# CLIMATE MODELING, DROUGHT RISK ASSESSMENT AND ADAPTATION STRATEGIES IN THE WESTERN PART OF BANGLADESH

**PhD Thesis**

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# DEDICATION

*Dedicated*

*to*

*My Beloved Parents*

*and*

*My Family Members*

# DECLARATION

I hereby declare that the thesis entitled **"Climate Modeling, Drought Risk Assessment and Adaptation Strategies in the Western Part of Bangladesh"** submitted to the Institute of Bangladesh Studies (IBS), University of Rajshahi, Bangladesh for the degree of Doctor of Philosophy is my own research work and the material contained within the thesis has not been submitted previously for the award of any other degree or diploma at this University or any other institutions.

I also declare that any help received in preparing this thesis and all sources are acknowledged or cited.

31.03.2014

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# CERTIFICATE OF APPROVAL

We hereby certify that Mr. Md. Kamruzzaman has fulfilled the conditions of the rules and regulations for the degree of Doctor of Philosophy in Statistics from the University of Rajshahi, Bangladesh. We hope, this thesis is completely adequate to submit for the degree.

To the best of our knowledge, this piece of work is unique and not submitted elsewhere for any degree or diploma.

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**The Author**

# LIST OF ACRONYMS

| Short Form | | Full Name |
|---|---|---|
| ADPC | : | Asian Disaster Preparedness Center |
| AEZ | : | Agro Ecological Zones |
| AMS | : | American Metrological Society |
| *Aus* | : | A rice crop coinciding with late dry and early monsoon season |
| BARC | : | Bangladesh Agriculture Research Council |
| BARI | : | Bangladesh Agricultural Research Institute |
| *Barind* | : | Undulating uplands with red/yellow clay soils of Northwest Bangladesh |
| BBS | : | Bangladesh Bureau of Statistics |
| BIDS | : | Bangladesh Institute of Development Studies |
| BMD | : | Bangladesh Meteorological Department |
| BMDA | : | Barind Multi-purpose Development Authority |
| *Boro* | : | Dry season rice, grown from December to April |
| BRRI | : | Bangladesh Rice Research Institute |
| BWDB | : | Bangladesh Water Development Board |
| CCCS | : | Climate Change Country Study |
| CMI | : | Crop Moisture Index |
| DAE | : | Department of Agricultural Extension |
| DI | : | Drought Index |
| DM | : | Drought Monitor |
| DMB | : | Disaster Management Bureau |
| FAO | : | Food and Agriculture Organization |
| GDP | : | Gross Domestic Product |
| GIS | : | Geographic Information System |
| IPCC | : | Inter-Governmental Panel on Climate Changes |
| *Khari* | : | Traditional irrigation canals |

| Short Form | | Full Name |
|---|---|---|
| Kharif | : | Season typically from March to June |
| Pre-Kharif | : | Season typically from July to October |
| NAP | : | National Action Programme |
| NDMC | : | National Drought Mitigation Centre |
| NWP | : | National Water Plan |
| OECD | : | Organization for Economic Co-operation and Development |
| Rabi | : | Dry season, typically from November to February |
| SPARSO | : | Space Research and Remote Sensing Organization |
| SPI | : | Standardized Precipitation Index |
| *T.aman* | : | Transplanted *aman* rice typically from July to October |
| *T.aus* | : | Transplanted *aus* rice, typically grown from March to June/July |
| UNCCD | : | United Nations Convention to Combat Desertification |
| UNDP | : | United Nations Development Programme |
| UNFCC | : | United Nations Framework Conversation to Climate Change |
| WARPO | : | Water Resources Planning Organization |
| WMO | : | World Meteorological Organization |

# ABSTRACT

Climate change is the greatest environmental challenge facing the world today and meteorological extremes like drought have been a subject of global concern since long. Present study on climate modeling, drought risk assessment and adaptation strategies have been carried out in the western part of Bangladesh with the aims of assessing the agricultural drought risk to find out the sustainable adaptation measures in the context of global climate change. Daily rainfall data reduced in weekly form of 12 meteorological stations for the period 1960 to 2011 have been used in this study.

Climate modeling has been performed by Mann-Kendall (MK) test statistics (trend detection), Sen's slope estimator (rate of change) and Autoregressive Integrated Moving Average (ARIMA) model (future prediction). Drought hazards have been characterized by Markov chain analysis and drought vulnerability explored using socio-economic indicators. Drought risk map has been developed by integrating drought hazard and vulnerability indices by Geographical Information System (GIS).

Annual average temperature in the area is about 25.44°C. The lowest mean annual temperature experiences in the north-east and the highest in south-western part of the area. The spatial pattern of seasonal temperature is similar like annual temperature. Predicted annual mean temperatures by ARIMA model may vary from 24.47 to 25.97, 24.57 to 26.03, 24.69 to 26.03, 24.54 to 26.03 and 24.73 to 26.75°C in the area during the period 2012 to 2016 respectively and they are higher than the long term observed mean temperature. Though temperature is rising, the predicted spatial pattern will remain same in the future.

The north-west of the area is more drought prone and less crops prospect area due to the low values of drought index (DI), probability of getting at least 8, 10 and 12 consecutive wet weeks is comparatively low, probability of at least 3 consecutive dry weeks is comparatively high and expected number of wet weeks lies between 7 to 9. The southern part is less drought prone and high crops prospect areas due to the high values of DI, probability of getting at least 8, 10 and 12 consecutive wet weeks is comparatively high, probability of

at least 3 consecutive dry weeks is comparatively low and expected number of wet weeks lies between 10 to 13. Decade and year wise analysis also indicate almost similar results. Annual occurrences and percentage of annual probability indicate that probability of extreme drought occurrence increases in recent decades in Dinajpur, Ishwardi and Rajshahi areas, but frequency is decreasing i.e. drought event is becoming more frequent in these areas. In the study area, drought hazard index (DHI) ranges from 15 to 32. Spatial pattern of DHI indicates that northern districts like Panchagarh, Thakurgoan, Dinajpur, Nilphamari, Nawabganj, Naogaon, Rajshahi and Natore suffer from more extreme drought hazards in comparison to rest of the districts. Drought vulnerability index (DVI) indicates that the northern part of the area are exposed to high to very high drought vulnerable as higher percentage of illiterate people, higher dependence on agricultural practices and high percentage of irrigated to cultivable land. The southern part of the study area exposes moderate to low vulnerable as all the values of vulnerability indicators are comparatively low.

Drought risk map has been prepared integrating DHI and DVI values and show agricultural drought poses high risk in northern districts and low in southern districts (coastal areas). It is also found that 21.63%, 26.54% and 29.68% of the study area are exposed to very high, high and moderate drought risk respectively. High DHI value due to high variability of rainfall and high DVI due to weak socio-economic conditions has made the northern part turn more drought vulnerable area than other parts. Hazard risk ranking based on frequency and severity of agricultural drought classes indicate even low risk areas also suffer from extreme agricultural drought due to uneven spatio-temporal nature of rainfall during cropping season.

To minimize the adverse effect of drought, some adaptation strategies have been suggested based on study findings: socio-economic and physical factors should be included in management policy to make more effective planning. The drought mitigating hydrological adaptation measures should be taken after ranking risks, importance of sector and climate associated events, and effective drought forecasting and warning techniques need to be considered. Therefore, it is urgent to act on adaptation keeping in mind about climate features such as rainfall and temperature variability, possible impacts of climate change and risk ranking to make viable mitigation measures.

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# Chapter I

# Thesis Preliminary

# CHAPTER I

# THESIS PRELIMINARY

## 1.1 Introduction

Drought differs from other natural hazards, because of its slow onset nature but it can have the greatest impact and affect large number of peoples. Drought must be considered as relative, rather than an absolute condition. It is temporary but complex feature of the climatic system of a given region with wide-spread significance (Olapido, 1985), that is usually caused by precipitation deficit (Gregory, 1986), and can occur in both high and low rainfall areas. Commonly the main cause of a drought is the lack of precipitation for extensive period of time. Through hydrological process, this lack of precipitation will make lower in soil moisture, ground water, and stream flow. As slow onset event, drought can cover extensive areas that effects may be accumulated over time and may remain for several years. The impact of drought results from the shortage of water or the unbalance condition between supply and demand for water as one of the environmental aspect. Such natural disasters leave a long term effect on a socio-economic fabric of a region where it strikes, sometimes requiring relief efforts on a global scale (Ahmed, 1995).

Historically drought has persistently affected human activity (e.g. Hodell et al. 1995, Stine, 1994). The reduction of the drought impacts has obvious benefits economically and environmentally. Development towards this involves making progresses to operational monitoring and seasonal forecasting which in turn requires greater understanding of the occurrence of drought and the mechanisms that drive its initiation, persistence and recovery. There is also a need to understand the potential changes in drought under future climate warming. Despite its omnipresent nature, our knowledge of the onset, development and recession of drought is in deficient, that hampers not only our ability to monitor but also to predict its occurrence at seasonal time scales, and to evaluate climate model for projections of future changes. The

impacts of drought (first order impacts such as food security concerns and second order impacts such as increasing food imports from abroad) produce a range of effects for many in society (Benson and Clay, 1998) and its impacts are varying in different degrees. Food insecurity, for example, is one of the biggest associated drought impacts as the level of food is usually reduced during a drought thereby increasing the vulnerability of people.

Bangladesh is one of the most disaster-prone countries in the world. Almost every year, the country experiences disasters of one kind or another, such as tropical cyclones, storm surges, coastal erosion, floods and droughts causing heavy loss of life and property with hampering the development activities (Ali 1996). High spatial and temporal climatic variability, extreme weather events, high population density, high incidence of poverty and social inequity, poor institutional capacity, inadequate financial resources, and poor infrastructure have made Bangladesh highly vulnerable to disaster (Ahmed, 2004). Drought is a recurrent phenomenon in northwest part of Bangladesh and has suffered from nine droughts of major magnitude since its independence in 1971, (Paul, 1998). Although it's recurrent and devastating nature in Bangladesh, it has attracted far reaching less scientific attention than floods or cyclones (Alexander, 1995; Brammer, 1987). Many studies have been carried out in Bangladesh on the impact of droughts on agriculture (Karim et al. 1990; Jabber, 1990; Jabber et al. 1982; Saleh et al. 2000; Mazid et al. 2005), food production (Ahmed and Bernard, 1989; Ericksen et al. 1993). The first agricultural drought risk map of Bangladesh was prepared by Karim et al. (1990) by considering the cumulative effect of dry days, higher temperatures during pre-monsoon period and soil moisture availability. Karim and Iqbal (2001) produced three different drought risk maps for winter, pre-monsoon, and monsoon seasons and they defined drought risk classes as slight, moderate, severe, and very severe related to the yield losses of 15-20%, 20-35%, 35-45%, and 45-70%, respectively, for different crops.

A few studies have been carried out on drought impact using standard drought modeling in Bangladesh but a study has been performed on the extent and impacts of drought in the western part of Bangladesh using

Standardized Precipitation Index (SPI) method considering socio-economic and physical indicators of drought vulnerability (Shahid and Behrawan, 2008). They also prepared drought risk map accordingly, but fails to prepare more accurate composite drought vulnerability map because they are taken a linear combination of different socio-economic and physical indicators with different units which is a mathematically unsound concepts. Besides these, they emphasized meteorological drought risk assessment only, but agricultural drought risk assessment is a major concern of the agro-based countries like Bangladesh. So far, no comprehensive studies have been carried out on climate modeling, drought risk assessment and adaptation strategies in Bangladesh due to the global warming. Therefore, there is a genuine scope to carry out an extensive research work on climate modeling, agricultural drought risk assessment and sustainable adaptation strategies, and also draw an attention to the researchers for future potential research work. This study will help for the Government and Non-Government Organizations (NGOs) to take appropriate measures to reduce adverse effect in agriculture and social environment due to drought hazard. It is also expected that this study will provide better insight into the spatial and temporal aspect of drought, as well as water deficit volume during drought events under the impact of global climate change to the academicians, researchers, policy makers and development workers.

## 1.2 Statement of the Research Problem

In the western part of Bangladesh, agriculture is only a primary economic sector. In the study area, the water deficit is often the most limiting factor for crop production. Both long term and short term drought has severe impacts on agriculture. Even though most of the study area receives enough rainfall in every year, but in dry season some areas start to become drought. In drought mitigation actions and programs, it is important to understand the drought characteristics through analysis that will provide reliable information as a main factor in the decision making process for policy makers. A drought analysis based only on rainfall data is often done as rainfall data are mostly more available than other meteorological or remote sensing data. So,

appropriate climate modeling with drought disk assessment and sustainable adaptation strategies is expected to provide drought characterization in more efficient ways that will be applicable in agricultural sector. Moreover, the information is essential for a broad group of users within the geo-informatics society who are interested in monitoring, mitigation and management of drought.

### 1.3 Research Objectives

The general objective of this research is to explore the climate condition, drought risk assessment and sustainable adaptation strategies in the western part of Bangladesh based on rainfall and temperature data. The specific objectives of this research are as follows:

- To explore the climatic condition of the study area based on rainfall and temperature data;
- To develop an appropriate climate model using rainfall and temperature data for prediction of future climate scenarios;
- To analyze agricultural drought characteristics based on daily rainfall using Markov chain model;
- To identify drought hazard with its spatial extends, frequency and severity using year-wise drought events produced by Markov chain model;
- To compute drought vulnerability map depending on socio-economic and physical indicators of vulnerability using Geographical Information System (GIS);
- To compute district level drought risk map depending on drought hazard and vulnerability indexes using GIS; and
- Finally, to suggest sustainable management strategies for adaptation of drought risk under the changing climate.

## 1.4 Structure of the Thesis

The thesis contains five chapters. The first chapter highlights introduction, objectives, statement of the research problem and structure of the thesis. Chapter two provides an extensive literature review on concepts of climate modeling, rainfall and temperature trend analysis, prediction of climate variable using Autoregressive Integrated Moving Average (ARIMA), concepts of drought hazard, drought impacts, monitoring drought by Markov chain, drought vulnerability and sustainable adaptation strategies. The third chapter provides details in the selection of study area with its map, data sources and collection, missing data estimation and using other methods in order to achieve the research objectives. Chapter four presents the obtained results and discussed them into four sections, first- climate assessing and modeling by Mann-Kendall test of trend analysis and ARIMA, second- modeling and monitoring agricultural drought by Markov chain analysis, third- drought hazard, vulnerability and risk analysis by using probability analysis of drought (drought occurrence, frequency and severity) and socio-economic and physical indicators, and forth- risk ranking and sustainable adaptation strategies using year-wise probability of drought occurrence, frequency and severity of each meteorological station in the study area only but not considered the socio-economic and physical indicators. The last chapter draws conclusions based on discussions and findings of the entire study and suggests some sustainable adaptation strategies for mitigating the drought risk over the study area that will be helpful for academicians, researchers, policy makers and development workers.

# Chapter II
# Literature Review

# CHAPTER II

# LITERATURE REVIEW

## 2.1 Introduction

The main focus of this chapter is to review the significant number of relevant studies in home and abroad on climate change; climate variables; rainfall and temperature trend analysis; climate modeling; drought and it's impacts especially in agriculture; modeling and monitoring of agricultural drought; drought hazards; vulnerability and risk; risk raking and sustainable adaptation strategies etc. This will be made present study more effective for mitigating the adverse effects due to drought hazards.

## 2.2 Climate Modeling

Climate model is a mathematical representation of the climate variables. Basically, it has been developed from weather forecasting models where prediction is complex and involving so many calculations. The values of the predicted variables, such as surface pressure, wind, temperature, humidity and rainfall are calculated over time to predict their future values (WMO, 2013). Climate models such as trend analysis, ARIMA model and Markov chain analysis are applied to predict future behavior of the climatic variables like rainfall and temperature in different scales.

Agriculture is one of the most climate-sensitive industries, with outdoor production processes that depend on particular levels of temperature and precipitation. Although only a small part of the world economy, it has always played a large role in estimation of overall economic impacts of climate change. In monetary terms, agriculture represents less than 2 percent of GDP in high-income countries, and 2.9 percent for the world as a whole data on agricultural value added as a share of GDP in 2008 (World Bank, 2010). It is more important for low-incoming countries, amounting to almost one-fourth of GDP in the least developed countries and agricultural product is an absolute necessity of life, with virtually no substitutes (fisheries, another food-producing sector will also be heavily impacted by climate change). In

economic terms, the fact that food is a necessity means that it has a very low price elasticity of demand, implying that it has a very large consumer surplus. If contributions to well-being are measured by consumer surplus rather than shares of GDP, as economic theory suggests, then agriculture looms much larger in importance. In the 1990s, it was common to project that the initial stages of climate change would bring net benefits to global agriculture (e.g., Mendelsohn et al. 1994). As late as 2001, the U.S. Global Change Research Program still anticipated that U.S. agriculture would experience yield increases due to climate change throughout this century (Reilly et al. 2001). The more sophisticated and detailed PESETA (Projection of Economic impacts of climate change in Sectors of the European Union based on bottom-up Analysis) project, analyzing climate impacts throughout Europe, assumed linear relationships between average temperatures and crop yields. It projected that temperature changes in the end of this century would cause yield declines in Mediterranean and Southern Atlantic Europe, and yield increases elsewhere (Iglesias et al. 2011). For Europe as a whole, PESETA estimated little change in crop yields for average European temperature increases up to 4.1°C, with a 10 percent yield decline at 5.4°C, the highest temperature analyzed in the study (Ciscar et al. 2011) and such estimates have fallen well behind the state of the art in the research literature. There are three major areas in which recent results and models suggest a more complex relationship between climate and agriculture: the revised understanding of carbon fertilization; the threshold model of temperature effects on crop yields; and the emerging analyses of climate and regional precipitation changes.

The nature of climate change in Bangladesh is a major concern in recent years and it is important to predict physical, economic, environmental and social impacts that may help to take future planning. Agriculture is always vulnerable to unfavorable weather events and climatic conditions. Despite technological advances such as improved crop varieties and irrigation systems, weather and climate are still key factors in agricultural productivity. In Bangladesh, agricultural impacts of climate change could have profound effect

as in other poor and developing countries in south Asia as it has a humid tropical climate (BARC, 1991).

The impacts of climate change on agricultural food production are global concerns, and they are very important for Bangladesh. Agriculture is the single most and the largest sector of Bangladesh's economy which accounts for about 35% of the GDP and about 70% of the labor force. Agriculture in Bangladesh is already under pressure both from huge and increasing demands for food, and from problems of agricultural land and water resources depletion (Ahmad and Shibasaki, 2000). So, estimation of quantitative impacts of potential climate change on environment and various aspects of human being requires high-resolution surface weather data (Dubrovsky, 1997).

## 2.3 Rainfall and Temperature Trend Analysis

Many studies have been carried out related to the climate modeling based on rainfall and temperature variability throughout the world:

Buffoni et al. (1999) studied series of annual and seasonal precipitation from 32 stations for the period of 1833-1996 and results showed a decreasing trend in annual series overall Italy, but it was statistically significant only in the central-south. On a seasonal basis, a decreasing trend was significant only for spring in central-south and for autumn in the north.

Tomozeiu et al. (2000) analyzed the main characteristics of the spatial and temporal variability of summer precipitation observed in 40 rainfall stations of the Emilia-Romagna region in northern Italy for the period 1922-1995. Their results indicated an increasing trend with a systematic significant upward shift around 1962 for almost all stations. In addition, the climate signal was more significant in the north-western, central and north-eastern part of the region.

Partal and Kahya (2006) determined trends in long-term annual mean and monthly total precipitation series in Turkey for 1929-1993 and found some significant trends of precipitation especially in January, February and September and in the annual means. A noticeable decrease in annual mean precipitation was also observed mostly in western and southern Turkey, as well as along the coasts of the Black Sea.

Jiang et al. (2007) studied temporal and spatial trends in daily precipitation data for 147 meteorological stations in the Yangtze River Basin, China. They concluded a positive trend in summer precipitation, rainstorm frequency and flood discharge in most of the stations.

Liu et al. (2008) investigated the spatial and temporal patterns of the precipitation trends in the Yellow River Basin, China during 1960-2006 and results showed a decreasing trend in most of the stations.

Kampata et al. (2008) studied on the trends of precipitation data from five rain gauges located in the headstream regions of the Zambezi river basin in Zambia. In this research, through the five stations showed marginal downward trends, these were not significant.

Zhang et al. (2008) analyzed annual, winter and summer precipitation records from 160 stations in China for the period 1951-2005. They found an increasing trend in annual, summer and winter precipitation in the middle and lower sections of the Yangtze River.

Krishnakumer et al. (2009) studied temporal variations in monthly, seasonal and annual rainfall over Kerala, India during the period from 1871-2005. The analysis revealed significant decrease in south-west monsoon rainfall and increase in post-monsoon season over the state Kerala. The rainfall during winter and summer seasons also showed insignificant increasing trend. On the monthly scale, rainfall during June and July indicated significant decreasing trend and increasing trend in January, February and April.

Raziei et al. (2005) checked annual precipitation from 1965 to 2000 for climate variability and possible trend using the Mann-Kendall test and results showed that there was no evidence of climate change in Iran. Although many stations demonstrated negative trends, these trends were not statistically significant at the 95% significant level.

Modarres and Silva (2007) analyzed the time series of annual rainfall, number of rainy-days per year and monthly rainfall of 20 stations by the Mann-Kendall test to assess climate variability in the arid and semi-arid regions of Iran, where results showed that there was no significant climate variability.

Tabari and Talaee (2011) investigated the annual and seasonal precipitation trends of 41 stations in Iran for the period 1966 to 2005 by using Mann-Kendall test, Sen's slope and linear regression. Their results indicated a decreasing trend in annual precipitation about 60% of the stations which were significant at several stations at 95% and 99% confidence levels.

Shahid and Khairulmaini (2009) studied on spatial and temporal variability of rainfall in Bangladesh with 24 rain gauge stations for the period 1969-2003 using Mann-Kendall test, Sen's slope method and GIS and observed the existence of moderate variation in inter-annual rainfall and high variation in intra-annual rainfall. Insignificant positive trend of annual, monsoon and pre-monsoon rainfall and a negative trend in winter rainfall are found in Bangladesh. Spatial distribution of rainfall trends shows that rainfall is increasing in the coastal zone and northern Bangladesh and decreasing in the central part of the country. A declining trend of precipitation is also observed in most of the stations. These results may be a first indication of the precipitation response to global warming a hypothesis which needs to be further investigated by means of climate model projections.

Rahman and Begum (2013) applied non-parametric test for trend detection of rainfall in the largest island of Bangladesh. They analyze one of the most important climatic variable i.e., precipitation, for analyzing the rainfall trend in Bhola region from 1966 to 2011 by using Mann-Kendall test and Sen's slope estimator. Their results showed insignificant trends from January to December in the study area.

## 2.4 Prediction of Climate Variable using ARIMA

Kaushik and Singh (2008) studied prediction of temperature and rainfall on a seasonal time scales has been attempted by various research groups using different techniques. They applied Box-Jenkins time series seasonal ARIMA (Autoregressive Integrated Moving Average) approach for prediction of temperature and rainfall on monthly scales. The Box Jenkins technique is applied to predict temperature and rainfall of next five years by analyzing last twelve years data (1994-2006). Previous years data is used to formulate the

seasonal ARIMA model and in determination of model parameters. The study was conducted at Mirzapur, Uttar Pradesh (India) and the results indicated that the seasonal ARIMA model provide reliable and satisfactory predictions for rainfall and temperature parameters on monthly scale.

Nury et al. (2013) studied time series analysis and forecasting has become a major tool in numerous applications in meteorology and other environmental areas to understand phenomena, like rainfall, humidity, temperature, draught etc. Here ARIMA models have been set-up and used to carry out short-term predictions of monthly maximum and minimum temperatures in the Sylhet and Moulovibazar districts in north-east Bangladesh. Using the classical Box-Jenkins methodology, stationary, seasonal ARIMA models for the temperatures recorded at two stations in Sylhet division during the period of 1977 to 2011 are set up. Verification of the models has been done for the period of 2010-2012 based on the inspection of the ACF, PACF autocorrelation plots; the most appropriate orders of the ARIMA models are determined and evaluated using the AIC criterion. Using these ARIMA models with one month ahead to forecast temperature of two stations for the years 2010 and 2011 are carried out.

Syeda (2012) investigated the trend and variability pattern for decadal, annual and seasonal (three crop seasons) average dry bulb temperature (ADBT) for the six divisional stations of Bangladesh namely Dhaka, Khulna, Rajshahi, Barisal, Sylhet and Chittagong. The monthly ADBT for the period of 2009-2012 is forecasted using univariate Box-Jenkin's ARIMA modeling technique. The rates of linear trend for ADBT were found negative for Rajshahi and Barisal but positive for Dhaka, Khulna, Sylhet and Chittagong. The rates for seasonal ADBT were positive for all the three seasons for Dhaka and Chittagong, but negative for all the three seasons for Barisal while positive for Kharif and Rabi seasons and negative for Pre-Kharif seasons for Khulna and Sylhet. The rates were positive for Kharif season but negative for Pre-Kharif and Rabi seasons in Rajshahi.

Sarraf et al. (2011) studied the resultant changes in global climate with one of the main issues propounded among water resource experts in the country;

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and observed that temperature and humidity forecasts can efficiently be applied in decision making and optimum usage of water resources. Temperature and humidity have irrefutable effects on hydrologic cycle, production cycle of agricultural products, water consumptions (especially agriculture), human efforts and environment. Utilization of statistical distribution is one of the main rules that have the capability of forecasting hydrologic events with largeness and distinctive incidence probability. Theory of time series is implemented by two main aims of perception or modeling random mechanisms and prospect of future amounts of series based on its past. Relative humidity and the average monthly temperature of Ahvaz synoptic station is used in present research of 20 years old statistics and a proper model is achieved by applying time series analysis software (ITSM) in accordance with ARIMA model with autocorrelation and partial autocorrelation function and by evaluation of all probabilistic models in terms of being static and study of parameters and types of models, in order to forecast average monthly temperature ARIMA $(0,0,1)\times(0,1,1)_{12}$ based on Box-Jenkins algorithm and after validation and evaluation of model. They determined that selection of given models was more accurate and forecast of relative humidity measure and average monthly temperature was implemented during the agricultural years 2009-2010 and 2010-2011.

## 2.5 Drought Hazard

The word "drought" has been drawn world-wide attention in recent years because of its widespread effect in the USA in 1987-88 (Ahmed, 1991) and its devastating effect in the Somalia in 1991-93 and similar effect in Ethiopia few years ago and in the Sahel region of Africa in the late 1980's. In the rain dependent agricultural regions of the world, availability of rainwater is one of the most important considerations of agricultural planning. Rainfall varies from year to year and from place to place, sometimes leading to the occurrence of drought. It is obvious, when drought occurs during dry season; it affects crop seasons and also increase the food shortage and misery of the people (Ahmed, 1995). Inference problems, such as estimation and hypothesis testing involving Markov chains have been considered by several authors like

Bartlett (1955); Whittle (1955); Anderson and Goodman (1957); Billingsley (1961); Lee et al. (1970). They have not only their theoretical interest but also for their applications in diverse areas especially in agriculture.

### 2.5.1 The Concept of Drought

Drought is a normal, recurrent feature of climate, although it is erroneously considered as a rare and random event. It differs from aridity, which is restricted to low rainfall regions and it is a permanent feature of climate. Drought should be considered relative to some long-term average conditions of the balance between precipitation and evapotranspiration (i.e., evaporation + transpiration) in a particular area. It is also related to the timing (principal season of occurrence, delays in the start of the rainy season, occurrence of rains in relation to principal crop growth stages) and the effectiveness (i.e., rainfall intensity, number of rainfall events) of the rains. However, these are only conceptual definitions that are unable to give an operational definition of drought (Monacelli, 2005). There are two main definitions of drought- conceptual and operational.

#### 2.5.1.1 Conceptual Drought

Conceptual definitions, formulated in general terms, help people understand the concept of drought. For example, drought is a protracted period of deficient precipitation resulting in extensive damage to crops, further resulting in loss of yield. Conceptual definitions may also be important in establishing drought policy (Monacelli, 2005).

#### 2.5.1.2 Operational Drought

An operational definition of drought helps people to identify the beginning, end, and degree of severity of a drought. This definition is usually made by comparing the current situation to the historical average, often based on a 30-year period of record (World Meteorological Organization, 2005).

### 2.5.2 Types of Drought

Sequence of drought occurrence and impacts for commonly accepted drought types. All droughts originate from a deficiency of precipitation or

meteorological drought but other types of drought and impacts cascade from this deficiency. The concept of drought types, inter-relationship with economic, social and environmental impacts has discussed in the following sections that shown in figure 2.1 (Source: National Drought Mitigation Center, University of Nebraska-Lincoln, U.S.A.).

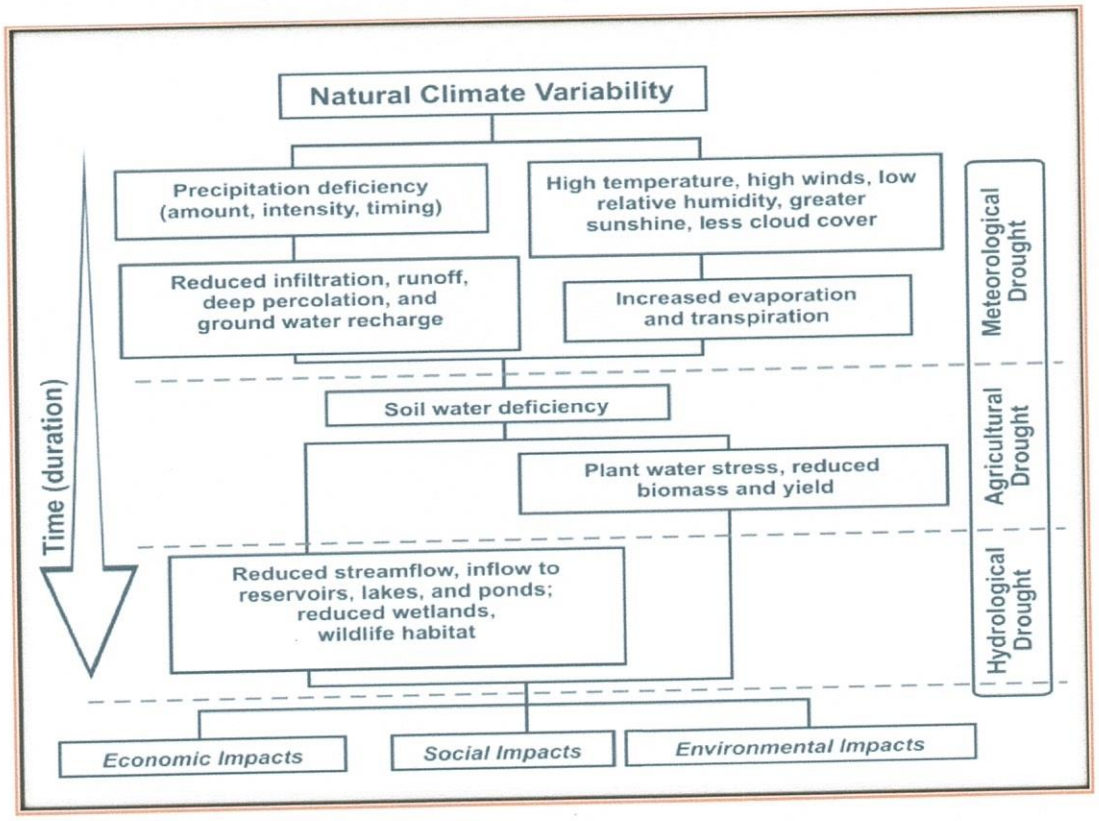


**Figure 2.1** Diagram of drought types with impacts

### 2.5.2.1 Meteorological Drought

Meteorological drought is usually defined on the basis of the degree of dryness (in comparison to some "normal" or average amount) and the duration of the dry period. Definitions of meteorological drought must be considered for a specific region, since the atmospheric conditions that result in deficiencies of precipitation are highly variable from region to region.

