthly ARH, AWBT, ADBT and ASLP during 1948-2004

Month	AMXT		ARNT		AMNT	
	DO	RYEO	DO	RYEO	DO	RYEO
Jan	(LO: 196, 202, 206, 207) Leaf Unit = 0.10	LO: 196 - 2003	(LO: 100) Leaf Unit = 0.10	LO: 100 - 2004	-	-
Feb	(LO: 236 and HI: 305, 306) Leaf Unit = 0.10	LO: 236 - 1981 HI: 306 - 1960	(HI: 189, 190) Leaf Unit = 0.10	HI: 190 - 1951	-	-
Mar	(LO: 262, 284) Leaf Unit = 0.10	LO: 262- 1981	-	-	(LO: 143, 146 and HI: 195, 200) Leaf Unit = 0.10	LO: 143 - 1981 and HI: 200 - 1953
Apr	(LO: 287) Leaf Unit = 0.10	LO: 287 - 1981	(LO: 88 and HI: 177, 189) Leaf Unit = 0.10	LO: 88 - 2004 , HI: 189 -1957	(LO: 149, 187, 187, 188, 192 and HI: 233, 236) Leaf Unit = 0.10	LO: 149 – 1981 HI: 236 - 1954
May	(HI: 390) Leaf Unit = 0.10	HI: 390- 1957	(HI: 133, 151, 164) Leaf Unit = 0.10	HI: 164 - 1957	(LO: 151, 222 and HI: 246, 249, 251) Leaf Unit = 0.10	LO: 151 – 1981 HI: 251 -1995
Jun	(HI: 344, 349, 350) Leaf Unit = 0.10	HI: 350- 1972	(LO: 56, 56, 57, 57 and HI: 84, 85, 87, 93, 94, 123, 179) Leaf Unit = 0.10	LO: 56 (2) - 1949, 1961 , HI: 179 - 1981	(LO: 157, 221 and HI: 269) Leaf Unit = 0.10	LO: 157 – 1981 HI: 269 - 1998
Jul	(LO: 300, 302 and HI: 332, 335, 337) Leaf Unit = 0.10	LO: 300 - 1987 , HI: 337 - 1972	(LO: 43, 45 and HI: 74, 74, 80, 135) Leaf Unit = 0.10	LO: 43- 1965 , HI: 135 - 1981	(LO: 182, 239) Leaf Unit = 0.10	LO: 182- 1981
Aug	(LO: 296) Leaf Unit = 0.10	LO: 296 - 1965	(LO: 41 and HI: 76, 81) Leaf Unit = 0.10	LO: 41 - 1965 , HI: 81 - 1957	(LO: 241, 247) Leaf Unit = 0.10	LO: 241- 1957
Sep	-	-	(HI: 83, 84, 98) Leaf Unit = 0.10	HI: 98 - 1957	(LO: 2343, 2408, 2431) Leaf Unit = 0.010	LO: 2343 - 1957
Oct	(LO: 287, 291 and HI: 335) Leaf Unit = 0.10	LO: 287 – 1986 HI: 335- 1972	(HI: 129) Leaf Unit = 0.10	HI: 129 - 1957	(LO: 189) Leaf Unit = 0.10	LO: 189 - 1957
Nov	(HI: 312) Leaf Unit = 0.10	HI: 312 - 1972	(HI: 160) Leaf Unit = 0.10	HI: 160 - 1957	-	-
Dec	(LO: 231 and HI: 283) Leaf Unit = 0.10	LO: 231 – 1997, HI: 283 - 1972	(LO: 102 and HI: 177) Leaf Unit = 0.10	LO: 102 - 1997 and HI: 177 - 1972	-	-

DO-Detected outliers *RYEO-Respective years for extreme outliers

Table A.4.8 Within-Year Variability for Monthly Total Rainfall during 1948-2004

Month	Mean	Median	Tr Mean	StDev	Min	Max	Q1	Q3	QD	CV (%)	CV (Med)	(QD/ Med)%	CV (TRM)	QD/ TRM	Range
Jan	9.09	0.00	6.76	15.79	0.00	85.00	0.00	11.50	5.75	173.71	#DIV/0!	#DIV/0!	233.58	85.059	85.00
Feb	6.00	0.00	4.02	11.77	0.00	52.00	0.00	6.00	3.00	196.17	#DIV/0!	#DIV/0!	292.79	74.627	52.00
Mar	14.42	3.00	10.10	27.01	0.00	151.00	0.00	16.50	8.25	187.31	900.33	275.000	267.43	81.683	151.00
Apr	50.61	29.00	47.08	53.46	0.00	163.00	0.00	92.50	46.25	105.63	184.34	159.483	113.55	98.237	163.00
May	149.20	119.00	138.30	132.20	0.00	595.00	61.00	226.50	82.75	88.61	111.09	69.538	95.59	59.834	595.00
Jun	306.50	285.00	293.80	192.30	42.00	1054.00	198.00	396.00	99.00	62.74	67.47	34.737	65.45	33.696	1012.00
Jul	391.60	404.00	377.90	218.90	114.00	1196.00	186.00	534.00	174.00	55.90	54.18	43.069	57.93	46.044	1082.00
Aug	302.30	278.00	288.90	196.30	45.00	848.00	160.50	367.00	103.25	64.94	70.61	37.140	67.95	35.739	803.00
Sep	280.90	253.00	265.90	191.30	10.00	1026.00	141.50	356.50	107.50	68.10	75.61	42.490	71.94	40.429	1016.00
Oct	113.60	76.00	104.50	118.30	0.00	382.00	27.50	189.00	80.75	104.14	155.66	106.250	113.21	77.273	382.00
Nov	6.95	0.00	4.18	15.51	0.00	74.00	0.00	6.00	3.00	223.17	#DIV/0!	#DIV/0!	371.05	71.770	74.00
Dec	5.79	0.00	3.71	13.44	0.00	53.00	0.00	2.50	1.25	232.12	#DIV/0!	#DIV/0!	362.26	33.693	53.00

Table A.4.9 Trend of Means and CVs for Climatic Variables during 1948-2004

Variable	Trend Equations for Means	Residual's Stationarity	Residual's Normality	Trend Equations for CVs	Residual's Stationarity	Residual's Normality
AMXT	Yt = 31.0054 - 2.08E-02*t	NS	N	Yt = 10.0563 + 3.03E-02*t	S	N
AMNT	Yt = 19.4611 + 8.78E-03*t	S	NN	Yt = 31.3779 - 4.19E-02*t	S	N
ARNT	Yt = 11.5340 - 2.94E-02*t	S	NN	Yt = 39.1032 - 0.143504*t	S	NN
ADBT	Yt = 24.8901 - 4.07E-04*t	S	N	Yt = 19.5501 - 1.96E-02*t	NS	N
AWBT	Yt = 21.1663 + 1.64E-02*t	S	NN	Yt = 24.2544 - 4.83E-02*t	S	N
AWS	Yt = 0.614113 + 1.95E-02*t	NS	NN	Yt = 96.6889 - 1.30456*t	NS	N
AMWS	Yt = 3.63625 + 7.51E-02*t	NS	N	Yt = 69.6542 - 0.540325*t	NS	NN
ASLP	Yt = 1007.51 + 8.56E-04*t	S	NN	Yt = 0.638711 - 1.05E-03*t	S	NN
ARH	Yt = 71.8207 + 0.107859*t	NS	N	Yt = 18.7073 - 0.159994*t	S	N
AC	Yt = 2.41737 + 1.55E-02*t	NS	N	Yt = 89.5955 - 0.470093*t	S	N

S=Stationary, NS=Nonstationary, N=Normal, NN=Nonnormal

Table A.4.10 Trend of Minimum and Maximum Values for Climatic Variables (1948-2004)

Variable	Trend Equations for Minimum Values	Residual's Stationarity	Residual's Normality	Trend Equations for Maximum Values	Residual's Stationarity	Residual's Normality
AMXT	Yt = 25.7411 - 5.78E-02*t	S	N	Yt = 35.8767 - 3.82E-02*t	S	N
AMNT	Yt = 10.1191 + 3.01E-03*t	S	N	Yt = 25.9482 + 7.20E-03*t	S	NN
ARNT	Yt = 5.67638 + 8.75E-04*t	S	NN	Yt = 17.4573 - 6.16E-02*t	S	N
ADBT	Yt = 16.6018 - 3.97E-03*t	NS	N	Yt = 29.8771 - 7.33E-03*t	S	NN
AWBT	Yt = 13.4817 + 1.16E-02*t	S	N	Yt = 26.7023 + 1.01E-02*t	S	NN
AWS	Yt = -7.6E-02 + 1.63E-02*t	NS	NN	Yt = 1.64286 + 1.56E-02*t	NS	NN
AMXW	Yt = 0.362782 + 6.73E-02*t	NS	N	Yt = 8.80013 + 0.122440*t	NS	NN
ASLP	Yt = 997.621 + 3.76E-02*t	S	NN	Yt = 1016.27 - 9.27E-03*t	S	N
ARH	Yt = 44.3875 + 0.338483*t	S	N	Yt = 86.4801 + 2.45E-03*t	S	N
AC	Yt = 0.112657 + 1.02E-02*t	NS	N	Yt = 6.04887 + 3.58E-03*t	S	N

S=Stationary, NS=Nonstationary, N=Normal, NN=Nonnormal

Table A.4.11 Trend of 1st and 3rd Quartiles for Climatic Variables during 1948-2004

Variable	Trend Equations for 1st Quartiles	Residual's Stationarity	Residual's Normality	Trend Equations for 3rd Quartiles	Residual's Stationarity	Residual's Normality
AMXT	Yt = 28.2605 - 2.11E-02*t	S	N	Yt = 33.0839 - 1.54E-02*t	NS	NN
AMNT	Yt = 12.9445 + 1.80E-02*t	S	N	Yt = 25.1856 + 2.66E-03*t	S	NN
ARNT	Yt = 6.84806 - 8.10E-04*t	S	NN	Yt = 15.7531 - 5.49E-02*t	S	N
ADBT	Yt = 19.8107 + 1.10E-02*t	S	N	Yt = 28.6692 - 8.43E-04*t	S	N
AWBT	Yt = 15.7174 + 2.61E-02*t	S	N	Yt = 26.1481 + 7.05E-03*t	S	NN
AWS	Yt = 8.44E-02 + 1.96E-02*t	NS	N	Yt = 1.09014 + 1.87E-02*t	NS	NN
AMXW	Yt = 1.59487 + 6.72E-02*t	NS	N	Yt = 5.38033 + 7.37E-02*t	NS	NN
ASLP	Yt = 1001.73 - 5.83E-05*t	S	N	Yt = 1013.46 - 2.59E-03*t	S	N
ARH	Yt = 61.9182 + 0.195809*t	NS	N	Yt = 83.0542 + 1.47E-02*t	NS	NN
AC	Yt = 0.522321 + 1.47E-02*t	S	N	Yt = 4.74563 + 1.19E-02*t	S	N

S=Stationary, NS=Nonstationary, N=Normal, NN=Nonnormal

Table A.4.12 Trend Equations for TR, TFIR and MXR during 1948-2004

Month	Trend Equations of TR	RS	RN	Month	Trend Equations of TFIR	RS	Trend Equations of MXR	RS
Jan	Yt = 8.47870 + 2.10E-02*t	S	NN	Jan	Yt = 30.5244 - 1.75E-03*t	S	Yt = 6.65351 - 1.36E-03*t	S
Feb	Yt = 0.699248 + 0.182785*t	S	NN	Feb	Yt = 28.2481 - 1.22E-02*t	S	Yt = -4.0E-01 + 0.169951*t	S
Mar	Yt = 16.3778 - 6.75E-02*t	S	NN	Mar	Yt = 30.2876 - 8.10E-03*t	S	Yt = 11.7519 - 0.109411*t	NS
Apr	Yt = 25.8734 + 0.853124*t	S	N	Apr	Yt = 28.0088 - 3.54E-02*t	S	Yt = 14.7688 + 0.242092*t	S
May	Yt = 102.724 + 1.60358*t	S	N	May	Yt = 26.3891 - 6.97E-02*t	S	Yt = 37.6535 + 0.290835*t	S
Jun	Yt = 296.749 + 0.335948*t	S	N	Jun	Yt = 19.9398 - 3.42E-02*t	S	Yt = 82.0586 - 0.114240*t	S
Jul	Yt = 358.904 + 1.12853*t	S	N	Jul	Yt = 16.3377 + 5.90E-03*t	S	Yt = 79.0467 + 0.223133*t	S
Aug	Yt = 291.911 + 0.358180*t	S	N	Aug	Yt = 19.5670 + 5.25E-03*t	S	Yt = 79.7431 + 0.161913*t	S
Sep	Yt = 158.283 + 4.22680*t	NS	N	Sep	Yt = 21.8697 - 7.96E-02*t	S	Yt = 41.9712 + 1.71182*t	S
Oct	Yt = 70.7231 + 1.47718*t	S	N	Oct	Yt = 27.6848 - 1.39E-02*t	S	Yt = 35.0031 + 0.845022*t	S
Nov	Yt = 5.23496 + 5.90E-02*t	S	NN	Nov	Yt = 29.5771 + 6.48E-05*t	S	Yt = 3.04323 + 5.66E-02*t	S
Dec	Yt = -2.44737 + 0.284029*t	S	N	Dec	Yt = 31.1629 - 1.71E-02*t	NS	Yt = -1.62155 + 0.189007*t	S

RS-Residual's Stationarity S=Stationary, NS=Nonstationary N=Normal, NN=Nonnormal

Table A.4.13 Trend Equations for Monthly ADBT, AWBT and AT(D-W) during 1948-2004

Month	Trend Equations of ADBT	RS	RN	Trend Equations of AWBT	RS	RN	Trend Equations of AT(D-W)	RS	RN
Jan	Yt = 16.9658 – 1.25E-02*t	NS	N	Yt = 13.8261 + 4.85E-03*t	S	N	Yt = 3.13976 – 1.73E-02*t	NS	N
Feb	Yt = 19.2830 + 6.61E-03*t	S	N	Yt = 14.6031 + 3.03E-02*t	S	N	Yt = 4.67983 – 2.37E-02*t	NS	N
Mar	Yt = 24.9549 – 1.40E-02*t	S	N	Yt = 17.6794 + 2.99E-02*t	S	NN	Yt = 7.27549 – 4.39E-02*t	S	N
Apr	Yt = 29.4341 – 4.40E-02*t	S	N	Yt = 21.1798 + 2.56E-02*t	S	N	Yt = 8.25439 – 6.96E-02*t	S	N
May	Yt = 29.3195 – 2.31E-02*t	S	N	Yt = 24.5973 + 6.57E-03*t	S	N N	Yt = 4.72215 – 2.97E-02*t	S	N
Jun	Yt = 28.4867 + 9.34E-03*t	S	NN	Yt = 26.0121 + 1.13E-02*t	S	N N	Yt = 2.47463 – 1.91E-03*t	S	NN
Jul	Yt = 28.3532 + 8.55E-03*t	S	N	Yt = 26.4506 + 8.12E-03*t	S	NN	Yt = 1.90258 + 4.38E-04*t	S	NN
Aug	Yt = 28.4080 + 1.49E-02*t	S	N	Yt = 26.5332 + 1.13E-02*t	S	N	Yt = 1.87479 + 3.57E-03*t	S	N
Sep	Yt = 28.3894 – 4.06E-03*t	S	N	Yt = 26.2588 + 2.09E-03*t	S	N	Yt = 2.13067 – 6.15E-03*t	S	N
Oct	Yt = 26.4170 + 3.97E-03*t	S	N	Yt = 23.8712 + 7.83E-03*t	S	N	Yt = 2.54581 – 3.86E-03*t	NS	NN
Nov	Yt = 21.3330 + 2.77E-02*t	NS	N	Yt = 18.4127 + 3.03E-02*t	S	N	Yt = 2.92034 – 2.64E-03*t	NS	N
Dec	Yt = 17.3418 + 2.15E-02*t	S	N	Yt = 14.5694 + 2.94E-02*t	S	N	Yt = 2.77246 – 7.89E-03*t	NS	N

RS-Residual's Stationarity S-Stationary NS –Nonstationary RN-Residual's Normality NN-Nonnormal, N-Normal

Table A.4.14 Trend Equations for Monthly AMXT, AMNT and ARNT during 1948-2004

Month	Trend Equations of AMXT	RS	RN	Trend Equations of AMNT	RS	RN	Trend Equations of ARNT	RS	RN
Jan	Yt = 26.0508 - 6.38E-02*t	S	N	Yt = 10.3389 – 5.26E-04*t	S	N	Yt = 15.7115 – 6.32E-02*t	S	N
Feb	Yt = 28.2586 - 3.69E-02*t	S	N	Yt = 11.8551 + 2.05E-02*t	S	N	Yt = 16.4030 – 5.74E-02*t	S	N
Mar	Yt = 33.2860 - 4.84E-02*t	S	NN	Yt = 16.4885 + 1.56E-02*t	S	NN	Yt = 16.7972 – 6.39E-02*t	S	NN
Apr	Yt = 36.0428 - 6.25E-02*t	S	N	Yt = 20.8098 + 5.76E-03*t	S	NN	Yt = 15.2330 – 6.83E-02*t	S	N
May	Yt = 34.2046 - 3.18E-02*t	S	N	Yt = 23.4374 – 2.52E-03*t	S	NN	Yt = 10.7663 – 2.93E-02*t	S	NN
Jun	Yt = 32.1122 + 1.09E-02*t	S	NN	Yt = 24.9375 + 7.06E-03*t	S	NN	Yt = 7.17522 + 3.81E-03*t	S	NN
Jul	Yt = 31.6540 + 5.54E-03*t	S	N	Yt = 25.6988 + 2.16E-03*t	S	NN	Yt = 5.95405 + 3.38E-03*t	S	NN
Aug	Yt = 31.6694 + 1.38E-02*t	S	N	Yt = 25.7588 + 8.87E-03*t	S	NN	Yt = 5.91220 + 4.92E-03*t	S	N
Sep	Yt = 32.3103 - 1.53E-02*t	S	N	Yt = 25.2830 – 1.31E-03*t	S	NN	Yt = 7.02977 – 1.41E-02*t	S	NN
Oct	Yt = 31.4429 - 8.96E-03*t	S	N	Yt = 22.3124 – 4.05E-04*t	S	NN	Yt = 9.12828 – 8.51E-03*t	S	NN
Nov	Yt = 28.6777 + 7.21E-03*t	S	NN	Yt = 15.5414 + 2.58E-02*t	S	N	Yt = 13.1372 – 1.86E-02*t	S	N
Dec	Yt = 26.3488 - 1.90E-02*t	S	N	Yt = 11.0868 + 2.42E-02*t	S	N	Yt = 15.2623 – 4.31E-02*t	NS	NN

RS-Residual's Stationarity S-Stationary NS –Nonstationary RN-Residual's Normality NN-Nonnormal, N-Normal

Table A.4.15 Trend Equations for Monthly AMWS, AWS and AC during 1948-2004

Month	Trend Equations of AMWS	RS	RN	Trend Equations of AWS	RS	RN	Trend Equations of AC	RS	RN
Jan	Yt = 1.13346 + 9.70E-02*t	S	N	Yt = -1.1E-01 + 2.98E-02*t	S	NN	Yt = 0.567043 + 1.51E-02*t	NS	NN
Feb	Yt = 2.64098 + 9.77E-02*t	NS	N	Yt = 0.259273 + 2.52E-02*t	NS	N N	Yt = 0.552757 + 1.25E-02*t	NS	N
Mar	Yt = 3.07769 + 0.170340*t	S	NN	Yt = 0.692920 + 2.86E-02*t	NS	NN	Yt = 0.975313 + 9.77E-03*t	S	N
Apr	Yt = 6.30576 + 8.69E-02*t	NS	NN	Yt = 1.38772 + 1.78E-02*t	NS	NN	Yt = 1.06397 + 3.58E-02*t	S	N
May	Yt = 4.28321 + 8.94E-02*t	S	NN	Yt = 1.40739 + 1.02E-02*t	NS	N N	Yt = 2.90564 + 2.45E-02*t	S	N
Jun	Yt = 3.80201 + 6.79E-02*t	NS	NN	Yt = 1.16291 + 1.65E-02*t	NS	N N	Yt = 5.19612 + 6.73E-03*t	S	N
Jul	Yt = 4.47995 + 4.76E-02*t	S	NN	Yt = 0.854762 + 2.09E-02*t	S	NN	Yt = 5.66566 + 9.96E-03*t	S	N
Aug	Yt = 4.70238 + 3.87E-02*t	S	NN	Yt = 0.834837 + 1.81E-02*t	NS	N	Yt = 5.58465 - 6.81E-04*t	S	N
Sep	Yt = 5.23496 + 3.18E-02*t	S	NN	Yt = 0.522243 + 1.85E-02*t	NS	N	Yt = 3.97162 + 2.58E-02*t	S	N
Oct	Yt = 4.61842 + 2.59E-02*t	S	NN	Yt = 0.234273 + 1.56E-02*t	NS	NN	Yt = 1.78841 + 2.02E-02*t	NS	N
Nov	Yt = 1.09586 + 8.02E-02*t	S	NN	Yt = 6.75E-02 + 1.64E-02*t	NS	NN	Yt = 0.547744 + 1.31E-02*t	NS	N N
Dec	Yt = 2.27506 + 6.73E-02*t	S	NN	Yt = 5.75E-02 + 1.70E-02*t	NS	NN	Yt = 0.188722 + 1.38E-02*t	NS	N N

RS-Residual's Stationarity S-Stationary NS –Nonstationary RN-Residual's Normality NN-Nonnormal, N-Normal

Table A.4.16 Trend Equations for ASLP and ARH during 1948-2004

Month	Trend Equations of ASLP	RS	RN	Trend Equations of ARH	RS	RN
Jan	Yt = 1015.95 - 1.83E-02*t	S	N	Yt = 70.4394 + 0.155297*t	NS	N
Feb	Yt = 1012.40 + 1.16E-02*t	S	NN	Yt = 60.6571 + 0.188175*t	NS	N
Mar	Yt = 1009.89 - 1.72E-02*t	S	N	Yt = 49.2605 + 0.256577*t	S	N
Apr	Yt = 1005.27 + 2.34E-02*t	S	NN	Yt = 49.0456 + 0.350326*t	S	N
May	Yt = 1003.57 - 7.44E-03*t	S	N	Yt = 68.5883 + 0.149001*t	S	N
Jun	Yt = 999.587 + 3.18E-03*t	S	NN	Yt = 81.6352 + 3.14E-03*t	S	NN
Jul	Yt = 998.854 + 1.79E-02*t	S	NN	Yt = 85.3203 - 8.50E-03*t	S	NN
Aug	Yt = 1000.94 + 5.44E-03*t	S	N	Yt = 85.4446 - 2.91E-02*t	S	N
Sep	Yt = 1004.33 + 9.85E-03*t	S	NN	Yt = 83.7354 + 3.99E-02*t	S	N
Oct	Yt = 1009.62 + 1.51E-03*t	S	N	Yt = 79.9735 + 3.11E-02*t	NS	NN
Nov	Yt = 1014.06 - 1.89E-02*t	S	N	Yt = 74.6526 + 5.25E-02*t	NS	NN
Dec	Yt = 1015.66 - 1.79E-03*t	S	N	Yt = 73.0878 + 0.106095*t	NS	N

RS-Residual's Stationarity S-Stationary NS –Nonstationary RN-Residual's Normality NN-Nonnormal, N-Normal

Table A.4.17 Trend Equations for ARH(0), ARH(12) and ARH(0-12) during 1948-2004

Month	Trend Equations of ARH(0)	RS	RN	Trend Equations of ARH (12)	RS	RN	Trend Equations of ARH(0-12)	RS	RN
Jan	**Yt = 87.4765 + 0.166199*t**	**S**	**N**	**Yt = 56.2068 + 0.317419*t**	**S**	**N**	**Yt = 31.2682 – 0.151209*t**	**NS**	**N**
Feb	**Yt = 82.4902 + 0.203032*t**	**NS**	**N**	**Yt = 44.1332 + 0.259229*t**	**S**	**NN**	**Yt = 38.3588 – 5.63E-02*t**	**S**	**NN**
Mar	**Yt = 74.2915 + 0.234909*t**	**S**	**N**	**Yt = 33.5263 + 0.279806*t**	**S**	**NN**	**Yt = 40.7631 – 4.49E-02*t**	**S**	**NN**
Apr	**Yt = 71.9907 + 0.293533*t**	**S**	**N**	**Yt = 35.4957 + 0.397784*t**	**S**	**N**	**Yt = 36.4972 – 0.104321*t**	**S**	**N**
May	**Yt = 84.6751 + 0.128089*t**	**S**	**N**	**Yt = 61.2412 + 0.135447*t**	**S**	**N**	**Yt = 23.4333 – 7.33E-03*t**	**S**	**N**
Jun	**Yt = 90.3125 + 5.70E-02*t**	**S**	**NN**	**Yt = 76.9155 - 1.10E-02*t**	**S**	**NN**	**Yt = 13.3971 + 6.81E-02*t**	**S**	**NN**
Jul	**Yt = 92.2410 + 4.03E-02*t**	**S**	**NN**	**Yt = 80.4595 - 1.16E-02*t**	**S**	**NN**	**Yt = 11.7818 + 5.18E-02*t**	**S**	**NN**
Aug	**Yt = 92.5638 + 3.48E-02*t**	**S**	**NN**	**Yt = 80.8088 - 3.05E-02*t**	**S**	**N**	**Yt = 11.7564 + 6.53E-02*t**	**S**	**N**
Sep	**Yt = 92.4973 + 6.20E-02*t**	**S**	**N**	**Yt = 78.5906 + 8.73E-02*t**	**S**	**N**	**Yt = 13.9082 – 2.54E-02*t**	**S**	**N**
Oct	**Yt = 91.7384 + 8.18E-02*t**	**S**	**NN**	**Yt = 73.1890 + 0.130029*t**	**S**	**N**	**Yt = 18.5483 – 4.82E-02*t**	**S**	**NN**
Nov	**Yt = 89.4377 + 0.124920*t**	**NS**	**N**	**Yt = 65.3663 + 0.228640*t**	**S**	**N**	**Yt = 24.0705 – 0.103737*t**	**S**	**N**
Dec	**Yt = 89.0085 + 0.145770*t**	**S**	**N**	**Yt = 60.9502 + 0.321360*t**	**NS**	**N**	**Yt = 28.0577 – 0.175572*t**	**NS**	**N**

RS-Residual's Stationarity S-Stationary NS –Nonstationary RN-Residual's Normality NN-Nonnormal, N-Normal

Table A.5.1 Estimated Missing Values for Monthly TR during 1973-1980

TR	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
1973	0.72	0.18	5.52	17.20	67.25	255.86	345.48	272.94	200.64	86.19	0.49	0.07
1974	1.74	0.00	7.28	19.76	71.51	262.87	352.37	278.11	204.35	88.22	0.63	0.04
1975	1.90	0.00	7.46	19.98	71.77	263.13	352.43	277.96	204.08	87.96	0.60	0.05
1976	1.83	0.00	7.30	19.71	71.22	262.04	351.11	276.76	203.03	87.25	0.54	0.06
1977	5.24	5.18	5.51	50.36	200.88	302.32	439.15	336.02	341.45	100.29	2.13	4.34
1978	5.36	5.30	5.63	50.73	201.60	303.26	440.23	336.98	342.44	100.84	2.21	4.44
1979	5.51	5.47	5.74	51.15	202.95	303.63	441.84	337.84	343.10	100.94	2.29	4.58
1980	5.02	4.64	6.43	50.44	190.37	316.70	431.80	341.29	351.00	111.26	2.29	4.20

Table A.5.2 Estimated Missing Values for Monthly AMWS during 1973-1980

AMWS	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
1973	1.90	2.65	5.71	7.52	5.49	4.00	4.61	5.34	6.08	4.54	2.19	2.86
1974	1.53	2.49	5.59	7.62	5.53	4.07	4.72	5.39	6.17	4.72	2.17	2.83
1975	1.53	2.51	5.62	7.66	5.56	4.10	4.75	5.43	6.21	4.76	2.19	2.86
1976	1.54	2.53	5.66	7.70	5.59	4.13	4.79	5.46	6.24	4.79	2.21	2.88
1977	8.63	11.66	16.82	16.18	12.22	11.36	10.15	11.04	9.19	7.92	6.65	7.59
1978	8.37	11.32	16.32	15.69	11.86	11.02	9.85	10.72	8.92	7.68	6.45	7.37
1979	8.12	10.98	15.84	15.23	11.51	10.69	9.56	10.39	8.65	7.45	6.25	7.14
1980	7.84	10.62	15.39	14.83	11.16	10.44	9.33	10.18	8.60	7.43	6.55	7.14

Table A.5.3 Estimated Missing Values for Monthly MXR during 1973-1980

MXR	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
1973	2.96	0.35	8.17	12.17	30.67	77.79	85.97	91.86	66.32	53.40	1.50	0.18
1974	3.49	0.50	8.66	12.62	31.17	78.31	86.35	92.13	66.52	53.55	1.54	0.19
1975	3.54	0.52	8.72	12.68	31.23	78.31	86.33	92.10	66.53	53.57	1.57	0.20
1976	3.58	0.53	8.77	12.74	31.28	78.29	86.30	92.06	66.53	53.60	1.60	0.22
1977	1.82	2.31	1.37	16.29	52.81	61.33	85.57	80.01	78.53	39.95	0.59	2.59
1978	2.27	2.81	1.76	17.59	55.19	63.89	88.61	82.92	81.40	41.94	0.83	3.08
1979	2.73	3.31	2.16	18.84	57.44	66.31	91.48	85.67	84.11	43.83	1.10	3.57
1980	3.19	3.82	2.57	20.04	59.57	68.59	94.18	88.25	86.64	45.61	1.38	3.93

Table A.5.4 Estimated Missing Values for Monthly TFIR during 1973-1980

TFIR	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
1973	30.96	28.72	30.79	28.37	27.21	20.79	17.90	20.68	21.77	28.29	30.19	31.54
1974	31.10	28.80	30.86	28.43	27.27	20.85	17.96	20.74	21.83	28.35	30.25	31.60
1975	31.16	28.86	30.92	28.49	27.33	20.91	18.02	20.80	21.89	28.41	30.31	31.66
1976	31.22	28.92	30.98	28.55	27.40	20.97	18.09	20.86	21.95	28.47	30.37	31.72
1977	30.53	27.90	30.21	26.70	22.89	19.32	16.23	19.65	18.04	27.47	29.75	30.54
1978	30.51	27.88	30.19	26.68	22.88	19.30	16.21	19.63	18.03	27.45	29.73	30.52
1979	30.48	27.85	30.17	26.66	22.83	19.31	16.19	19.61	18.01	27.45	29.71	30.50
1980	30.57	27.96	30.10	26.69	23.22	18.82	16.18	19.63	17.92	27.18	29.73	30.51

Table A.5.5 Estimated Missing Values for Monthly ADBT during 1973-1980

ADBT	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
1973	16.59	19.18	24.77	29.16	29.35	28.79	28.60	28.56	28.35	26.45	21.66	17.63
1974	16.59	19.18	24.78	29.17	29.35	28.80	28.61	28.56	28.36	26.46	21.67	17.64
1975	16.60	19.19	24.79	29.18	29.36	28.81	28.62	28.57	28.37	26.47	21.68	17.65
1976	16.61	19.20	24.80	29.19	29.37	28.82	28.63	28.58	28.38	26.48	21.68	17.66
1977	15.20	17.87	22.39	25.27	25.87	26.68	26.45	27.09	26.20	24.95	20.99	16.73
1978	15.52	18.19	22.71	25.59	26.18	27.00	26.76	27.40	26.51	25.26	21.30	17.04
1979	15.82	18.49	23.01	25.88	26.48	27.29	27.05	27.69	26.80	25.55	21.58	17.32
1980	16.20	18.78	23.20	26.05	26.66	27.50	27.32	28.00	27.12	25.89	21.91	17.63

Table A.5.6 Estimated Missing Values for Monthly AMXT during 1973-1980

AMXT	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
1973	26.56	29.56	34.81	37.73	36.19	34.46	33.91	33.85	34.20	33.25	30.73	27.95
1974	26.75	29.68	35.04	37.99	36.43	34.77	34.20	34.13	34.48	33.54	31.01	28.21
1975	26.98	29.94	35.35	38.32	36.75	35.07	34.50	34.43	34.78	33.84	31.29	28.47
1976	27.23	30.21	35.67	38.67	37.09	35.40	34.82	34.76	35.11	34.16	31.59	28.74
1977	21.31	24.08	28.15	30.15	29.80	29.84	29.07	29.54	28.87	28.50	26.47	23.22
1978	21.57	24.37	28.48	30.50	30.14	30.18	29.41	29.88	29.20	28.83	26.77	23.48
1979	21.81	24.64	28.79	30.84	30.48	30.51	29.73	30.21	29.51	29.14	27.06	23.73
1980	22.04	24.90	29.09	31.16	30.79	30.83	30.03	30.51	29.81	29.43	27.33	23.96

Table A.5.7 Estimated Missing Values for Monthly AC during 1973-1980

AC	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
1973	0.54	0.44	0.79	1.25	2.83	5.03	5.48	5.27	3.88	1.78	0.43	0.08
1974	0.52	0.42	0.77	1.23	2.81	5.01	5.46	5.25	3.86	1.76	0.41	0.06
1975	0.50	0.40	0.75	1.21	2.79	4.99	5.44	5.23	3.84	1.74	0.39	0.04
1976	0.48	0.38	0.73	1.19	2.77	4.97	5.42	5.21	3.82	1.72	0.37	0.02
1977	1.85	1.81	1.93	3.04	4.52	5.82	6.79	6.17	5.89	3.05	1.71	1.48
1978	1.76	1.72	1.85	2.96	4.43	5.73	6.71	6.08	5.80	2.97	1.63	1.40
1979	1.70	1.65	1.77	2.87	4.37	5.65	6.64	6.02	5.73	2.87	1.55	1.34
1980	1.46	1.56	1.68	2.89	4.21	5.61	6.50	5.82	5.61	3.01	1.48	1.17

Table A.5.8 Estimated Missing Values for Monthly AMNT during 1973-1980

AMNT	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
1973	10.32	12.09	16.76	21.16	23.72	25.35	26.06	26.05	25.51	22.71	16.28	11.71
1974	10.68	12.39	17.01	21.37	23.90	25.50	26.19	26.16	25.61	22.79	16.35	11.77
1975	10.74	12.44	17.06	21.41	23.94	25.54	26.23	26.20	25.64	22.82	16.38	11.80
1976	10.77	12.47	17.09	21.44	23.96	25.56	26.25	26.22	25.67	22.85	16.40	11.83
1977	9.82	12.11	16.56	20.51	22.81	24.82	25.26	25.49	24.54	21.58	15.95	11.43
1978	9.85	12.15	16.60	20.54	22.85	24.86	25.30	25.53	24.58	21.62	15.99	11.46
1979	9.89	12.19	16.64	20.58	22.89	24.89	25.34	25.56	24.62	21.66	16.03	11.50
1980	9.93	12.23	16.68	20.62	22.93	24.93	25.38	25.60	24.65	21.69	16.04	11.48

Table A.5.9 Estimated Missing Values for Monthly ARNT during 1973-1980

ARNT	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
1973	17.26	18.43	18.66	17.09	13.18	9.79	8.66	8.61	9.53	11.44	15.47	17.42
1974	17.49	18.47	18.87	17.28	13.37	10.20	9.00	8.97	9.88	11.88	15.90	17.91
1975	17.93	18.93	19.31	17.73	13.83	10.63	9.44	9.42	10.33	12.32	16.34	18.35
1976	18.38	19.38	19.77	18.19	14.28	11.10	9.90	9.88	10.80	12.79	16.81	18.83
1977	14.59	15.40	15.53	13.74	10.77	8.46	7.23	7.48	7.67	10.12	13.69	14.63
1978	14.43	15.25	15.38	13.59	10.62	8.31	7.08	7.33	7.52	9.97	13.54	14.48
1979	14.28	15.10	15.23	13.44	10.47	8.16	6.93	7.18	7.38	9.83	13.40	14.34
1980	14.14	14.95	15.09	13.30	10.33	8.01	6.79	7.04	7.24	9.69	13.26	14.20

Table A.5.10 Estimated Missing Values for Monthly AWBT during 1973-1980

AWBT	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
1973	13.77	14.99	17.93	21.69	24.80	26.29	26.64	26.62	26.28	23.96	18.73	14.90
1974	13.76	14.84	18.04	21.70	24.81	26.29	26.65	26.61	26.26	23.95	18.81	14.93
1975	13.76	14.85	18.03	21.70	24.81	26.29	26.65	26.61	26.26	23.95	18.80	14.93
1976	13.76	14.85	18.03	21.70	24.81	26.29	26.65	26.61	26.26	23.95	18.80	14.93
1977	13.92	15.52	18.56	21.80	24.56	26.35	26.54	26.69	26.01	23.92	19.47	15.63
1978	13.94	15.55	18.58	21.82	24.58	26.38	26.56	26.71	26.04	23.94	19.49	15.66
1979	13.97	15.57	18.61	21.85	24.61	26.40	26.59	26.74	26.06	23.97	19.52	15.68
1980	13.99	15.60	18.63	21.87	24.63	26.43	26.61	26.76	26.09	23.99	19.55	15.72

Table A.5.11 Estimated Missing Values for Monthly AWS during 1973-1980

AWS	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
1973	0.07	0.35	1.03	1.46	1.41	1.49	1.38	1.44	1.18	0.54	0.42	0.36
1974	0.15	0.46	1.14	1.54	1.46	1.53	1.40	1.45	1.19	0.55	0.43	0.37
1975	0.16	0.46	1.13	1.53	1.45	1.52	1.39	1.44	1.19	0.55	0.44	0.37
1976	0.17	0.47	1.13	1.52	1.45	1.51	1.38	1.43	1.18	0.56	0.44	0.38
1977	1.46	1.92	2.51	2.90	2.28	2.35	2.12	2.26	1.78	1.32	1.17	1.13
1978	1.41	1.87	2.44	2.83	2.21	2.28	2.05	2.19	1.71	1.26	1.11	1.07
1979	1.35	1.79	2.36	2.73	2.12	2.18	1.96	2.09	1.62	1.18	1.03	0.99
1980	1.25	1.68	2.22	2.58	1.98	2.03	1.81	1.93	1.47	1.04	0.90	0.86

Table A.5.12 Estimated Missing Values for Monthly ARH during 1973-1980

ARH	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
1973	73.82	62.45	51.81	53.15	69.45	81.85	85.21	85.08	83.72	80.11	74.56	73.47
1974	72.43	62.47	51.52	53.03	69.57	81.16	84.87	84.67	83.43	79.83	74.89	73.81
1975	72.49	62.34	51.37	52.87	69.46	81.16	84.84	84.64	83.39	79.79	74.77	73.68
1976	72.39	62.23	51.20	52.71	69.37	81.09	84.77	84.58	83.32	79.71	74.69	73.61
1977	61.13	45.78	28.47	41.50	63.39	72.99	78.31	75.34	77.68	69.99	63.03	64.74
1978	62.64	48.38	34.30	44.60	64.78	74.05	79.22	76.33	78.61	71.12	64.41	66.05
1979	64.04	50.66	38.49	47.23	66.08	75.04	80.09	77.26	79.49	72.18	65.70	67.27
1980	65.33	52.68	41.82	49.52	67.28	75.98	80.91	78.13	80.30	73.15	66.81	68.21