### 2.5.2.2 Agricultural Drought

Agricultural drought links various characteristics of meteorological (or hydrological) drought to agricultural impacts, focusing on precipitation

shortages, differences between actual and potential evapotranspiration, soil water deficits, reduced groundwater or reservoir levels, and so forth.

#### 2.5.2.3 Hydrological Drought

Hydrological drought is associated with the effects of periods of precipitation (including snowfall) shortfalls on surface or subsurface water supply (i.e., stream flow, reservoir and lake levels, groundwater). The frequency and severity of hydrological drought is often defined on a watershed or river basin scale. Hydrology with respect to land use, although climate is a primary contributor to hydrological drought, other factors such as changes in land use (e.g., deforestation), land degradation, construction of dams that affect the hydrological characteristics of the basin.

## 2.6 Impacts of Drought

Drought affects all parts of our environment and our communities severely. Different types of drought impacts are often grouped as "economic", "environmental", and "social" impacts. All of these impacts must be considered in planning for sustainable agriculture, and safe accommodation responding to drought conditions (NDMC, 2013).

### 2.6.1 Economic Impacts

Economic impacts of drought means impacts related to economic activities which are generally hampered by drought such as loss of lives, crops damage, creation of unemployment, shortage of water supply and so on. A few examples of economic impacts are given below:

- Farmers may lose money if a drought destroys their crops;
- If farmers get low water supply, then they may have to spend more money on irrigation or to drill new wells;
- Farmers may have to spend more money on feed and water for their animals;
- Businesses that depend on farming, like industries that make food processing may lose business when drought damages crops or livestock;

- People who work in the timber industry may be affected when wildfires destroy stands of timber;
- Businesses that sell boats and fishing equipment may not be able to sell some of their goods because drought has dried up canals, rivers and other water sources;
- Companies that normally rely on hydroelectric power (electricity that is created from the energy of running water) may have to spend more money on other fuel sources if drought dries up too much of the water supply. The power companies' customers would also have to pay more;
- Water companies may have to spend money on new or additional water supplies;
- Barges and ships may have difficulty navigating streams, rivers, and canals because of low water levels, which would also affect businesses that depend on water transportation for receiving or sending goods and materials; and
- People might have to pay more for food.

### 2.6.2 Environmental Impacts

Drought also affects the environment in many different ways. Plants and animals depend on water, just like people. When a drought occurs, their food supply can shrink and habitat can be damaged. Sometimes the damage is only temporary, and habitat and food supply return to normal situation when the drought is over. But sometimes drought's impact on the environment can continue long time may be forever. Examples of environmental impacts include:

- Losses or destruction of fish and wildlife habitat;
- Lack of food and drinking water for wild animals;
- Increase in disease in wild animals, because of reduced food and water supplies;
- Migration of wildlife;
- Increased stress on endangered species or even extinction;
- Lower water levels in reservoirs, lakes, and ponds;
- Loss of wetlands;

- More wildfires;
- Wind and water erosion of soils; and
- Poor soil quality.

### 2.6.3 Social Impacts

Social impacts of drought are ways that affects people's health and safety that include public safety, health, conflicts between people and changes in lifestyle. Examples of social impacts include:

- Anxiety or depression about economic losses caused by drought;
- Health problems related to low water flows and poor water quality;
- Health problems related to dust;
- Loss of human life;
- Threat to public safety from an increased number of forest and range fires;
- Reduced incomes;
- People may have to move from farms into cities, or from one city to another; and
- Fewer recreational activities.

In Bangladesh, drought is defined as the period when moisture content of soil is less than the required amount for satisfactory crop growth during the normal crop-growing season. It is common in the north-western districts of Bangladesh. Depending on the intensity of drought, the estimated yield reduction of different crops varies from 10 to 70% and the loss may considerably be reduced through judicious and limited irrigation at the critical stages of crop growth (http://www.banglapedia.net/HT/C0284.HTM).

## 2.7 Impacts of Agricultural Drought

Among several types of weather related droughts, agricultural drought is of considerable importance. Agriculture is the backbone of the economy of developing countries like Bangladesh with more than 70% of the working population engaged in this sector. The dependence of the majority of farmers on rain feed agriculture and pastures have made the economy extremely vulnerable to the vagaries of weather. As a result, failure of rains and the occurrence of drought during any particular growing season lead to severe food shortage. The knowledge of current weather throughout the growing season helps the early detection of agricultural drought and/or the crop condition and the crop production that is useful for timely relief and rehabilitation measures and other decisions by several governmental and non-governmental agencies (Reddy, 1986).

## 2.8 Relationship among Meteorological, Agricultural and Hydrological Drought

Agricultural drought links various characteristics of meteorological (or hydrological) drought to agricultural impacts, focusing on precipitation shortages, differences between actual and potential evapotranspiration, soil water deficits, reduced ground water reservoir levels, and so forth. Plant water demand depends on prevailing weather conditions, biological characteristics of the specific plant, its stage of growth, and the physical and biological properties of the soil. A good definition of agricultural drought should be able to account for the variable susceptibility of crops during different stages of crop development, from emergence to maturity. Deficient topsoil moisture at planting may hinder germination, leading to low plant populations per hectare and a reduction of final yield.

Drought impacts can spread over a large geographical area, affecting all aspects of economic, environmental and social life. Agricultural drought links meteorological drought and deficits of soil moisture to impacts on crop and forage yields as well as livestock production (Wilhite and Glantz, 1987). Agriculture is often the first economic sector to be affected by drought because soil moisture supplies are often quickly depleted (Wilhite, 2000).

The agricultural planners and irrigation engineers identify the areas where agricultural development should be focused as long terms drought mitigation strategy. It will also contribute toward a better understanding of the climatology of drought in a major drought-prone region of the world (Rahman, 2001).

## 2.9 Monitoring Drought by Markov Chain Model

Statistical Inference is an essential tool for concluding any research. The probability theory of Markov chain has been extensively developed, whereas, statistical inference concerning Markov chain model has not yet been comparatively developed (Billingley, 1961).

Drought occurs when various combinations of the physical factors of the environment produce an internal water stress in crop plants sufficient to reduce their productivity. In the low rainfall areas especially in tropics, the importance of rainfall overrides that of all other climatic factors, which determine yield. So, agricultural drought is mainly concerned with inadequacy of rainfall. The rainfall occurs mainly due to due to south-west monsoon and ranges from June to September. Hence the crop yield in the area depends on variation of rainfall in this season (Banik et al. 2000).

Different units of time period are used for rainfall analysis. For agriculture, week may be nearer to the optimum length of time. The week with rainfall greater than the threshold value (a minimum amount, say 2.5 mm) is considered to be a wet week. The expected number of wet weeks in a given period of time can decide the crop production of an area. The probability of sequences of wet weeks can indicate the adequacy of water and that of dry weeks indicate the reverse and recurrence of the risk of crop failure. Wet and dry sequences of weeks can be well represented by the Markov chain model (Banik et al. 2000; Richardson, 1981; 1982). The occurrence of daily precipitation at a station can seldom be properly considered as an independent random event described by Bernoulli's trials. Analysis of daily precipitation time series always tends to reveal the existence of stochastic dependence.

Drought is a temporary but complex feature of the climatic system of a given region with wide spread significance (Olapido, 1985), which is usually caused by precipitation deficit (Gregory, 1993). Such natural disasters leave a long lasting effect on a social and economic fabric of a region where it strikes, sometimes requiring relief efforts on a global scale (Ahmad, 1995). Although we can recognize a drought when it hits a region, there is no universal definition of this term. Various characteristics of droughts, including definitions and their meteorological, hydrological and economic aspects were discussed by Doornkamp et al., (1980), Giambelluca et al. (1988), Landsberg (1982), Dennet et al. (1985), Olapido (1985), Ahmad (1991) and reviewed extensively by Gregory (1986) and Nieuwolt (1986).

Liu et al. (2009) found that the continuity of drought in Laohahe catchment was very strong, durations of which were almost more than 2 years. There is an increasing tendency in the frequency of drought occurring, which may be the result of temperature increase. Drought states of 12 months in year 2000 were forecasted using Markov chain model with different steps. The prediction performance of Markov chain model is related with the forecasting steps, little steps always getting good performance. As a result, the Markov chain model is able to work for the early warning.

Mishra et al. (2007) studied drought characterization using SPI (Standardized Precipitation Index) and Markov chain model (the alternative renewable process and run theory). The study investigates the distribution of drought interval time, mean drought inter arrival time, joint probability density function and transition probabilities of drought events in the Kansabati River basin in India. The SPI series is employed in the investigation. The time interval of SPI is found to have a significant effect of the probabilistic characteristics of drought.

Alam et al., (2013) studied agricultural drought in Barind area, Bangladesh by Markov chain model. Details analysis of spatio-temporal drought dynamics during Pre-Kharif (pre-monsoon) and Kharif (monsoon) have been carried out through drought indices map generated by GIS environment. Analysis and interpretation of these maps evaluate that meteorological drought is not always correspond to agricultural drought and a chronic agricultural drought

can be occurred because of a limited rainfall deficit. In Barind region meteorological drought shows a similar pattern in pre-monsoon season but in monsoon season rainfall deficits shifts its position from time to time and in some pockets where it is more frequent. In agricultural sphere, the Markov chain shows a very chronic (extreme) pattern during pre-monsoon season in the entire area but in monsoon it behaves like meteorological drought.

Rahman and Mian (2002) studied stochastic study of asymptotic behavior of rainfall distribution in Rajshahi. Daily rainfall data for a period of 27 years during 1972 to 1998 of Rajshahi district were collected from Bangladesh Meteorological Department (BMD) and analyzed to estimate the asymptotic behaviors of rainfall distribution. A Markov chain model was developed based on daily rainfall data considering the various aspects of rainfall occurrences.

## 2.10 Drought Vulnerability

The concepts and definitions of vulnerability have been analyzed by many researchers. Some of them are discussed below.

Shahid and Behrawan (2008) studied spatial assessment of drought risk in the western part of Bangladesh. A conceptual framework was developed to combine the role of hazard and vulnerability in defining risk. SPI and GIS environment were used to map the spatial extents of drought hazards in different time steps. The social and physical key factors that define drought vulnerability in the context of Bangladesh were identified and corresponding thematic maps in district level were prepared. Composite drought vulnerability map was developed through the integration of those thematic maps. Finally, the risk was computed as the product of the hazard and vulnerability and results showed that droughts posed highest risk to the northern and north-western districts of Bangladesh.

Blaikie et al. (1994) defined risk as the product of hazard and vulnerability which has been used to identify drought risk pattern.

Shahid et al. (2008) studied spatial and temporal characteristics of drought risk analysis that requires assimilation of physical and socio-economic information from many sites with unique geographic location. GIS maintains

the spatial location of sampling points or area, and provide tools to relate the sampling data contained through a relational database.

Karim et al. (1990) prepared the first agricultural drought risk map of Bangladesh by considering the cumulative effect of dry days, higher temperatures during pre-monsoon period and soil moisture availability.

WARPO-EGIS (1996) prepared maps of winter and pre-monsoon drought prone areas of Bangladesh using the agro-ecological zones database and land resources inventory map at 1:1,000,000 scale. Karim and Iqbal (2001) reviewed the concept of WARPO-EGIC (1996) and produced three different drought risk maps for winter, pre-monsoon and monsoon seasons. They defined drought risk classes as slight, moderate, severe and very severe related to the yield losses of 15-20%, 20-35%, 35-45%, and 45-70%, respectively, for different crops. No standard drought index method has been used for the assessment of droughts in Bangladesh. Furthermore, no study has been carried out so far to identify the geographic distribution of human vulnerability to drought.

Cutter (1993) defined vulnerability is the likelihood that an individual or group will be exposed and adversely affected by a hazard. It is the interaction of the hazards of a place (risk and mitigation) with social profile of communities.

Watts and Bhole (1993) defined vulnerability in terms of exposure, capacity and potentiality. Accordingly, the perspective and normative response to vulnerability is to reduce exposure, enhance coping capacity, strengthen recovery potential and bolster damage control (i.e., minimize destructive consequences) via private and public means.

The most common concept of vulnerability is that it describes the degree to which a socio-economic system or physical assets are either susceptible or resilient to the impact of natural hazards (Wilhelmi and Wilhite, 2002). It is determined by a combination of several factors including condition of human settlements, infrastructure, public policy and administration, organizational abilities, social inequalities, gender relations, economic patterns, etc. Drought vulnerability is different for different individuals and nations. In developing

countries, drought vulnerability constitutes a threat to livelihoods, the ability to maintain productive systems, and economies. In developed economies, drought poses significant economic risks and costs for individuals, public enterprises, commercial organizations, and governments (Downing and Bakker, 2000). Therefore, selection of vulnerability indicators is directly relevant to the local study context and the particular hazard (United Nation Development Program, 2004).

Smit and Wandel (2006) gave the basic vulnerability relationships using Venn diagram (Figure 2.2). The larger sets represent the broader stresses and forces that determine exposure and sensitivity and shape adaptive capacity at the local or community level, denoted by the smaller embedded sets. The interaction of environmental and social forces determines exposures and sensitivities, and various social, cultural, political and economic forces shape adaptive capacity.

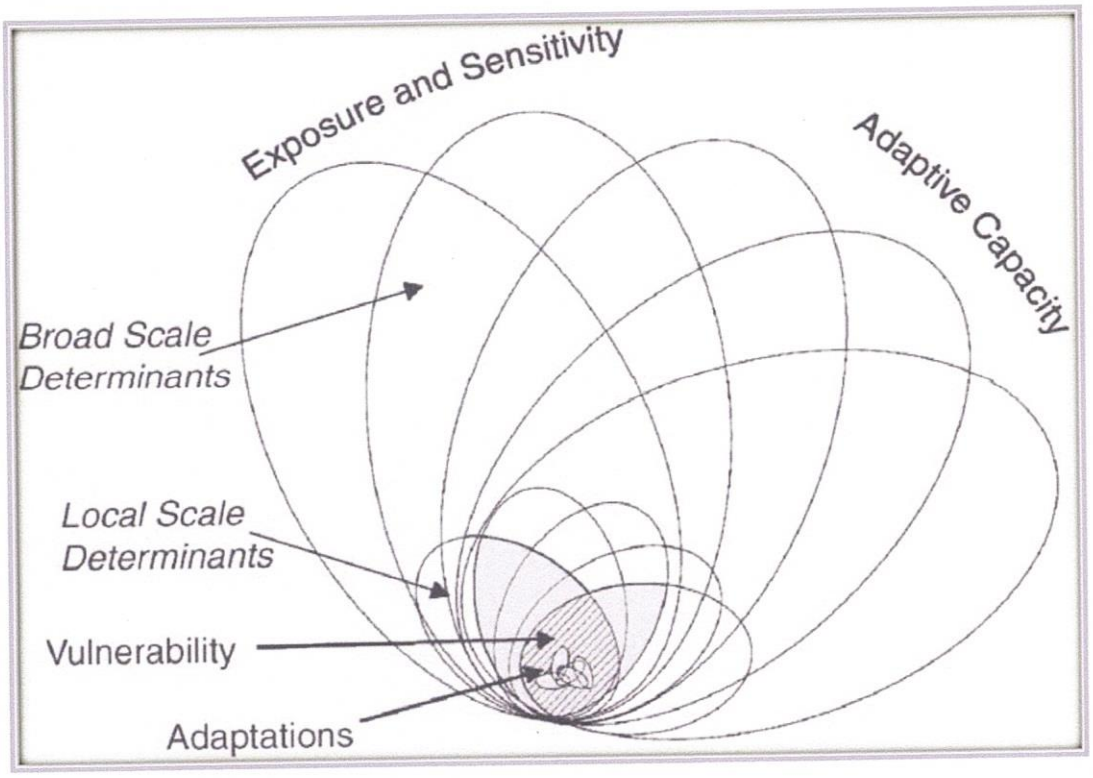


**Figure 2.2** Nested hierarchy model of vulnerability (Smit and Wandel, 2006).

Gain et al. (2012) reviewed the evolution of approaches to vulnerability assessment related to water resources. They identified the current main constraints (e.g., lack of institutional coordination) and opportunities (e.g., adaptation) of LBRB River based on the feasibility study. The results of this study can be helpful for innovative research and management initiatives. They also described framework that can be widely used as a guideline for the vulnerability assessment of water resources systems, particularly in developing countries like Bangladesh.

### 2.11 Study of Adaptation

Adaptation is usually implicit in the political ecology field. The relationships between ecosystems and political economy are often treated as issues of adaptive management of risks related to political and social power relations, resource use, and global economies (Blaikie and Brookfield, 1987; Sen, 1981; Walker, 2005). Research on global environmental risk and the social amplification of risk places adjustments and adaptations in the context of human driving forces, biophysical constraints and the social, economic and political attenuation of risks (Kasperson and Kasperson, 2001; Pidgeon et al., 2003).

According to Smit and Wandel (2006), there is very little consensus (or documented support) for a robust, specific model of the elements and processes of local exposure, sensitivity, and adaptive capacity, beyond broad categories. The broad factors or determinants that influence sensitivities and constrain the abilities of communities to deal with hazards or stressful conditions are too general guide in practical adaptation programs.

Some research conducted by scientists of Food and Agricultural Organization (FAO) about drought adaptation in Bangladesh. In 2007, Ramamasy and Baas proposed a simple drought adaptation model based on risk ranking considering frequency and severity of drought hazards in NW Bangladesh. They described both the magnitude and frequencies of climate event are given qualitative measures that permit the prioritization of selected climate risks among multiple risks. Because the low frequency events may become high frequency events under climate change, they need to be given sufficient consideration for adaptation.

# Chapter III

# Materials and Methods

# CHAPTER III
# MATERIALS AND METHODS

## 3.1 Selection of Study Area

The study has been conducted on the western part of Bangladesh. Geographically Bangladesh divided into four principal parts such as northern part, southern part, eastern part and western part. The western part covers 36 districts where 12 meteorological stations such as Dinajpur, Rangpur, Bogra, Ishwardi, Rajshahi, Faridpur, Jessore, Khulna, Satkhira, Barisal, Bhola and Khepupara are installed by Bangladesh Meteorological Department (BMD) under Rangpur, Rajshahi, Dhaka, Khulna and Barisal divisions. The study area map with location of the meteorological stations is shown in figure 3.1. The study area has been suffering very much from extreme temperature and drought due to the impact of global warming and climate change, and this part is becoming more vulnerable to natural disasters according to Intergovernmental Panel on Climate Change (IPCC, 2007). For achieving the study objectives, researcher has chosen the western part of Bangladesh as study area due to people's suffering mostly by the extreme temperature and drought. The location (latitude and Longitude), name and ID of the meteorological stations with geographical and agro-ecological zones of the western part of Bangladesh are given in table 3.1.

**Table 3.1** Location, geographical zone, agro-ecological zone and name and ID of meteorological stations of the study area

| Division | Station Name | Station ID | Location | | Geographical Zone | Agro-ecological Zone |
|---|---|---|---|---|---|---|
| | | | Latitude | Longitude | | |
| Rangpur | Dinajpur | 10120 | 25.65 | 88.68 | Old Himalayan Piedmont Plain and Tista Flood Plain | AEZ 1, 25, 27 |
| | Rangpur | 10208 | 25.73 | 89.27 | Old Himalayan Piedmont Plain and Tista Flood Plain | AEZ 3, 27 |
| Rajshahi | Bogra | 10408 | 24.85 | 89.37 | Karatoya Flood plain and Atrai Basin | AEZ 4, 25 |
| | Ishwardi | 10320 | 24.37 | 88.7 | High Ganges River Flood Plain | AEZ 11 |
| | Rajshahi | 10910 | 24.15 | 89.03 | Karatoya Flood plain and Atrai Basin | AEZ 11 |
| Dhaka | Faridpur | 11505 | 23.93 | 89.85 | Low Ganges River Flood Plain | AEZ 10, 12 |
| Khulna | Jessore | 11407 | 23.2 | 89.33 | High Ganges River Flood Plain | AEZ 11, 14 |
| | Khulna | 11604 | 22.78 | 89.53 | Ganges Tidal Flood Plain | AEZ 13, 14 |
| | Satkhira | 11610 | 22.72 | 89.08 | Ganges Tidal Flood Plain | AEZ 13 |
| Barisal | Barisal | 11704 | 22.72 | 90.37 | Ganges Tidal Flood Plain | AEZ 13, 14, 19 |
| | Bhola | 11706 | 22.68 | 90.65 | Ganges Tidal Flood Plain | AEZ 18 |
| | Khepupara | 12110 | 21.98 | 90.23 | Ganges Tidal Flood Plain | AEZ 13, 18 |

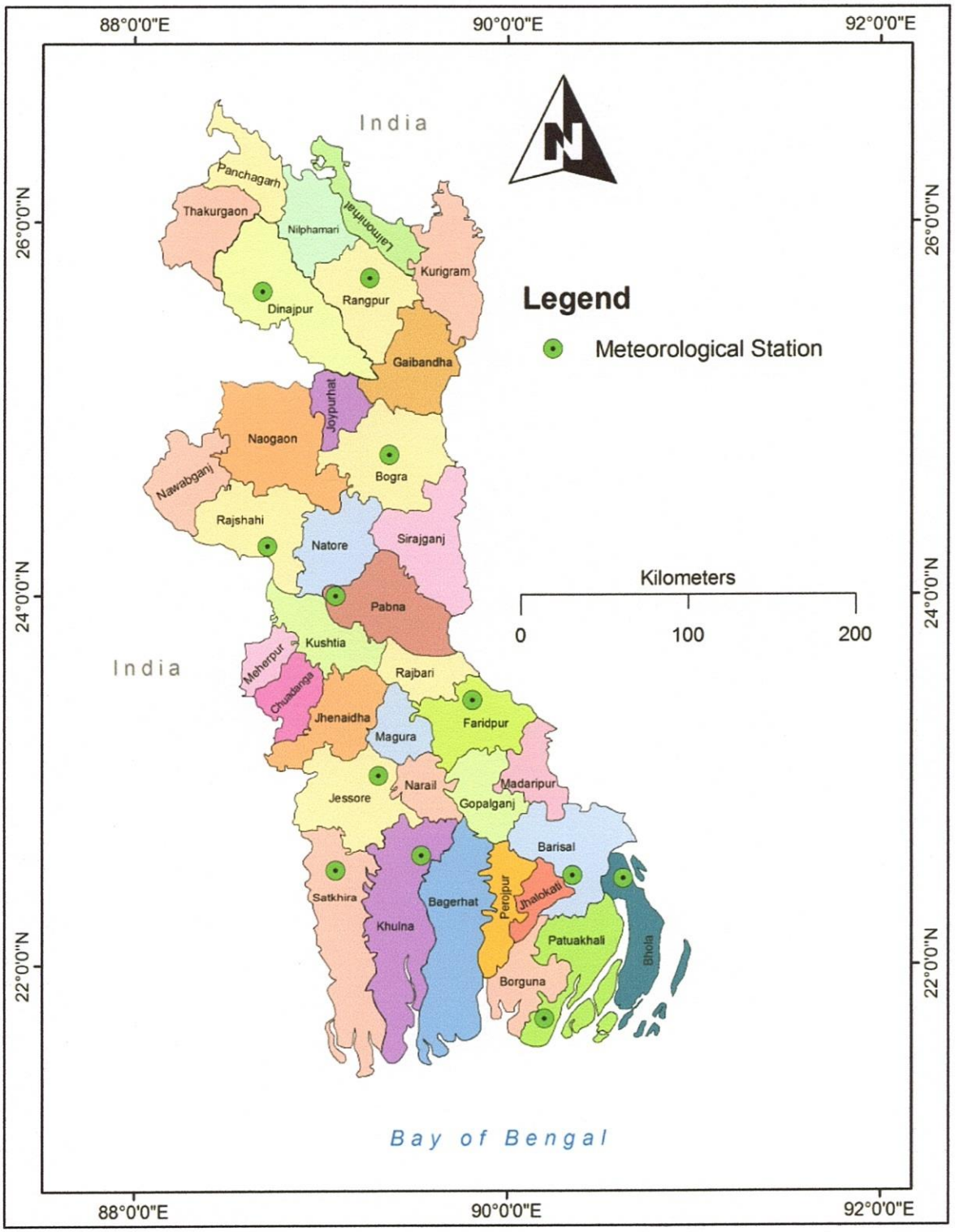


**Figure 3.1** Study area map with location of meteorological stations

### 3.2 Data Collection and Sources

There are twelve metrological stations in the western part of Bangladesh. Meteorological station-wise daily rainfall and temperature data have been collected that is available for the period of 1960-2011 except Bhola (from 1966 to 2011) and Khepupara (from 1975 to 2011) from Bangladesh Meteorological Department (BMD), Agargaon, Dhaka as a secondary source. Each station has missing less than 10% of total except in Dinajpur station (16.59%). The names of the meteorological stations, location (latitude and longitude), ID numbers, geographical and agro-ecological zones under the study area have been collected from BMD. Beside these, population density, female to male ratio, literacy rate, percentage of people depending on agriculture, irrigated land to cultivable land and crop production per unit area are also collected from Statistical Year Book published by BBS (2011).

### 3.3 Missing Data Estimation

The collected data for each station contains several missing values, but according to World Meteorological Organization (WMO) it is possible to estimate successfully because less than 10% missing data is required and estimated by using Statistical Package for Social Sciences (SPSS) software. The global nature of missing daily temperature data has created problems in many climatological applications. Researchers have relied on a variety of techniques to estimate missing daily temperature data depending on the region, time of year, or spatial distribution of neighboring stations. Collectively, these methods can be organized into three basic categories: (i) within-station; (ii) between-station; and (iii) regression-based (Allen, 2001). Within-station methods make use of temperatures recorded on the previous and following days to estimate a missing observation. For example, to estimate a missing maximum temperature on 1 July, the maximum temperatures from 30 June to 2 July could be averaged (Oliver, 1973). Averages can also be computed using more than 1 day on either side of the missing day. To estimate the missing daily temperature data up to three days, the study used within station method, where more than three days data are missed then regression based approach is performed and data from neighboring stations is used. Where the

monthly data is missed then regression based approach is also performed since this method is applied for both monthly and daily data (Eischeid et al. 1995, cited by Allen, 2001). With the regression-based approach, data from one or more neighboring stations is used to develop a regression equation, which is subsequently used to estimate missing temperatures. Using several different regression techniques, Kemp et al. (1983) have shown that this type of approach tends to produce more accurate estimates than both within-station and between-station methods. To fill missing rainfall, multiple imputation methods is used for both daily (Recha et al. 2012) and monthly (Ingsrisawang and Potawee, 2012) data that creates several copies of data sets and imputed each copy with different plausible estimates of the missing values. This method is preferred to single imputation and regression imputation methods. Multiple imputations do not suffer from the problem of underestimating the sampling error because it appropriately adjusts the standard error for missing data (Enders, 2010). Moreover, fact is that it yields complete data set for analysis. Although many other studies have recommended regression imputation, its requirement to use complete variables to fill incomplete variables (Enders, 2010) made it difficult, given the scant nature of data in the neighboring stations.

### 3.4 Rainfall and Temperature Trend Analysis

One of the necessary requirements for climate change research is to analyze trend in the climatic variables like temperature, rainfall, humidity etc. In recent years, lot of studies have been carried out for historical analysis of climatic parameters trend around the world like temperature (Yue and Hashino, 2003; Gadgil and Dhorde, 2005; Wu et al. 2006; El Kenawy et al. 2011; Tabari et al. 2012; del Río et al. 2011; Croitoru et al. 2012, Shifteh Some'e et al. 2012) and precipitation (Partal and Kahya, 2006; Liu et al. 2008; Kampata et al. 2008; Zhang et al, 2008). In Bangladesh few previous studies have obtained good results in identifying trends in climatic data series such as temperature (Azad et al. 2012) and precipitations (Shahid and Khairulmaini, 2009). In the present study, Mann-Kendall test for trend and Sen's slope

estimates are used to analyze the temporal evolution of the time series of annual rainfall and temperature data.

### 3.4.1 Mann-Kendall Test

The non-parametric rank based Mann-Kendall (MK) method (Mann, 1945; Kendall, 1975) is commonly used to assess the significance of monotonic trends in hydro-climatic time series data. This test has the advantage of not assuming any distribution form for time series data but it is powerful as its parametric competitors (Serrano et al. 1999). Therefore, it is recommended highly for general use of trend assessment by WMO (Mitchell et al. 1966). It is based on the test statistics S, which is given as:

$$S = \sum_{k=1}^{n-1} \sum_{j=k+1}^{n} \mathrm{sign}(x_j - x_k) \tag{3.1}$$

$$\text{Where, } \mathrm{sign}(x_j - x_k) = \mathrm{sign}(R_J - R_i) = \begin{cases} +1 \text{ if } (x_j - x_k) > 0 \\ 0 \text{ if } (x_j - x_k) = 0 \\ -1 \text{ if } (x_j - x_k) < 0 \end{cases} \tag{3.2}$$

The value of S indicates the direction of trend where a negative value indicates decreasing trend and that of positive value indicates rising trend.

Mann-Kendall has documented that when $n \geq 8$, the test statistics S is approximately normally distributed with mean and variance are as follows:

$$E(S) = 0 \tag{3.3}$$

$$\mathrm{Var}(S) = \frac{[n(n-1)(2n+5)] - \sum_{i=1}^{m} t_i(t_i-1)(2t_i+5)}{18} \tag{3.4}$$

Where n is the number data point, $t_i$ is the number of ties for the i the value, and m is the number of tied values. Using equation 3.1 and 3.2 the test statistics Z is computed from the following formula:

$$Z = \begin{cases} \frac{S-1}{\sqrt{\mathrm{Var}(S)}}, \text{for } S > 0 \\ 0, \text{for } S = 0 \\ \frac{S+1}{\sqrt{\mathrm{Var}(S)}}, \text{for } S < 0 \end{cases} \tag{3.5}$$

The null hypothesis, $H_o$, that there is no trend in the records is either accepted or rejected depending on whether the computed value of Z statistics is less than or more than the critical value of Z statistics obtained from the area

under normal curve table. At the 5% level of significance, the null hypothesis of no trend is rejected if $|Z|>1.965$; and at 10% level of significance, the null hypothesis of no trend is rejected if $|Z|>1.645$.