Table A.5.13 Forecasted Values for Monthly AMWS during 2005-2012

AMWS	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
2005	3.37	4.44	7.06	6.07	5.23	4.30	4.34	3.93	4.11	3.76	2.79	2.92
2006	3.28	4.32	6.90	5.93	5.11	4.19	4.23	3.83	4.01	3.66	2.71	2.84
2007	3.19	4.21	6.74	5.79	4.98	4.08	4.12	3.73	3.90	3.57	2.63	2.76
2008	3.10	4.11	6.59	5.65	4.86	3.98	4.01	3.63	3.80	3.47	2.55	2.68
2009	3.00	3.99	6.43	5.54	4.75	3.88	3.92	3.55	3.71	3.38	2.47	2.60
2010	2.92	3.89	6.29	5.41	4.63	3.78	3.82	3.45	3.62	3.29	2.40	2.52
2011	2.84	3.79	6.15	5.28	4.52	3.68	3.72	3.36	3.52	3.20	2.33	2.45
2012	2.76	3.69	6.00	5.16	4.41	3.59	3.62	3.27	3.43	3.11	2.26	2.38

Table A.5.14 Forecasted Values for Monthly MXR during 2005-2012

MXR	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
2005	6.10	5.37	7.41	26.14	56.59	94.46	102.60	100.33	108.94	71.04	3.22	3.66
2006	6.26	5.61	7.51	26.10	56.82	94.95	102.94	101.86	110.43	70.86	3.38	3.77
2007	6.39	5.73	7.65	26.35	57.20	95.44	103.45	102.38	110.97	71.28	3.47	3.87
2008	6.52	5.85	7.79	26.61	57.58	95.93	103.96	102.89	111.50	71.71	3.57	3.96
2009	6.72	5.84	8.13	26.72	57.97	96.78	104.88	103.86	111.14	71.54	3.73	4.01
2010	6.85	5.96	8.28	26.97	58.36	97.28	105.41	104.39	111.64	71.94	3.83	4.11
2011	6.98	6.08	8.42	27.23	58.74	97.78	105.93	104.90	112.17	72.37	3.93	4.21
2012	7.12	6.21	8.57	27.50	59.13	98.28	106.45	105.42	112.70	72.80	4.03	4.32

Table A.5.15 Forecasted Values for Monthly TFIR during 2005-2012

TFIR	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
2005	29.59	26.82	29.05	25.55	22.63	17.34	15.62	18.94	17.86	26.05	28.53	29.47
2006	29.37	26.70	28.94	25.44	22.52	17.23	15.51	18.83	17.75	25.94	28.42	29.36
2007	29.26	26.59	28.83	25.33	22.41	17.12	15.40	18.72	17.64	25.83	28.30	29.24
2008	29.15	26.48	28.71	25.22	22.29	17.00	15.28	18.60	17.52	25.71	28.18	29.12
2009	28.88	26.29	28.49	25.21	22.45	17.12	14.98	18.25	17.62	25.56	27.91	28.92
2010	28.75	26.16	28.36	25.09	22.32	16.99	14.84	18.11	17.49	25.42	27.77	28.79
2011	28.61	26.03	28.23	24.95	22.19	16.86	14.71	17.97	17.36	25.29	27.63	28.65
2012	28.47	25.89	28.09	24.81	22.05	16.72	14.57	17.83	17.22	25.15	27.49	28.51

Table A.5.16 Forecasted Values for Monthly ADBT during 2005-2012

ADBT	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
2005	15.10	18.96	23.58	26.11	27.63	28.31	28.38	28.80	27.81	25.93	21.99	17.73
2006	15.04	18.90	23.52	26.05	27.57	28.25	28.32	28.74	27.75	25.87	21.93	17.68
2007	14.99	18.85	23.46	25.99	27.51	28.19	28.26	28.68	27.69	25.82	21.88	17.62
2008	14.94	18.79	23.40	25.94	27.46	28.13	28.21	28.62	27.64	25.76	21.82	17.57
2009	14.88	18.74	23.35	25.89	27.40	28.08	28.16	28.57	27.58	25.71	21.77	17.52
2010	14.84	18.69	23.30	25.83	27.35	28.03	28.11	28.52	27.53	25.66	21.72	17.47
2011	14.79	18.65	23.25	25.79	27.30	27.98	28.06	28.47	27.49	25.61	21.68	17.43
2012	14.75	18.60	23.21	25.74	27.26	27.93	28.01	28.42	27.44	25.57	21.63	17.39

Table A.5.20 Forecasted Values for Monthly ARNT during 2005-2012

ARNT	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
2005	12.14	13.53	13.24	10.95	8.99	6.95	5.93	6.15	6.41	8.41	11.93	12.78
2006	12.06	13.45	13.18	10.91	8.96	6.93	5.92	6.14	6.40	8.39	11.90	12.75
2007	12.03	13.42	13.16	10.88	8.94	6.92	5.90	6.12	6.38	8.37	11.88	12.73
2008	12.00	13.40	13.13	10.86	8.92	6.90	5.89	6.11	6.37	8.36	11.85	12.70
2009	11.98	13.37	13.10	10.84	8.90	6.89	5.88	6.10	6.36	8.34	11.82	12.67
2010	11.95	13.34	13.07	10.81	8.88	6.87	5.86	6.08	6.34	8.32	11.80	12.64
2011	11.93	13.31	13.04	10.79	8.87	6.86	5.85	6.07	6.33	8.30	11.77	12.62
2012	11.90	13.28	13.01	10.77	8.85	6.84	5.84	6.06	6.32	8.28	11.75	12.59

Table A.5.21 Forecasted Values for Monthly AWBT during 2005-2012

AWBT	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
2005	13.86	16.07	19.18	22.63	25.19	26.82	27.11	27.23	26.56	24.47	20.05	16.04
2006	14.04	16.26	19.40	22.75	25.29	26.88	27.15	27.29	26.59	24.46	20.04	16.07
2007	14.06	16.28	19.42	22.77	25.30	26.90	27.17	27.30	26.61	24.48	20.06	16.09
2008	14.07	16.29	19.43	22.78	25.32	26.92	27.19	27.32	26.62	24.50	20.07	16.11
2009	14.09	16.31	19.45	22.80	25.34	26.93	27.20	27.34	26.64	24.51	20.09	16.12
2010	14.11	16.32	19.47	22.81	25.35	26.95	27.22	27.35	26.65	24.53	20.10	16.14
2011	14.12	16.34	19.48	22.83	25.37	26.96	27.23	27.37	26.67	24.54	20.12	16.15
2012	14.14	16.36	19.50	22.84	25.38	26.98	27.25	27.38	26.69	24.56	20.13	16.17

Table A.5.22 Forecasted Values for Monthly AWS during 2005-2012

AWS	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
2005	0.98	0.98	1.38	1.59	1.44	1.47	1.36	1.21	1.08	0.73	0.55	0.61
2006	0.99	0.98	1.38	1.59	1.44	1.47	1.36	1.21	1.08	0.73	0.55	0.61
2007	0.99	0.99	1.39	1.59	1.44	1.47	1.36	1.21	1.09	0.73	0.55	0.62
2008	0.99	0.99	1.39	1.60	1.45	1.48	1.37	1.22	1.09	0.74	0.56	0.62
2009	1.00	1.00	1.40	1.60	1.45	1.49	1.37	1.23	1.10	0.74	0.56	0.63
2010	1.00	1.00	1.41	1.61	1.46	1.50	1.38	1.24	1.10	0.75	0.57	0.63
2011	1.01	1.01	1.42	1.62	1.47	1.51	1.39	1.24	1.11	0.75	0.58	0.64
2012	1.02	1.02	1.43	1.64	1.48	1.52	1.40	1.26	1.12	0.76	0.58	0.65

Table A.5.23 Forecasted Values for Monthly ARH during 2005-2012

ARH	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
2005	81.74	74.61	67.84	74.14	79.80	85.26	87.22	85.87	87.34	84.69	80.89	81.88
2006	82.55	75.18	68.34	74.50	80.09	85.51	87.46	86.11	87.57	84.93	81.16	82.14
2007	82.82	75.50	68.73	74.82	80.37	85.76	87.69	86.36	87.81	85.19	81.44	82.41
2008	83.08	75.82	69.11	75.15	80.66	86.01	87.93	86.61	88.05	85.44	81.72	82.69
2009	83.36	76.15	69.51	75.49	80.94	86.26	88.18	86.86	88.30	85.70	82.00	82.97
2010	83.63	76.48	69.90	75.83	81.24	86.52	88.43	87.11	88.54	85.97	82.29	83.25
2011	83.91	76.81	70.30	76.17	81.54	86.79	88.68	87.37	88.80	86.24	82.58	83.54
2012	84.19	77.15	70.71	76.51	81.84	87.05	88.93	87.64	89.05	86.51	82.88	83.83

Table A.7.1 Dist. of Opinion about ARRS by Upazila and DPRS by Upazila

ARRS / Upazila	Not reduced	Reduced	Total	DPRS / Upazila	Not shorter	Shorter	Total
Hakimpur	20	50	70	Hakimpur	19	51	70
Ranisankail	6	42	48	Ranisankail	8	40	48
Atwari	6	189	195	Atwari	12	183	195
Total	32	281	313	Total	39	274	313
	Chi-Square = 36.797	DF = 2	P-Value = 0.000		Chi-Square = 21.72	DF = 2	P-Value =.000

*ARRS-Amount of rainfall in Rainy season *DPRS-Duration period of Rainy season

Table A.7.2 Dist. of Opinion about DPRS by Upazila and BPRS by Upazila

Dist. of opinion about DPRS by Upazila				Dist. of opinion about BPRS by Upazila						
Upazila \ DPRS	Not shorter	Shorter	Total	Upazila \ BPRS	Happen early	Happen Later	Unchanged	Irregular	Others	Total
Hakimpur	19	51	70	Hakimpur	25	18	10	15	2	70
Ranisankail	8	40	48	Ranisankail	15	4	8	16	5	48
Atwari	12	183	195	Atwari	21	54	0	120	0	195
Total	39	274	313	Total	61	76	18	151	7	313
	Chi-Square = 21.72	DF = 2	P-Value =.000		Chi-Square =95.15	DF=8	P-Value=0			

DPRS-Duration period of Rainy season ARS- Amount of rain in Rainy season BPRS-Beginning period of Rainy season

Table A.7.3 Dist. of Opinion about CA by Upazila and CS by Upazila

Dist. of opinion about CA by Upazila				Dist. of opinion about CS by Upazila			
Upazila \ CA	Not drier	Drier	Total	Upazila \ CS	others	not rain like previous	Total
Hakimpur	32	38	70	Hakimpur	12	58	70
Ranisankail	3	45	48	Ranisankail	9	39	48
Atwari	2	193	195	Atwari	7	188	195
Total	37	276	313	Total	28	285	313
	Chi-Square =100.39	DF=2	P-Value=0		Chi-Square = 18.306	DF=2	P-Value = 0

CA-Characteristics of Ashar CS-Characteristics of Srabon

Table A.7.4 Dist. of Opinion about ST by Upazila and IN by Upazila

Dist. of opinion about ST by Upazila				Dist. of opinion about IN by Upazila			
Upazila \ ST	Decrease	Not Decrease	Total	Upazila \ IN	Lower	Not lower	Total
Hakimpur	34	36	70	Hakimpur	46	24	70
Ranisankail	21	27	48	Ranisankail	41	7	48
Atwari	160	35	195	Atwari	193	2	195
Total	215	98	313	Total	280	33	313
	Chi-Square = 43.243	DF = 2	P-Value = 0		Chi-Square = 61.397	DF=2	P-Value = 0

ST-Summer temperature IN- Intensity of Norwester

Table A.7.5 Dist. of Opinion about DA by Upazila and FW by Upazila

Dew in Autumn By Upazila				Future of wheat in Dinajpur				
Upazila \ DA	Not reduced	Reduced	Total	Upazila \ FW	Under threat	Brighter	Others	Total
Hakimpur	36	34	70	Hakimpur	55	3	12	70
Ranisankail	27	21	48	Ranisankail	37	6	5	48
Atwari	16	179	195	Atwari	182	10	3	195
Total	79	234	313	Total	274	19	20	313
	Chi-Square = 79.894	DF = 2	P-Value = 0.000		Chi-Square = 26.979	DF = 4	P-Value = 0.000	