### 3.4.2 Sen's Slope Estimator

Sen's method (Sen, 1968) for the estimation of slope requires a time series of equally spaced data. It proceeds by calculating the slope as a change in measurement per unit change in time, as in the following equation

$$Q = \frac{x_{\acute{t}} - x_t}{\acute{t} - t} \tag{3.6}$$

Sen's estimator of slope is given by the median slope,

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

$$= \frac{\left(Q_{[\![(\acute{N})/2]\!]} + Q_{[\![(\acute{N}+2)/2]\!]}\right)}{2} \text{ if } \acute{N} \text{ is even}$$

Where, $\acute{N}$ = number of calculated slopes

### 3.5 Prediction of Climate Variables

There are many variables in nature but the temperature and rainfall are the very significant factor of natural environment. The variation of temperature and rainfall over the decades is most responsible for climate change. The forecasting of temperature and rainfall on a time scale has been attempted by various research groups using different climate modeling. The forecasting of these factors on annual and seasonal time scales is not only scientifically challenging but is also important for planning and developing sustainable agricultural strategies. This study describes the Box-Jenkins time series ARIMA approach for forecasting of temperature on annual average. The Box Jenkins technique is applied to forecast temperature of next five years by analyzing last fifty years data. Previous years data is used to formulate the ARIMA model and in determination of model parameters by using best fitted ARIMA model to the univariate time series, "Package: forecast, Version: 4.8 of R Package". The performance evaluations of the adopted models are carried out on the basis of log likelihood, AIC (Akike Information Criteria) and BIC (Bayesian Information Criteria). This study indicates that the ARIMA model provides reliable and satisfactory forecast for temperature data on annual average

scale. On the other hand, the auto ARIMA models of annual rainfall data do not so well fit and the forecasting performances are also insignificant. That is why Markov chain climate model has been carried out for reliable and satisfactory climate model using rainfall data discussed at section 4.2 in chapter-4.

### 3.5.1 Modeling of Temperature using ARIMA

Average annual and seasonal temperature data of the study area is used to find out an appropriate temperature forecasting model using time series analysis. Time series models have been extensively studied by Box and Jenkins (1976) and as their names have frequently been used with synonymously with general Autoregressive Integrated Moving Average (ARIMA) process applied to time series analysis and forecasting. Autoregressive (AR) models were first introduced by Yule (1926) and later generalized by Walker (1931), while Moving Average (MA) models were first introduced by Slutzky (1937). Wold (1938) provided theoretical foundation for combined Autoregressive Moving Average (ARMA) process. Box and Jenkins (1976) theorized the ARIMA Model. It has been formulized in the following way.

Differencing is often needed to make a time series stationary. Suppose $Y_t$ be a time series variable and consider the model: $Y_t - Y_{t-1} = C+\varepsilon_t$

Where, $\varepsilon_t$ is a white noise disturbance term. Then, $Y_t$ is said to be generated by an integrated process of order one and is denoted as I (1). In compact way, the model can be written as

$$\nabla Y_t = C + \varepsilon_t \qquad \text{Where, } \nabla = 1 - B$$

Similarly an integrated process of order p is denoted by I (d) and written as

$$\nabla^d Y_t = C + \varepsilon_t$$

The theoretical ACF (Auto Correlation Function) of an integrated process decays slowly. From the above discussion, it is clear that an ARIMA process is nothing but the combination of the three processes, AR, MA and integrated processes. The general ARIMA process of order p, d and q is denoted by ARIMA (p, d, q) and it can be written in a compact way:

$$\phi(B)\nabla^d Y_t = C + \theta(B)\varepsilon_t \tag{3.7}$$

$\nabla^d = (1-d)^d$ (The d order differencing operator)

$\phi(B) = (1-\phi_1 B - \phi_2 B^2 - \phi_3 B^3 - \cdots - \phi_p B^p)$ (The p order AR operator)

$\theta(B) = (1-\theta_1 B - \theta_2 B^2 - \theta_3 B^3 - \cdots - \theta_p B^p)$ (The q order MA operator)

$\varepsilon_t$ = Random Shocks, C is the constant and $Y_t$ is any time series.

When difference is not necessary to achieve stationarity, d=0 and the model reduced to ARIMA.

### 3.5.2 Model Selection Criteria

According to Package: forecast, Version: 4.8 of R Package, the return best ARIMA model has been chosen depending on the value of AIC and BIC. The function conducts a search over possible model within the order constraints provided. Finally, select this model that provides smallest value of AIC and BIC. Akike Information Criteria (AIC) (Sakamoto et al. 1986) is one of the most important criteria for checking the adequacy as well as the lag order of a model. AIC is defined as:

$$AIC = \log\left(\frac{\sum \hat{\varepsilon}_i^2}{N}\right) + \frac{2k}{N}$$

Where, $\sum \hat{\varepsilon}_i^2$ indicates sum of squares of residuals. In principle, one could select a lag structure by increasing the number of lags up to the point where AIC reaches a minimum value.

The Bayesian information Criteria (BIC) is another penalized Maximum Likelihood criteria and was originally proposed by Schwarz in 1978. BIC was derived in a Bayesian context and approximates a variant of Laplace's method. The BIC criterion is to be minimized and defined as

$$BIC = \log\left(\sigma^{\hat{2}}\right) + \frac{n\log(N)}{N}$$

Where, n is the dimensionality of the model,

$(1-\phi_1 L - \phi_2 L^2 - \cdots - \phi_p L^p)y_t = c + (1-\theta_1 L - \theta_2 L^2 - \cdots - \theta_q L^q)\varepsilon_t$ is the estimate of the variance and N is the sample size.

### 3.6 Interpolation with GIS

In the present study, Geographic Information System (GIS) is used for the spatial modeling. The ordinary kriging method is used for estimating the value of the climatic variable at a given point by considering the values at neighboring stations and from a variogram model for the considered variable. There are many kriging methods; but ordinary kriging is used in this study through ArcGIS 9.3 extensions (Spatial Analyst and Geostatistical Analyst). The same method was used to perform the spatial analysis of different aridity indices or climatic parameters in Bangladesh with good result. At the same time, previous studies showed that kriging offers better global predictions (van Beers and Kleijnen, 2004) in regional areas of Greece (Baltas, 2007) and Turkey (Apaydin et al. 2004) than other methods.

### 3.7 Modeling Agricultural Drought using Markov Chain

In this study, Markov chain model has been used for agricultural drought assessment with proper prediction based on daily rainfall data. Two states Markov chain model involves the calculation of two conditional probabilities: (1) $\alpha$, the probability of wet week following a dry week, and (2) $\beta$, the probability of a dry week following a wet week. The two states Markov chain for the combination of conditional probabilities is given below:

| | | **Future State** | |
|---|---|---|---|
| **Present State** | | Dry | Wet |
| | Dry | $1-\alpha$ | $\alpha$ |
| | Wet | $\beta$ | $1-\beta$ |

Several authors have found that the sequences in daily rainfall occurrences can be described by a simple Markov chain model. Additional evidence to indicate the feasibility of using a Markov chain model has been presented by Katz (1974), Anderson and Goodman (1957), Todorovic and Woolhiser (1974), Rahman (1999 a&b), Banik et al. (2002), Borkatulla (2007) and Alam et al. (2013). The theory of Markov chain is described below.

Let $X_0, X_1, X_2, \ldots, X_n$, be the random variables distributed identically and taking only two values, namely 0 and 1, with total probability one, i.e.,

$$X_n = \begin{cases} 0 & \text{if the nth week is dry} \\ 1 & \text{if the nth week is wet} \end{cases}$$

Firstly, it may be assume that,

$$P\,(X_{n+1} = x_{n+1} | X_n = x_n, X_{n-1} = x_{n-1}, \ldots, X_0 = x_0) = P\,(X_{n+1} = x_{n+1} | X_n = x_n)$$

where, $x_0, x_1, \ldots, x_{n+1} \in \{0, 1\}$

In other words, it is assumed that probability of wetness in any week depends only on whether of the previous week was wet or dry. Given the event on previous week, the probability of wetness is assumed independent of further preceding weeks. So, the stochastic process $\{X_n, n = 0, 1, 2\ldots\ldots\}$ is a Markov chain (Medhi, 1981).

Considering the transition matrix as;

$$\begin{bmatrix} P_{00} & P_{01} \\ P_{10} & P_{11} \end{bmatrix}$$

where $P_{ij} = P\,(X_1 = j | X_0 = i)$ , $i, j = 0, 1$. Note $P_{00}+P_{01} = 1$ and $P_{10}+P_{11} = 1$

Let $p = \mathrm{P}(X_0 = 1)$. Here $p$ is the absolute probability of a week being wet during the monsoon period.

Clearly, $P(X_0 = 0) = 1 - p$.

For a stationary distribution

$$[1-p \quad p]\begin{bmatrix} P_{00} & P_{01} \\ P_{10} & P_{11} \end{bmatrix} = [1-p \quad p]$$

which gives

$$p = \frac{P_{01}}{1-(P_{11}-P_{01})} \tag{3.8}$$

It is further assumed that $P_{ij}$'s remains constant over the years. The maximum likelihood estimate of $P_{01}$ and $P_{11}$ are appropriate relative functions (Woolhiser and pegram, 1979). A wet spell of length $k$ is defined as sequences of $k$ wet weeks preceded and followed by weeks. Dry spells are defined correspondingly. By "probability of wet spell of length $k$" we mean the probability of a wet spell of length $k$ given that this week is wet, i.e.,

$$P(W = k) = (1 - P_{11})P_{11}^{k-1} \quad (3.8)$$

and probability of wet sequences with length greater than k is:

$$P(W > k) = \sum_{t=k+1}^{\infty} P\,(W = t) = P_{11}^{k}. \quad (3.9)$$

Similarly, probability of a dry spell of length m is:

$$P(D = m) = (1 - P_{01})P_{01}^{m-1}$$

and probability of dry sequences with length greater than m is:

$$P(D > m) = (1 - P_{01})^{m} \quad (3.10)$$

Let Y be the random variable such that Y- number of wet weeks among a n-week period

i.e., $Y = X_0 + X_1 + \cdots + X_{n-1}$.

For large n, Y follows normal distribution with

$$\text{Mean} = n \times p \quad (3.11)$$

$$\textbf{Variance} = n \times p \times (1 - p) \times \frac{1+P_{11}-P_{01}}{1-P_{11}+P_{01}} \quad (3.12)$$

where p is the stationary probability of a week being wet. This is an asymptotic result which indicates neither the exact distribution for small n nor the rapidly of approach to normality (Feller, 1957).

### 3.7.1 Index of Drought Proneness

$P_{11}$ gives the probability of a week to be wet given that previous week was wet also. When $P_{11}$ is large, the chance of wet weeks is also large. But only a small value of $P_{11}$ may not indicate high drought proneness. In this case, large value of $P_{01}$ implies a large number of short wet spells which can prevent occurrence of drought.

Hence, an index of drought proneness may be defined as:

$$DI = P_{11} \times P_{01} \quad (3.13)$$

This index of drought proneness is bounded by zero and one. Higher the value of DI indicates the lower degree of drought proneness and vice-versa.

**Table 3.2:** Index of drought proneness with corresponding drought classes

| Drought Classes | Markov Chain Model |
|---|---|
| Extreme/Chronic | 0.000 < DI < 0.125 |
| Severe | 0.125 < DI < 0.180 |
| Moderate | 0.180 < DI < 0.235 |
| Mild | 0.235 < DI < 0.310 |
| Occasional | 0.310 < DI < 1.000 |

### 3.8 Assessment of Annual Occurrences, Average Recurrence Interval and Percentage of Annual Probability of Drought Events

In those disciplines that inherently deal with probabilities, frequencies and statistical information to characterize natural hazards (floods, droughts, storms, waves, earthquake, stream flow etc.) and design criteria for control structures, the application of risk and uncertainty analysis is a central feature for decision making. Extensions of commonly used method that have evolved for dealing with historical climatic variability can be employed for climate change impact studies, especially in the important areas of hydrology, water management and shore protection (Stakhiv et al. 1991; IPCC, 1994). According to Raghunath (1995) annual occurrence, average recurrence interval and percentage of annual probability is calculated by the following equations:

Annual occurrence, $P_a = m/y$ (3.14)

Where, m is number of years during a time period and y is a time period

The return period or recurrence interval or frequency (T) is the average number of years during which a drought of a given magnitude will be equaled or exceed once. The return period is the mean time that elapses between occurrence of an event of a given size; for example, total rainfall at a location exceeding or matching a certain (Nzewi, 2001);

$$P(x \geq X) = \frac{1}{T} = P(X),$$ where T is return period (year)

$$P(x < X) = 1 - P(x \geq X) = P(\overline{X}) = 1 - \frac{1}{T}$$

Therefore, return period or frequency (T) calculated by

$$T = \frac{1}{1 - P(x \leq X)} = \frac{1}{1 - [1 - P(x \leq X)]} \quad (3.15)$$

And percentage of annual probability, $P = (1-e^{-Pa})*100$ (3.16)

### 3.9 Drought Hazard Index (DHI) Calculation

Shahid and Behrawan (2008) calculated DHI by the following formula:

$$DHI = (MDr \times MDw) + (SDr \times SDw) + (VSDr \times VSDw)$$

where, MDr, ratings assigned to moderate droughts occurrence classes; MDw, weight given to the theme of moderate drought occurrence theme; SDr, ratings assigned to severe droughts occurrence classes; SDw, weight given to the theme of severe drought occurrence theme; VSDr, ratings assigned to very severe droughts occurrence classes and VSDw, weight given to the theme of very severe drought occurrence theme. They did not assign weight for occasional and mild drought.

In this study, mild, moderate, severe and extreme drought events are considered and according to equal interval method assigned rating based on the percentage of occurrence are given in table 3.3. Beside this, the drought hazard index (DHI) has been calculated by the help of the following formula:

$$DHI = (MIDr \times MIDw) + (MDr \times MDw) + (SDr \times SDw) + (EDr \times EDw) \quad (3.17)$$

Where, MIDr, ratings assigned to mild droughts occurrence classes; MIDw, weight given to the theme of mild drought occurrence theme; MDr, ratings assigned to moderate droughts occurrence classes; MDw, weight given to the theme of moderate drought occurrence theme; SDr, ratings assigned to severe droughts occurrence classes; SDw, weight given to the theme of severe drought occurrence theme; EDr, ratings assigned to extreme droughts occurrence classes and EDw, weight given to the theme of extreme occurrence theme.

**Table 3.3** Weights and ratings assigned to drought severity themes and corresponding features of the themes respectively

| Drought Severity | Weight | Percentage of occurrences | Rating |
|---|---|---|---|
| Mild | 1 | 5.88-9.27 | 1 |
| | | 9.27-12.66 | 2 |
| | | 12.66-16.05 | 3 |
| | | 16.05-19.44 | 4 |
| Moderate | 2 | 7.84-10.29 | 1 |
| | | 10.29-12.74 | 2 |
| | | 12.74-15.19 | 3 |
| | | 15.19-17.65 | 4 |
| Severe | 3 | 8.00-14.82 | 1 |
| | | 14.82-21.65 | 2 |
| | | 21.65-28.47 | 3 |
| | | 28.47-35.29 | 4 |
| Extreme | 4 | 31.37-36.27 | 1 |
| | | 36.27-41.17 | 2 |
| | | 41.17-46.08 | 3 |
| | | 46.08-50.98 | 4 |

The spatial distribution of drought hazard index map has been prepared using equation 3.17. The resulting drought hazard map is overlaid on the district map of the study area to produce the district scale drought hazard map (Shahid and Behrawan, 2008). GIS is used to overlay drought hazards dataset onto the district map and then calculate the range of each district DHI values and several point values of DHI have been calculated using shown map tips i.e. predicted value at cursor on spatial distribution map of DHI in GIS. Area-weighted average of DHI values for each district is calculated and used to prepare district level drought hazard map.

## 3.10 Calculation and Classification of Drought Vulnerability Index (DVI)

The most common concept of vulnerability is that it describes the degree to which a socio-economic system or physical assets are either susceptible or resilient to the impact of natural hazards (Wilhelmi and Wilhite, 2002). In this study, collected data related to the socio-economic indicators such as population density, female to male ratio, percentage of agriculture depending people, literacy rate and physical indicator such as irrigated land to cultivable land and crop production per unit area have been considered for vulnerability calculation. Socio-economic and physical vulnerability indicators have been classified by equal interval method. This method ensures that the ranges are well represented by their averages, and the values within each range are fairly close together (Smith, 1986).

A composite vulnerability map is generated by integrating the district level maps of all indicators. First transform all the value of the vulnerability indicators to standardized Z-score value using transform criteria like $Z = \frac{\{X - Mean(X)\}}{SD(X)}$ for comparison as unit free values. For mapping purpose, each class of an indicator is assigned a rating within a scale of Z-score values according to their original values. For all the indicators except literacy rate, classes with higher values of Z-scores are given higher ratings and the classes with lower values of Z-scores are assigned with lower ratings. For literacy rate indicator, classes with higher values of Z-scores are given lower ratings and classes with lower values of Z-scores are given higher ratings as low literacy rate is more vulnerable to drought compared to high literacy rate. The composite drought vulnerability index (DVI) of all indicators is calculated as:

$$\mathrm{DVI} = \frac{\mathrm{PD_r + FMR_r - LR_r + PADP_r + ILCL_r + CP_r}}{\text{Number of indicators}} \qquad (3.18)$$

where, PDr, ratings assigned to population density classes; FMRr, ratings assigned to female to male ratio classes; LRr, ratings assigned to literacy rate classes; PPDAr, ratings assigned to percentage of people depending on agricultural classes; ILCLr, ratings assigned to irrigated land to cultivable land classes and CPr, ratings assigned to crop production per unit area classes.

### 3.11 Drought Risk Index (DRI)

Risk is the probability of harmful consequences, or expected losses resulting from interactions between hazards and vulnerable conditions. Therefore, a conceptual approach to risk assessment can be broken down into a combination of the hazard and vulnerability. Risk patterns will be mapped using the following formula (Blaikie et al. 1994; Downing and Bakker 2000; Wilhite 2000),

$$DRI = DHI \times DVI \tag{3.19}$$

where, DRI represent the drought risk index; DHI represents the drought hazard index and DVI represents the broadest concept of drought vulnerability in a region.

### 3.12 Drought Risk Ranking and Adaptation

Drought risks ranking has been done according to their frequency and severity (Ramamasy and Baas, 2007). The criteria for categorizing severity might include an examination of potential damage, loss of products, and the environmental and economic impacts on agriculture and allied sectors. The criteria for categorizing drought frequency might include the following options.

- **High frequency** - Events that occur more frequently than once in three years;
- **Moderate frequency** - Events that occur once in three years to five years;
- **Low frequency** - Events that occur once in five years to ten years; and
- **Very low frequency** - Events that occur less than once in ten years.

The ranking climate risk and accordingly adaptation measures as described by Ramamasy and Baas (2007) are given below, along with the risk ranking diagram in figure 3.2.

- **Class A:** High-risk condition with highest priority for implementing adaptation measures;
- **Class B:** Moderate-to-high risk condition with risk to be addressed by adaptation;

- **Class C:** Risk condition sufficiently high to give consideration for further adaptation initiatives; and
- **Class D:** Low-risk condition with additional adaptation initiatives.

| Frequency | Minor | Serious | Extensive | Catastrophe |
|---|---|---|---|---|
| High | C | B | A | A |
| Moderate | C | B | B | A |
| Low | D | C | B | B |
| Very Low | D | D | C | C |

Severity

**Figure 3.2** General risk ranking diagram

# Chapter IV

# Results and Discussions

# CHAPTER IV

# RESULTS AND DISCUSSIONS

## 4.1 Climate Assessing and Modeling

### 4.1.1 Introduction

A scenario is a coherent, internally consistent and plausible description of a possible future state of the world (IPCC, 1994). Ramamasy et al. (2006) define climate scenario as: "A plausible and often simplified description of how the future may develop based on a coherent and internally consistent set of assumptions about driving forces and key relationships. Scenarios may be derived from projections, but are often based on additional information from other sources, sometimes combined with a narrative story line."

Bangladesh has a humid, warm and tropical climate where climate is influenced primarily by monsoon and partly by pre-monsoon and post-monsoon circulations. The south-west monsoon originates over the Indian Ocean and carries warm, moist, and unstable air. According to Rashid (1991), there are seven climate sub-zones in Bangladesh and the study area covers six sub-zones that are shown in figure 4.1.

### 4.1.2 Climate Scenario in the Study Area

There are twelve meteorological stations in the study area which are located at Dinajpur, Rangpur, Bogra, Ishwardi, Rajshahi, Faridpur, Jessore, Khulna, Satkhira, Barisal, Bhola and Khepupara. Rainfall and temperature data of all the stations are available for the period of 1960-2011 except Bhola where the data is available for the period of 1966-2011 and that of Khepupara for the period of 1975-2011. The climate scenario of the study area is described in the light of rainfall and temperature data as follows:

#### 4.1.2.1 Annual Rainfall Features

In the study area, the long term (1960-2011) mean annual rainfall is 1925 mm. The driest part of the area is Rajshahi and receives long term minimum mean annual rainfall of amount 1492 mm.

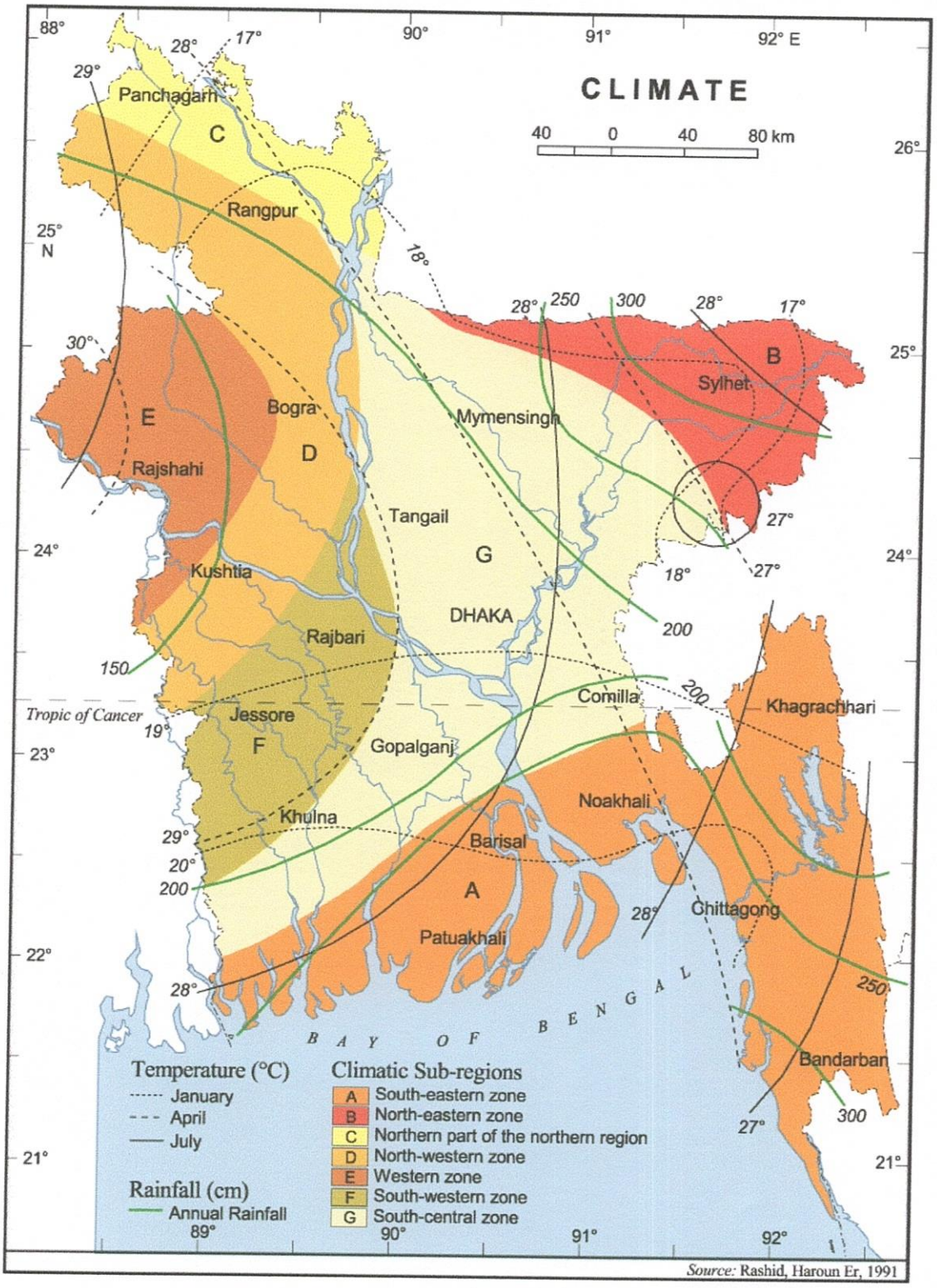


**Figure 4.1** Climate map of Bangladesh (Source: Rashid, 1991)

On the other hand, the wettest area is Khepupara and receives long term maximum mean annual rainfall amount of 2766 mm. Moreover, stations like Rangpur, Bhola and Barisal also receive rainfall more than 2000 mm and others received less than 2000 mm. The standard deviation of annual rainfall is high in Rangpur station with 465 mm and low in Rajshahi station with 300 mm. The summary statistics of annual rainfall in the study area is given in table 4.1.

**Table 4.1** Summary statistics of annual rainfall in the study area

| Station | Minimum | Maximum | Mean | Standard Deviation |
|---|---|---|---|---|
| Dinajpur | 1062 | 3179 | 1929 | 440 |
| Rangpur | 1231 | 3748 | 2189 | 465 |
| Bogra | 1106 | 2601 | 1750 | 371 |
| Ishwardi | 893 | 2798 | 1579 | 392 |
| Rajshahi | 792 | 2241 | 1492 | 300 |
| Faridpur | 1336 | 2599 | 1830 | 340 |
| Jessore | 871 | 2444 | 1647 | 331 |
| Khulna | 862 | 2763 | 1764 | 383 |
| Satkhira | 697 | 2366 | 1714 | 318 |
| Barisal | 1277 | 3394 | 2111 | 396 |
| Bhola | 1255 | 3148 | 2330 | 443 |
| Khepupara | 2169 | 3510 | 2766 | 369 |

Spatial distribution of long term mean annual rainfall in the study area is shown in figure 4.2 and varies from 1492 to 2766 mm. Southern part of the area along the coast of the Bay of Bengal receives the highest amount of rainfall. On the other hand, Rajshahi and northern portion of Khulna division receive the lowest amount of rainfall. Again, rainfall in the north, located at the foot of the Himalaya ranges from 1874 to 2256 mm. Therefore, it can be

generally stated that rainfall in the south and north of the area is much higher than that of the central part.

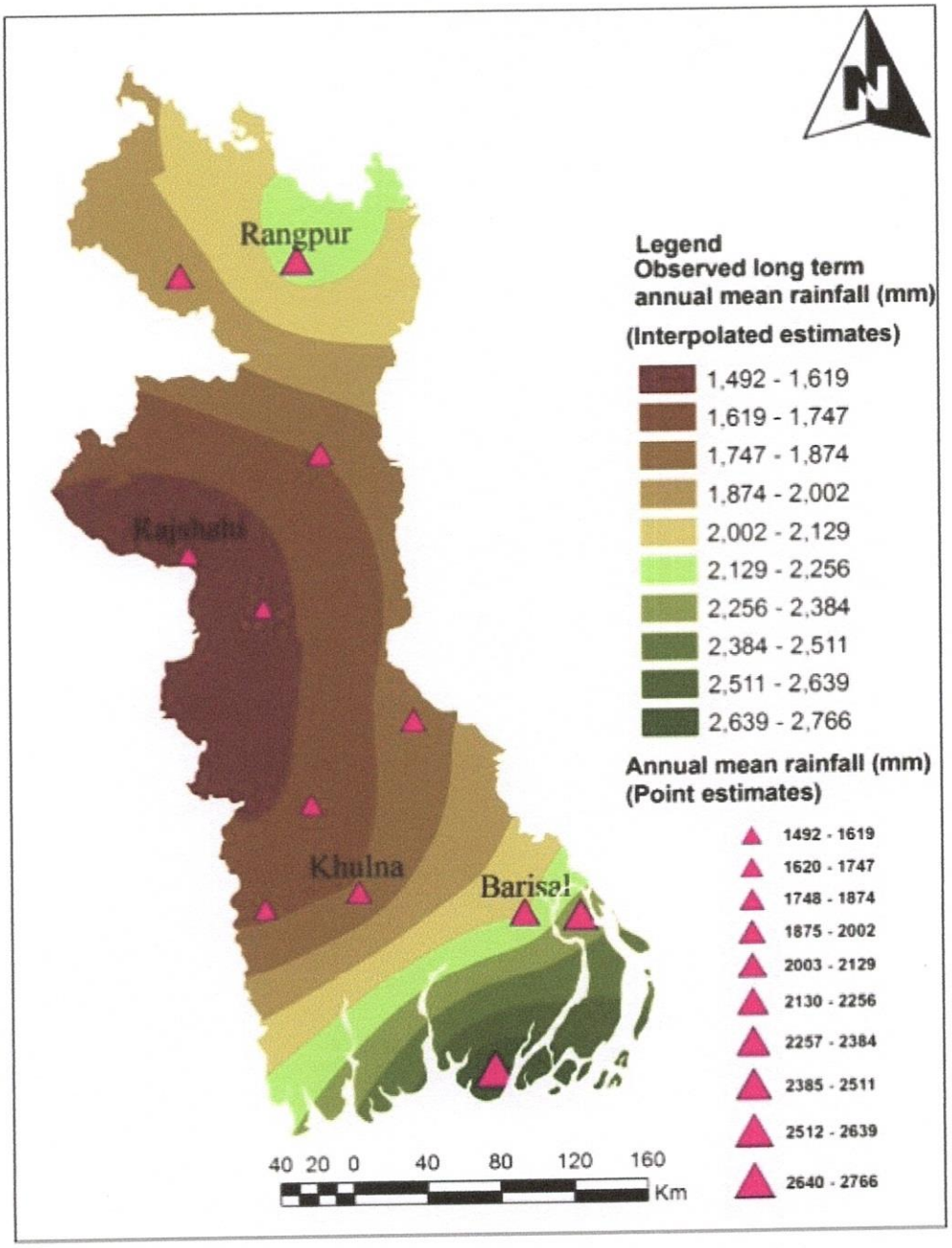


**Figure 4.2** Spatial distribution of annual rainfall in the study area

#### 4.1.2.2 Spatio-Temporal Analysis of Rainfall

Both positive and negative trends of annual rainfall are found in the study area. The positive slope is associated with an increase of annual rainfall while that of negative slopes indicate a decrease trend. But most of them (70.83%)

are statistically insignificant at the 90% and 95% confidence levels. Increasing and decreasing trends in annual rainfall are observed in 58.3 and 41.67% of the stations respectively with the MK test shown in table 4.2.

The strongest significant positive trends at 95% confidence levels in annual rainfall are observed at the rates of 8.56 and 11.15 and 13.66 mm/year at Dinajpur, Rangpur and Khepupara stations respectively. The graph of time series and linear trends of annual rainfall at these stations with significant trends are presented in figure 4.3. One station like Khulna also shows an increasing annual rainfall trend at 90% confidence level with the magnitude of change is 5.19 mm/year. MK analysis of annual rainfalls of Bogra, Jessore and Satkhira stations indicate also positive trend but these are not statistically significant.

**Table 4.2** Summary of annual rainfall trend analysis

| Station | Sen's Slope | Kendall's tau | Z Statistic |
|---|---|---|---|
| Dinajpur | 8.595 | 0.196 | 2.044 |
| Rangpur | 11.151 | 0.248 | 2.596 |
| Bogra | 4.093 | 0.102 | 1.065 |
| Ishwardi | -1.750 | -0.062 | -0.634 |
| Rajshahi | -5.951 | -0.122 | -1.769 |
| Faridpur | -1.586 | -0.045 | -0.466 |
| Jessore | 4.742 | 0.155 | 1.610 |
| Khulna | 5.192 | 0.158 | 1.649 |
| Satkhira | 3.599 | 0.115 | 1.176 |
| Barisal | -3.146 | -0.072 | -0.750 |
| Bhola | -11.667 | -0.186 | -2.140 |
| Khepupara | 13.664 | 0.249 | 2.132 |

The two significant decreasing trends (Figure 4.3) at 95% and 90% confidence levels are found at Bhola and Rajshahi stations at the rates of -11.667 and

-5.951 mm/year respectively. Furthermore, another three stations like Ishwardi, Faridpur and Barisal also show decreasing trend but these are not statistically significant.

Spatial distribution of Mann-Kendall test statistic (Z) of annual rainfall time series is shown in figure 4.4. The significant increasing trend at 95% confidence level is found in the northern part of the area where Z values range from 1.96 to 2.596. Major part of the area from north to south shows insignificant positive trend at 90% and 95% confidence interval except some parts of Rajshahi and Barisal division where trend is negative and insignificant.

#### 4.1.2.3 Seasonal Rainfall Analysis

There are three cropping seasons in Bangladesh named as Rabi, Pre-Kharif and Kharif (Banglapedia, 2003). Rabi season starts in November and ends in February is the climatically dry season; Pre-Kharif season starts in March and ends in June; and Kharif season starts in July and ends in October. Percentage of annual rainfall receives in each season is shown in figure 4.5. Kharif season is the wettest season when almost 62% of rainfall occurs, while that of driest Rabi season receives only 3.23% of total annual rainfall. The rest 35.20% of annual rainfall occurs during the Pre-Kharif season.

##### 4.1.2.3.1 Rabi Season Rainfall

In study area, the long term (1960-2011) average Rabi season receives amount of rainfall is 62.29 mm. The stations in the north receive less rainfall during this season than that are in the south. Moreover, from table 4.3 the stations like Rangpur, Dinajpur, Bogra, Ishwardi and Rajshahi receive rainfall less than 50 mm, whereas, stations like Faridpur, Jessore, Khulna and Satkhira receive rainfall amount of about 70 mm and southern stations like Bhola and Khepupara receive rainfall more than 90 mm during this season. The standard deviation of Rabi season rainfall is high in Khepupara station with an amount of 100.21 mm and low in Rangpur station and the amount is 27.59 mm.

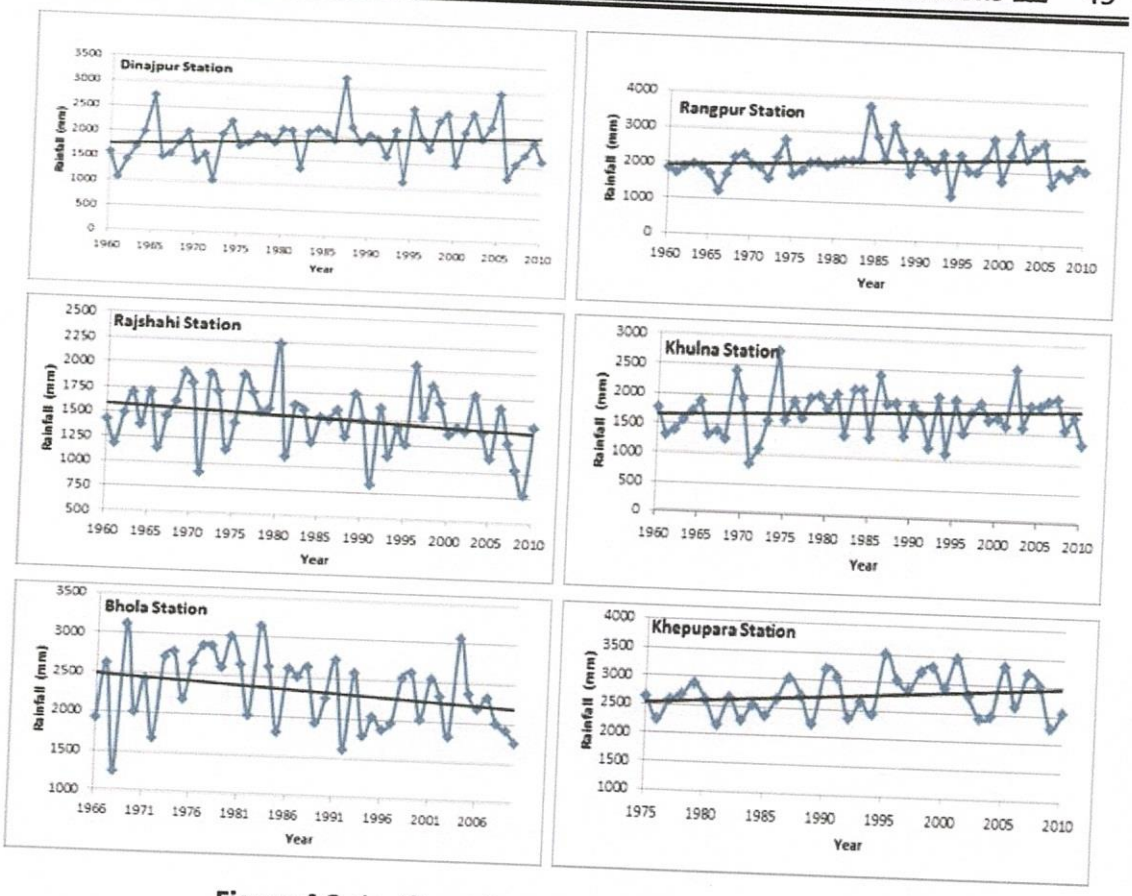


**Figure 4.3** significant linear trends in annual rainfall

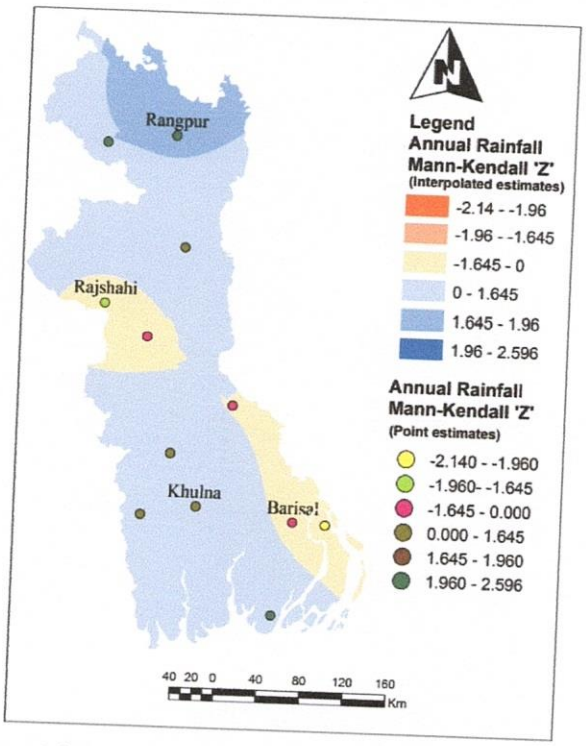


**Figure 4.4** Spatial distribution of MK test statistic (Z) of annual rainfall

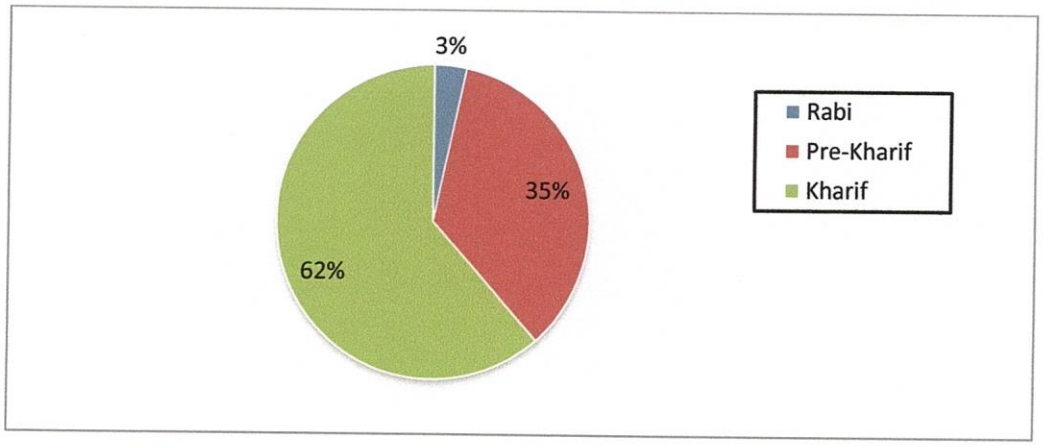


**Figure 4.5** Percentage of annual rainfall receives during the cropping seasons

**Table 4.3** Summary of rainfall statistics in Rabi season

| Station | Minimum | Maximum | Mean | Standard Deviation |
|---|---|---|---|---|
| Dinajpur | 0 | 99 | 33.2 | 27.96 |
| Rangpur | 0 | 125 | 34.72 | 27.59 |
| Bogra | 0 | 126 | 38.91 | 31.02 |
| Ishwardi | 0 | 168 | 47.98 | 39.1 |
| Rajshahi | 0 | 126 | 43.19 | 34.63 |
| Faridpur | 1 | 243 | 68.55 | 58.61 |
| Jessore | 0 | 218 | 67.47 | 54.09 |
| Khulna | 0 | 267 | 65.78 | 63.72 |
| Satkhira | 0 | 236 | 70.67 | 62.07 |
| Barisal | 0 | 370 | 88.53 | 80.69 |
| Bhola | 3 | 348 | 92.05 | 76.68 |
| Khepupara | 0 | 540 | 96.44 | 100.21 |

Figure 4.6 shows spatial distribution of long term mean rainfall of Rabi season in the study area. During this season rainfall gradually increases from north to south and varies from 33.2 to 96.4 mm. Rainfall in the south-eastern corner is almost 100 mm. One third of this amount of rainfall occurs in the north (33.2 to 37 mm) whereas middle portion of the area *i.e.,* Rajshahi division receives 42.1 to 53.3 mm rainfall during this cropping season.

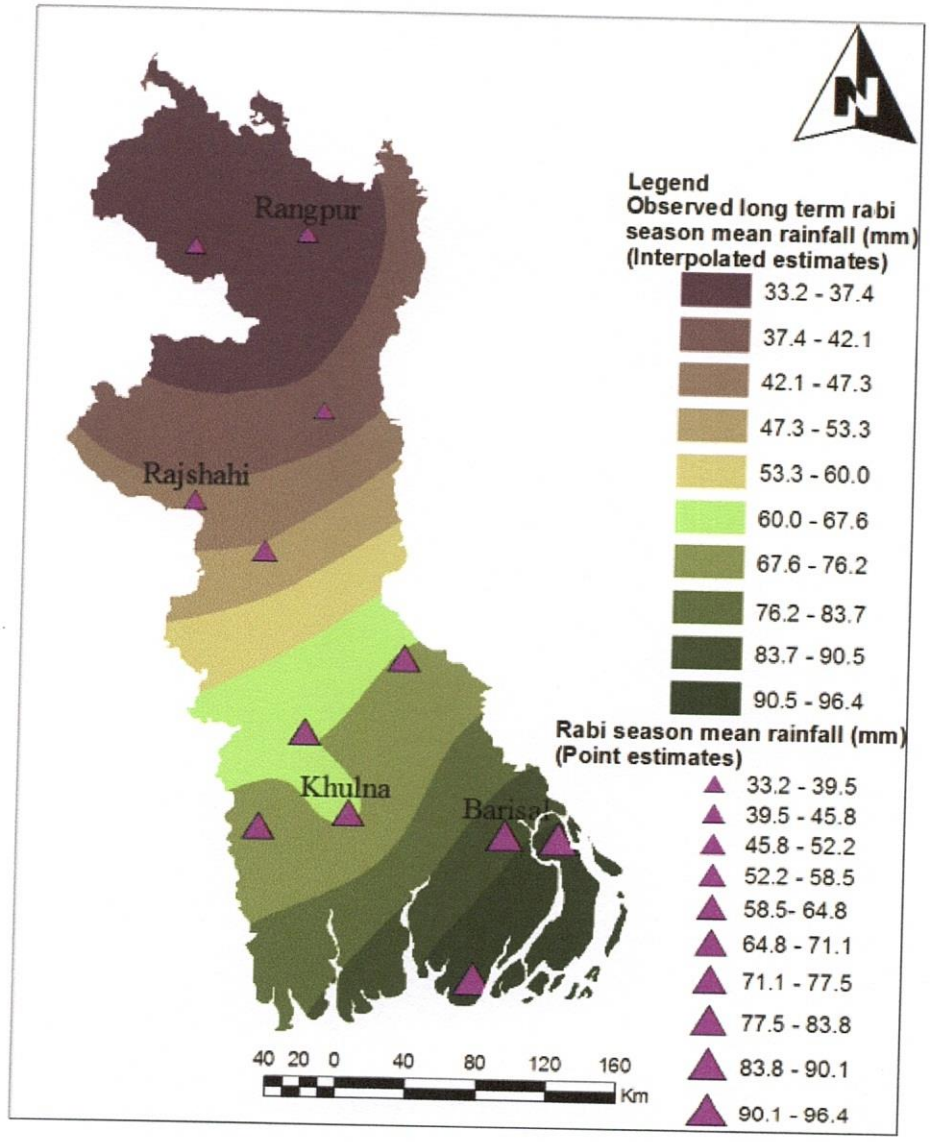


**Figure 4.6** Spatial distribution of Rabi season rainfall

#### 4.1.2.3.2 Spatio-Temporal Analysis of Rabi Season Rainfall

The Rabi season rainfall series shows a rising trend at 58.33% and a falling trend at 33.33% of the stations respectively. However, rainfall of one station shows no trend (Table 4.4). Calculated Z statistics of MK test indicate that only two stations out of 12 like Jessore and Satkhira show statistically significant trends at 95% and 90% confidence interval respectively. The magnitudes of changes assessed by Sen's slope analysis of rainfall data of these two stations are 0.18 and 0.735 mm/year respectively. On the other hand, stations like Bogra, Rajshahi, Barisal and Bhola show insignificant negative trends.

**Table 4.4** Summary of Rabi season rainfall trend analysis

| Station | Sen's Slope | Kendall's tau | Z Statistic |
|---|---|---|---|
| Dinajpur | 0.250 | 0.089 | 0.911 |
| Rangpur | 0.067 | 0.022 | 0.382 |
| Bogra | -0.250 | -0.110 | -1.129 |
| Ishwardi | 0.026 | 0.011 | 0.100 |
| Rajshahi | -0.156 | -0.043 | -0.586 |
| Faridpur | 0.278 | 0.068 | 0.650 |
| Jessore | 0.171 | 0.045 | 0.382 |
| Khulna | 1.071 | 0.226 | 2.300 |
| Satkhira | 0.778 | 0.179 | 1.811 |
| Barisal | -0.267 | -0.036 | -0.455 |
| Bhola | -0.830 | -0.107 | -1.194 |
| Khepupara | 0.016 | 0.002 | 0.000 |

The graph of time series and linear trends of Rabi season rainfall at these stations with significant trends are presented in figure 4.7. The strongest significant increasing trends at 95% and 90% confidence levels in Rabi season rainfall are observed at the rates of 1.071 and 0.778 mm/year at Khulna and Satkhira stations respectively.

Spatial distribution of Mann-Kendall test statistic (Z) of Rabi season rainfall time series is shown in figure 4.8 where values of Z statistic over the area vary from -1.645 to 2.596. Major part of the area shows statistical insignificant trend at 90% and 95% confidence interval except small part located in the north western corner of Khulna division. The whole Rajshahi division and major part of Barisal division, eastern part of Rangpur division show insignificant negative trend. On the other hand, Khulna and Rangpur division shows insignificant positive trend.

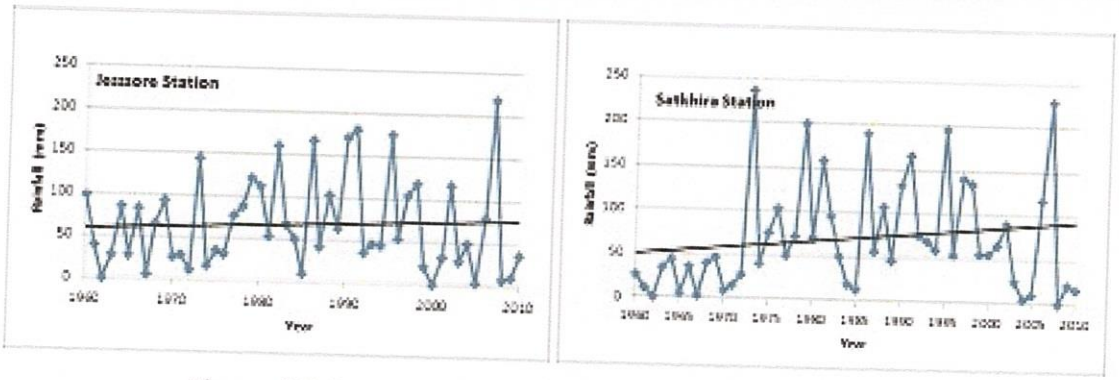


**Figure 4.7** Significant linear trends in Rabi season rainfall

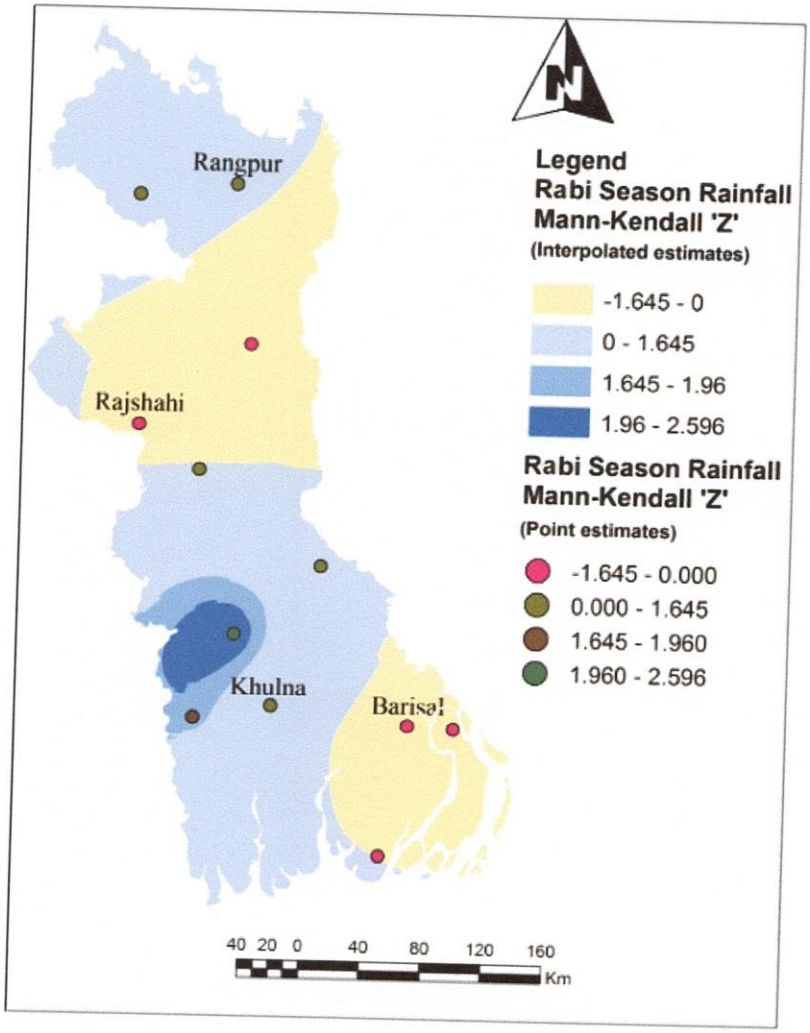


**Figure 4.8** Spatial distribution of MK test statistic (Z) in Rabi season rainfall

#### 4.1.2.3.3 Pre-Kharif Season Rainfall

The long term (1960-2011) mean rainfall in Pre-Kharif season is 678 mm in the study area. From table 4.5, it is clear that Rajshahi station receives the lowest

amount of annual rainfall (481 mm) during this cropping season, while that of Khepupara station receives the highest amount (896 mm). Moreover, stations like Rangpur and Bhola receive rainfall more than 800 mm and that of Faridpur and Barisal receive more than 700 mm. The standard deviation of this seasonal rainfall is high in Bhola station (310.16 mm) and low in Rajshahi station (164.67 mm).

**Table 4.5** Summary of rainfall statistics in Pre-Kharif season

| Station | Minimum | Maximum | Mean | Standard Deviation |
|---|---|---|---|---|
| Dinajpur | 252 | 1204 | 648 | 204.70 |
| Rangpur | 411 | 1667 | 827 | 244.37 |
| Bogra | 262 | 1280 | 625 | 237.35 |
| Ishwardi | 223 | 1752 | 568 | 255.88 |
| Rajshahi | 96 | 1013 | 481 | 164.67 |
| Faridpur | 356 | 1427 | 713 | 218.08 |
| Jessore | 176 | 1145 | 576 | 200.54 |
| Khulna | 275 | 1188 | 628 | 198.57 |
| Satkhira | 183 | 1029 | 549 | 173.54 |
| Barisal | 272 | 1411 | 762 | 266.81 |
| Bhola | 0 | 1427 | 862 | 310.16 |
| Khepupara | 469 | 1420 | 896 | 241.91 |

Spatial distribution of long term mean rainfall in Pre-Kharif season shows similar pattern like annual rainfall (Figure 4.9). Rainfall during this season varies from 481 to 896 mm. In the southern part of the area receives the highest amount of rainfall. On the other hand, Rajshahi and northern part of Khulna division receives the lowest amount of rainfall. Hence, rainfall during this cropping period in the south and north of the area is much higher than that of middle part.

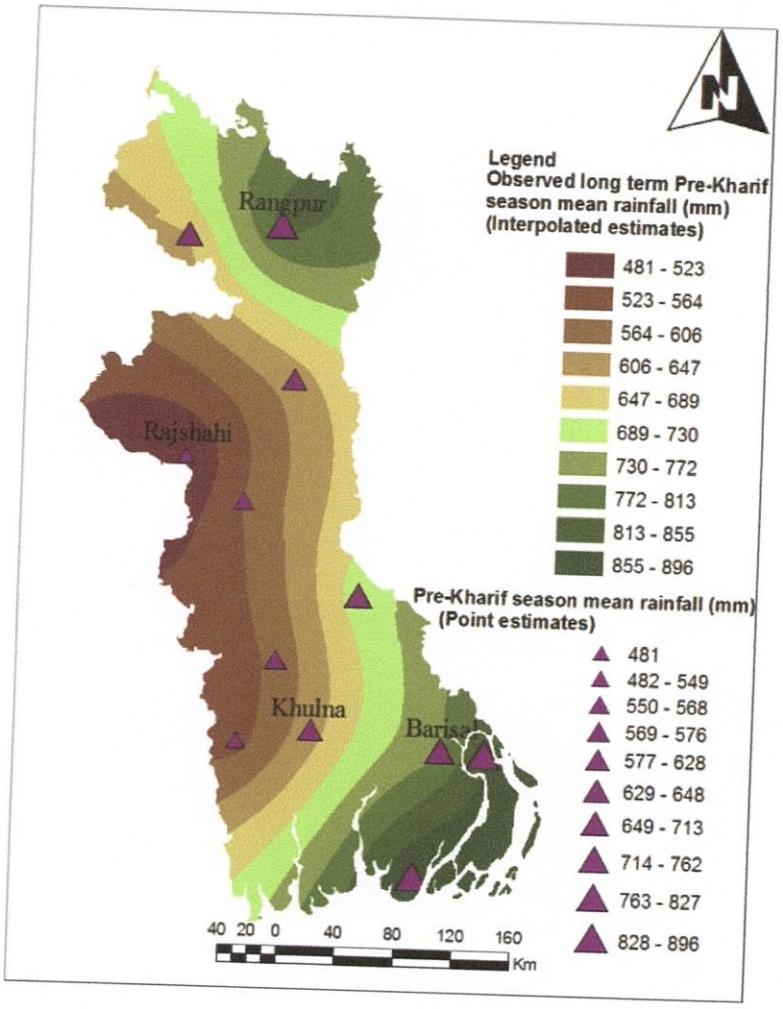


**Figure 4.9** Spatial distribution of mean rainfall in Pre-Kharif season

### 4.1.2.3.4 Spatio-Temporal Analysis of Pre-Kharif Rainfall

Both increasing and decreasing trends in Pre-Kharif rainfall series are found in the study area, but most of them are not statistically significant (83.34%) at the 90% and 95% confidence levels. Increasing and decreasing trends of test in Pre-Kharif rainfall are observed by MK in 41.67% and 58.33% of the stations respectively (Table 4.6).

The strongest significant positive trend at 95% confidence levels during this season is observed at the rate of 4.104 mm/year at Dinajpur station. Rangpur station also shows an increasing annual rainfall trend at 90% confidence interval with the magnitude of change is 3.114. Moreover, Bogra, Jessore and Satkhira also show increasing rainfall trend during this season, but the trends are not

statistically significant. Seven stations like Ishwardi, Rajshahi, Faridpur, Khulna, Barisal, Bhola and Khepupara show insignificant negative trends as shown in table 4.6. The graph of time series and linear trends of Pre-Kharif season rainfall at these stations with significant trends are presented in figure 4.10. The strong significant increasing trends at 95% and 90% confidence levels in Pre-Kharif season rainfall are observed at the rates of 4.104 and 3.114 mm/year at Dinajpur and Rangpur stations respectively.

**Table 4.6** Summary statistics of Pre-Kharif season rainfall trend analysis

| Station | Sen's Slope | Kendall's tau | Z Statistic |
|---|---|---|---|
| Dinajpur | 4.104 | 0.220 | 2.296 |
| Rangpur | 3.114 | 0.161 | 1.673 |
| Bogra | 2.225 | 0.111 | 1.152 |
| Ishwardi | -2.600 | -0.137 | -1.413 |
| Rajshahi | -1.200 | -0.076 | -0.780 |
| Faridpur | -1.965 | -0.094 | -0.979 |
| Jessore | 1.156 | 0.074 | 0.765 |
| Khulna | -1.450 | -0.08 | -0.829 |
| Satkhira | 2.282 | 0.111 | 1.152 |
| Barisal | -0.967 | -0.051 | -0.529 |
| Bhola | -3.667 | -0.120 | -1.165 |
| Khepupara | -1.328 | -0.020 | -0.157 |

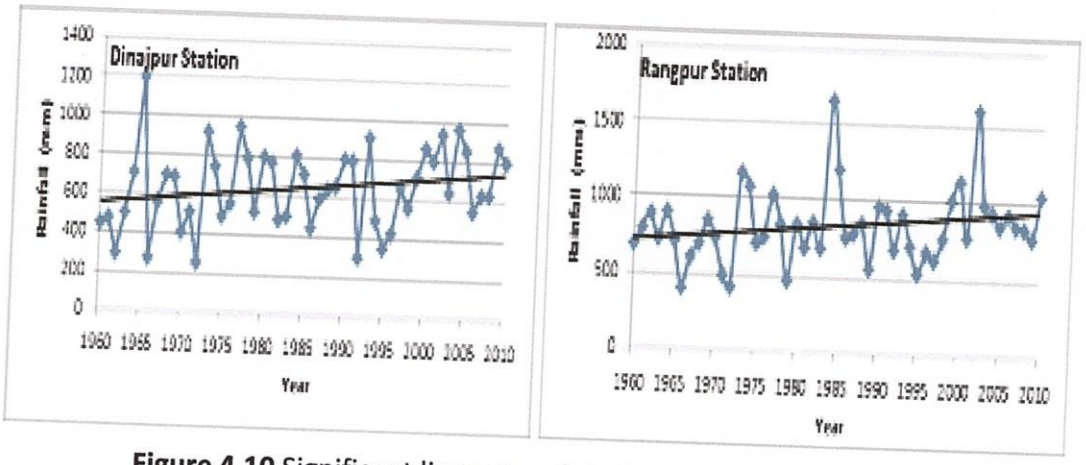


**Figure 4.10** Significant linear trends in Pre-Kharif season rainfall

Mann-Kendall test statistic (Z) of Pre-Kharif season rainfall time series varies from -1.645 to 2.296 (Figure 4.11). Amount of rainfall during this season shows significant increasing trend at 90% and 95% confidence interval in the north-western part of the area. South-western part and some parts of north show insignificant positive trend in rainfall time series during this season, whereas the middle portions of the area and south-eastern part show insignificant negative trend in rainfall time series of this season.

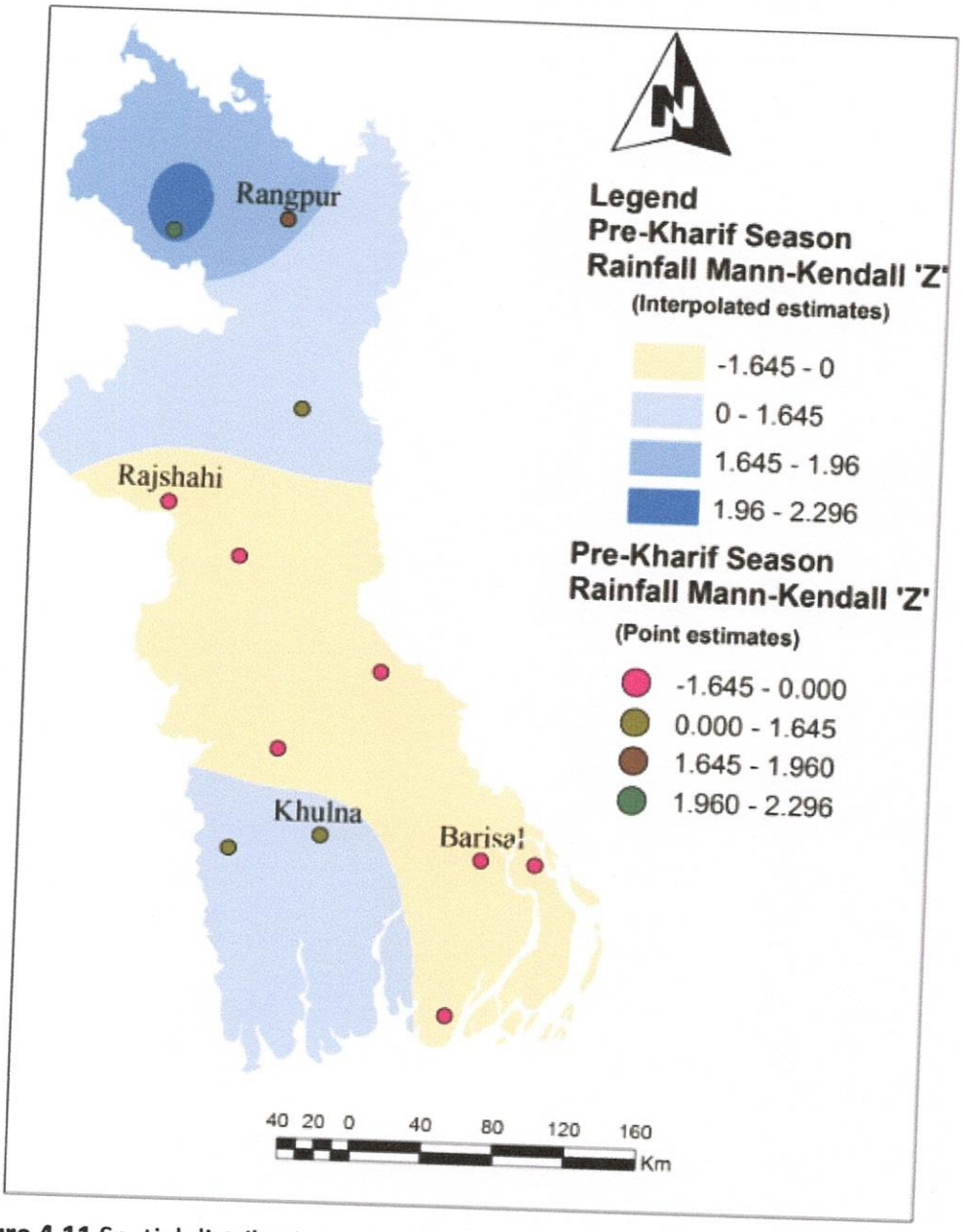


**Figure 4.11** Spatial distribution of MK test statistic (Z) in Pre-Kharif season rainfall

#### 4.1.2.3.5 Kharif Season Rainfall

Kharif is the wettest season in Bangladesh. During this season, the rainfall dependent *Aman* rice is transplanted which is the staple food in the country. Food security of the country is largely dependent on the production of the *Aman* rice. Kharif season mean rainfall in the area is 1178 mm. Stations like Rajshahi and Ishwardi in the north-west receive less than 1000 mm rainfall during this season (Table 4.7). On the other hand, stations like Bogra, Faridpur, Jessore, Khulna and Satkhira receive more than 1000mm but less than 1100 mm rainfall. Again stations like Dinajpur, Rangpur, Barisal and Bhola receive rainfall amount between 1200 and 1300 mm. The highest amount of mean rainfall (1777 mm) occurs during this season at Khepupara station. The standard deviation of this seasonal rainfall is high at Khepupara station with 353.05 mm and low at Faridpur station with 242.57 mm (Table 4.7).