DA-Dew in Autumn FW-Future of Wheat

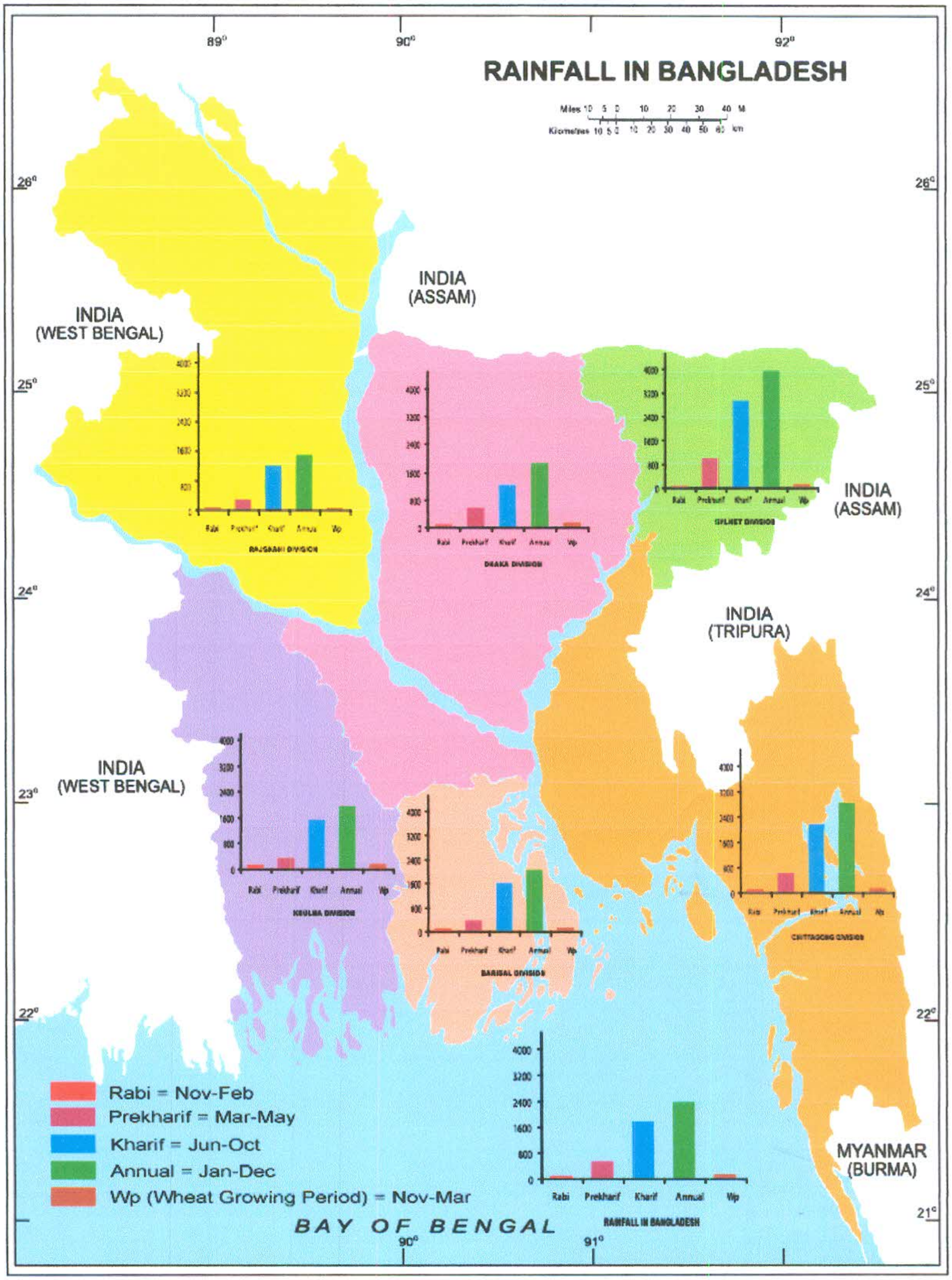


Figure 1 A. 8 Rainfall in Bangladesh

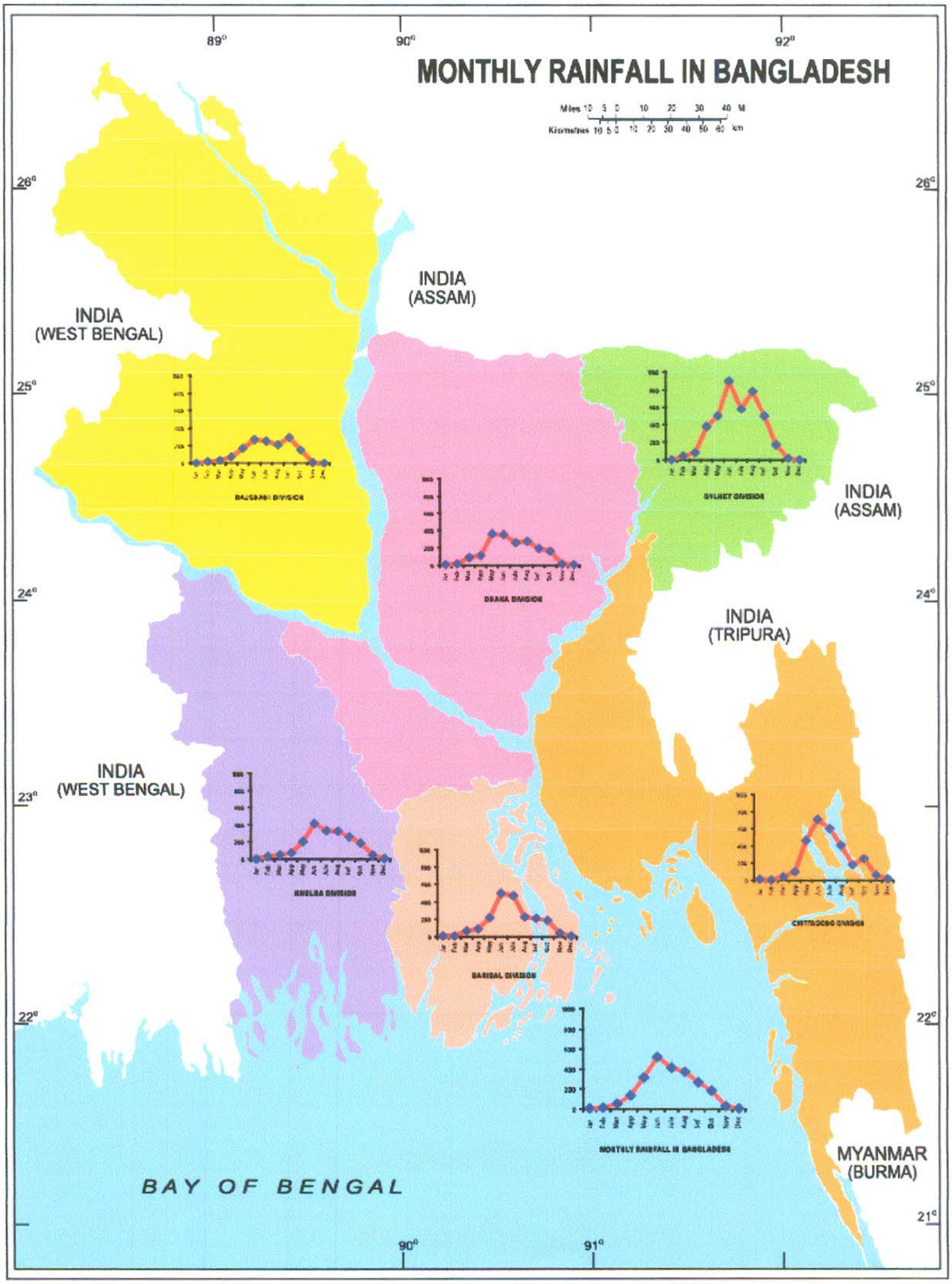


Figure 1 A. 9 Monthly Rainfall in Bangladesh

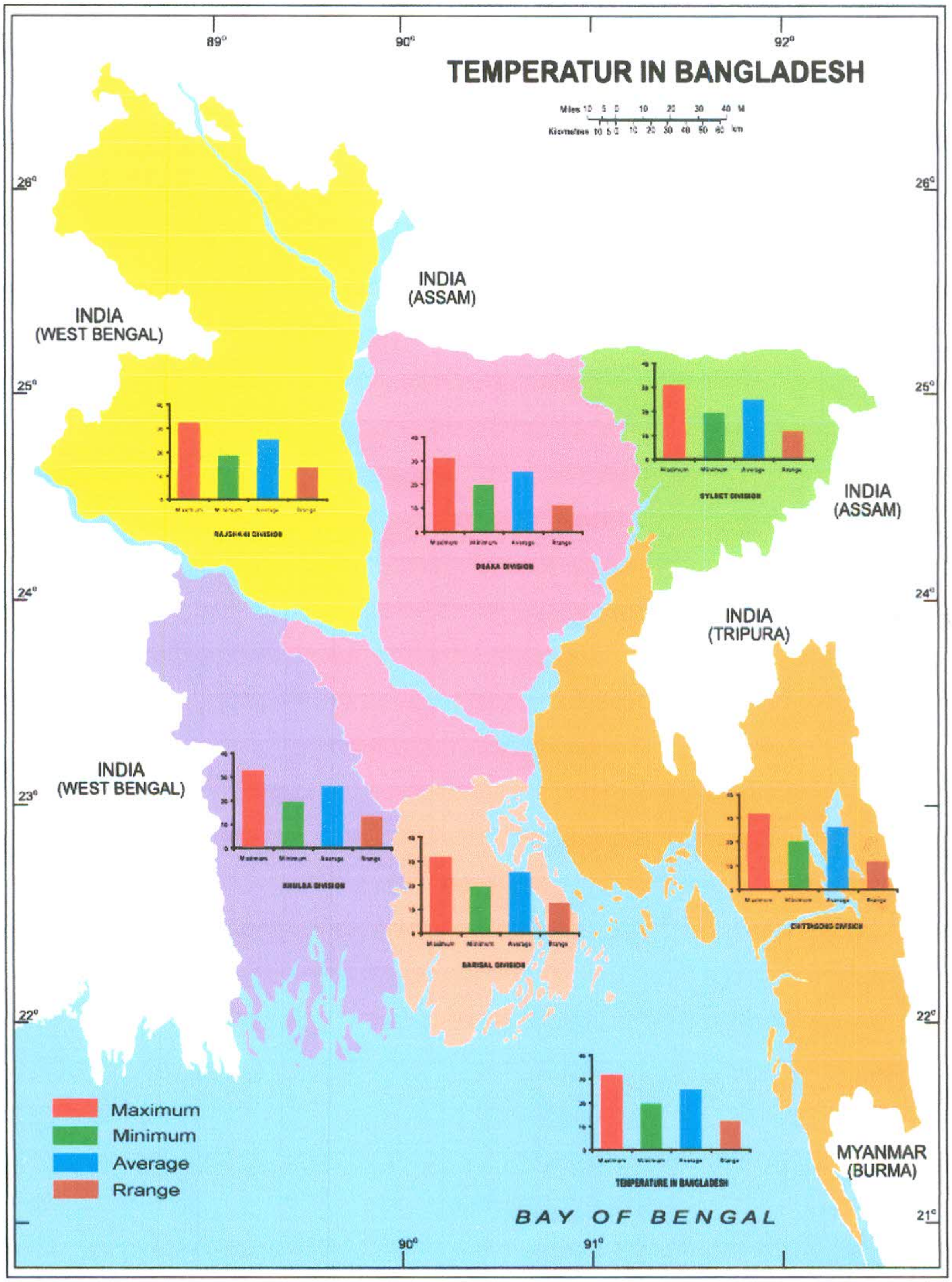


Figure 1 A. 10 Temperature in Bangladesh

Trend Figures for Some Minimum and Maximum Values and the Quartiles of Monthly Climatic Data