**Table 4.7** Summary of rainfall statistics in Kharif season

| Station | Minimum | Maximum | Mean | Standard Deviation |
|---|---|---|---|---|
| Dinajpur | 579 | 2536 | 1255 | 374.61 |
| Rangpur | 540 | 2440 | 1327 | 361.05 |
| Bogra | 573 | 1948 | 1094 | 289.98 |
| Ishwardi | 440 | 1710 | 963 | 262.81 |
| Rajshahi | 423 | 1583 | 968 | 244.27 |
| Faridpur | 653 | 1524 | 1050 | 242.57 |
| Jessore | 543 | 1919 | 1005 | 285.74 |
| Khulna | 578 | 1998 | 1072 | 308.49 |
| Satkhira | 465 | 1655 | 1096 | 260.99 |
| Barisal | 743 | 2505 | 1263 | 306.90 |
| Bhola | 810 | 2202 | 1378 | 325.51 |
| Khepupara | 1232 | 2510 | 1777 | 353.05 |

Spatial distribution (Figure 4.12) of long term mean Kharif season rainfall shows similar pattern like annual and Pre-Kharif rainfall. Rainfall during this season varies from 963 to 1777 mm. In the southern part of the area, the highest amount of rainfall is received. On the other hand, Rajshahi and northern part of Khulna division receive the lowest amount of rainfall where rainfall amount vary from 963 to 1126 mm. Northern part of the area i.e. Rangpur division received rainfall ranges from 1207 to 1370 mm.

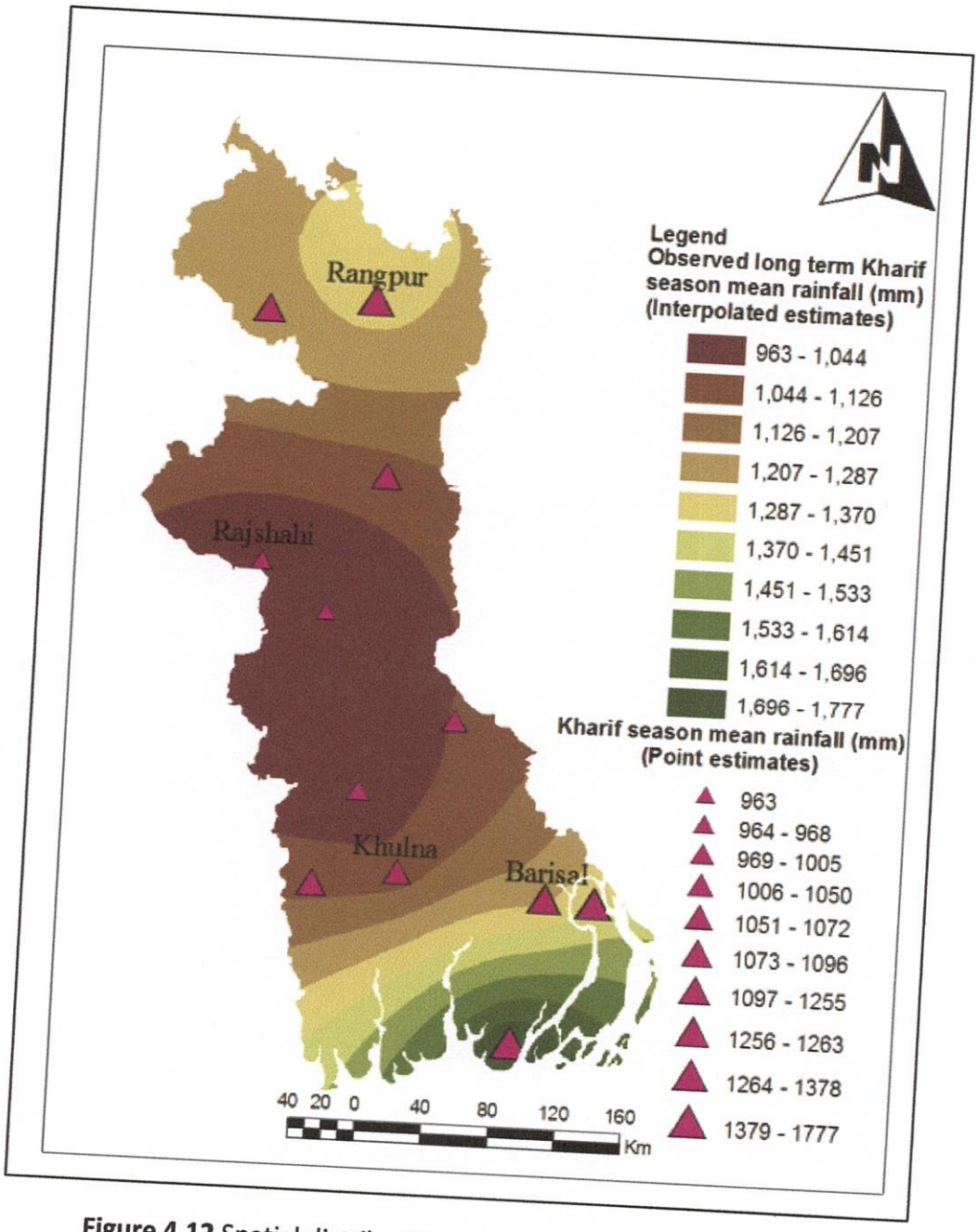


**Figure 4.12** Spatial distribution of mean rainfall in Kharif season

#### 4.1.2.3.6 Spatio-Temporal Analysis of Kharif Rainfall

The Kharif season rainfall series shows a rising trend at 75% of stations and a falling trend at 25% of stations respectively (Table 4.8). Three stations (25% of stations) like Rangpur, Khulna and Khepupara show statistically significant trends at 95% confidence interval and the magnitudes of changes assessed by Sen's slope analysis of these stations are 7.407, 6.157 and 12.733 mm/year respectively. Moreover, stations like Dinajpur, Bogra, Ishwardi, Jessore, Satkhira and Barisal also show positive trends but these are not statistically significant. The rates of changes assessed by Sen's slope analysis of these stations are given in table 4.8. On the other hand, three stations Rajshahi, Faridpur and Bhola show insignificant negative trends during this wet cropping season, but all these are statistically insignificant.

The strongest significant positive trend (Figure 4.13) at 95% confidence levels during this season is observed at the rate of 7.407, 6.157 and 12.733 mm/year at Rangpur, Khulna and Khepupara stations respectively. Moreover, Dinajpur, Bogra, Ishwardi, Jessore, Satkhira and Barisal also show increasing rainfall trend during this season, but the trends are not statistically significant. Three stations like Rajshahi, Faridpur and Bhola show insignificant negative trends.

Spatial distribution of MK test statistic (Z) of Kharif season rainfall time series is shown in figure 4.14. The values of Z statistic over the area vary from -1.004 to 2.596. The spatial map of Z statistics indicates that rainfall in all over the area except Rajshahi increases, but the trend is not significant at 90% and 95% confidence level. One pocket in Khulna and some portion of north show significant positive trend at 95% confidence interval, whereas Rajshahi and pocket area in Barisal show insignificant negative trend.

**Table 4.8** Summary of Kharif season rainfall trend analysis

| Station | Sen's Slope | Kendall's tau | Z Statistic |
|---|---|---|---|
| Dinajpur | 3.168 | 0.131 | 1.365 |
| Rangpur | 7.407 | 0.211 | 2.202 |
| Bogra | 1.409 | 0.054 | 0.552 |
| Ishwardi | 0.237 | 0.007 | 0.065 |
| Rajshahi | -2.063 | -0.089 | -0.918 |
| Faridpur | 0.000 | -0.002 | -0.008 |
| Jessore | 3.442 | 0.109 | 1.128 |
| Khulna | 6.157 | 0.249 | 2.596 |
| Satkhira | 2.016 | 0.075 | 0.773 |
| Barisal | 0.624 | 0.030 | 0.308 |
| Bhola | -3.955 | -0.103 | -1.004 |
| Khepupara | 12.733 | 0.251 | 2.171 |

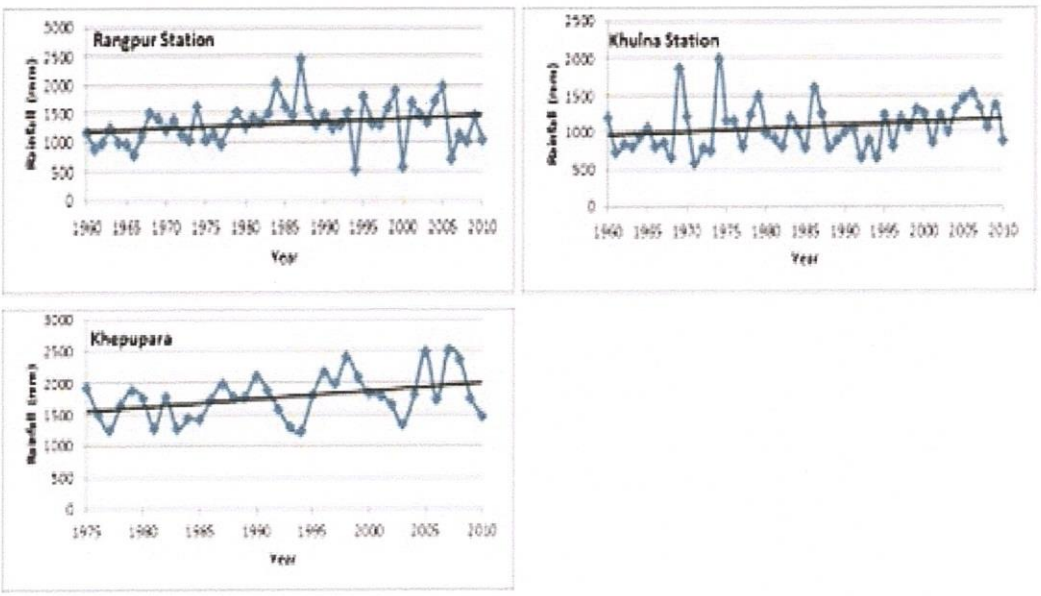


**Figure 4.13** Significant linear trends in Kharif season rainfall

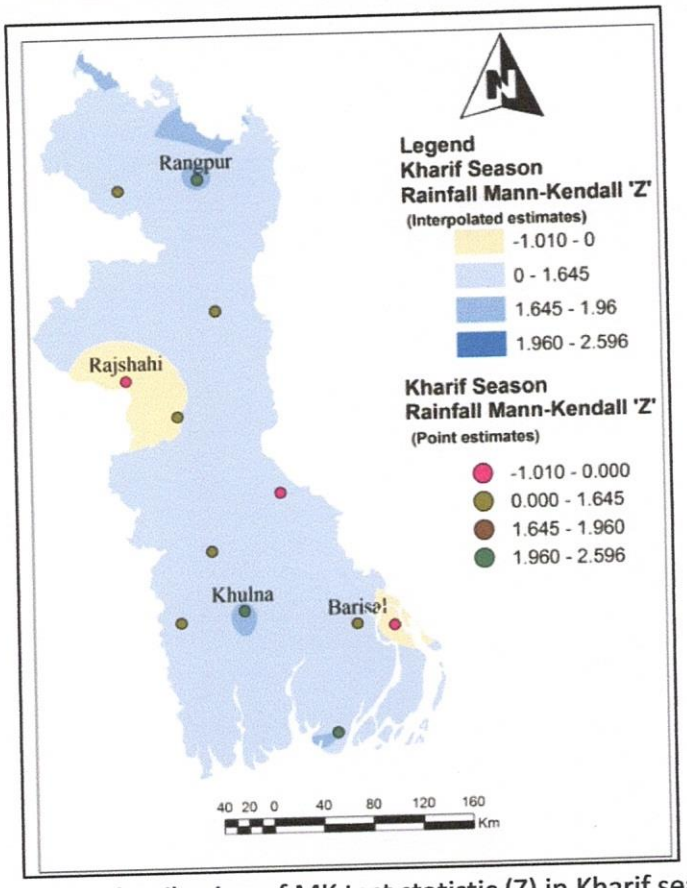


**Figure 4.14** Spatial distribution of MK test statistic (Z) in Kharif season rainfall

### 4.1.2.4 Annual Mean Temperature Features

The long term mean annual temperature in the study area ranges from 24.18°C (Rangpur) to 26.17°C (Khepupara) (Table 4.9). From north i.e., close to the Himalayans towards south *i.e.,* close to the Bay of Bangle mean annual temperature rises. Some years experiences warmer temperature that's why average maximum temperature ranges between 25.26 and 28.98°C. Further, some years' experience cooler temperature than that of mean annual temperature, annual mean minimum temperature ranges from 20.64 to 25.65°C. The standard deviation of annual mean temperature is high in Rangpur station with 0.75573°C and low in Bhola station with 0.27114°C (Table 4.9).

Figure 4.15 shows the spatial distribution of long term annual mean temperature in the study area. Annual average temperature is about 25.44°C. Mean annual temperature is the lowest in the north-east, ranging from 24.18 to 24.43°C. It increases towards the south and reaching in the extreme south-west along the coast of the Bay of Bengal where it ranges from 25.92 to 26.17°C.

**Table 4.9** Summary statistics of annual mean temperature

| Station | Mean Minimum | Mean Maximum | Mean | SD |
|---|---|---|---|---|
| Dinajpur | 24.10 | 26.03 | 24.91 | 0.46455 |
| Rangpur | 20.64 | 25.26 | 24.18 | 0.75573 |
| Bogra | 24.67 | 25.87 | 25.18 | 0.27834 |
| Ishwardi | 24.12 | 26.26 | 25.07 | 0.39702 |
| Rajshahi | 24.43 | 26.57 | 25.28 | 0.50100 |
| Faridpur | 24.80 | 28.98 | 25.63 | 0.58359 |
| Jessore | 25.10 | 26.33 | 25.64 | 0.30066 |
| Khulna | 24.91 | 27.37 | 26.03 | 0.48077 |
| Satkhira | 25.11 | 27.91 | 26.15 | 0.69965 |
| Barisal | 24.99 | 27.30 | 25.56 | 0.43010 |
| Bhola | 24.83 | 26.10 | 25.43 | 0.27114 |
| Khepupara | 25.65 | 27.06 | 26.17 | 0.28811 |

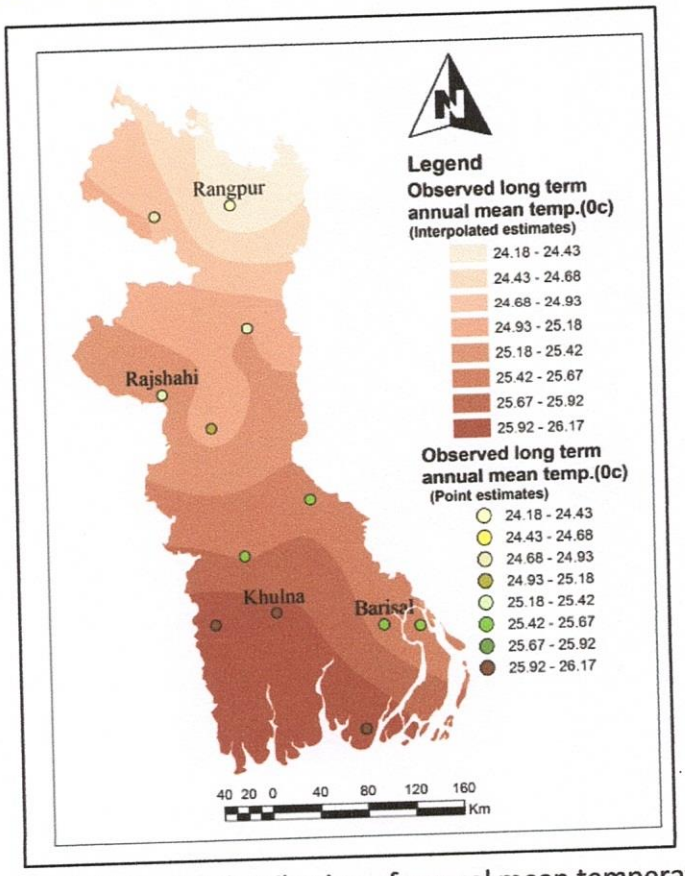


**Figure 4.15** Spatial distribution of annual mean temperature

### 4.1.2.5 Spatio-Temporal Analysis of Annual Mean Temperature

The number stations in the area showing a rising trends in annual mean temperature is 83.33% of stations and that of a falling trends at 16.67% of stations (Table 4.10). The strongest significant positive trends at 95% confidence intervals in annual mean temperature are observed at the rates of 0.015, 0.007, 0.013, 0.009 and 0.08°C/year at Rangpur, Bogra, Faridpur, Jessore and Bhola stations respectively. Five stations (Ishwardi, Rajshahi, Khulna, Satkhira, and Barisal) also show rising mean annual temperature trends, but the trends are not statistically significant with MK test. The rates of changes (°C/year) assessed by Sen's slope analysis of these stations are given in table 4.10. Two stations out of 12 like Dinajpur and Khepupara show falling trends in annual mean temperature where Dinajpur station is not significant at 90% or 95% confidence intervals but Khepupara station is significant at 95% confidence interval. The rates of changes (°C/year) assessed by Sen's slope analysis of these stations are -0.005 and -0.014°C/year respectively.

**Table 4.10** Summary of annual mean temperature trend analysis

| Station | Sen's Slope | Kendall's tau | Z Statistic |
|---|---|---|---|
| Dinajpur | -0.005 | -0.114 | -1.184 |
| Rangpur | 0.015 | 0.382 | 3.993 |
| Bogra | 0.007 | 0.267 | 2.786 |
| Ishwardi | 0.004 | 0.104 | 1.064 |
| Rajshahi | 0.002 | 0.049 | 0.495 |
| Faridpur | 0.013 | 0.367 | 3.835 |
| Jessore | 0.009 | 0.300 | 3.133 |
| Khulna | 0.005 | 0.143 | 1.491 |
| Satkhira | 0.009 | 0.134 | 1.397 |
| Barisal | 0.002 | 0.087 | 0.907 |
| Bhola | 0.008 | 0.270 | 2.650 |
| Khepupara | -0.014 | -0.346 | -3.042 |

The graph of time series and linear trends of annual mean temperature at these stations with significant trends are shown in figure 4.16. The strongest significant increasing trends at 95% confidence levels in mean temperature are observed at the rates of 0.015, 0.007, 0.013, 0.009 and 0.008 (°C/year) at Rangpur, Bogra, Faridpur, Jessore and Bhola stations respectively. The strongest significant decreasing trends at 95% confidence levels in mean temperature are observed at the rate of -0.014 (°C/year) at Khepupara station. Spatial distribution of MK test statistic (Z) of annual mean temperature time series is shown in figure 4.17. The values of Z statistic over the area vary from -3.042 to 3.993. The spatial map of Z statistics indicates that rising trends of annual mean temperature are significant at 90% and 95% confidence level in the north east and the rest of the area except a pocket area in south rising trends are not significant at these confidence levels. Further, insignificant (at 90% and 95% confidence level) rising trends in mean annual temperature are also found in the north-west of the study area.

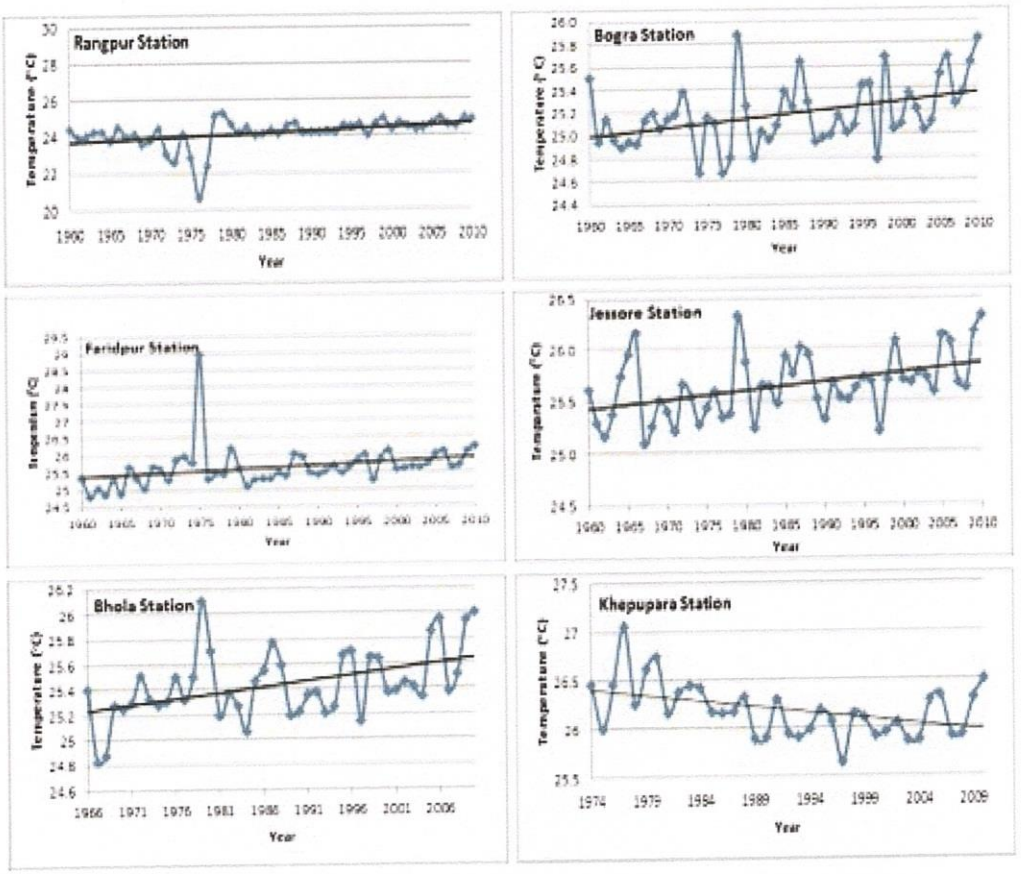


**Figure 4.16** Significant linear trends in annual mean temperature

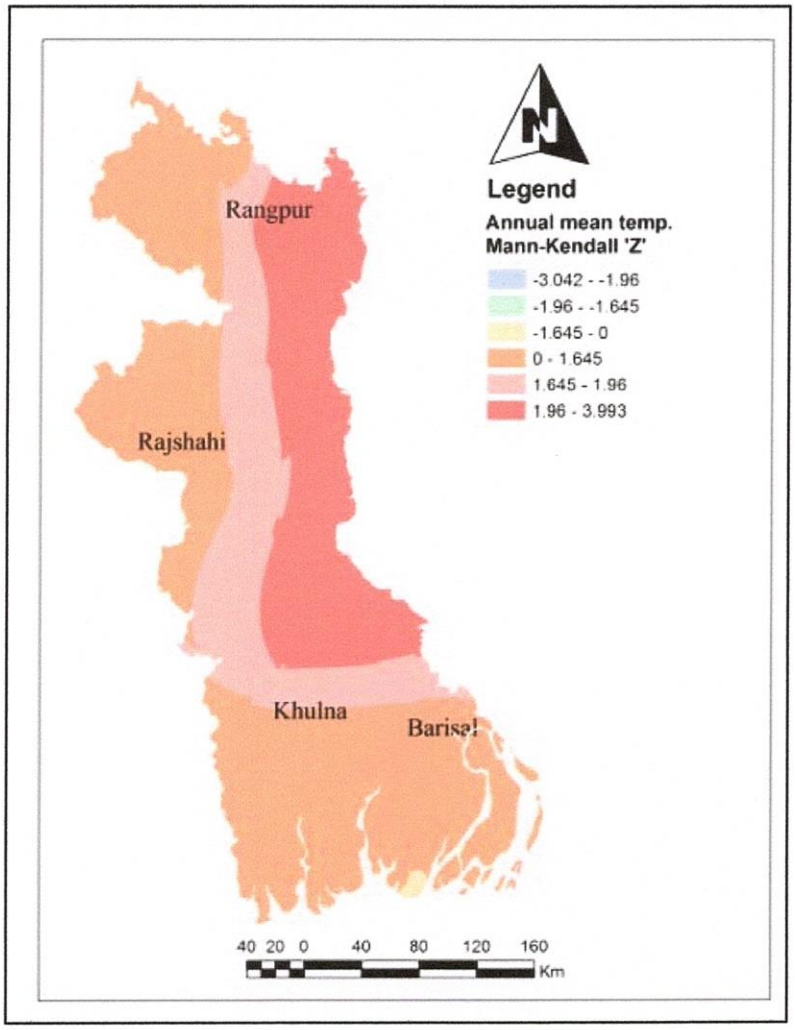


**Figure 4.17** Spatial distribution of MK test statistic (Z) for annual mean temperature

### 4.1.2.6 Seasonal Mean Temperature Analysis

#### 4.1.2.6.1 Rabi Season Mean Temperature

Rabi season is the climatically winter season in Bangladesh. During this season different variety of winter vegetables are produced in Bangladesh. In Rabi season, temperature ranges from 19.15 to 21.06°C during this season (Table 4.11) with mean value of 20.06°C in the area, where northern part is cooler than that of the south. Long term observed mean temperatures of two northern stations for this season are 18.89°C at Rangpur and 19.15°C at Dinajpur station respectively, while southern stations like Khulna, Satkhira, Barisal, Bhola and Khepupara are 21.06, 21.00, 20.71, 20.72 and 21.80°C respectively. Mean minimum temperature during this season varies from 16.83 to 20.94°C, whereas mean maximum ranges from 20.63 to 24.21°C.

**Table 4.11** Summary statistics of Rabi season mean temperature

| Station | Mean minimum temperature (°C) | Mean maximum Temperature (°C) | Mean temperature (°C) | Standard Deviation |
|---|---|---|---|---|
| Dinajpur | 17.89 | 21.37 | 19.15 | 0.8331 |
| Rangpur | 16.83 | 21.30 | 18.89 | 0.7873 |
| Bogra | 18.65 | 20.94 | 19.89 | 0.5155 |
| Ishwardi | 17.42 | 20.63 | 19.25 | 0.6070 |
| Rajshahi | 18.31 | 21.48 | 19.48 | 0.7363 |
| Faridpur | 18.59 | 21.88 | 20.36 | 0.6424 |
| Jessore | 19.02 | 21.32 | 20.18 | 0.5035 |
| Khulna | 19.72 | 23.33 | 21.06 | 0.7101 |
| Satkhira | 18.73 | 23.69 | 21.00 | 1.0858 |
| Barisal | 19.75 | 24.21 | 20.71 | 0.8306 |
| Bhola | 19.74 | 21.80 | 20.72 | 0.4332 |
| Khepupara | 20.94 | 23.04 | 21.80 | 0.6216 |

The spatial distribution of long term mean Rabi season temperature in the study area is shown in figure 4.18 and also shows similar pattern like annual mean temperature. Long term mean temperature in Rabi season shows the lowest in the north-east and ranging from 18.92 to 19.28°C. It increases towards the south and reaching in the extreme in south along the coast of the Bay of Bengal where it ranges from 21.44 to 21.80°C.

#### 4.1.2.6.2 Spatio-Temporal Analysis of Rabi Season Mean Temperature

Both increasing and decreasing trends of mean temperature series in Rabi season are found in the area, but most of them (about 75%) are not statistically significant at 90% and 95% confidence levels. Increasing and decreasing trends in Rabi season mean temperature series are observed by MK in 75% and 25% of the stations respectively (Table 4.12).

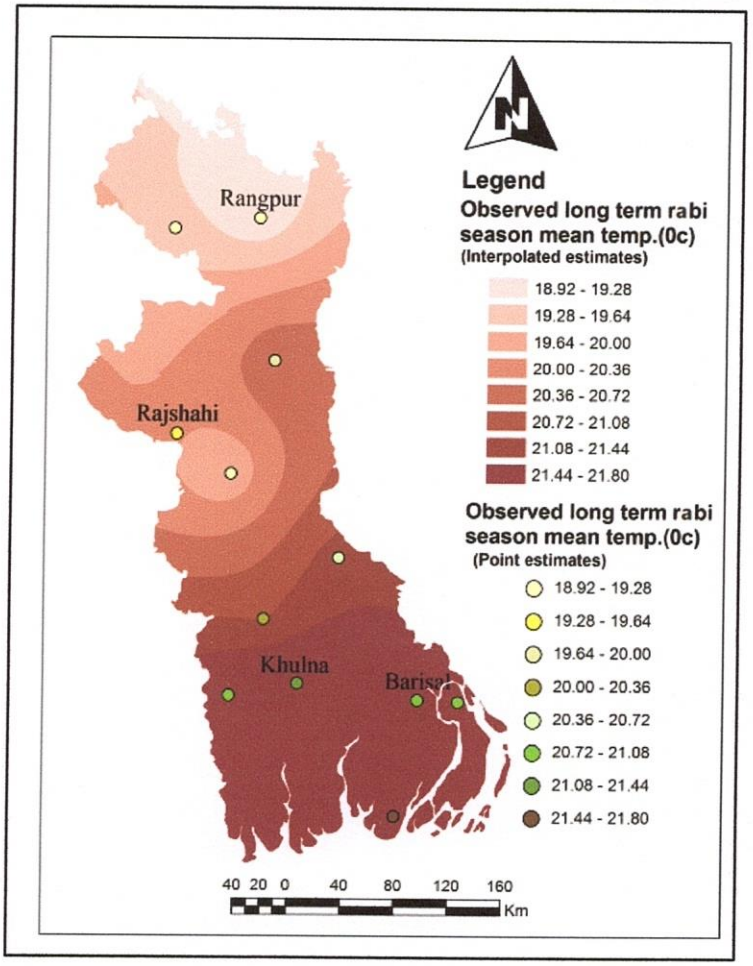


**Figure 4.18** Spatial distribution of the Rabi season mean temperature

The strongest significant positive trends at 95% confidence intervals in mean temperature of Rabi season are observed at the rates of 0.020 and 0.018°C/year at Rangpur and Faridpur stations respectively. Bogra station also show increasing trend at 90% confidence interval at a rate of 0.01°C/year. Five stations like Dinajpur, Ishwardi, Jessore, Satkhira, and Bhola also show rising mean Rabi season temperature trends, but the trends are not statistically significant with MK test. Five stations out of 12 stations like Ishwardi, Rajshahi, Khulna, Barisal and Khepupara show falling trends in mean temperature during this season, falling trends of Ishwardi, Rajshahi, Khulna and Barisal stations are not significant at 90% or 95% confidence intervals but falling trends of Khepupara station is significant at 90% and 95% confidence interval respectively. The rate of changes (°C/year) as assessed by Sen's slope analysis of all stations is given in table 4.12.