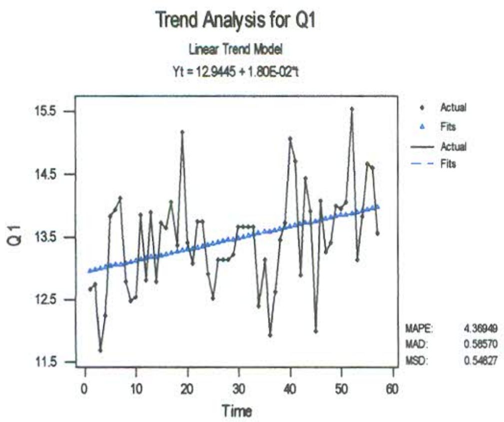


Figure 4.A.1 Trend for 1st quartile of monthly AMNT

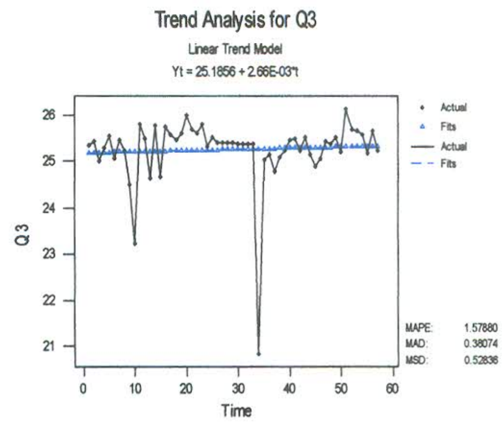


Figure 4.A.2 Trend for 3rd quartile of monthly AMNT

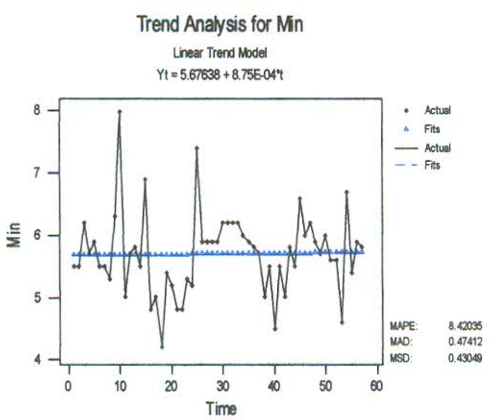


Figure 4.A.3 Trend of minimum for monthly ARNT

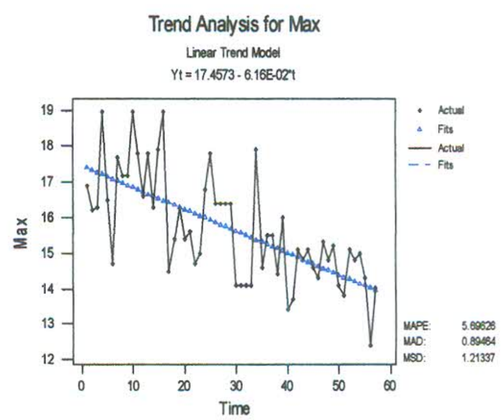


Figure 4.A.4 Trend of maximum for monthly ARNT

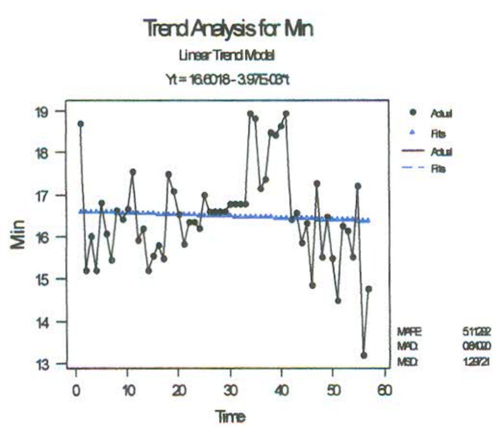


Figure 4.A.5 Trend for minimum monthly ADBT

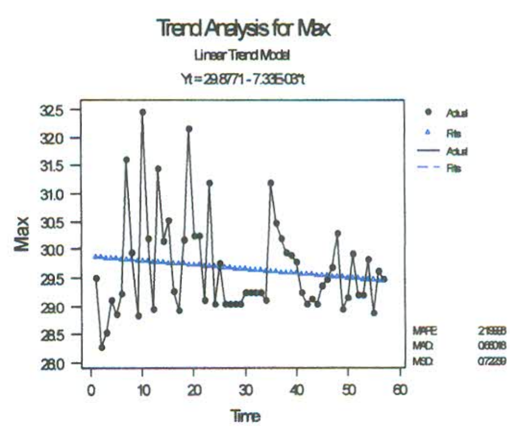


Figure 4.A.6 Trend for maximum monthly ADBT

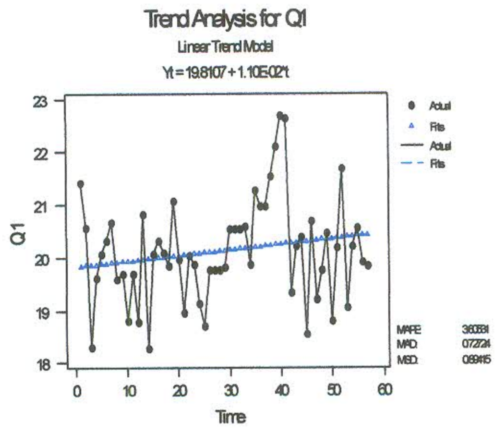


Figure 4.A.7 Trend of 1st quartile for monthly ADBT

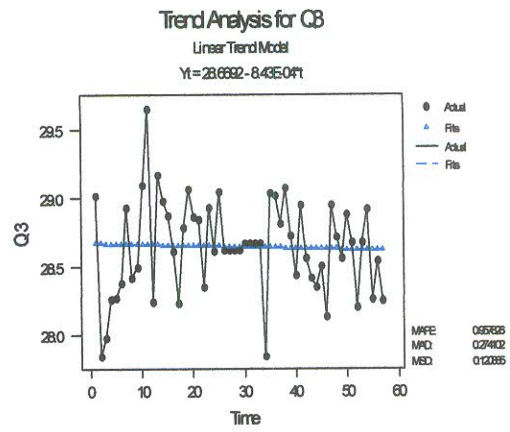


Figure 4.A.8 Trend of 3rd quartile for monthly ADBT

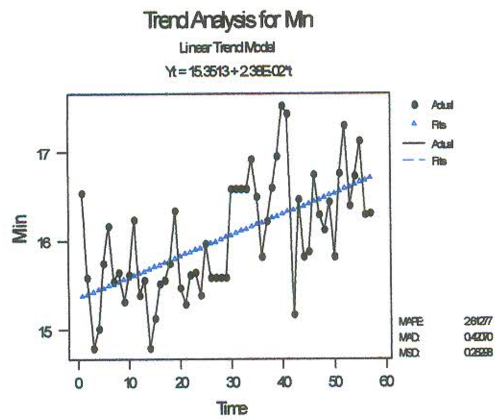


Figure 4.A.9 Trend for minimum monthly AWBT

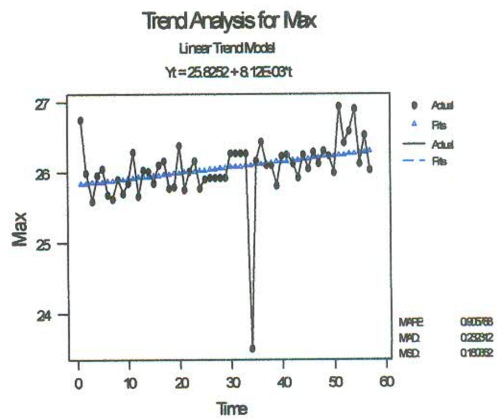


Figure 4.A.10Trend for maximum monthly AWBT

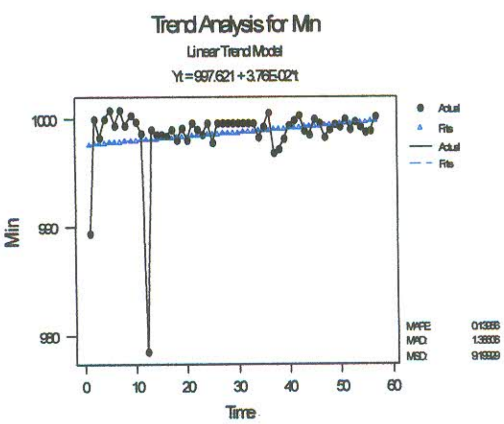


Figure 4.A.11 Trend for minimum monthly ASLP

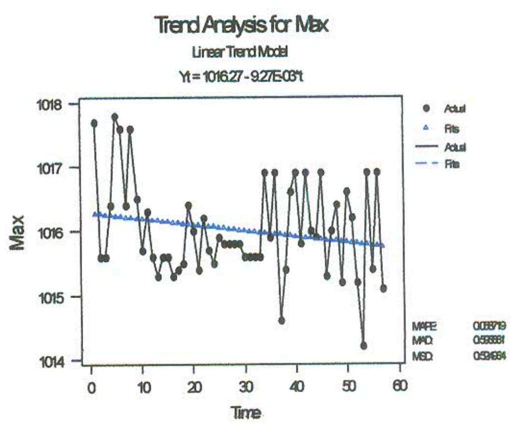


Figure 4.A.12 Trend for maximum monthly ASLP

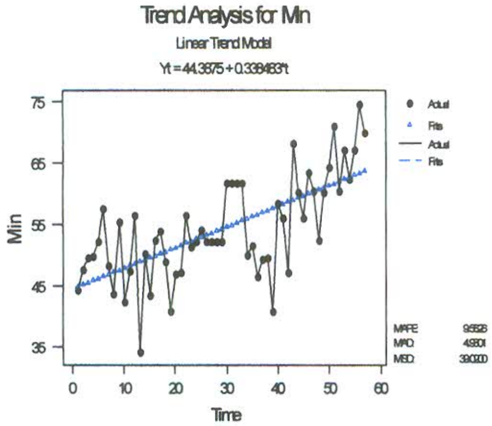


Figure 4.A.13 Trend for minimum monthly ARH

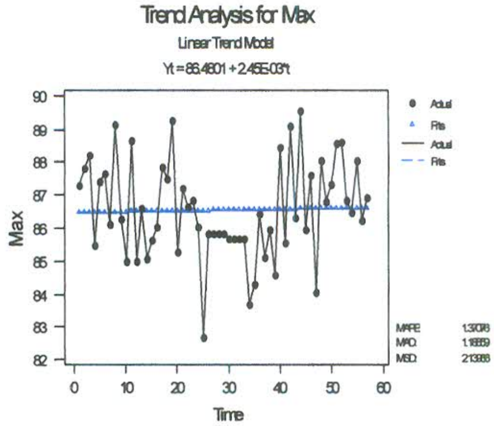


Figure 4.A.14 Trend for maximum monthly ARH

Trends for Some Climatic Variations

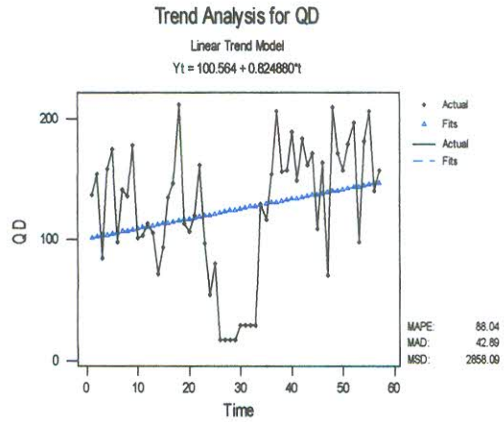


Figure 4.A.15 Trend for QD of TR

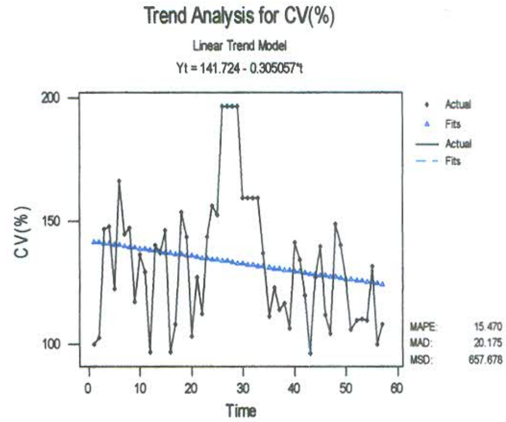


Figure 4.A.16 Trend for CV of TR

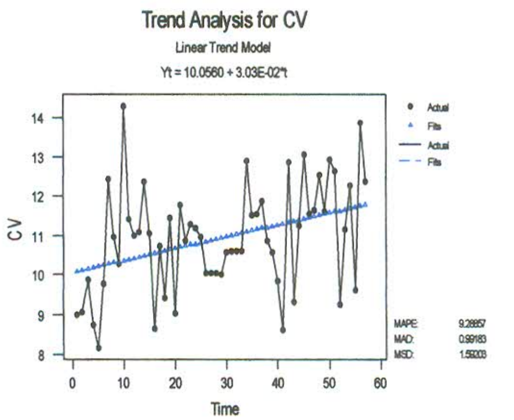


Figure 4.A.17 Trend for CV of AMXT

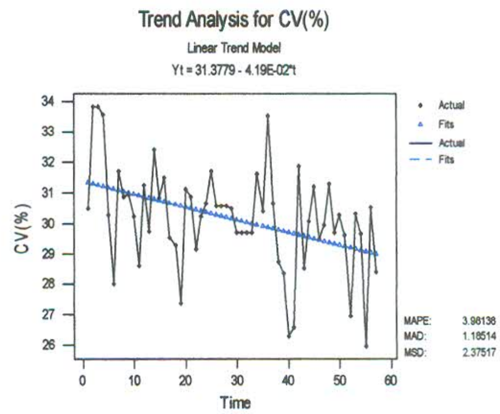


Figure 4.A.18 Trend for CV of AMNT

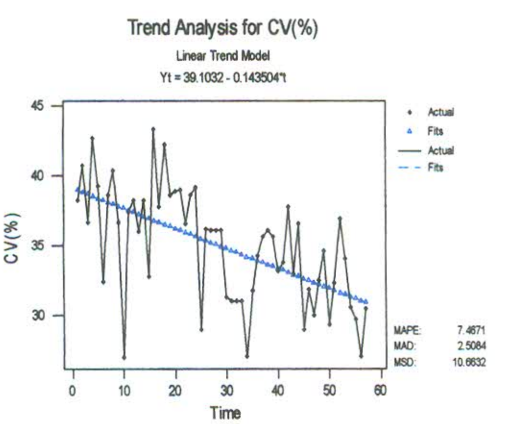


Figure 4.A.19 Trend for CV of ARNT

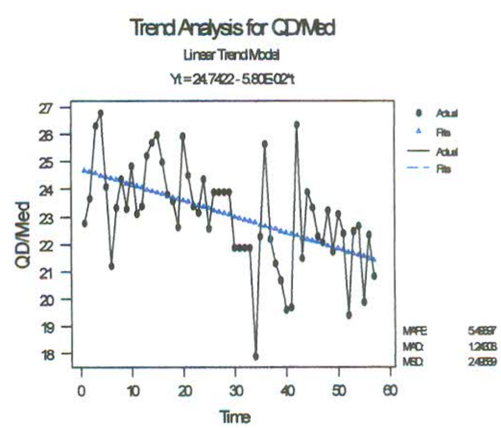


Figure 4.A.20 Trend for QD/Med of AWBT

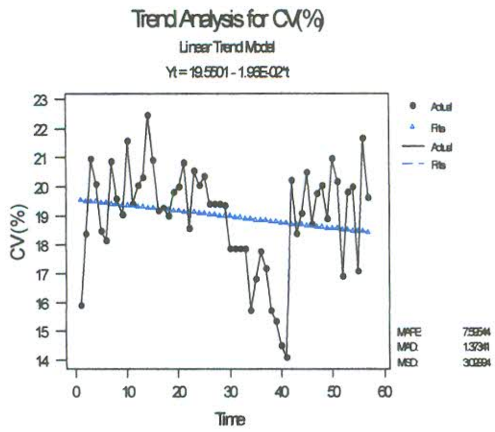


Figure 4.A.21 Trend for CV of ADBT

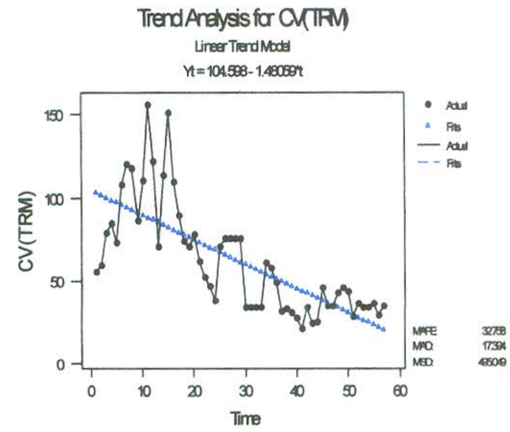


Figure 4.A.22 Trend for CV (TRM) of AWS

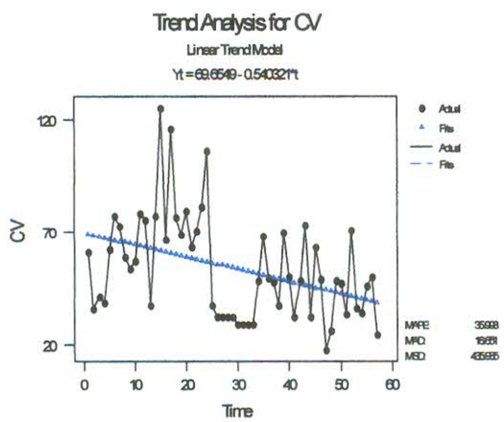


Figure 4.A.23 Trend for CV of AMWS

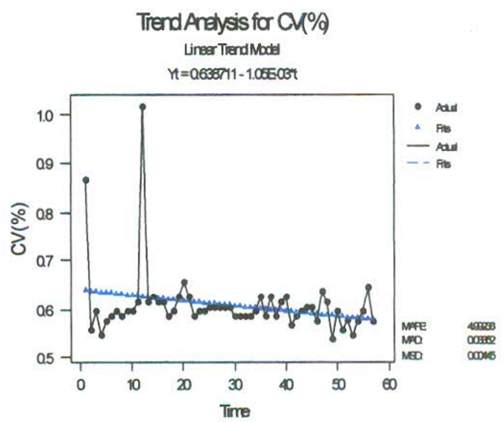


Figure 4.A.24 Trend for CV of ASLP

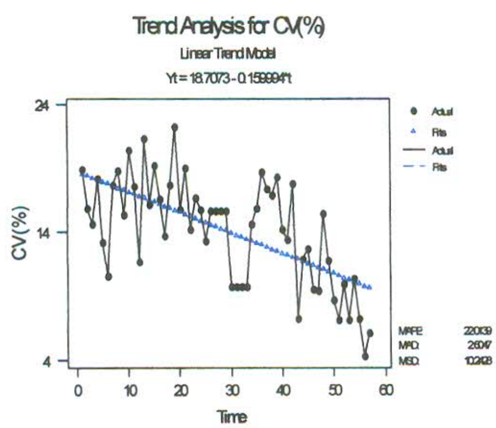


Figure 4.A.25 Trend for CV of ARH

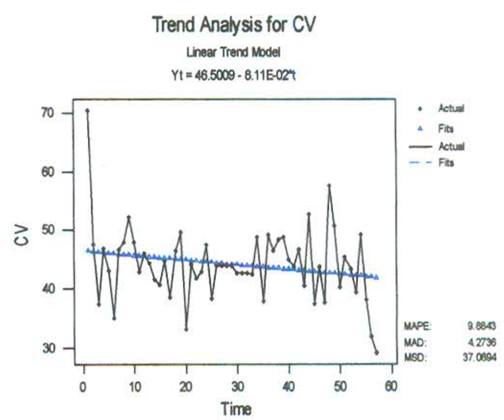


Figure 4.A.26 Trend for CV of ARH(0-12)

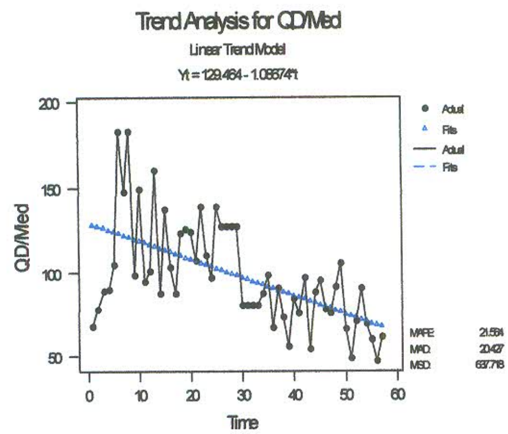


Figure 4.A.27 Trend for QD(Med) of AC

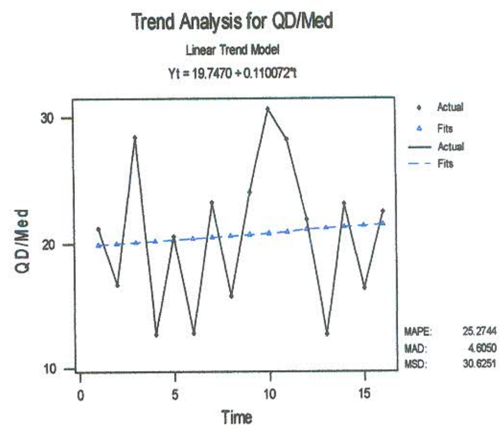


Figure 4.A.28 Trend for QD(Med) of ASH

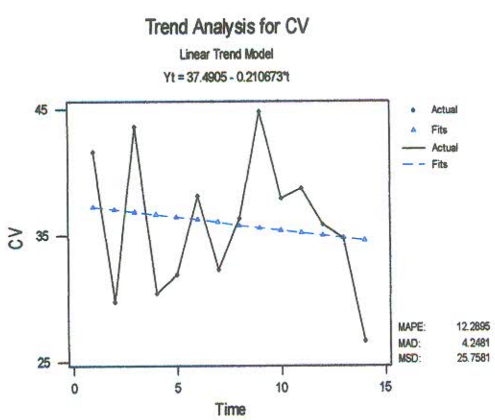


Figure 4.A.29 Trend for CV of AE

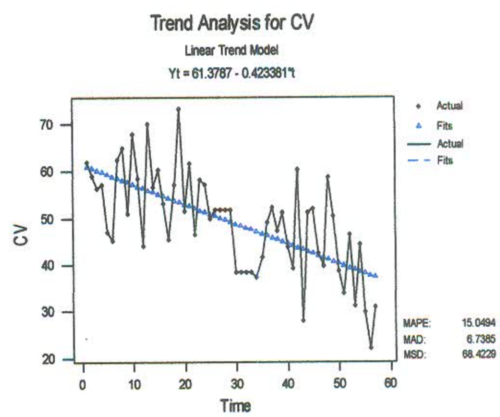


Figure 4.A.30 Trend for CV of AT (D-W)

Trend for Some Climatic Averages (Robust)

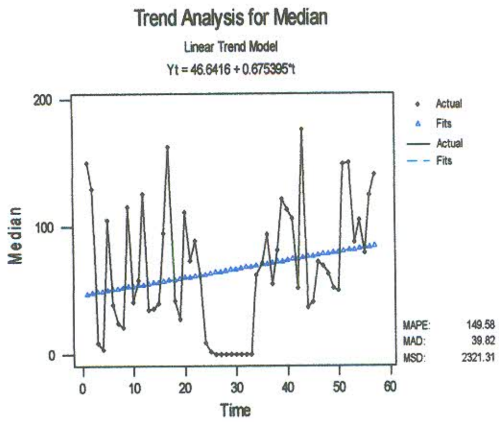


Figure 4.A.31 Trend for median of TR

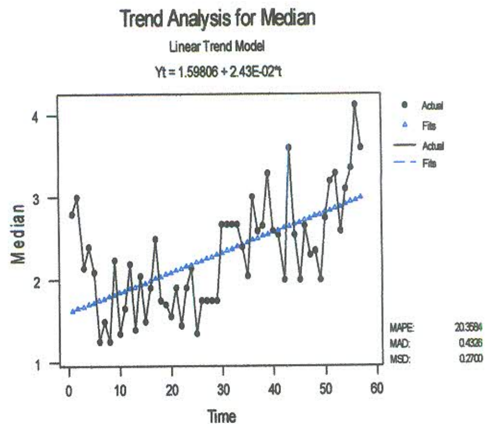


Figure 4.A.32 Trend for median of AC

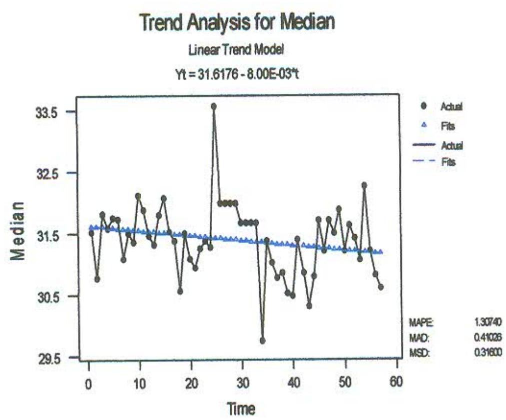


Figure 4.A.33 Trend for median of AMXT

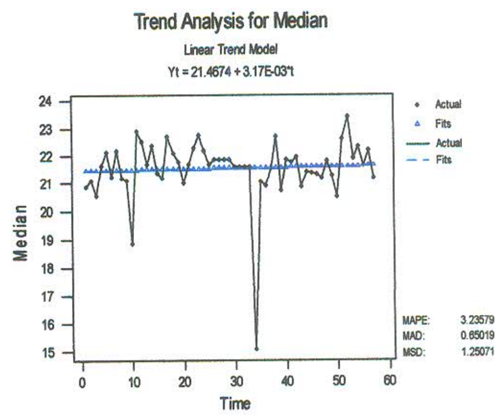


Figure 4.A.34 Trend for median of AMNT

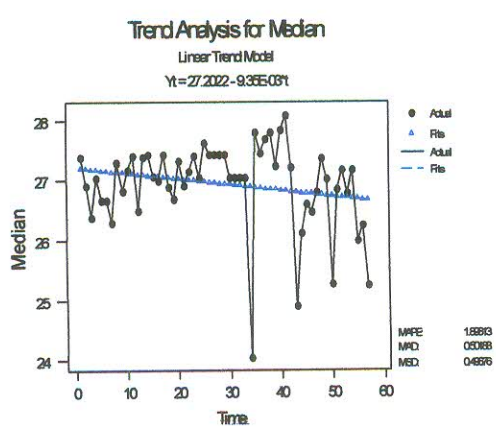


Figure 4.A.35 Trend for median of ADBT

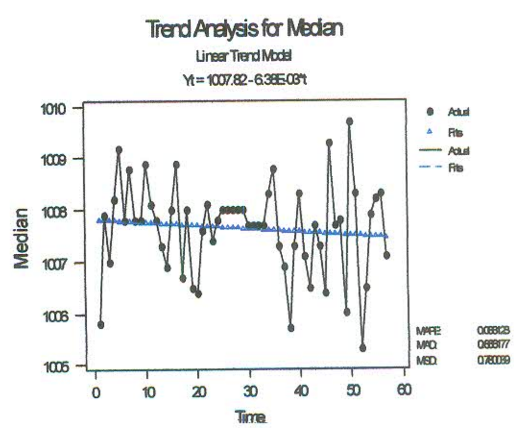


Figure 4.A.36 Trend for median of ASLP

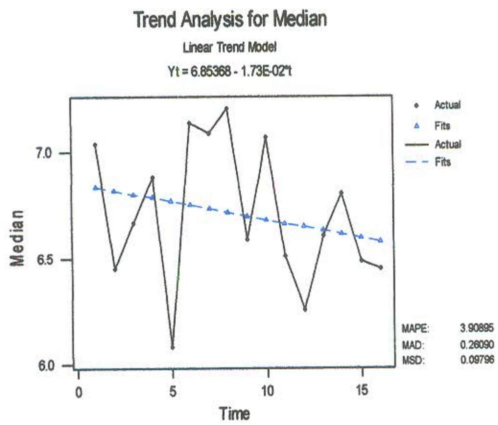


Figure 4.A.37Trend for median of ASH

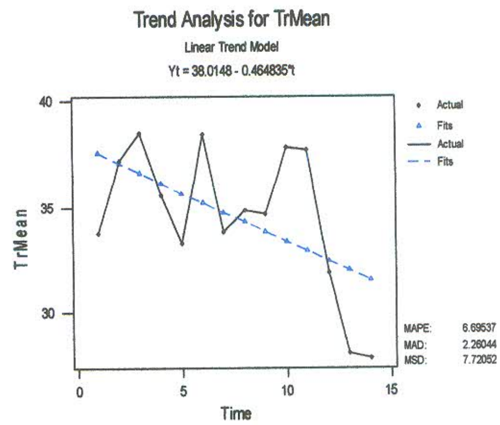


Figure 4.A.38 Trend for trimmed mean of AE

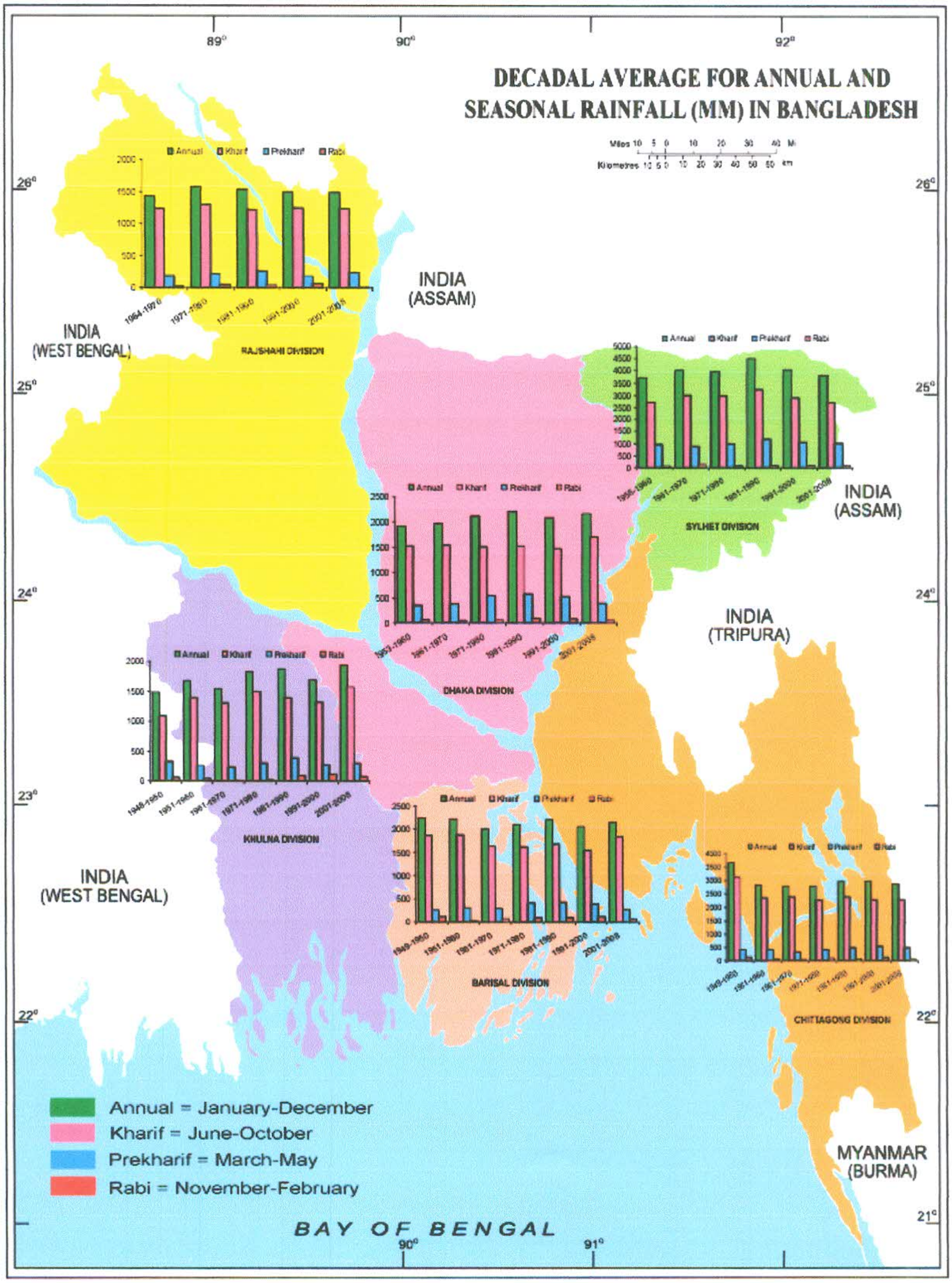


Figure 4 A. 39 Decadal Average for Annual and Seasonal Rainfall (mm) in Bangladesh

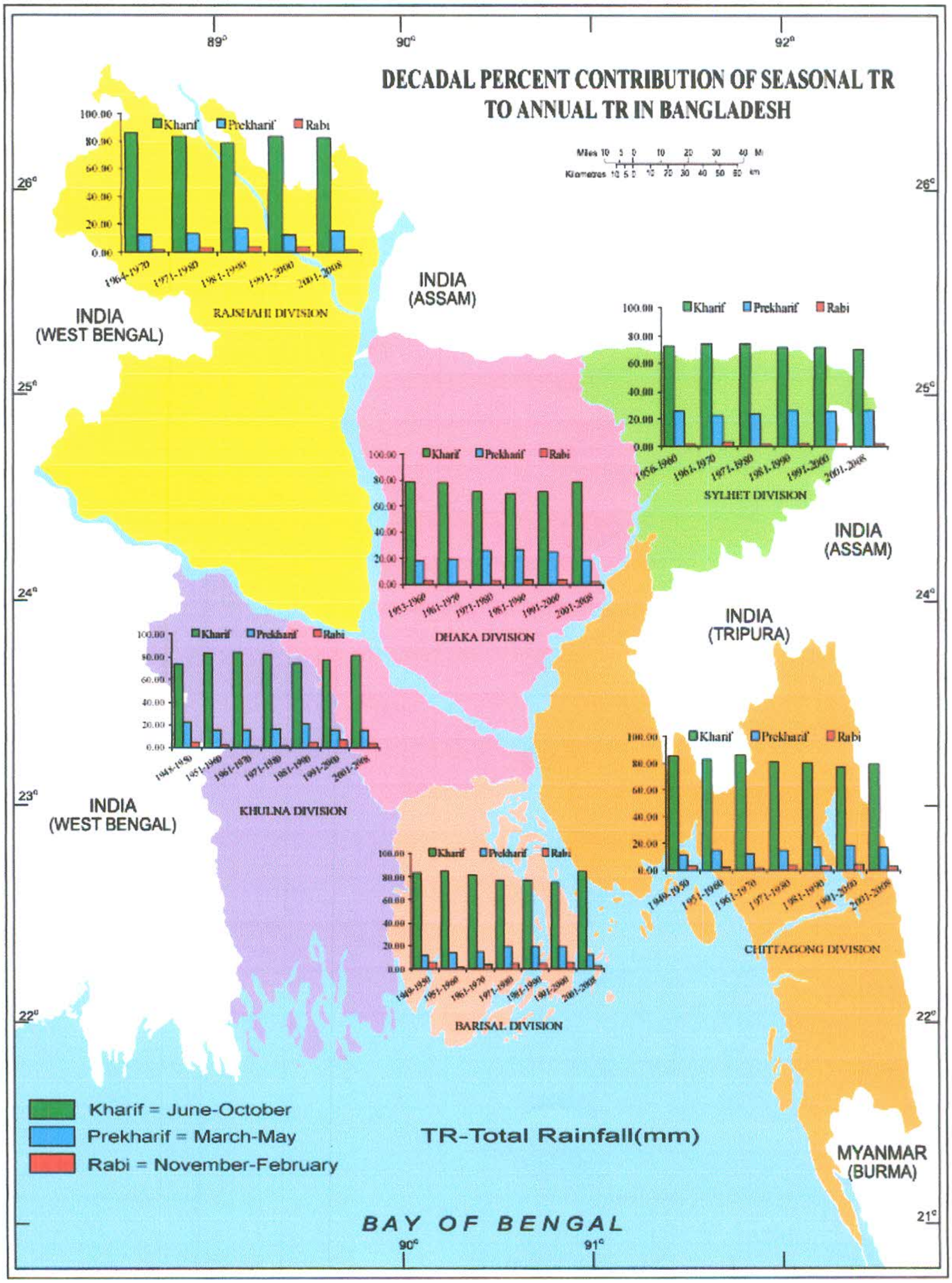
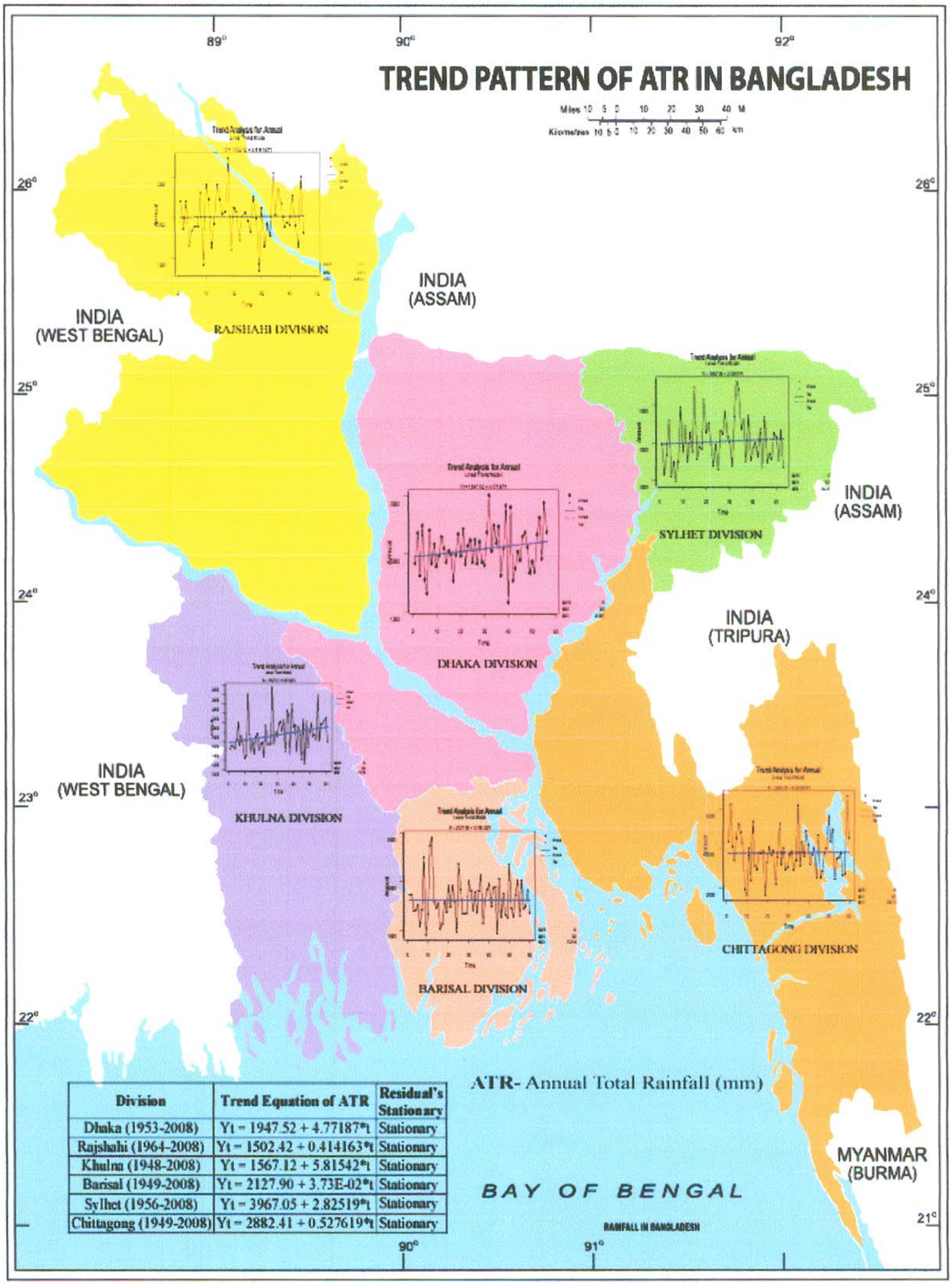


Figure 4 A. 40 Decadal Percent Contribution of Seasonal TR to Annual TR in Bangladesh



Division	Trend Equation of ATR	Residual's Stationary
Dhaka (1953-2008)	$Y_t = 1947.52 + 4.77187*t$	Stationary
Rajshahi (1964-2008)	$Y_t = 1502.42 + 0.414163*t$	Stationary
Khulna (1948-2008)	$Y_t = 1567.12 + 5.81542*t$	Stationary
Barisal (1949-2008)	$Y_t = 2127.90 + 3.73E\text{-}02*t$	Stationary
Sylhet (1956-2008)	$Y_t = 3967.05 + 2.82519*t$	Stationary
Chittagong (1949-2008)	$Y_t = 2882.41 + 0.527619*t$	Stationary

Figure 4 A. 41 Trend Pattern of ATR in Bangladesh

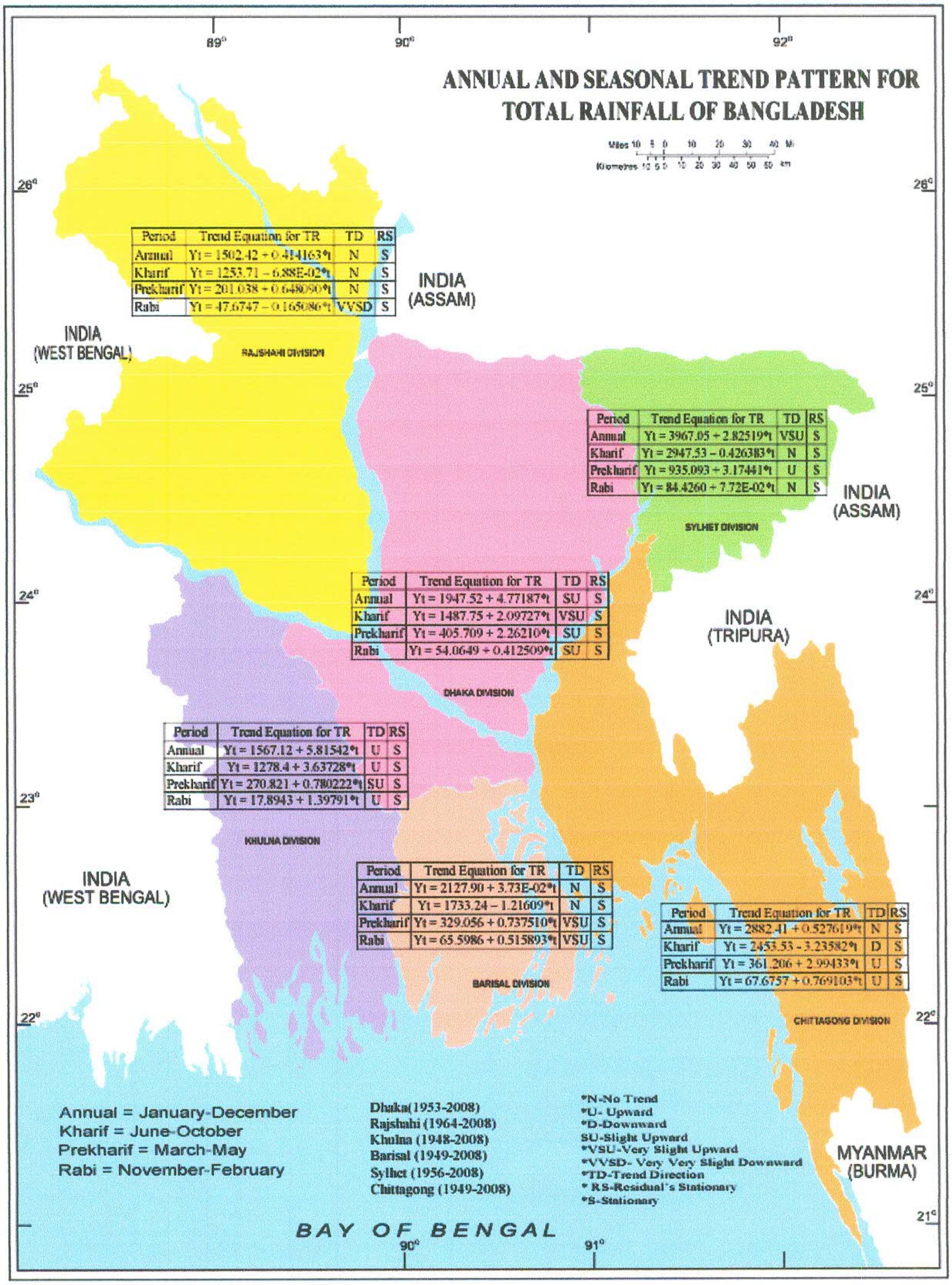


Figure 4 A. 42 Annual and Seasonal Trend Pattern for Total Rainfall of Bangladesh

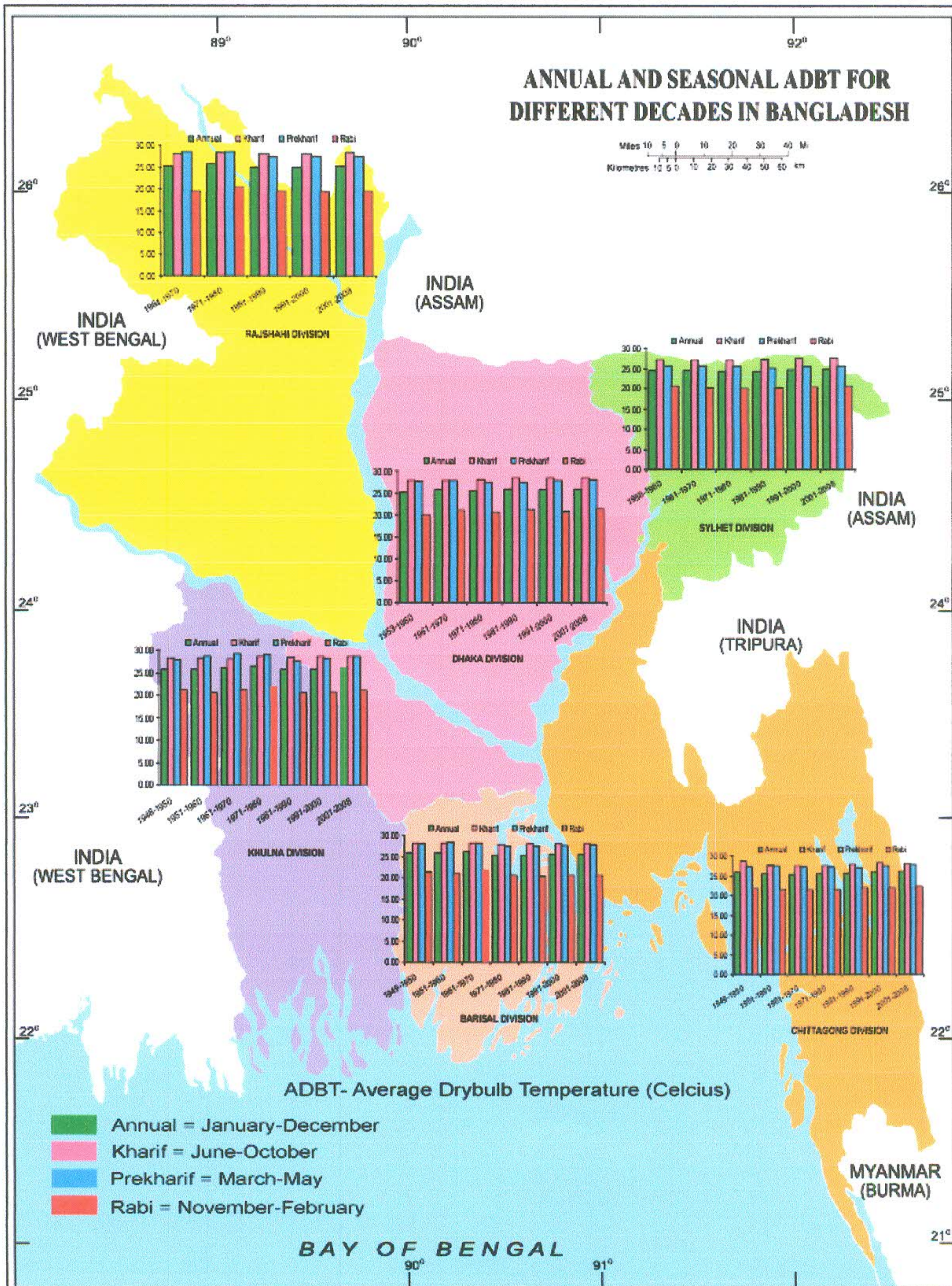


Figure 4 A. 43 Annual and Seasonal ADBT for Different Decades in Bangladesh

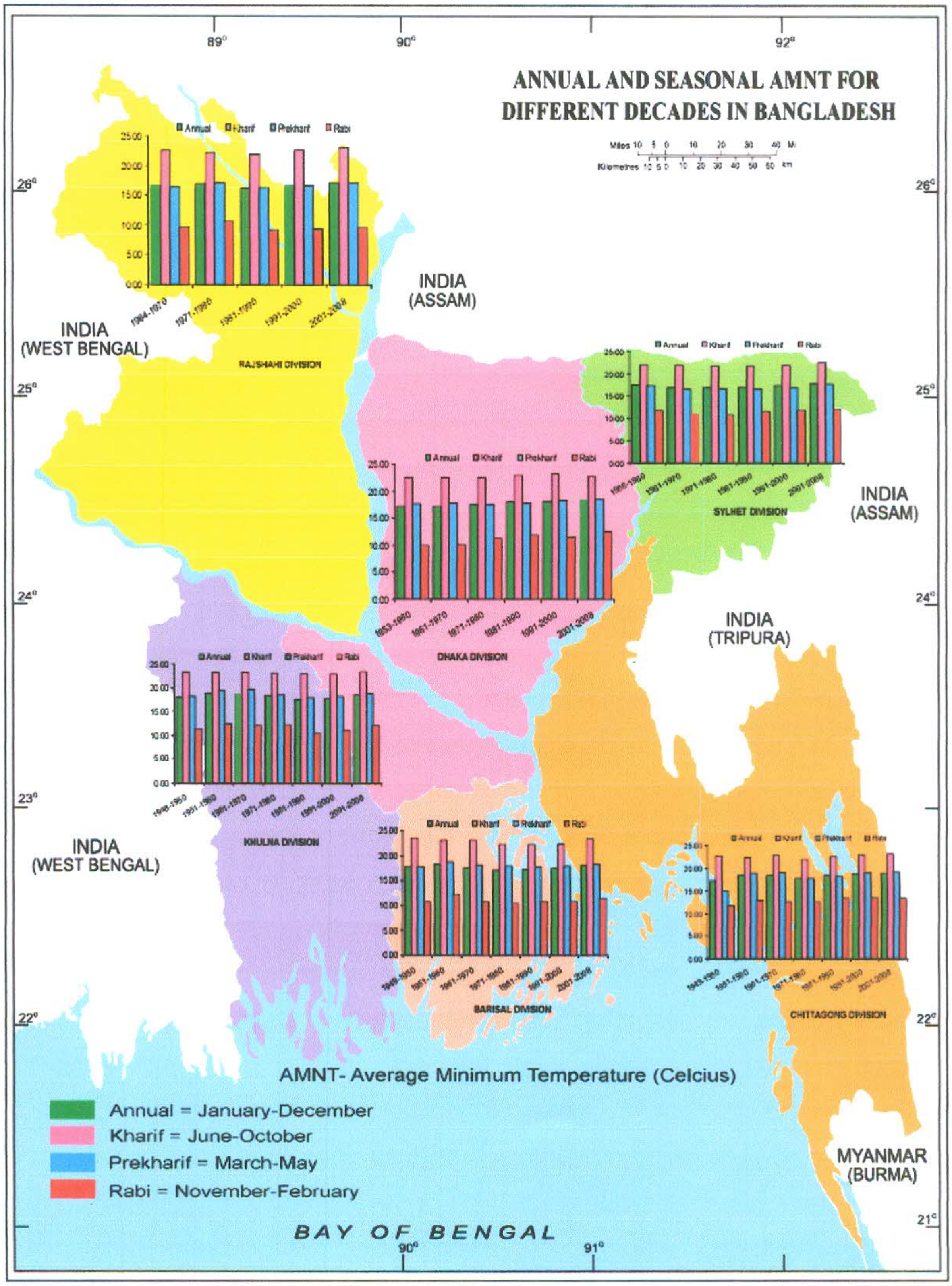
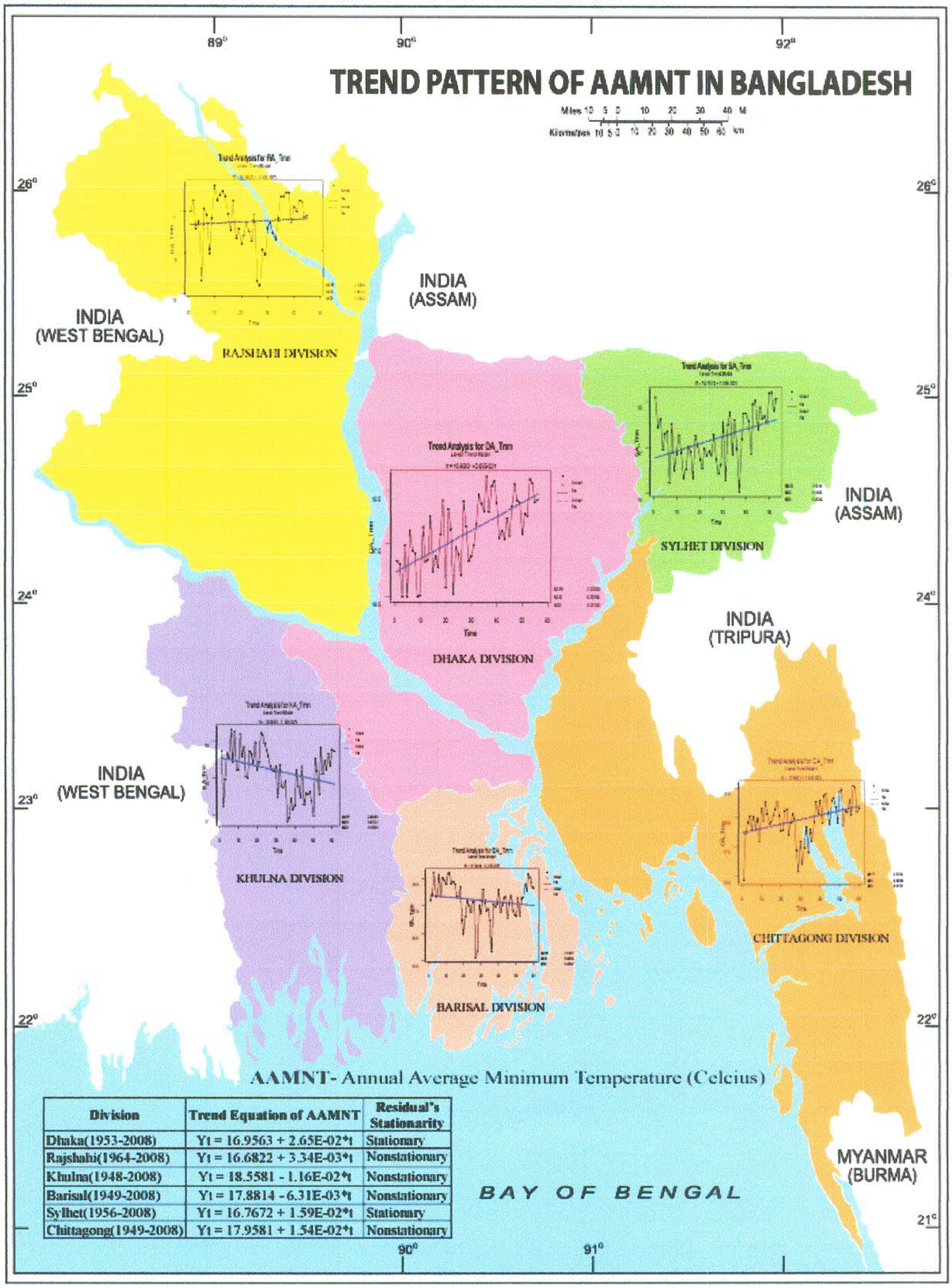
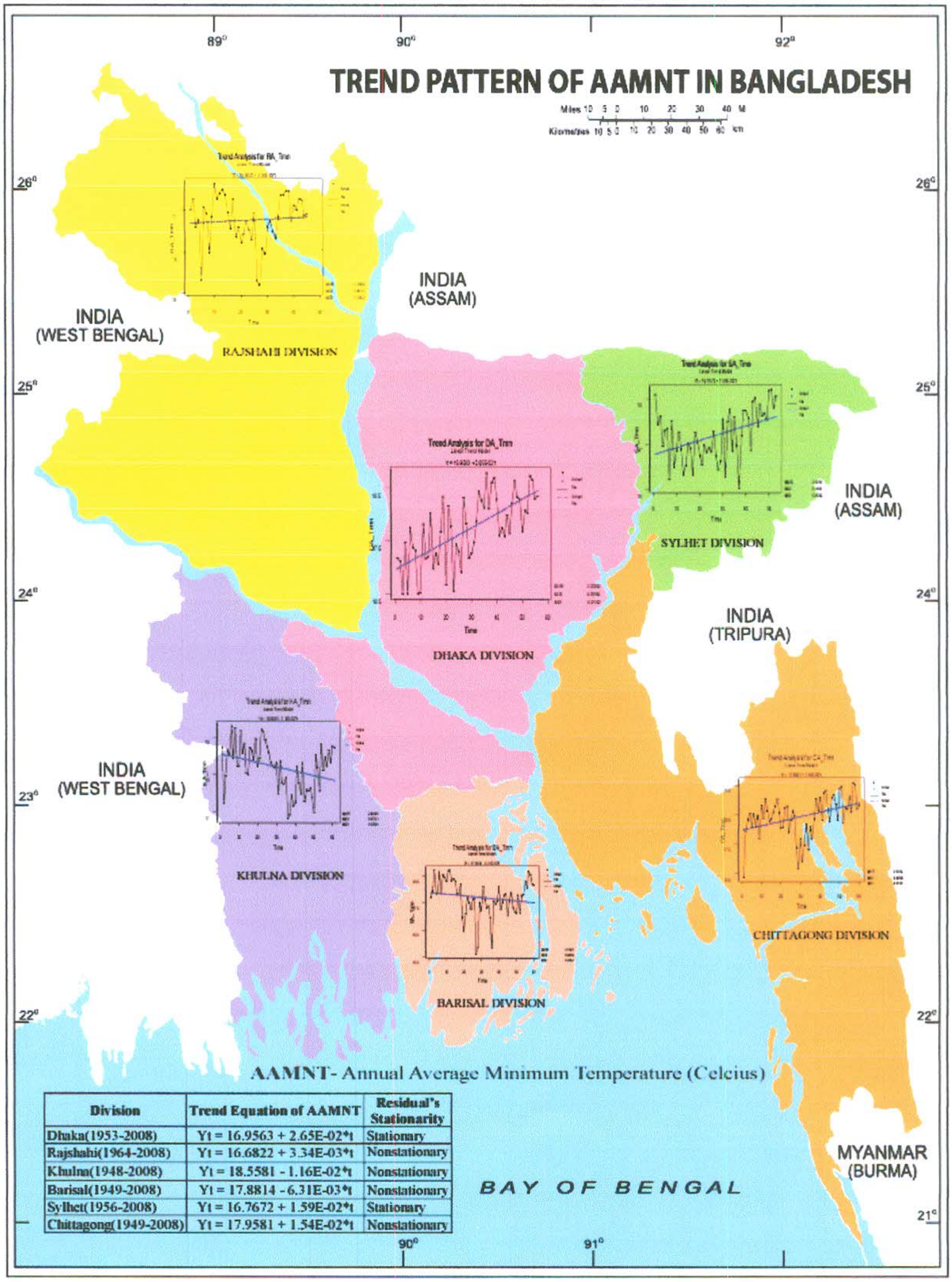