**Table 4.12** Summary of Rabi season mean temperature trend analysis

| Station | Sen's Slope | Kendall's tau | Z Statistic |
|---|---|---|---|
| Dinajpur | 0.004 | 0.056 | 0.569 |
| Rangpur | 0.020 | 0.272 | 2.810 |
| Bogra | 0.010 | 0.171 | 1.763 |
| Ishwardi | -0.002 | -0.034 | -0.335 |
| Rajshahi | -0.013 | -0.176 | -1.472 |
| Faridpur | 0.018 | 0.318 | 2.794 |
| Jessore | 0.001 | 0.027 | 0.268 |
| Khulna | -0.003 | -0.041 | -0.414 |
| Satkhira | 0.000 | 0.002 | 0.016 |
| Barisal | -0.002 | -0.026 | -0.260 |
| Bhola | 0.002 | 0.281 | 0.362 |
| Khepupara | -0.043 | -0.562 | -4.957 |

The graph of time series and linear trends of Rabi season mean temperature at these stations with significant trends are shown in figure 4.19. The strongest significant increasing trends at 95% confidence levels in mean temperature are observed at the rates of 0.020 and 0.018°C/year at Rangpur and Faridpur stations respectively and 90% confidence levels in mean temperature are observed at the rate of 0.010°C/year at Bogra station. The strongest significant decreasing trends at 95% confidence levels in Rabi season mean temperature are observed at the rate of -0.043°C/year at Khepupara station.

Figure 4.20 shows the spatial distribution of Mann-Kendall test statistic (Z) of Rabi season mean temperature time series. The values of Z statistics of Rabi season mean temperature series over the area ranges from -4.957 to 2.810 (Figure 4.20). The spatial map of Z statistics reveals that rising trends of Rabi season mean temperature is significant at 90% and 95% confidence level in the north-eastern part of the area. The southern part of the area shows significant negative trend at 90% and 95% confidence levels. The south-

western part shows the insignificant negative trend. From north-western to south-eastern part the area shows insignificant positive change.

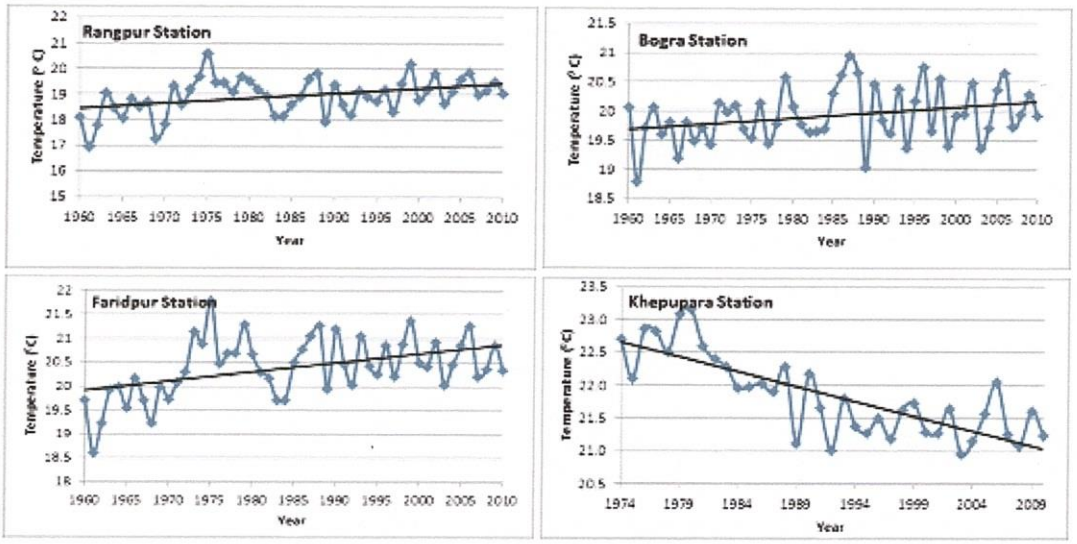


**Figure 4.19** Significant linear trends in Rabi season mean temperature

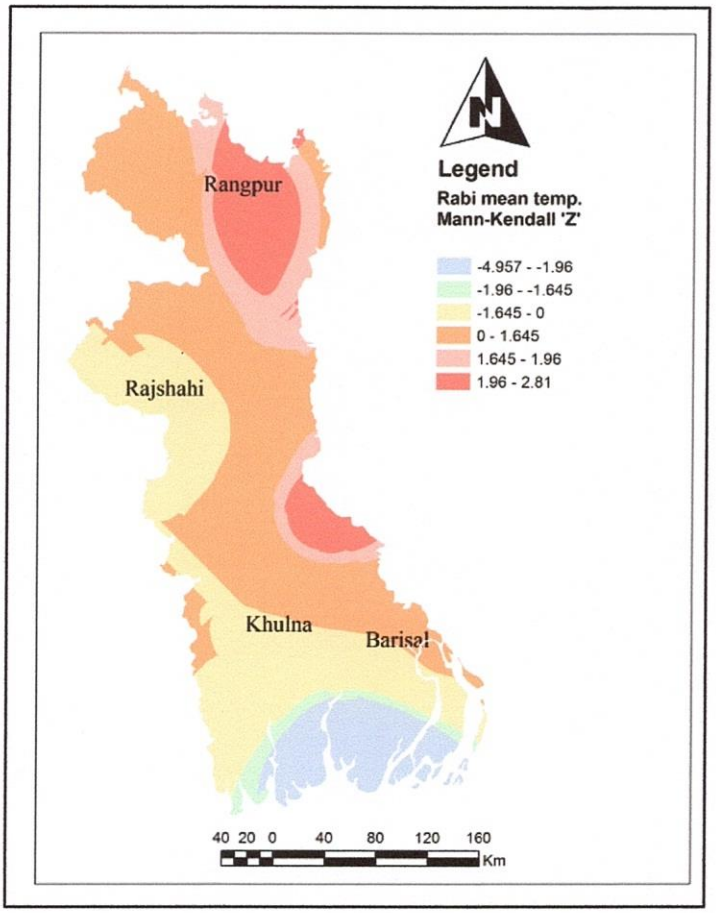


**Figure 4.20** Spatial distribution of MK test statistic (Z) for Rabi season mean temperature

#### 4.1.2.6.3 Pre-Kharif Season Mean Temperature

The Pre-Kharif is climatically summer season in Bangladesh. The long term Pre-Kharif mean temperature in the area ranges from 26.02 to 29.03°C with a mean of 27.99°C. The mean temperature is high (29.03°C) at Satkhira station. Stations like Rajshahi, Faridpur, Jessore, Khulna and Khepupara also experience high temperature and the amount is more than 28°C (Table 4.13). The standard deviation of mean Pre-Kharif season temperature ranges from 0.432 to 1.345°C with mean value 0.733°C.

**Table 4.13** Summary statistics of Pre-Kharif season mean temperature

| Station | Mean Min (°C) | Mean Max (°C) | Mean (°C) | Standard Deviation |
|---|---|---|---|---|
| Dinajpur | 23.85 | 29.31 | 27.44 | 0.931 |
| Rangpur | 20.68 | 28.15 | 26.02 | 1.345 |
| Bogra | 26.38 | 29.04 | 27.59 | 0.647 |
| Ishwardi | 26.43 | 29.78 | 27.96 | 0.724 |
| Rajshahi | 26.68 | 30.66 | 28.26 | 0.859 |
| Faridpur | 26.61 | 30.53 | 28.07 | 0.733 |
| Jessore | 27.31 | 29.85 | 28.53 | 0.566 |
| Khulna | 26.88 | 30.50 | 28.71 | 0.718 |
| Satkhira | 27.58 | 31.32 | 29.03 | 0.820 |
| Barisal | 26.91 | 29.37 | 27.99 | 0.557 |
| Bhola | 26.83 | 28.77 | 27.71 | 0.462 |
| Khepupara | 27.6 | 29.41 | 28.51 | 0.432 |

Spatial distribution of long term mean Pre-Kharif temperature in the area is shown in figure 4.21 with similar pattern as annual and Rabi season. During this season temperature is lowest in the north-east and varies from 26.02 to 29.03°C. It increases towards the south and reaching in the extreme south-west along the coast of the Bay of Bengal where it ranges from 28.65 to 29.03°C.

### 4.1.2.6.4 Spatio-Temporal Analysis of Pre-Kharif Season Mean Temperature

In the study area, 58.53% of stations show rising trend in Pre-Kharif (summer season) mean temperature while 41.67% of stations show falling trend, but most of them (83.33%) are not statistically significant at the 90% and 95% confidence levels. Only two (16.67%) out of 12 show significant trends where Bhola shows positive trend at the rate of 0.014°C/year with significant at 95% confidence level, on the other hand, Dinajpur show negative trend at 95% confidence levels and changes at a rate of -0.029°C/year.

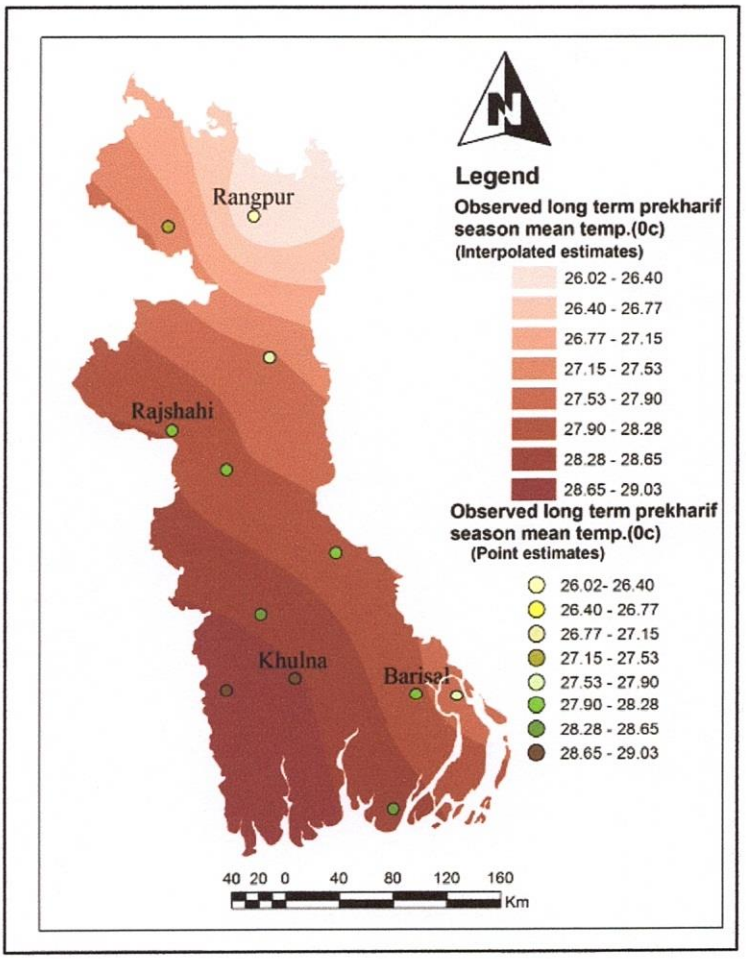


**Figure 4.21** Spatial distributions of the Pre-Kharif season mean temperature

Further, six stations (Rangpur, Ishwardi, Faridpur, Jessore, Satkhira and Barisal) show rising mean temperature trends, but the trends are not statistically significant at 90% and 95% confidence levels with MK test. The rate of changes (°C/year) assessed by Sen's slope analysis of all stations are given in table 4.14. However, four stations (Bogra, Rajshahi, Khulna and

Khepupara) show insignificant negative trends at the 90% and 95% confidence levels.

**Table 4.1.14** Summary of Pre-Kharif mean temperature trend analysis

| Station | Sen's Slope | Kendall's tau | Z Statistic |
|---|---|---|---|
| Dinajpur | -0.0290 | -0.363 | -3.79561 |
| Rangpur | 0.0120 | 0.155 | 1.61767 |
| Bogra | -0.0009 | -0.010 | -0.09470 |
| Ishwardi | 0.0006 | 0.010 | 0.09747 |
| Rajshahi | -0.0050 | -0.064 | -0.64982 |
| Faridpur | 0.0040 | 0.467 | 0.40247 |
| Jessore | 0.0070 | 0.103 | 1.06536 |
| Khulna | -0.0030 | -0.044 | -0.44979 |
| Satkhira | 0.0070 | 0.087 | 0.89967 |
| Barisal | 0.0001 | 0.000 | 0.00000 |
| Bhola | 0.0140 | 0.254 | 2.49000 |
| Khepupara | -0.0009 | -0.018 | -0.15100 |

The graph of time series and linear trends of annual mean temperature of Pre-Kharif season at these stations with significant trends are shown in figure 4.22. The strong significant decreasing trend at 95% confidence levels in mean temperature is observed with a rate -0.029°C/year at Dinajpur station. The strong significant increasing trends at 95% confidence levels in Pre-Kharif season mean temperature is observed at a rate of 0.014°C/year at Bhola station.

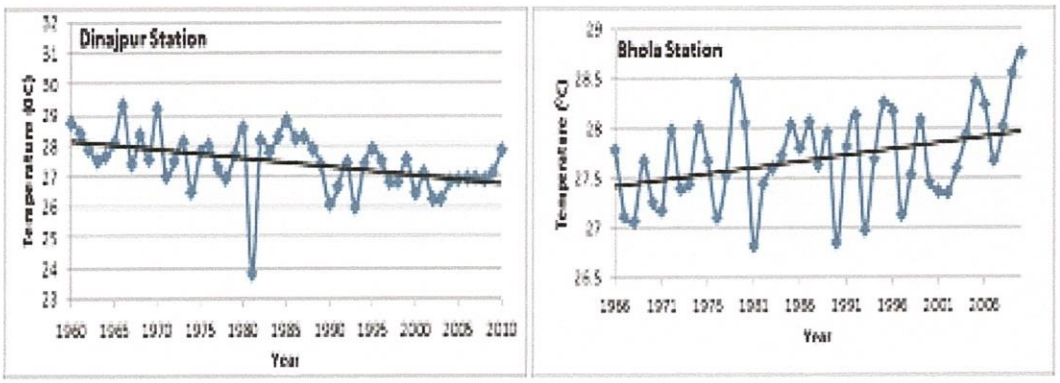


**Figure 4.22** Significant linear trends in Pre-Kharif season mean temperature

Figure 4.23 shows the spatial distribution of Mann-Kendall test statistic (Z) of Pre-Kharif season mean temperature time series. The values of Z statistics of Pre-Kharif season time series in the area ranges from -3.796 to 2.49. The spatial map of Z statistics indicates that both negative and positive trends over the area are not significant at 90 and 95% confidence levels, where northern side of the area shows insignificant negative trend that extends up to the middle part and that of from southern part to the middle shows insignificant positive trends, though station-wise estimation indicate significant trends.

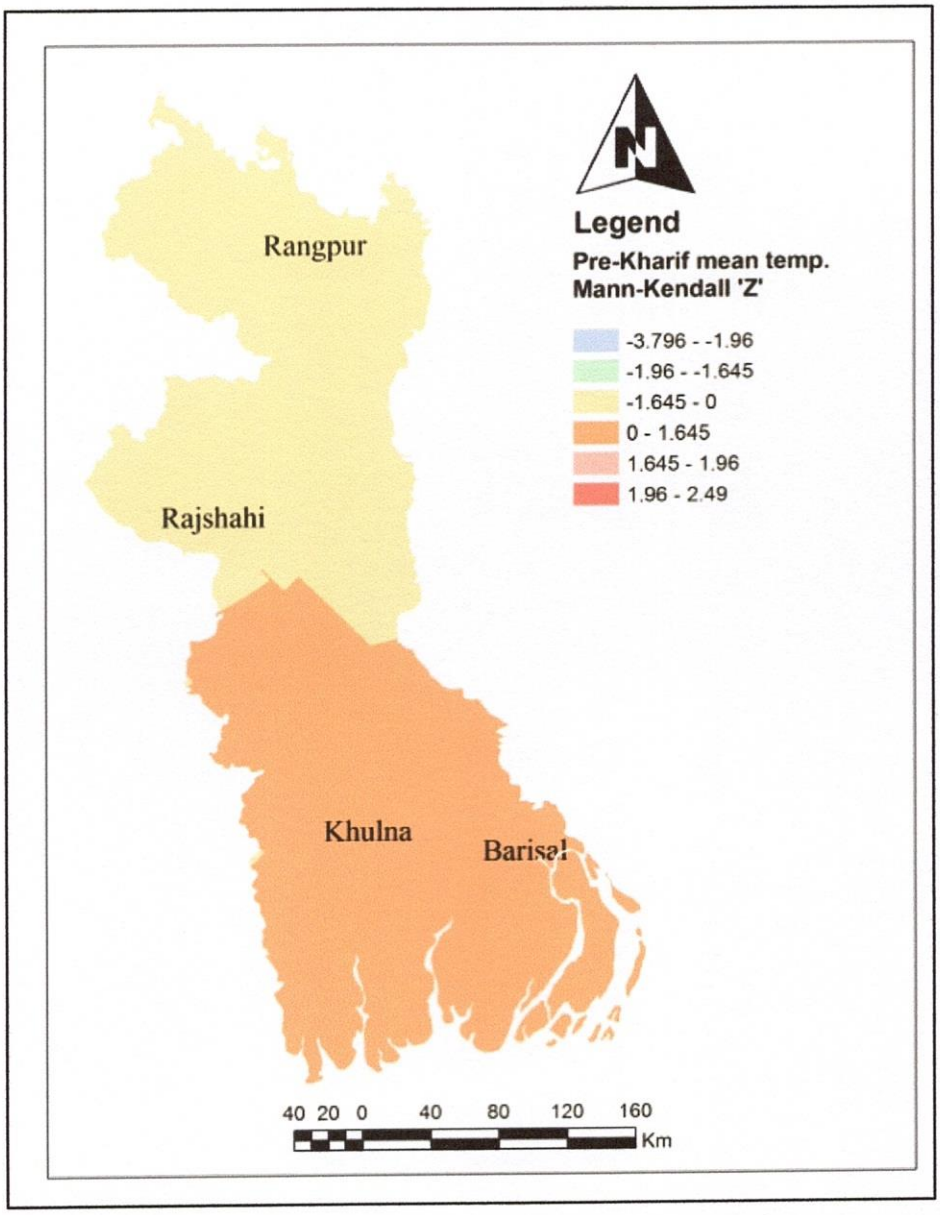


**Figure 4.23** Spatial distributions of MK test statistic (Z) of Pre-Kharif mean temperature

#### 4.1.2.6.5 Kharif Season Mean Temperature

Kharif season is climatically rainy season in Bangladesh. The long term Kharif season mean temperature in the area is 28.10°C and ranges from 27.61 to 28.42°C. The mean temperature is high in Faridpur station during this season and the amount is 28.42°C. Stations like Dinajpur, Bogra, Rajshahi, Jessore, Khulna, Satkhira and Khepupara also experience high temperature of more than 28°C (Table 4.15). The standard deviation of mean Kharif season temperature ranges from 0.27 to 1.160°C with a mean of 0.465°C.

The spatial distribution of long term mean Kharif season temperature in the area is shown in figure 4.24 and shows similar pattern as annual mean temperature. Long term mean Kharif season temperature is lowest in the northeast, ranging from 27.61 to 27.71°C. It increases towards the south with extreme value in south-west along the coast of the Bay of Bengal where it ranges from 28.32 to 28.43°C.

**Table 4.15** Summary statistics of Kharif season mean temperature

| Station | Minimum | Maximum | Mean | Standard Deviation |
|---|---|---|---|---|
| Dinajpur | 27.45 | 28.79 | 28.13 | 0.332 |
| Rangpur | 21.78 | 28.57 | 27.61 | 1.160 |
| Bogra | 26.70 | 28.92 | 28.03 | 0.464 |
| Ishwardi | 27.45 | 28.63 | 27.97 | 0.276 |
| Rajshahi | 27.60 | 28.72 | 28.11 | 0.301 |
| Faridpur | 27.67 | 34.60 | 28.42 | 0.929 |
| Jessore | 27.62 | 29.14 | 28.19 | 0.337 |
| Khulna | 25.96 | 29.15 | 28.30 | 0.490 |
| Satkhira | 27.50 | 29.64 | 28.39 | 0.447 |
| Barisal | 27.30 | 28.73 | 27.96 | 0.297 |
| Bhola | 27.13 | 28.50 | 27.84 | 0.270 |
| Khepupara | 27.43 | 29.02 | 28.22 | 0.277 |

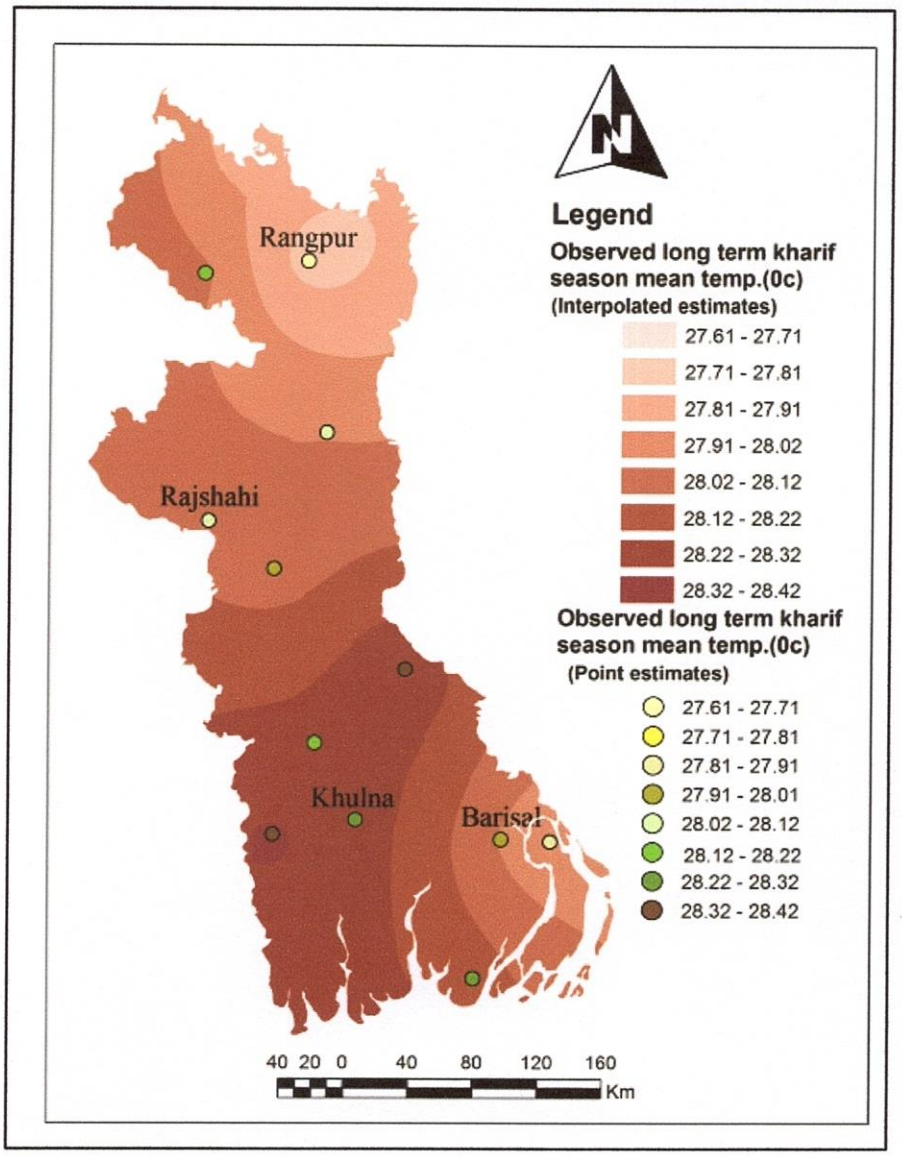


**Figure 4.24** Spatial distributions of Kharif season mean temperature

### 4.1.2.6.6 Spatio-Temporal Analysis of Kharif Season Mean Temperature

All stations show a rising trend in Kharif season (rainy season) mean temperature except Barisal show significant trends at the 90% and 95% confidence levels. Sen's Slope analysis indicates that the magnitude of change ranges from 0.004 to 0.016°C/year with an average value of 0.011°C/year (Table 4.16). Among the cropping season this season show the highest rate of changes and all most all trends are significant at 90 and 95% confidence levels. The graph of time series and linear trends of annual mean temperature of

Kharif season at these stations with significant trends are shown in figure 4.25 where the strongest significant increasing trends at 95% confidence levels in Kharif season mean temperature are observed at the rates 0.009, 0.012, 0.016, 0.011, 0.008, 0.014, 0.015, 0.016, 0.011, 0.013 and 0.007°C/year at Dinajpur, Rangpur, Bogra, Ishwardi, Rajshahi, Faridpur, Jessore, Khulna, Satkhira, Bhola and Khepupara stations respectively.

Spatial distribution of MK test statistic (Z) of Kharif season mean temperature time series is shown in figure 4.26, which indicates that all over the area shows a rising trend significant at 95% confidence level.

**Table 4.16** Summary of Kharif season mean temperature trend analysis

| Station | Sen's Slope | Kendall's tau | Z Statistic |
|---|---|---|---|
| Dinajpur | 0.009 | 0.243 | 2.53304 |
| Rangpur | 0.012 | 0.302 | 3.14854 |
| Bogra | 0.016 | 0.372 | 3.88277 |
| Ishwardi | 0.011 | 0.403 | 4.15885 |
| Rajshahi | 0.008 | 0.227 | 2.33935 |
| Faridpur | 0.014 | 0.467 | 4.87684 |
| Jessore | 0.015 | 0.488 | 5.09006 |
| Khulna | 0.016 | 0.451 | 4.71097 |
| Satkhira | 0.011 | 0.259 | 2.69883 |
| Barisal | 0.004 | 0.106 | 1.09700 |
| Bhola | 0.013 | 0.427 | 4.17564 |
| Khepupara | 0.006 | 0.300 | 1.52100 |

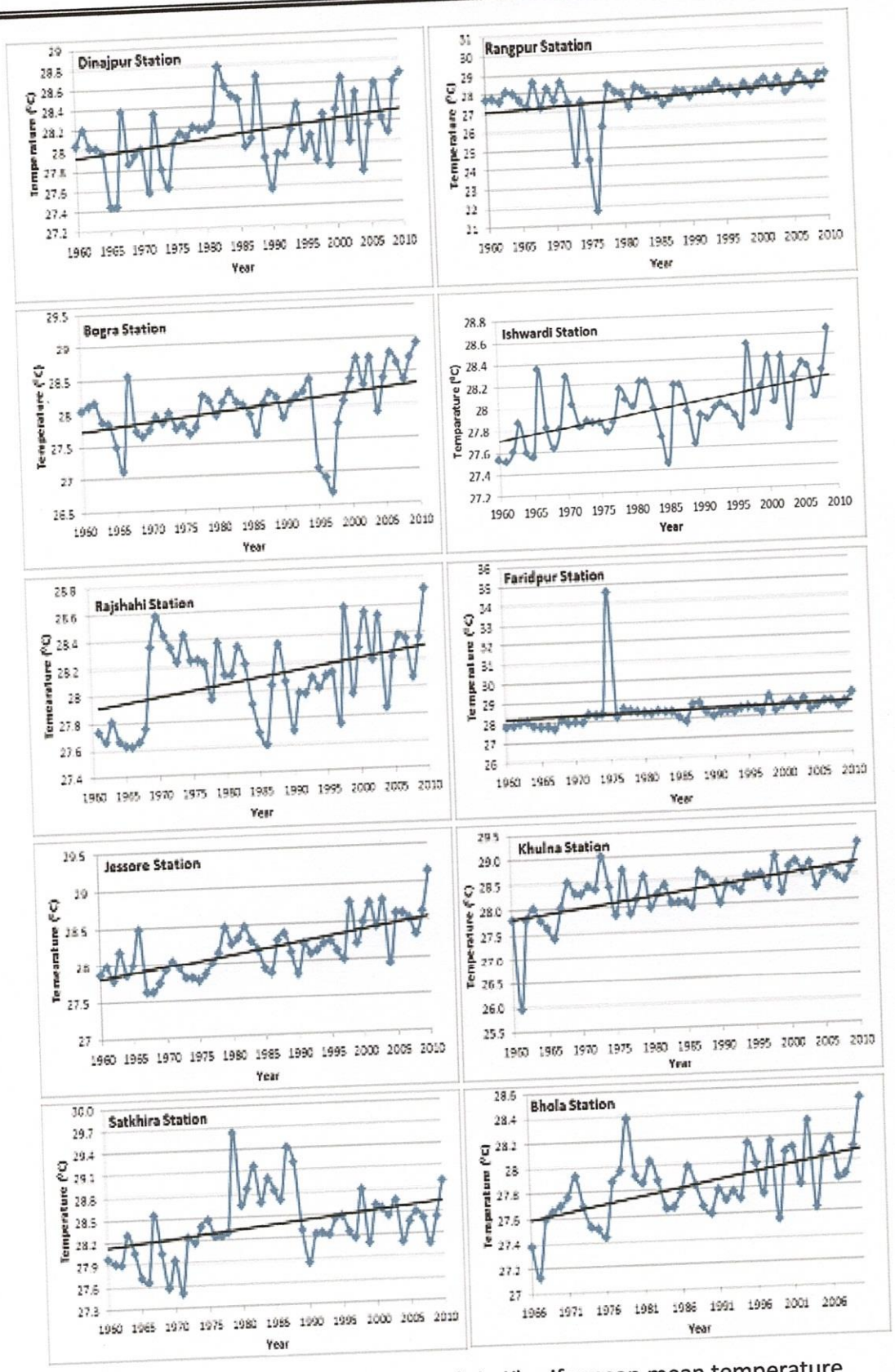


**Figure 4.25** Significant linear trends in Kharif season mean temperature

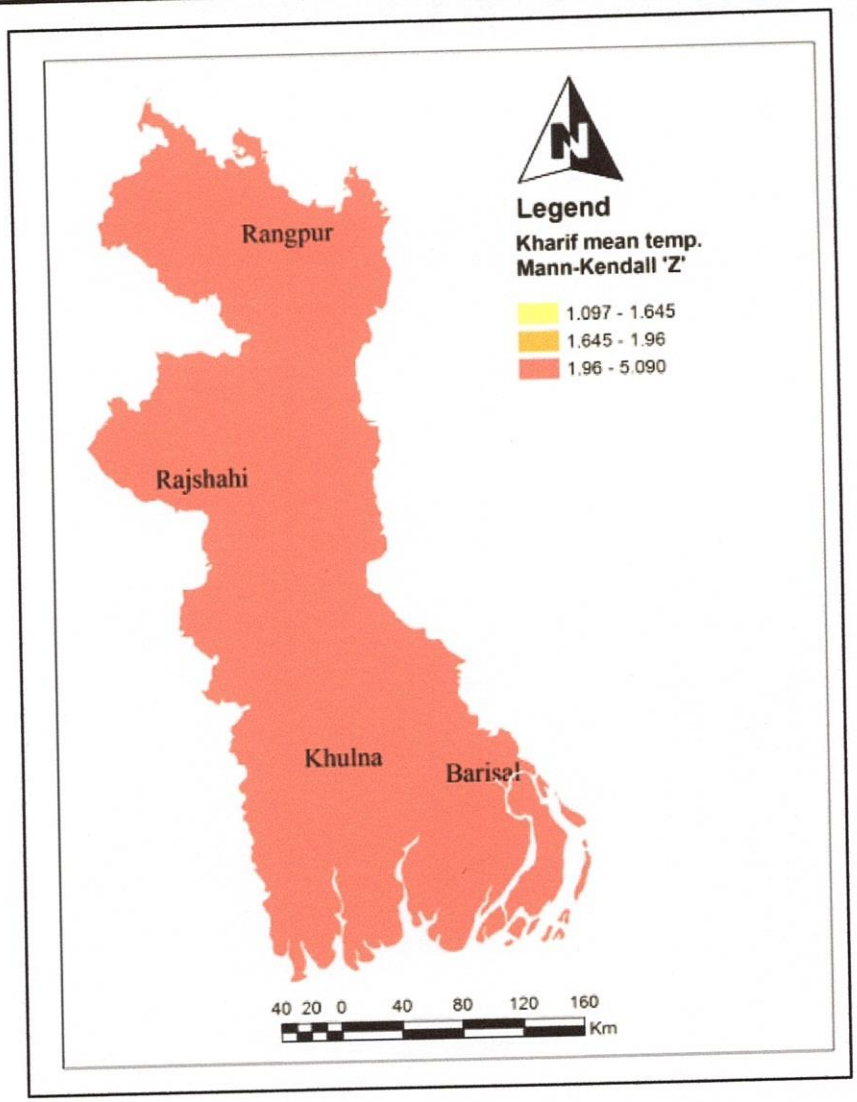


**Figure 4.26** Spatial distribution of MK test statistic (Z) for Kharif mean temperature

### 4.1.3 Station-wise Prediction of Climate Variables

The agricultural practices and crop yields of Bangladesh are heavily dependent on the climatic factors like rainfall and temperature and still today huge portion of cultivated land is under the influence of rain fed agriculture. Unlike irrigated agriculture, rain fed farming is usually diverse and risk prone. In monsoon season fact is that a substantial part of the annual rainfall occurs over a large part of the country. Small variations in the timing and the quantity of monsoon rainfall have the potential to impact on agricultural output. Prior knowledge of monsoon behavior will help our farmers and also policy makers, to take advantage of good monsoons and also to minimize crop damage for drought,

flood and human hardship during adverse monsoons. In addition, importance of annual rainfall of a particular year, the intra seasonal variability is also crucial. Even if the annual total rainfall is normal, the delay in the monsoon onset and unusual monsoon lulls or breaks in between may cause severe disruption of agricultural activities, hydroelectric power generation and even drinking water supply, as is observed in many years in the past. Therefore, farmers need to know the location and time-specific information about the monsoon behavior. The estimated parameters of auto ARIMA Model with five years forecasting values and confidence interval of annual temperatures are given in tables 4.17 to 4.28.