Figure 4. A. 45 Annual and Seasonal AMNT for Different Decades in Bangladesh



Division	Trend Equation of AAMNT	Residual's Stationarity
Dhaka(1953-2008)	Yt = 16.9563 + 2.65E-02*t	Stationary
Rajshahi(1964-2008)	Yt = 16.6822 + 3.34E-03*t	Nonstationary
Khulna(1948-2008)	Yt = 18.5581 - 1.16E-02*t	Nonstationary
Barisal(1949-2008)	Yt = 17.8814 -6.31E-03*t	Nonstationary
Sylhet(1956-2008)	Yt = 16.7672 + 1.59E-02*t	Stationary
Chittagong(1949-2008)	Yt = 17.9581 + 1.54E-02*t	Nonstationary

Figure 4. A. 46 Trend Pattern of AAMNT in Bangladesh



Division	Trend Equation of AAMNT	Residual's Stationarity
Dhaka(1953-2008)	Yt = 16.9563 + 2.65E-02*t	Stationary
Rajshahi(1964-2008)	Yt = 16.6822 + 3.34E-03*t	Nonstationary
Khulna(1948-2008)	Yt = 18.5581 - 1.16E-02*t	Nonstationary
Barisal(1949-2008)	Yt = 17.8814 -6.31E-03*t	Nonstationary
Sylhet(1956-2008)	Yt = 16.7672 + 1.59E-02*t	Stationary
Chittagong(1949-2008)	Yt = 17.9581 + 1.54E-02*t	Nonstationary

Figure 4. A. 46 Trend Pattern of AAMNT in Bangladesh

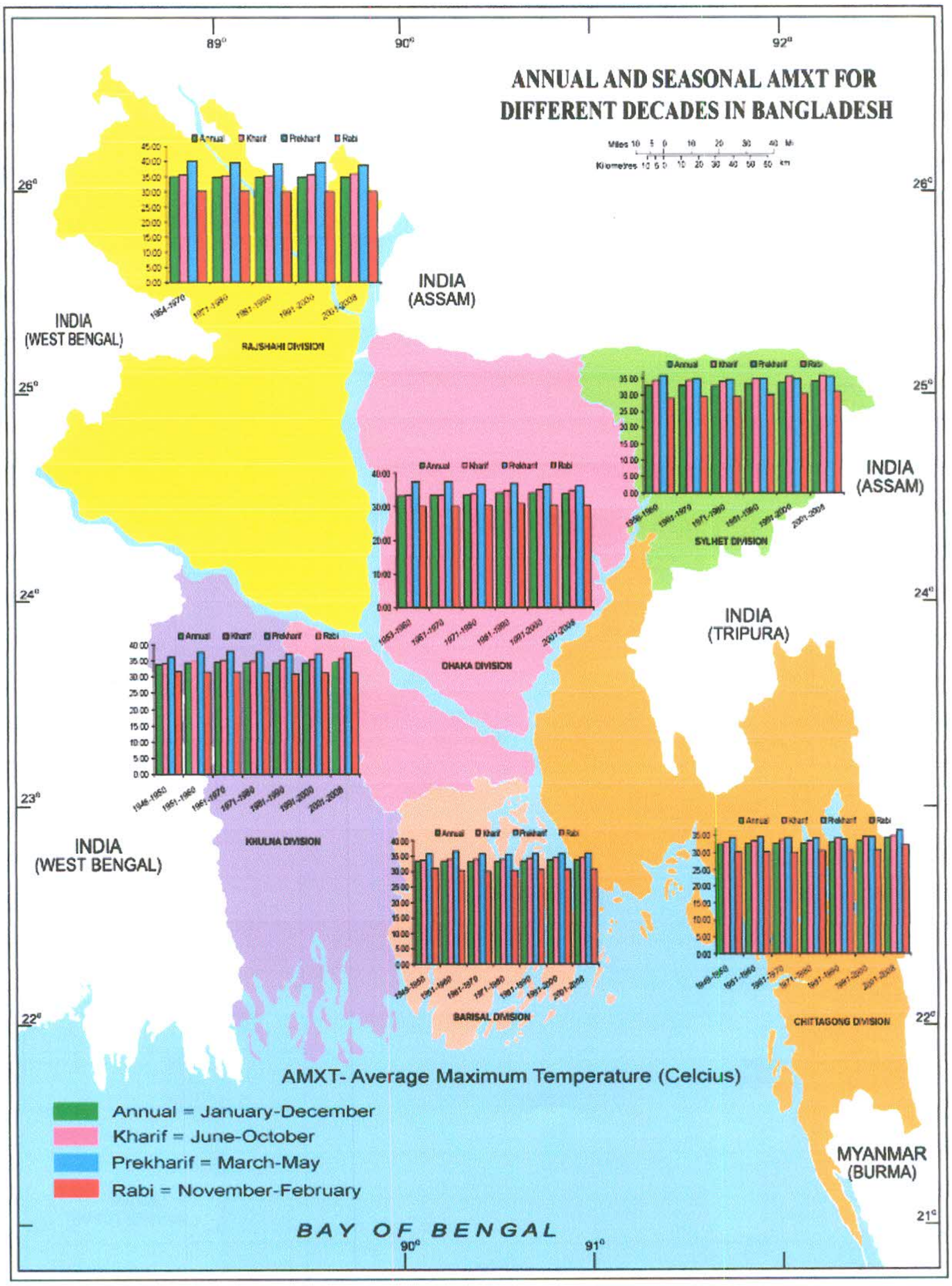
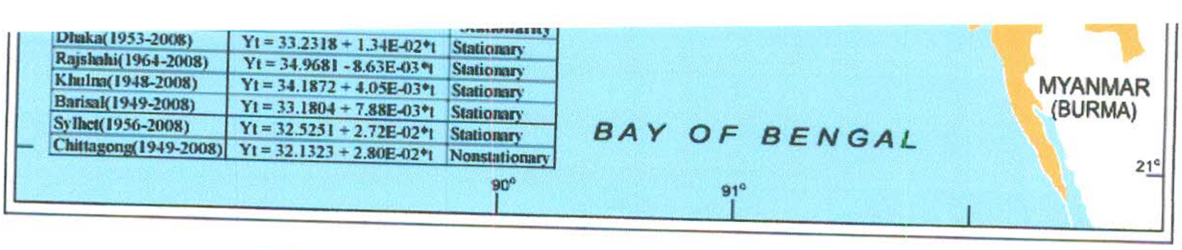
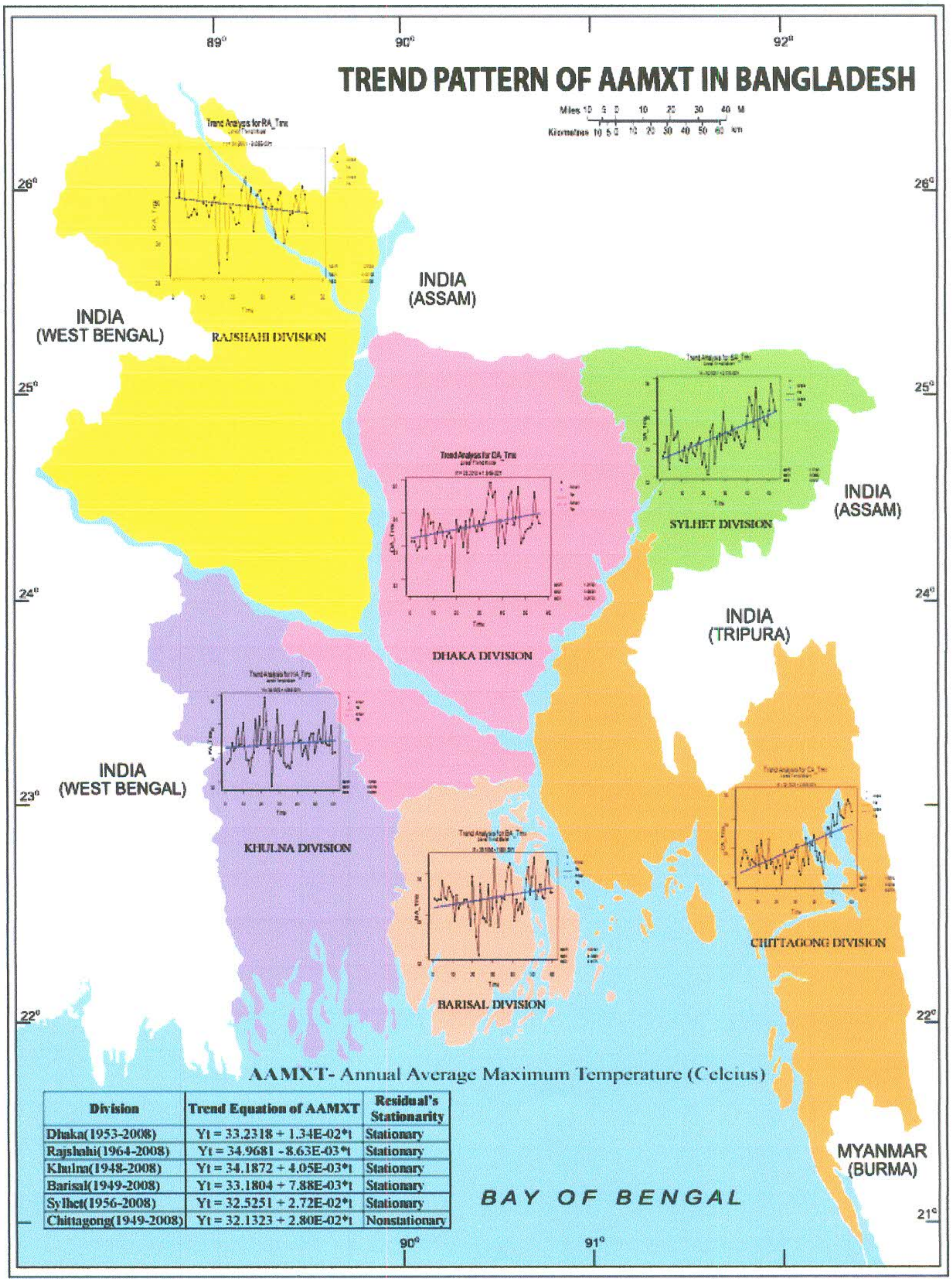


Figure 4. A. 47 Annual and Seasonal AMXT for Different Decades in Bangladesh



Dhaka(1953-2008)	Yt = 33.2318 + 1.34E-02*t	Stationary
Rajshahi(1964-2008)	Yt = 34.9681 - 8.63E-03*t	Stationary
Khulna(1948-2008)	Yt = 34.1872 + 4.05E-03*t	Stationary
Barisal(1949-2008)	Yt = 33.1804 + 7.88E-03*t	Stationary
Sylhet(1956-2008)	Yt = 32.5251 + 2.72E-02*t	Stationary
Chittagong(1949-2008)	Yt = 32.1323 + 2.80E-02*t	Nonstationary

Figure 4. A. 48 Trend Pattern of AAMXT in Bangladesh



Division	Trend Equation of AAMXT	Residual's Stationarity
Dhaka(1953-2008)	Yt = 33.2318 + 1.34E-02*t	Stationary
Rajshahi(1964-2008)	Yt = 34.9681 - 8.63E-03*t	Stationary
Khulna(1948-2008)	Yt = 34.1872 + 4.05E-03*t	Stationary
Barisal(1949-2008)	Yt = 33.1804 + 7.88E-03*t	Stationary
Sylhet(1956-2008)	Yt = 32.5251 + 2.72E-02*t	Stationary
Chittagong(1949-2008)	Yt = 32.1323 + 2.80E-02*t	Nonstationary