**Table 4.17** ARIMA model of annual mean temperature at Dinajpur station

| ARIMA(2,0,0) Model | | | | | | | |
|---|---|---|---|---|---|---|---|
| Observation | Estimates | | S.E. | sigma^2 estimated | log likelihood | AIC | BIC |
| January-1966 to December-2011 | Intercept | 24.9142 | 0.1157 | 0.1708 | -27.97 | 63.94 | 71.75 |
| | AR(1) | 0.2756 | 0.1348 | | | | |
| | AR(2) | 0.2434 | 0.1345 | | | | |

| Forecasting Annual Average Temperature | | | | | |
|---|---|---|---|---|---|
| Year | Temperature (°C) | 80% C.I | | 95% C.I | |
| | | Lower limit (°C) | Upper limit (°C) | Lower limit (°C) | Upper limit (°C) |
| 2012 | 24.85986 | 24.85986 | 24.33020 | 24.04982 | 25.66991 |
| 2013 | 24.80914 | 24.80914 | 24.25974 | 23.96890 | 25.64939 |
| 2014 | 24.87200 | 24.87200 | 24.29715 | 23.99284 | 25.75116 |
| 2015 | 24.87698 | 24.87698 | 24.29629 | 23.98889 | 25.76507 |
| 2016 | 24.89365 | 24.89365 | 24.30947 | 24.00022 | 25.78709 |

**Table 4.18** ARIMA model of annual mean temperature at Rangpur station

| ARIMA(2,1,0) Model | | | | | | | |
|---|---|---|---|---|---|---|---|
| Observation | Estimates | | S.E. | sigma^2 estimated | Log likelihood | AIC | BIC |
| January-1960 to December-2011 | AR(1) | -0.0505 | 0.1135 | 0.3502 | -46.01 | 98.02 | 103.82 |
| | AR(2) | -0.5749 | 0.1098 | | | | |

| Forecasting Annual Average Temperature | | | | | |
|---|---|---|---|---|---|
| Year | Temperature (°C) | 80% C.I | | 95% C.I | |
| | | Lower limit (°C) | Upper limit (°C) | Lower limit (°C) | Upper limit (°C) |
| 2012 | 24.47007 | 23.71168 | 25.22846 | 23.31021 | 25.62993 |
| 2013 | 24.57351 | 23.68320 | 25.77480 | 23.12959 | 26.32842 |
| 2014 | 24.69146 | 23.60723 | 25.77568 | 23.03328 | 26.34963 |
| 2015 | 24.54450 | 23.30162 | 25.67783 | 22.81123 | 26.27778 |
| 2016 | 24.72900 | 23.41118 | 25.84539 | 22.62833 | 26.51868 |

**Table 4.19** ARIMA model of annual mean temperature at Bogra station

| ARIMA(2,1,1) Model | | | | | | | |
|---|---|---|---|---|---|---|---|
| Observation | Estimates | | S.E. | sigma^2 estimated | Log likelihood | AIC | BIC |
| January-1960 to December-2011 | AR(1) | 0.0269 | 0.1613 | 0.07071 | -5.65 | 19.31 | 27.04 |
| | AR(2) | -0.2652 | 0.1537 | | | | |
| | MA(1) | -0.8415 | 0.0956 | | | | |

| Forecasting Annual Average Temperature | | | | | |
|---|---|---|---|---|---|
| Year | Temperature (°C) | 80% C.I | | 95% C.I | |
| | | Lower limit (°C) | Upper limit (°C) | Lower limit (°C) | Upper limit (°C) |
| 2012 | 25.25095 | 24.91016 | 25.59174 | 24.72976 | 25.77214 |
| 2013 | 25.43903 | 25.09244 | 25.78562 | 24.90896 | 25.96909 |
| 2014 | 25.41311 | 25.06479 | 25.76143 | 24.88041 | 25.94582 |
| 2015 | 25.36255 | 25.01234 | 25.71276 | 24.82695 | 25.89815 |
| 2016 | 25.36806 | 25.01202 | 25.72410 | 24.82355 | 25.91258 |

**Table 4.20** ARIMA model of annual mean temperature at Ishwardi station

| ARIMA(1,0,1) Model with non-zero mean | | | | | | | |
|---|---|---|---|---|---|---|---|
| Observation | Estimates | | S.E. | sigma^2 estimated | log likelihood | AIC | BIC |
| January-1961 to December-2011 | intercept | 25.0771 | 0.0630 | 0.1367 | -22.22 | 52.44 | 60.24 |
| | AR(1) | -0.4700 | 0.2027 | | | | |
| | MA(1) | 0.8116 | 0.1252 | | | | |

| Forecasting Annual Average Temperature | | | | | |
|---|---|---|---|---|---|
| Year | Temperature (°C) | 80% C.I | | 95% C.I | |
| | | Lower limit (°C) | Upper limit (°C) | Lower limit (°C) | Upper limit (°C) |
| 2012 | 25.39797 | 24.92421 | 25.87172 | 24.67342 | 26.12251 |
| 2013 | 24.92623 | 24.42560 | 25.42686 | 24.16058 | 25.69188 |
| 2014 | 25.14796 | 24.64159 | 25.65434 | 24.37353 | 25.92240 |
| 2015 | 25.04374 | 24.53611 | 25.55138 | 24.26738 | 25.82011 |
| 2016 | 25.09273 | 24.58481 | 25.60064 | 24.31594 | 25.86952 |

**Table 4.21** ARIMA model of annual mean temperature at Rajshahi station

| ARIMA(2,0,2) Model with non-zero mean | | | | | | | |
|---|---|---|---|---|---|---|---|
| Observation | Estimates | | S.E. | sigma^2 estimated | log likelihood | AIC | BIC |
| January-1961 to December-2011 | intercept | 25.3004 | 0.0966 | 0.139 | -23.09 | 58.18 | 69.88 |
| | AR(1) | 1.8059 | 0.1026 | | | | |
| | AR(2) | -0.9047 | 0.0889 | | | | |
| | MA(1) | -1.5097 | 0.1602 | | | | |
| | MA(2) | 0.6888 | 0.2039 | | | | |

| Forecasting Annual Average Temperature | | | | | |
|---|---|---|---|---|---|
| Year | Temperature (°C) | 80% C.I | | 95% C.I | |
| | | Lower limit (°C) | Upper limit (°C) | Lower limit (°C) | Upper limit (°C) |
| 2012 | 25.34508 | 24.86730 | 25.82286 | 24.61438 | 26.07578 |
| 2013 | 24.86730 | 24.83393 | 25.83051 | 24.57016 | 26.09429 |
| 2014 | 25.82286 | 24.79639 | 25.83852 | 24.52055 | 26.11435 |
| 2015 | 24.61438 | 24.76097 | 25.84386 | 24.47434 | 26.13048 |
| 2016 | 26.07578 | 24.73226 | 25.84496 | 24.43774 | 26.13948 |

**Table 4.22** ARIMA model of annual mean temperature at Faridpur station

| ARIMA(0,0,0) Model with non-zero mean | | | | | | | |
|---|---|---|---|---|---|---|---|
| Observation | Estimates | | S.E. | sigma^2 estimated | log likelihood | AIC | BIC |
| January-1960 to December-2011 | Intercept | 25.6255 | 0.0801 | 0.334 | -45.27 | 94.55 | 98.45 |

| Forecasting Annual Average Temperature | | | | | |
|---|---|---|---|---|---|
| Year | Temperature (°C) | 80% C.I | | 95% C.I | |
| | | Lower limit (°C) | Upper limit (°C) | Lower limit (°C) | Upper limit (°C) |
| 2012 | 25.6255 | 24.88483 | 26.36617 | 24.49274 | 26.75826 |
| 2013 | 25.6255 | 24.88483 | 26.36617 | 24.49274 | 26.75826 |
| 2014 | 25.6255 | 24.88483 | 26.36617 | 24.49274 | 26.75826 |
| 2015 | 25.6255 | 24.88483 | 26.36617 | 24.49274 | 26.75826 |
| 2016 | 25.6255 | 24.88483 | 26.36617 | 24.49274 | 26.75826 |

**Table 4.23** ARIMA model of annual mean temperature at Jessore station

| ARIMA(0,1,3) Model with non-zero mean | | | | | | | |
|---|---|---|---|---|---|---|---|
| Observation | Estimates | | S.E. | sigma^2 estimated | log likelihood | AIC | BIC |
| January-1960 to December-2011 | MA(1) | -0.6206 | 0.1423 | 0.07149 | -5.98 | 19.96 | 27.69 |
| | MA(2) | -0.5379 | 0.1285 | | | | |
| | MA(3) | 0.2906 | 0.1399 | | | | |

| Forecasting Annual Average Temperature | | | | | |
|---|---|---|---|---|---|
| Year | Temperature (°C) | 80% C.I | | 95% C.I | |
| | | Lower limit (°C) | Upper limit (°C) | Lower limit (°C) | Upper limit (°C) |
| 2012 | 25.62724 | 25.28458 | 25.96990 | 25.10319 | 26.15129 |
| 2013 | 25.90424 | 25.53775 | 26.27074 | 25.34373 | 26.46475 |
| 2014 | 25.81437 | 25.44388 | 26.18487 | 25.24775 | 26.38100 |
| 2015 | 25.81437 | 25.44112 | 26.18763 | 25.24353 | 26.38522 |
| 2016 | 25.81437 | 25.43838 | 26.19037 | 25.23934 | 26.38940 |

**Table 4.24** ARIMA model of annual mean temperature at Khulna station

| ARIMA(0,0,1) Model with non-zero mean | | | | | | | |
|---|---|---|---|---|---|---|---|
| Observation | Estimates | | S.E. | sigma^2 estimated | log likelihood | AIC | BIC |
| January-1960 to December-2011 | Intercept | 26.0305 | 0.0833 | 0.2064 | -32.82 | 71.64 | 77.49 |
| | MA(1) | 0.3284 | 0.1492 | | | | |

| Forecasting Annual Average Temperature | | | | | |
|---|---|---|---|---|---|
| Year | Temperature (oC) | 80% C.I | | 95% C.I | |
| | | Lower limit (oC) | Upper limit (oC) | Lower limit (oC) | Upper limit (oC) |
| 2012 | 25.95140 | 25.36913 | 26.53367 | 25.06089 | 26.84191 |
| 2013 | 26.03051 | 26.64338 | 26.64338 | 25.09320 | 26.96782 |
| 2014 | 26.03051 | 26.64338 | 26.64338 | 25.09320 | 26.96782 |
| 2015 | 26.03051 | 26.64338 | 26.64338 | 25.09320 | 26.96782 |
| 2016 | 26.03051 | 26.64338 | 26.64338 | 25.09320 | 26.96782 |

**Table 4.25** ARIMA model of annual mean temperature at Satkhira station

| **ARIMA(1,0,2) Model with non-zero mean** | | | | | | | |
|---|---|---|---|---|---|---|---|
| Observation | Estimates | | S.E. | sigma^2 estimated | log likelihood | AIC | BIC |
| January-1960 to December-2011 | intercept | 26.0684 | 0.2787 | 0.1988 | -32.39 | 74.78 | 84.54 |
| | AR(1) | 0.8751 | 0.1016 | | | | |
| | MA(1) | 0.0563 | 0.1612 | | | | |
| | MA(2) | -0.4515 | 0.1430 | | | | |

| Forecasting Annual Average Temperature | | | | | |
|---|---|---|---|---|---|
| Year | Temperature (oC) | 80% C.I | | 95% C.I | |
| | | Lower limit (oC) | Upper limit (oC) | Lower limit (oC) | Upper limit (oC) |
| 2012 | 25.80637 | 25.23495 | 26.37779 | 24.93246 | 26.68028 |
| 2013 | 25.99739 | 25.21652 | 26.77826 | 24.80315 | 27.19163 |
| 2014 | 26.00625 | 25.19822 | 26.81429 | 24.77048 | 27.24203 |
| 2015 | 26.01401 | 25.18578 | 26.84224 | 24.74734 | 27.28068 |
| 2016 | 26.02080 | 25.17743 | 26.86417 | 24.73098 | 27.31063 |

**Table 4.26** ARIMA model of annual mean temperature at Barisal station

| ARIMA(0,0,1) Model with non-zero mean | | | | | | | |
|---|---|---|---|---|---|---|---|
| Observation | Estimates | | S.E. | sigma^2 estimated | log likelihood | AIC | BIC |
| January-1960 to December-2011 | Intercept | 25.5628 | 0.0770 | 0.1303 | -20.97 | 47.94 | 53.79 |
| | MA(1) | 0.5492 | 0.1043 | | | | |

| Forecasting Annual Average Temperature | | | | | |
|---|---|---|---|---|---|
| Year | Temperature (oC) | 80% C.I | | 95% C.I | |
| | | Lower limit (oC) | Upper limit (oC) | Lower limit (oC) | Upper limit (oC) |
| 2012 | 25.44856 | 24.98604 | 25.91109 | 24.74119 | 26.15593 |
| 2013 | 25.56278 | 25.03509 | 26.09046 | 24.75575 | 26.36980 |
| 2014 | 25.56278 | 25.03509 | 26.09046 | 24.75575 | 26.36980 |
| 2015 | 25.56278 | 25.03509 | 26.09046 | 24.75575 | 26.36980 |
| 2016 | 25.56278 | 25.03509 | 26.09046 | 24.75575 | 26.36980 |

**Table 4.27** ARIMA model of annual mean temperature at Bhola station

| ARIMA(2,1,1) Model | | | | | | | |
|---|---|---|---|---|---|---|---|
| Observation | Estimates | | S.E. | sigma^2 estimated | log likelihood | AIC | BIC |
| January-1966 to December-2011 | AR(1) | 0.1632 | 0.1700 | 0.06451 | -3.16 | 14.32 | 22.04 |
| | AR(2) | -0.2961 | 0.1545 | | | | |
| | MA(1) | -0.8071 | 0.1265 | | | | |

| Forecasting Annual Average Temperature | | | | | |
|---|---|---|---|---|---|
| Year | Temperature (oC) | 80% C.I | | 95% C.I | |
| | | Lower limit (oC) | Upper limit (oC) | Lower limit (oC) | Upper limit (oC) |
| 2012 | 25.52072 | 25.84622 | 25.84622 | 25.02291 | 26.01852 |
| 2013 | 25.66212 | 26.00764 | 26.00764 | 25.13369 | 26.19055 |
| 2014 | 25.67980 | 26.02563 | 26.02563 | 25.15090 | 26.20871 |
| 2015 | 25.64082 | 25.98763 | 25.98763 | 25.11041 | 26.17123 |
| 2016 | 25.62922 | 25.98331 | 25.98331 | 25.08769 | 26.17075 |

**Table 4.28** ARIMA model of annual mean temperature at Khepupara station

| ARIMA(1,0,1) Model with non-zero mean | | | | | | | |
|---|---|---|---|---|---|---|---|
| Observation | Estimates | | S.E. | sigma^2 estimated | log likelihood | AIC | BIC |
| January-1974 to December-2011 | AR(1) | -0.4087 | 0.1110 | 0.0565 | 0.33 | 5.33 | 11.13 |
| | AR(2) | -0.6485 | 0.1086 | | | | |

| Forecasting Annual Average Temperature | | | | | |
|---|---|---|---|---|---|
| Year | Temperature (oC) | 80% C.I | | 95% C.I | |
| | | Lower limit (oC) | Upper limit (oC) | Lower limit (oC) | Upper limit (oC) |
| 2012 | 25.62277 | 25.31817 | 25.92738 | 25.15692 | 26.08863 |
| 2013 | 25.87681 | 25.52293 | 26.23068 | 25.33561 | 26.41801 |
| 2014 | 25.69498 | 25.33953 | 26.05043 | 25.15137 | 26.23859 |
| 2015 | 25.60455 | 25.20874 | 26.00035 | 24.99921 | 26.20988 |
| 2016 | 25.75943 | 25.31054 | 26.20832 | 25.07291 | 26.44594 |

**Table 4.29** Summary statistics of forecasting annual mean temperature

| Station | Mean | Minimum | Maximum | Standard Deviation |
|---|---|---|---|---|
| Dinajpur | 24.86233 | 24.80914 | 24.89365 | 0.032111 |
| Rangpur | 24.60171 | 24.47007 | 24.72900 | 0.106835 |
| Bogra | 25.36674 | 25.25095 | 25.43903 | 0.072116 |
| Ishwardi | 25.12173 | 25.39797 | 24.92623 | 0.174743 |
| Rajshahi | 25.34508 | 24.61438 | 26.07578 | 0.617331 |
| Faridpur | 25.62550 | 25.62550 | 25.62550 | 0.000000 |
| Jessore | 25.79492 | 25.62724 | 25.90424 | 0.101492 |
| Khulna | 26.01469 | 25.95140 | 26.03051 | 0.035379 |
| Satkhira | 25.96896 | 25.80637 | 26.02080 | 0.091312 |
| Barisal | 25.53994 | 25.44856 | 25.56278 | 0.051081 |
| Bhola | 25.62654 | 25.52072 | 25.67980 | 0.062273 |
| Khepupara | 25.71171 | 25.60455 | 25.87681 | 0.110915 |

The study observed from these tables, the station-wise forecasting temperature of next five years varies very little over the years except that of Faridpur station. From table 4.29, the forecasting statistics of annual average temperature (°C), we also see that the mean, minimum and maximum temperature of each station varies little amount except Faridpur station.

Figure 4.27 represents the bar chart of forecasting values of average yearly temperature of each station and observed that the yearly forecasting temperature is not only fluctuating very little over the years but also fluctuating from one station to another that may be because of geographical morphology or the effect of climate change.

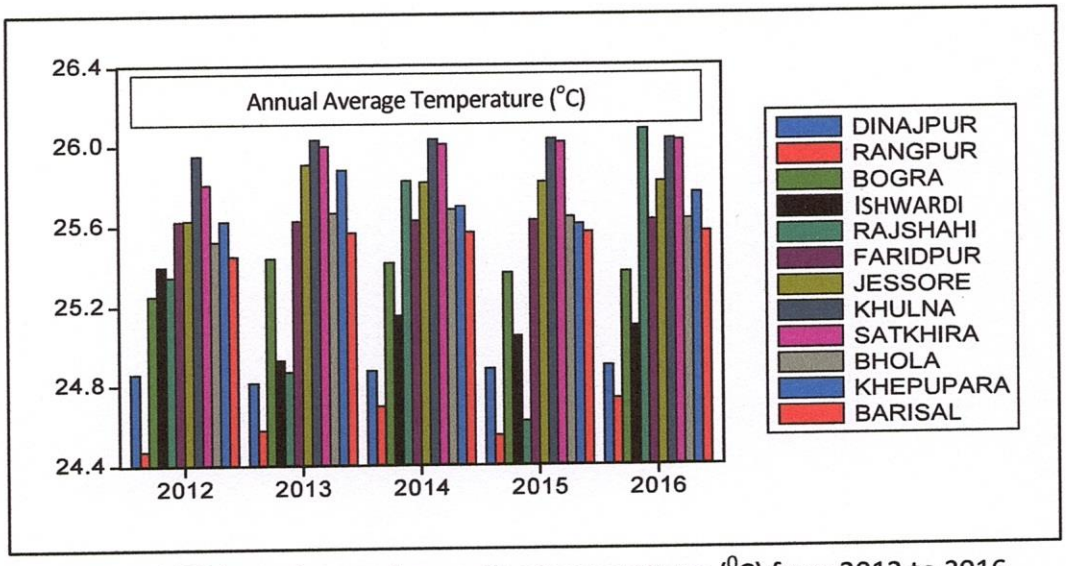


**Figure 4.27** Annual mean forecasting temperatures ($^0$C) from 2012 to 2016

Figure 4.28 shows the spatial distribution of annual average forecasting temperature (°C) in the study area. Annual average temperature over the area will vary from 24.47 to 25.97 in 2012, from 24.57 to 26.03 in 2013, from 24.69 to 26.03 in 2014, 24.54 to 26.03 in 2015 and 24.73 to 26.75°C in 2016 respectively, whereas long term annual average temperature ranges from 24.18 to 26.17°C. Therefore, forecasted temperatures for over years are higher than that of long term mean temperature and is also found that predicted temperature for the years 2014 and 2015 revels that temperatures in the southern part do not show variation. Though temperature is rising, spatial pattern will be remained same in the future as like as observed mean temperature.

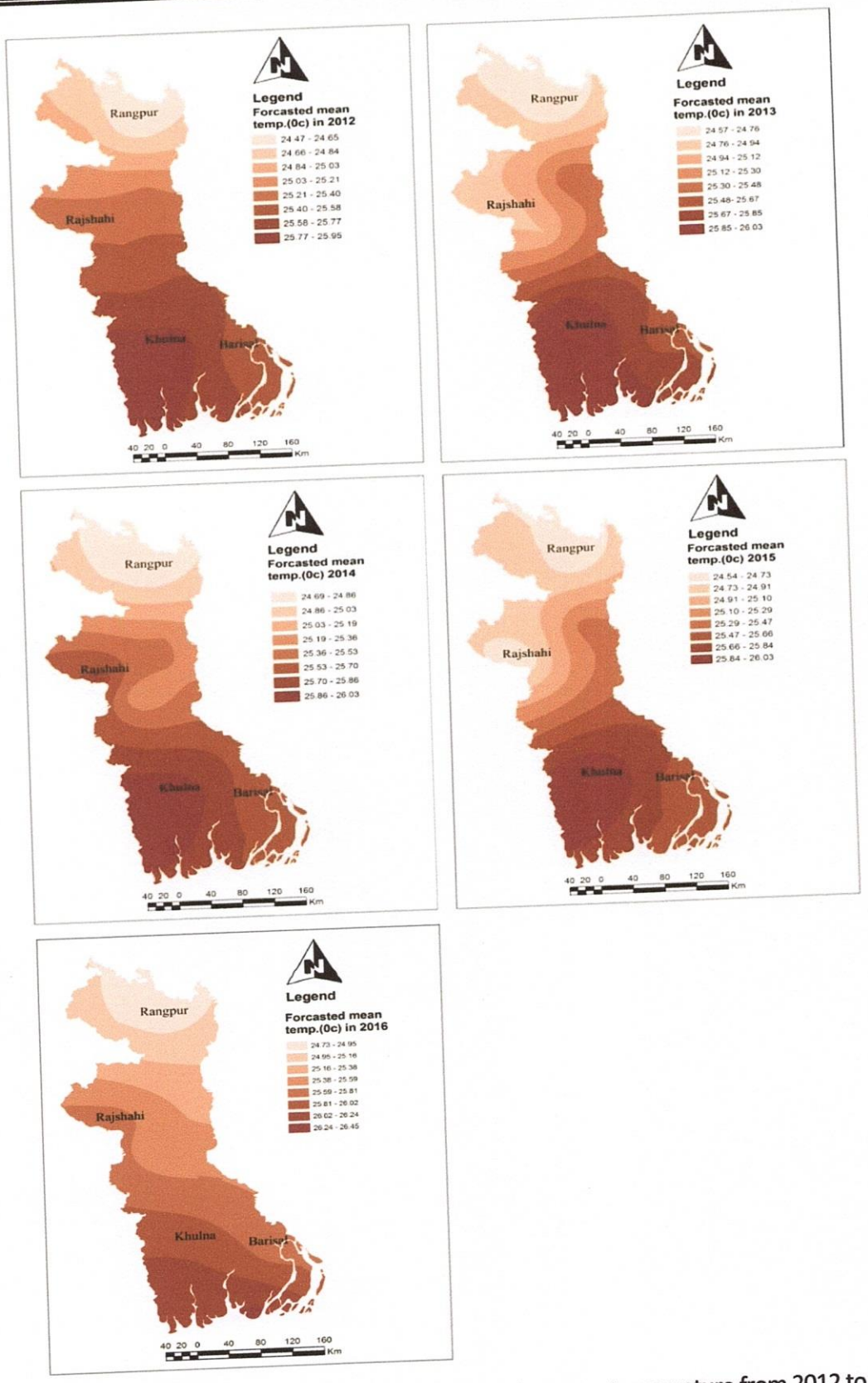


**Figure 4.28** Spatial distribution of forecasting annual average temperature from 2012 to 16

## 4.2 Modeling of Agricultural Drought

### 4.2.1 Introduction

The daily rainfall of Pre-Kharif, Kharif and Rabi seasons with 17 standard weeks for the period of 1960-2011 of 12 meteorological stations in the western part of Bangladesh have been considered for determining the parameters of Markov chain model. The choice of threshold values for Markov chain model is very important; especially when it is used for agricultural purpose because a small amount of water in dry regions may be very much useful whereas the same amount may be insignificant in humid regions (Banik et al. 2002). In present study, firstly, weekly total rainfall of 5, 10, 15, 20 and 25 mm are considered as threshold values in each station as well as year, decade and season wise for estimating the probabilities of wet and dry weeks, and index of drought proneness (DI). Finally the suitable threshold values are considered by satisfying the stationary properties of Markov chain model based on the changing state of DI. Again about 10–12 wet weeks are necessary in order to harvest a good crop and a continuous span of at least 3 consecutive dry weeks between the wet weeks would be responsible for total crop failure (Banik et al. 2002). So, the probability of getting at least 8, 10 and 12 consecutive wet weeks and the probability of getting at least 3 consecutive dry weeks have been computed using equations 3.9 and 3.10 respectively for each station by year, decade and season wise form and also considering the higher order constant values of $P_{01}$ and $P_{11}$. Finally, DI values have been computed based on above mentioned form using equation 3.13. In addition, the above mentioned parameters of Markov chain model have been calculated based on a detail computer programing which is shown in Appendix-I.

### 4.2.2 Station-wise Probability of Wet and Dry Weeks, and DI in Kharif Season

The station-wise daily rainfall reduced in weekly form have been considered for finding probability of getting at least 8, 10 and 12 consecutive wet weeks and the probability of getting at least 3 consecutive dry weeks and DI based on the higher order constant values of $P_{01}$ and $P_{11}$ and results are shown in table 4.30 and reveals that severe agricultural drought occurs in Ishwardi, Rajshahi, Bogra, Rangpur, Dinajpur, Jessore, Khulna, Satkhira, Barisal and Bhola

regions that ranges for DI as 0.125-0.163, but that of moderate agricultural drought occur in Faridpur and Khepupara regions where DI values ranges from 0.187 to 0.195. The highest value of DI is found at Bogra station (DI=0.163) and that of lowest at Dinajpur station (DI=0.125). The occasional and extreme agricultural drought prone regions are not found in the western part of Bangladesh. The probability of getting at least 3 consecutive dry weeks is highest at Rangpur station (0.652) and that of lowest in Faridpur station (0.506). The probability of getting at least 8, 10 and 12 consecutive wet weeks are high in Khepupara station (0.792, 0.741, 0.693), but low in Rajshahi station (0.550, 0.468, 0.395) respectively. The probability of getting at least 3 consecutive dry weeks high in Dinajpur station (0.650) and low in Faridpur station (0.506). The spatial distribution of DI is shown in figure 4.29 and reveals that the area mainly suffers from severe drought during the Kharif season and two pockets areas are identified as moderate agricultural drought prone areas.