Figure 4. A. 48 Trend Pattern of AAMXT in Bangladesh

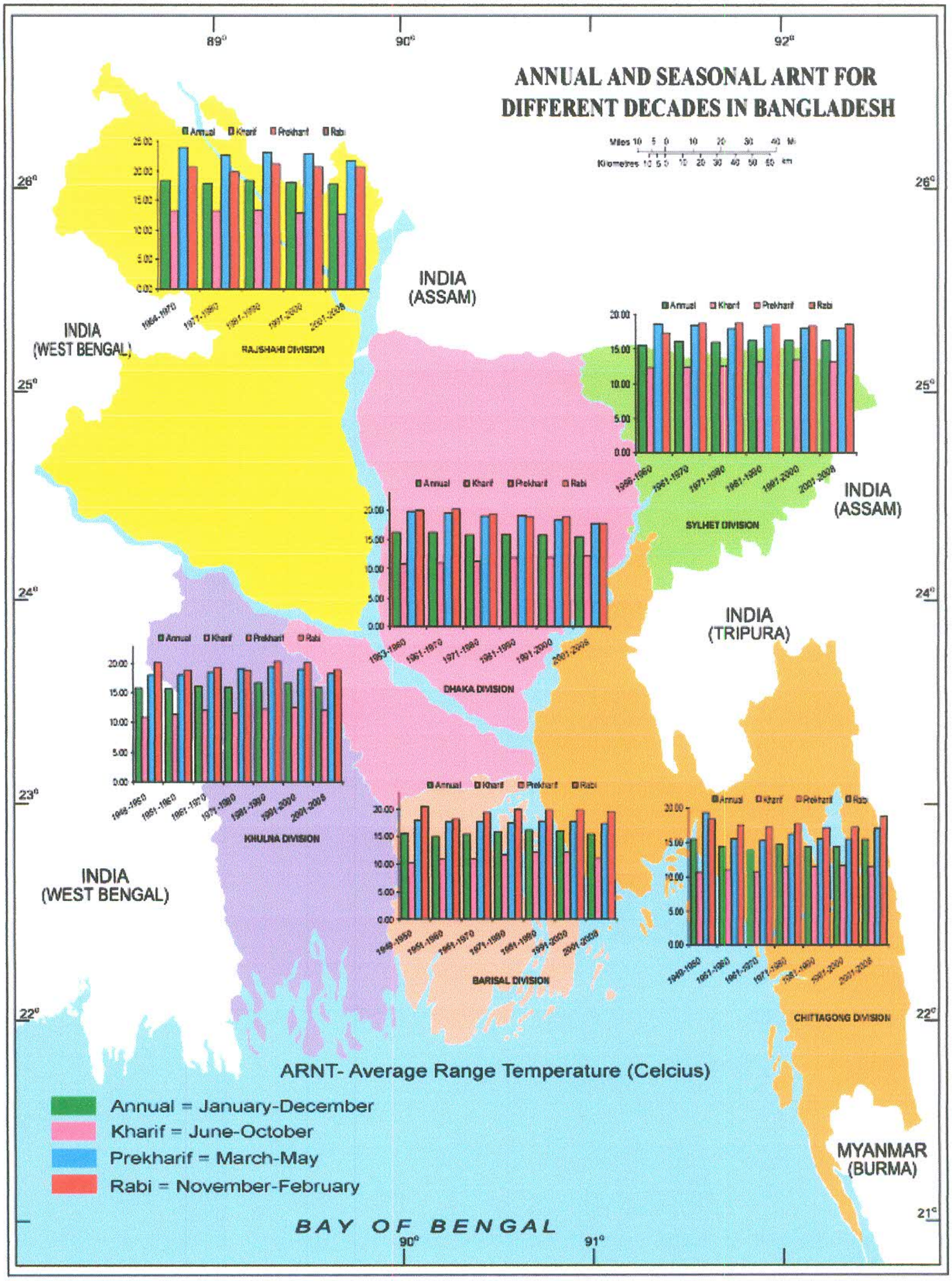
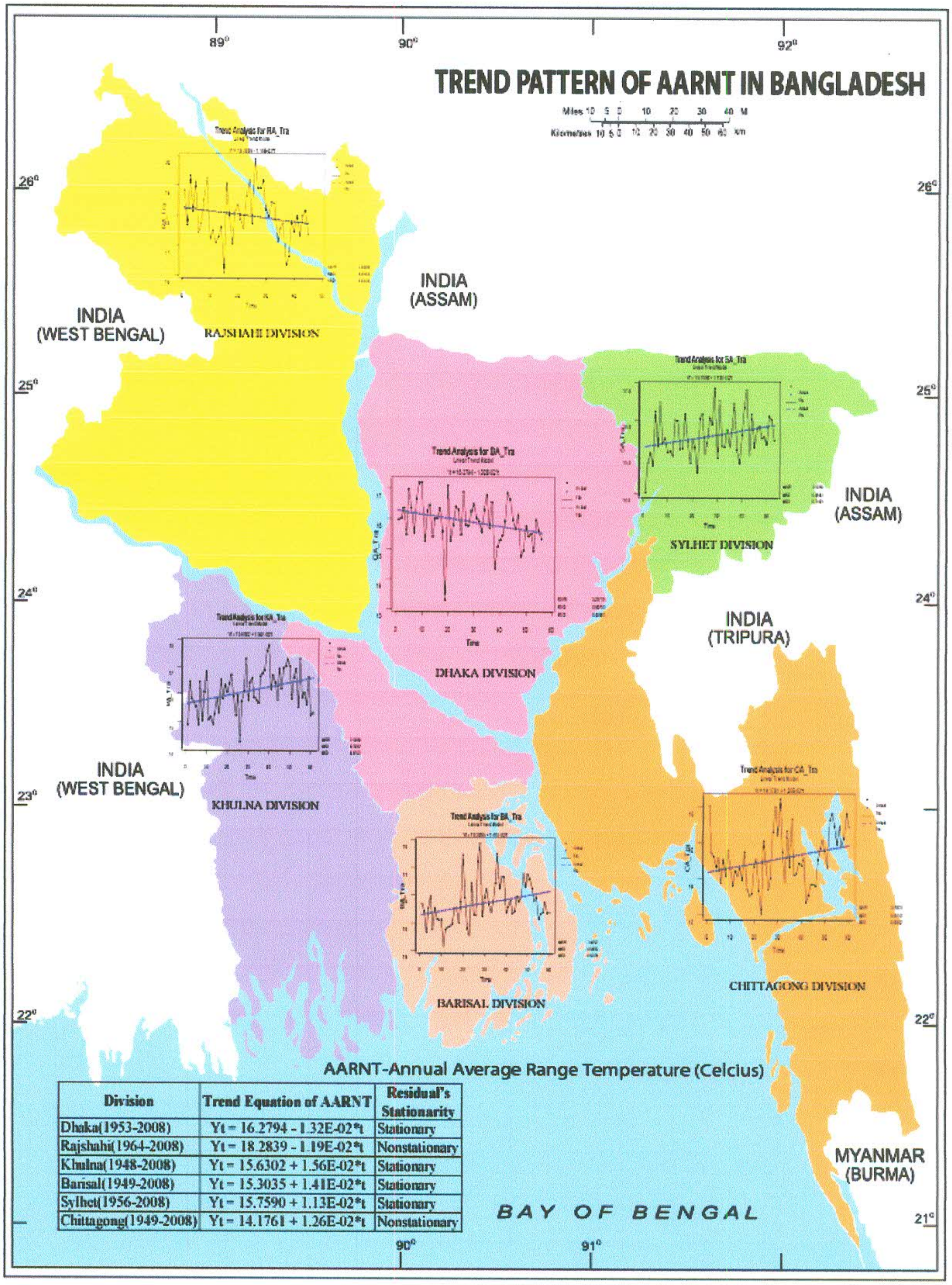
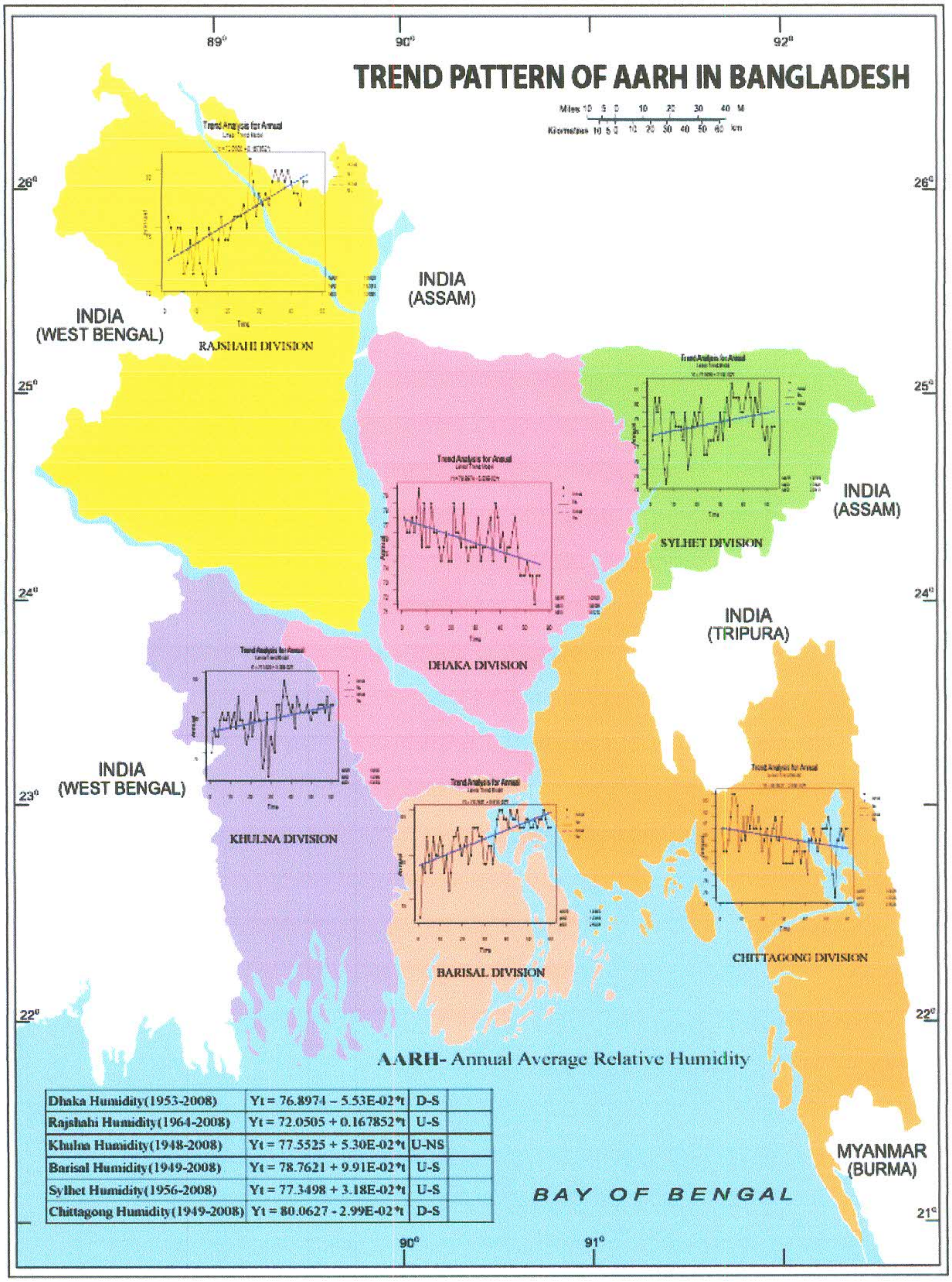


Figure 4. A. 49 Annual and Seasonal ARNT for Different Decades in Bangladesh



Division	Trend Equation of AARNT	Residual's Stationarity
Dhaka(1953-2008)	Yt = 16.2794 - 1.32E-02*t	Stationary
Rajshahi(1964-2008)	Yt = 18.2839 - 1.19E-02*t	Nonstationary
Khulna(1948-2008)	Yt = 15.6302 + 1.56E-02*t	Stationary
Barisal(1949-2008)	Yt = 15.3035 + 1.41E-02*t	Stationary
Sylhet(1956-2008)	Yt = 15.7590 + 1.13E-02*t	Stationary
Chittagong(1949-2008)	Yt = 14.1761 + 1.26E-02*t	Nonstationary

Figure 4. A. 50 Trend Pattern of AARNT in Bangladesh



Dhaka Humidity(1953-2008)	Yt = 76.8974 – 5.53E-02*t	D-S	
Rajshahi Humidity(1964-2008)	Yt = 72.0505 + 0.167852*t	U-S	
Khulna Humidity(1948-2008)	Yt = 77.5525 + 5.30E-02*t	U-NS	
Barisal Humidity(1949-2008)	Yt = 78.7621 + 9.91E-02*t	U-S	
Sylhet Humidity(1956-2008)	Yt = 77.3498 + 3.18E-02*t	U-S	
Chittagong Humidity(1949-2008)	Yt = 80.0627 - 2.99E-02*t	D-S	

Figure 4. A. 51 Trend Pattern of AARH in Bangladesh

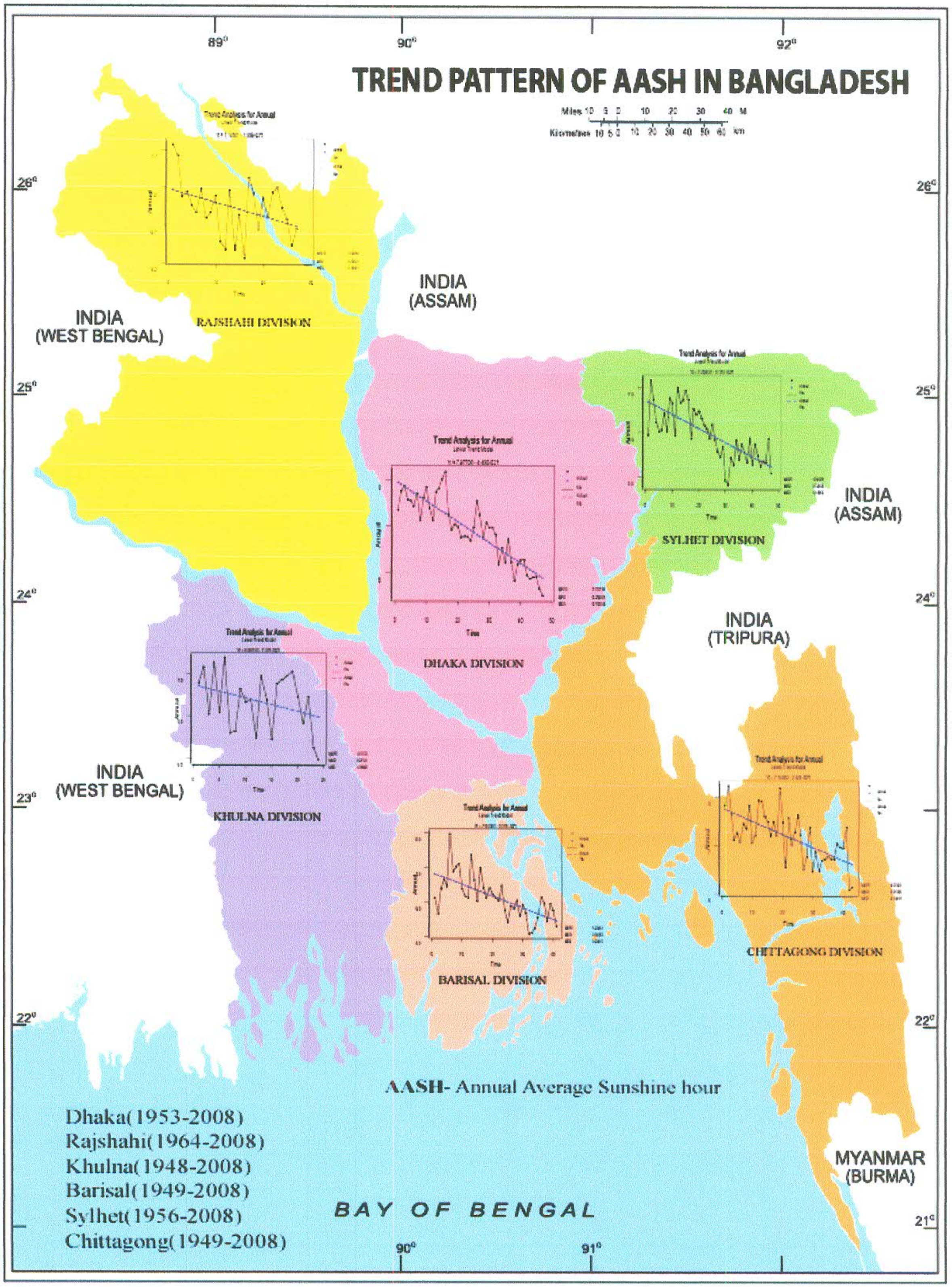
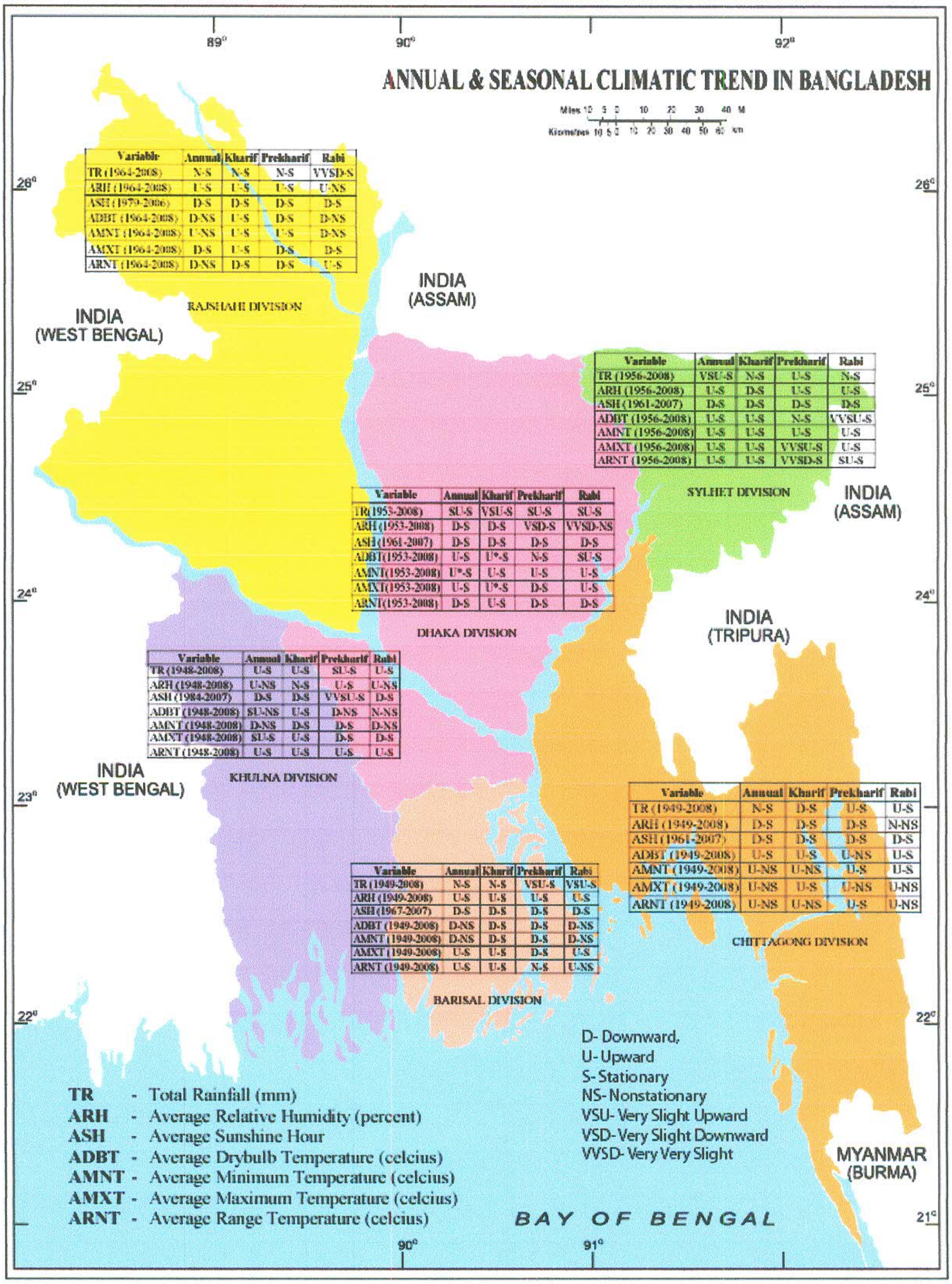


Figure 4. A. 52 Trend Pattern of AASH in Bangladesh



Rajshahi Division

Variable	Annual	Kharif	Prekharif	Rabi
TR (1964-2008)	N-S	N-S	N-S	VVSD-S
ARH (1964-2008)	U-S	U-S	U-S	U-NS
ASH (1979-2006)	D-S	D-S	D-S	D-S
ADBT (1964-2008)	D-NS	U-S	D-S	D-NS
AMNT (1964-2008)	U-NS	U-S	U-S	D-NS
AMXT (1964-2008)	D-S	U-S	D-S	D-S
ARNT (1964-2008)	D-NS	D-S	D-S	U-S

Sylhet Division

Variable	Annual	Kharif	Prekharif	Rabi
TR (1956-2008)	VSU-S	N-S	U-S	N-S
ARH (1956-2008)	U-S	D-S	U-S	U-S
ASH (1961-2007)	D-S	D-S	D-S	D-S
ADBT (1956-2008)	U-S	U-S	N-S	VVSU-S
AMNT (1956-2008)	U-S	U-S	U-S	U-S
AMXT (1956-2008)	U-S	U-S	VVSU-S	U-S
ARNT (1956-2008)	U-S	U-S	VVSD-S	SU-S

Dhaka Division

Variable	Annual	Kharif	Prekharif	Rabi
TR(1953-2008)	SU-S	VSU-S	SU-S	SU-S
ARH(1953-2008)	D-S	D-S	VSD-S	VVSD-NS
ASH(1961-2007)	D-S	D-S	D-S	D-S
ADBT(1953-2008)	U-S	U*-S	N-S	SU-S
AMNT(1953-2008)	U*-S	U-S	U-S	U-S
AMXT(1953-2008)	U-S	U*-S	D-S	U-S
ARNT(1953-2008)	D-S	U-S	D-S	D-S

Khulna Division

Variable	Annual	Kharif	Prekharif	Rabi
TR (1948-2008)	U-S	U-S	SU-S	U-S
ARH (1948-2008)	U-NS	N-S	U-S	U-NS
ASH (1984-2007)	D-S	D-S	VVSU-S	D-S
ADBT (1948-2008)	SU-NS	U-S	D-NS	N-NS
AMNT (1948-2008)	D-NS	D-S	D-S	D-NS
AMNT (1948-2008)	SU-S	U-S	D-S	D-S
ARNT (1948-2008)	U-S	U-S	U-S	U-S

Chittagong Division

Variable	Annual	Kharif	Prekharif	Rabi
TR (1949-2008)	N-S	D-S	U-S	U-S
ARH (1949-2008)	D-S	D-S	D-S	N-NS
ASH (1961-2007)	D-S	D-S	D-S	D-S
ADBT (1949-2008)	U-S	U-S	U-NS	U-S
AMNT (1949-2008)	U-NS	U-NS	U-S	U-S
AMXT (1949-2008)	U-NS	U-S	U-NS	U-NS
ARNT (1949-2008)	U-NS	U-NS	U-S	U-NS

Barisal Division

Variable	Annual	Kharif	Prekharif	Rabi
TR (1949-2008)	N-S	N-S	VSU-S	VSU-S
ARH (1949-2008)	U-S	U-S	U-S	U-S
ASH (1967-2007)	D-S	D-S	D-S	D-S
ADBT (1949-2008)	D-NS	D-S	D-S	D-NS
AMNT (1949-2008)	D-NS	D-S	D-S	D-NS
AMXT (1949-2008)	U-S	U-S	D-S	U-S
ARNT (1949-2008)	U-S	U-S	N-S	U-NS

Figure 4.A.53 Annual & Seasonal Climatic Trend in Bangladesh

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