**Table 4.30** Probability of getting wet and dry weeks, and DI in Kharif season

| | Kharif season using suitable threshold values (TV) in millimeters | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|
| Station | $P$ | $P_{11}$ | $P_{01}$ | E(Y) | Probability of getting wet week at least | | | P(D>3) | TV | DI | Drought Classes |
| | | | | | 8 | 10 | 12 | | | | |
| Dinajpur | 0.675 | 0.936 | 0.134 | 408.993 | 0.627 | 0.549 | 0.480 | 0.650 | 20 | 0.125 | Severe |
| Rangpur | 0.724 | 0.949 | 0.133 | 470.804 | 0.695 | 0.627 | 0.565 | 0.652 | 15 | 0.126 | Severe |
| Bogra | 0.801 | 0.958 | 0.170 | 576.060 | 0.740 | 0.679 | 0.622 | 0.571 | 10 | 0.163 | Severe |
| Ishwardi | 0.676 | 0.931 | 0.143 | 402.569 | 0.608 | 0.528 | 0.458 | 0.629 | 20 | 0.133 | Severe |
| Rajshahi | 0.633 | 0.919 | 0.139 | 359.280 | 0.554 | 0.468 | 0.395 | 0.638 | 25 | 0.128 | Severe |
| Faridpur | 0.836 | 0.960 | 0.203 | 626.942 | 0.752 | 0.693 | 0.639 | 0.506 | 10 | 0.195 | Moderate |
| Jessore | 0.670 | 0.932 | 0.139 | 402.856 | 0.610 | 0.529 | 0.459 | 0.639 | 25 | 0.129 | Severe |
| Khulna | 0.691 | 0.934 | 0.146 | 428.171 | 0.622 | 0.543 | 0.474 | 0.622 | 25 | 0.137 | Severe |
| Satkhira | 0.707 | 0.936 | 0.153 | 448.575 | 0.631 | 0.554 | 0.485 | 0.607 | 25 | 0.144 | Severe |
| Barisal | 0.741 | 0.944 | 0.160 | 492.263 | 0.668 | 0.596 | 0.531 | 0.593 | 25 | 0.151 | Severe |
| Bhola | 0.756 | 0.953 | 0.145 | 453.129 | 0.715 | 0.650 | 0.590 | 0.624 | 25 | 0.139 | Severe |
| Khepupara | 0.855 | 0.967 | 0.193 | 463.120 | 0.792 | 0.741 | 0.693 | 0.525 | 15 | 0.187 | Moderate |

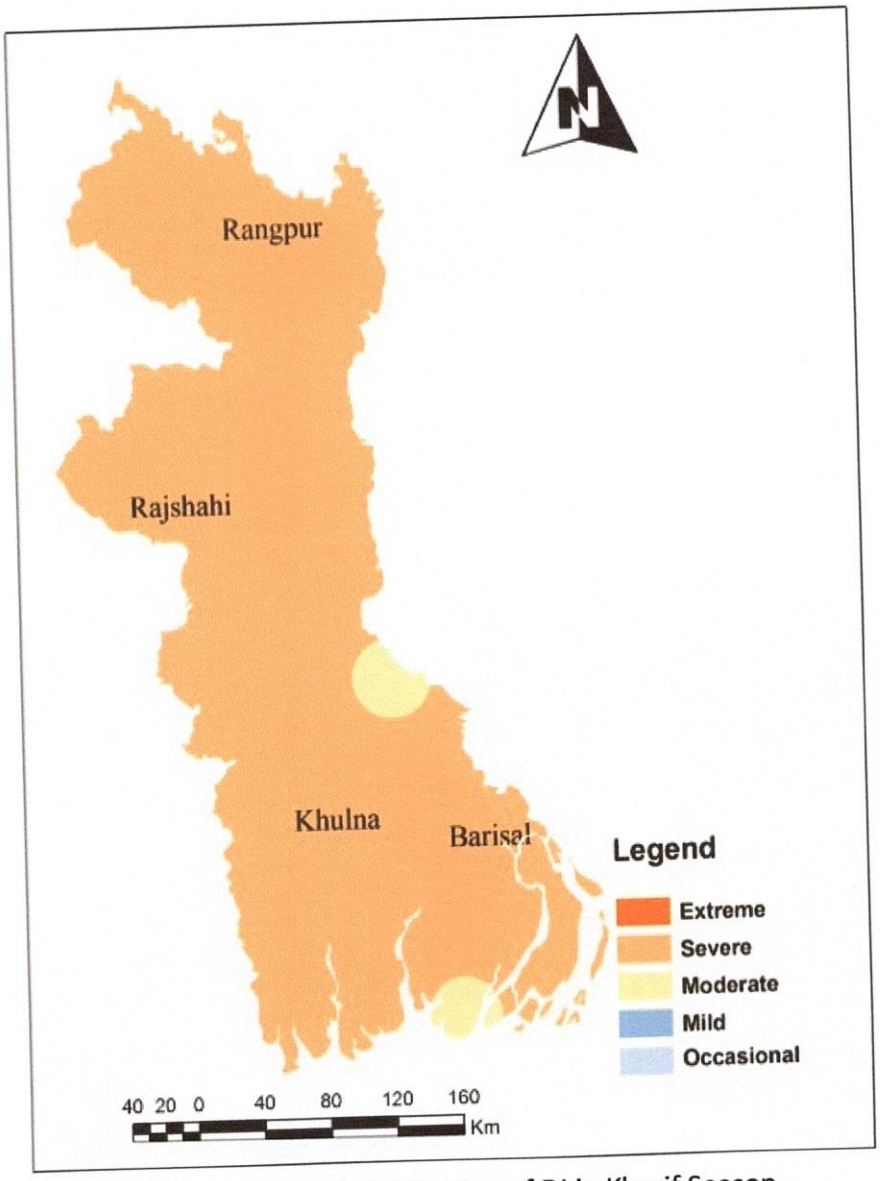


**Figure 4.29** Spatial distribution of DI in Kharif Season

The spatial distribution of the probability of at least 8, 10 and 12 consecutive weeks is shown in figure 4.30. The probability of at least 8 wet weeks is moderate all over the areas except in some parts of south-eastern corner where the probability is very high. Moreover, the probability of getting at least 10 consecutive weeks is also moderate in the area, but it is very low in some parts of Rajshahi. The probability of at least 12 consecutive wet weeks is low in the western part, whereas it is high in the north, south and eastern parts. On the other hand, the probability of at least 3 consecutive dry weeks is moderate over the study area.

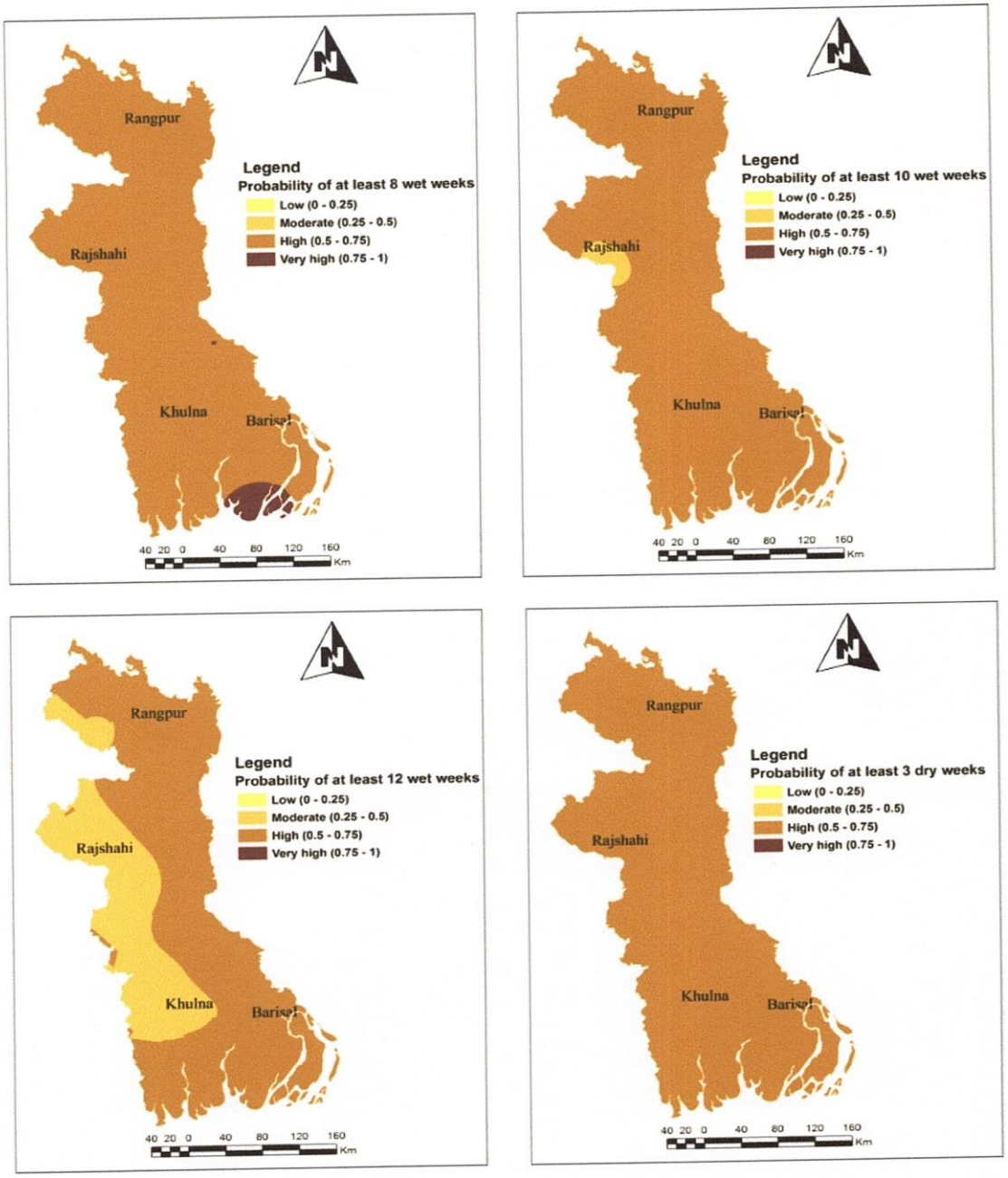


**Figure 4.30** Spatial distribution of probability of getting at least 8, 10 and 12 consecutive wet weeks and at least 3 consecutive dry weeks in Kharif season

### 4.2.3 Decade-wise Probability of Wet and Dry Weeks, and DI in Kharif Season

The decade-wise probability of at least 8, 10 and 12 consecutive wet weeks and probability of getting at least 3 consecutive dry weeks with DI for all stations in Kharif season have been computed using suitable threshold values which shown in Appendix-II. The ranges of DI during the decades of 1961-

1971, 1971-1980, 1980-1990, 1990-2000 and 2001-2010 are 0.126-0.187, 0.126-0.235, 0.124-0.188, 0.13-0.237 and 0.125-0.255 respectively (Appendix-II). It reveals that the ranges of the probability of getting at least 3 consecutive dry weeks during the decades of 1961-1971, 1971-1980, 1980-1990, 1990-2000 and 2001-2010 are 0.524-0.643, 0.436-0.65, 0.527-0.664, 0.43-0.633 and 0.399-0.649 respectively. The probability ranges of getting at least 8 consecutive wet weeks during the decades of 1961-1971, 1971-1980, 1980-1990, 1990-2000 and 2001-2010 are 0.567-0.791, 0.657-0.869, 0.656-0.845, 0.562-0.874 and 0.607-0.818 respectively. The ranges of the probability of getting at least 10 consecutive wet weeks during the decades of 1961-1971, 1971-1980, 1980-1990, 1990-2000 and 2001-2010 are 0.482-0.74, 0.582-0.835, 0.582-0.805, 0.476-0.84 and 0.526-0.772 respectively. The probability ranges of getting at least 12 consecutive wet weeks during the decades of 1961-1971, 1971-1980, 1980-1990, 1990-2000 and 2001-2010 are 0.41-0.692, 0.516-0.802, 0.516-0.767, 0.404-0.809 and 0.456-0.729 respectively.

The decade-wise spatial distribution of DI in Kharif season is shown in figure 4.31 where 4.31(a) reveals that the whole area mainly suffers from severe agricultural drought during the decade of 1961-1970. Most of the areas of Rangpur, Rajshahi and Barisal divisions suffer from severe agricultural drought except the north-western part of Rangpur and Rajshahi division and the whole area of Khulna division except northern part suffer from moderate agricultural drought during the decade of 1971-1980 [Figure 4.31(b)]. Figure 4.31(c) reveals that most of the study areas suffer from severe agricultural drought except in some parts of Rajshahi division. Major part of the area suffers from severe agricultural drought except north-eastern part of Rajshahi division and southern part of the study area [Figure 4.31(d)]. Figure 4.31(e) reveals that Rangpur division and the northern part of Rajshahi division suffers from severe agricultural drought and that of rest suffers from the moderate agricultural drought.

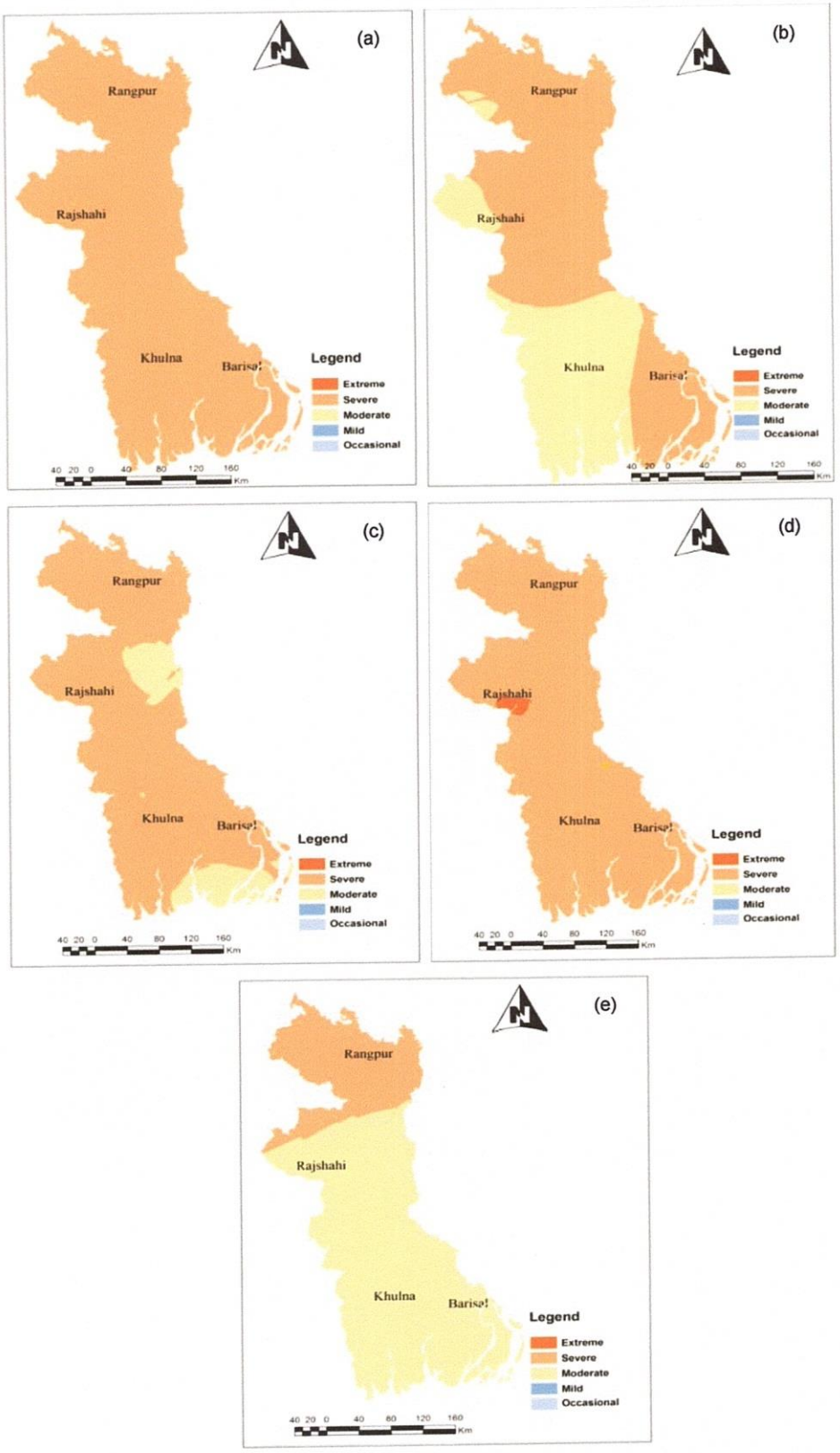


**Figure 4.31** Spatial distribution of DI during the decades (a) 1961-1970 (b) 1971-1980 (c) 1981-1990 (d) 1991-2000 and (e) 2001-2010 in Kharif season

### 4.2.4 Year-wise Probability of Wet and Dry Weeks, and DI in Kharif Season

The area potentially liable to suffer agricultural drought at different seasons have been identified on the basis of their occurrences. The percentage of agricultural drought occurrences have been computed by taking the ratio of drought occurrences in Kharif season to the total number of years considered in the same season and drought category (McKee et al., 1993; Shahid and Behrawan, 2008). The year-wise probability of wet and dry weeks and DI in each station with suitable threshold values are shown in Appendix III-XIV.

The year-wise line graph of DI in each station with suitable threshold values for assessing or identifying the trend of DI are shown in the following figure 4.32 and show, in generally the DI values all over the area increases except Rajshahi and Jessore area, i.e., the drought proneness of that area increases. The DI values of the Rajshahi area for the period of 1962-1980 are comparatively higher than that of the period 1981-2010. During the later period the lower DI values are mostly found and the similar results are also available for the Jessore, Dinajpur and Rangpur areas.

The percentages of annual occurrences of agricultural drought classes have been estimated and results are shown in table 4.31 and also in figure 4.33. Figure 4.33(a) indicates that the percentage of mild drought occurrence is very high in the south and that of relatively low in the north part (Rangpur division) of the area with annual occurrence about 8.19% to 11.94% in Rajshahi division and about 11.94% to 15.69% in the northern part of the Khulna division (central part of the study area). Figure 4.33(b) shows that the percentage of moderate drought occurrence is very high in northern and eastern parts, while it is relatively low in the south-western parts of Rajshahi division and some parts of Khulna and Barisal division. About 7.48% to 9.5325% of annual occurrence of moderate drought occurs in the middle part of Khulna division and that of about 9.5325% to 11.685% moderate drought in the southern part of Khulna division. In figure 4.33(c) the 21.645% to 28.4675 of annual

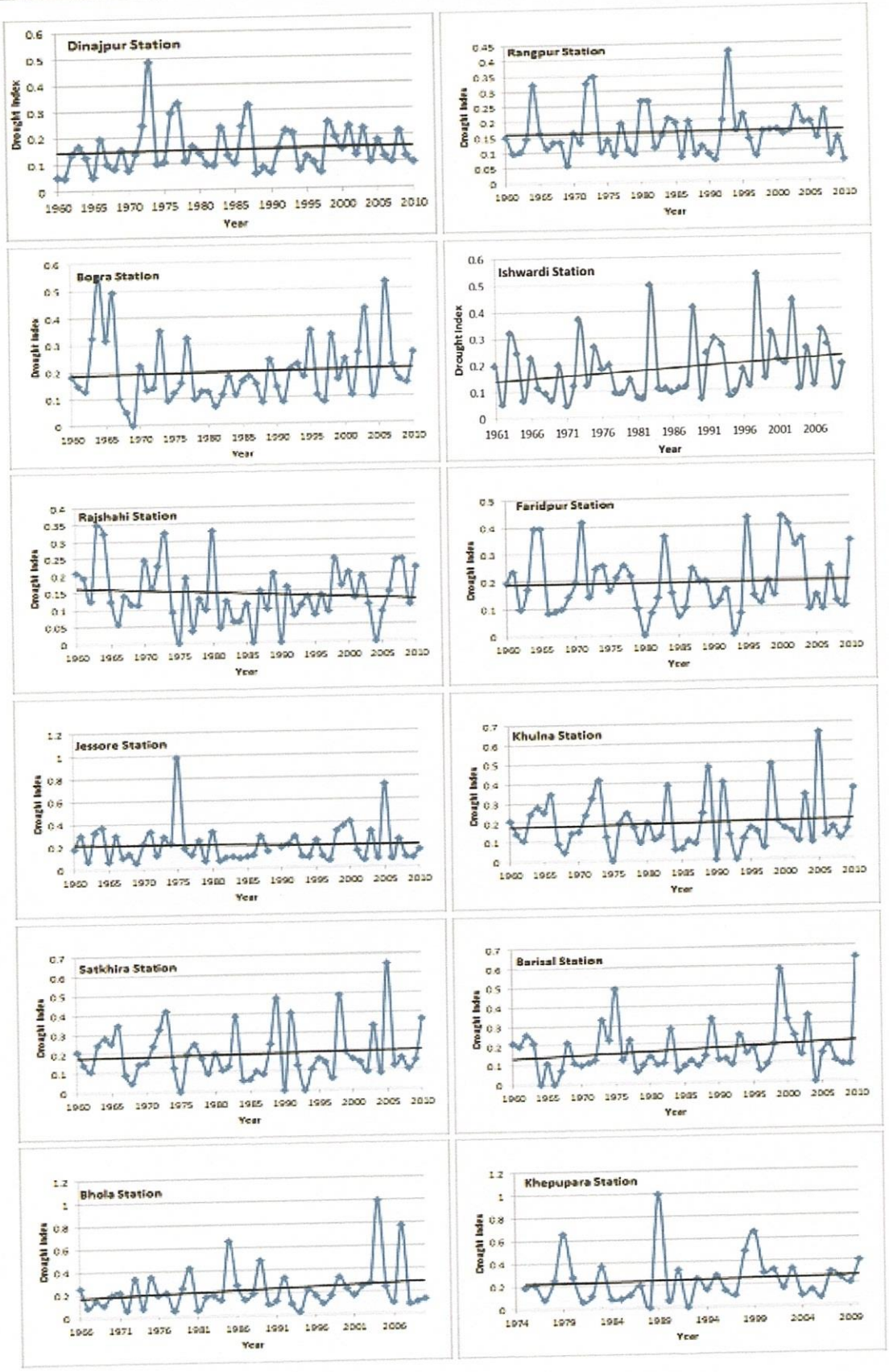


**Figure 4.32** Time series of DI with linear trends in Kharif season

occurrence of severe drought is observed in the northern part (Rangpur division) and that of 14.8225% to 21.645% severe drought in the rest of the area. Percentage of annual occurrence of extreme drought is high in the pockets in south-eastern, middle and north-western parts of Rajshahi division [Figure 4.33(d)]. The extreme drought occurs in 33.33% to 37.7425% in the north-eastern part of the Rangpur and Rajshahi division, some parts of Khulna division, and southern part of the study area. The extreme drought occurs at 37.7425% to 42.155% in the middle of the area having north to south extension.

The spatial distribution of the drought index is shown in figure 4.34 and reveals that the study area suffers from extreme agricultural drought during Pre-Kharif season.

**Table 4.31** Percentage of annual drought occurrences in Kharif season

| Stations | Occasional | Mild | Moderate | Severe | Extreme |
|---|---|---|---|---|---|
| Dinajpur | 5.88 | 9.80 | 13.73 | 17.65 | 49.02 |
| Rangpur | 7.84 | 5.88 | 15.69 | 35.29 | 33.33 |
| Bogra | 19.61 | 7.84 | 15.69 | 23.53 | 33.33 |
| Ishwardi | 16.00 | 14.00 | 14.00 | 8.00 | 48.00 |
| Rajshahi | 11.76 | 11.76 | 11.69 | 21.57 | 39.22 |
| Faridpur | 19.61 | 11.76 | 13.73 | 19.61 | 35.29 |
| Jessore | 19.61 | 15.69 | 7.48 | 11.76 | 43.14 |
| Khulna | 19.61 | 11.76 | 7.48 | 25.53 | 33.33 |
| Satkhira | 25.49 | 7.84 | 9.8 | 19.61 | 37.25 |
| Barisal | 13.73 | 7.84 | 15.69 | 11.76 | 50.98 |
| Bhola | 13.33 | 4.44 | 15.56 | 15.56 | 46.67 |
| Khepupara | 16.67 | 19.44 | 11.11 | 11.11 | 33.33 |

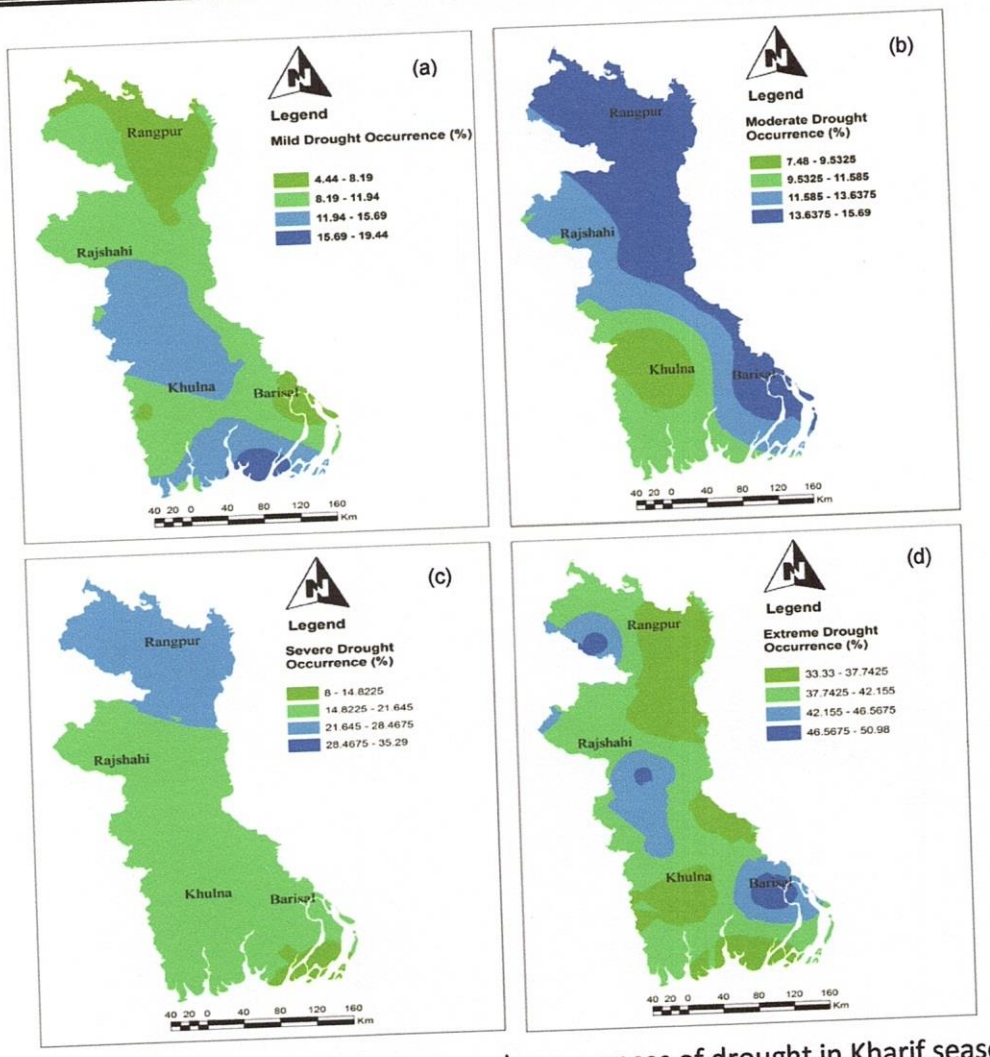


**Figure 4.33** spatial distributions of annual occurrences of drought in Kharif season

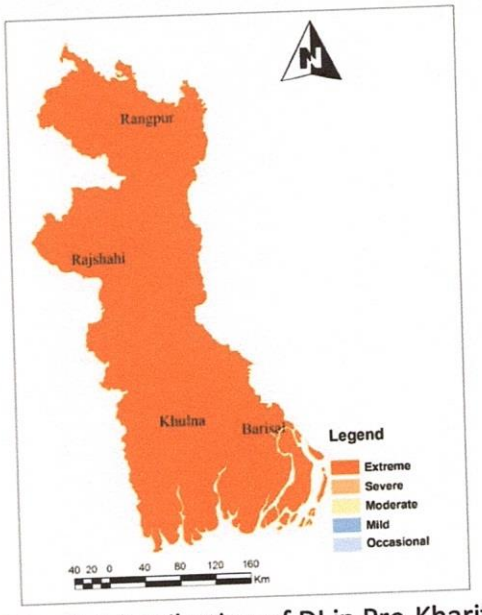


**Figure 4.34** Spatial distribution of DI in Pre-Kharif season

### 4.2.5 Station-wise Probability of Wet and Dry Weeks, and DI in Pre-Kharif Season

The station-wise weekly total rainfall in Pre-Kharif season have been considered for finding probability of getting at least 8, 10 and 12 consecutive wet weeks and the probability of getting at least 3 consecutive dry weeks, and DI based on the higher order constant values of $P_{01}$ and $P_{11}$, and the results are given in table 4.32. It reveals that the extreme agricultural drought occurs in all meteorological station with variations of DI ranges from 0.047 to 0.078 where the highest value is found at Faridpur station (DI=0.078) and that of lowest at Rajshahi station (DI=0.047). No other types of drought prone areas are found in the western part of Bangladesh.

The probability of getting at least 3 consecutive dry weeks is highest in Rajshahi station (0.851) and lowest in Faridpur station (0.765). The probability of getting at least 8, 10 and 12 consecutive wet weeks are observed high in Bhola station (0.596, 0.514 and 0.443) and low in Rajshahi station (0.485, 0.394 and 0.320) respectively.

**Table 4.32** Probability of getting wet and dry weeks, and DI in Pre-Kharif season

| | Pre-Kharif season using suitable threshold values (TV) in millimeters | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|
| Station | P | $P_{11}$ | $P_{01}$ | E(Y) | Probability of getting wet week at least | | | P(D>3) | TV | DI | Drought Classes |
| | | | | | 8 | 10 | 12 | | | | |
| Dinajpur | 0.411 | 0.921 | 0.055 | 153.005 | 0.561 | 0.475 | 0.403 | 0.843 | 25 | 0.051 | Extreme |
| Rangpur | 0.487 | 0.928 | 0.068 | 214.758 | 0.593 | 0.510 | 0.440 | 0.809 | 25 | 0.063 | Extreme |
| Bogra | 0.417 | 0.916 | 0.060 | 157.473 | 0.542 | 0.455 | 0.382 | 0.831 | 25 | 0.055 | Extreme |
| Ishwardi | 0.407 | 0.908 | 0.063 | 146.983 | 0.510 | 0.421 | 0.348 | 0.823 | 25 | 0.057 | Extreme |
| Rajshahi | 0.348 | 0.902 | 0.053 | 110.153 | 0.485 | 0.394 | 0.320 | 0.851 | 25 | 0.047 | Extreme |
| Faridpur | 0.491 | 0.911 | 0.085 | 218.374 | 0.523 | 0.434 | 0.361 | 0.765 | 25 | 0.078 | Extreme |
| Jessore | 0.406 | 0.908 | 0.063 | 149.883 | 0.509 | 0.419 | 0.346 | 0.823 | 25 | 0.057 | Extreme |
| Khulna | 0.405 | 0.908 | 0.062 | 148.174 | 0.511 | 0.422 | 0.348 | 0.825 | 25 | 0.056 | Extreme |
| Satkhira | 0.385 | 0.909 | 0.057 | 134.379 | 0.511 | 0.422 | 0.348 | 0.838 | 25 | 0.052 | Extreme |
| Barisal | 0.464 | 0.921 | 0.068 | 195.718 | 0.563 | 0.478 | 0.405 | 0.809 | 25 | 0.063 | Extreme |
| Bhola | 0.493 | 0.929 | 0.069 | 194.927 | 0.596 | 0.514 | 0.443 | 0.806 | 25 | 0.064 | Extreme |
| Khepupara | 0.456 | 0.927 | 0.061 | 133.884 | 0.587 | 0.504 | 0.433 | 0.827 | 25 | 0.057 | Extreme |

The spatial distribution of the probability of at least 8, 10 and 12 consecutive weeks is shown in figure 4.35. The probability of at least 8 wet weeks is high in the area except in south-western parts of Rajshahi division and party in Khulna division where probability is low. Moreover, the probability of getting at least 10 consecutive weeks is moderate in the area, but high in the northern part of Rangpur division and south-eastern part of Barisal division. The probability of at least 12 consecutive wet weeks is moderate in the study area. On the other hand, the probability of at least 3 consecutive dry weeks is very high in whole study area.

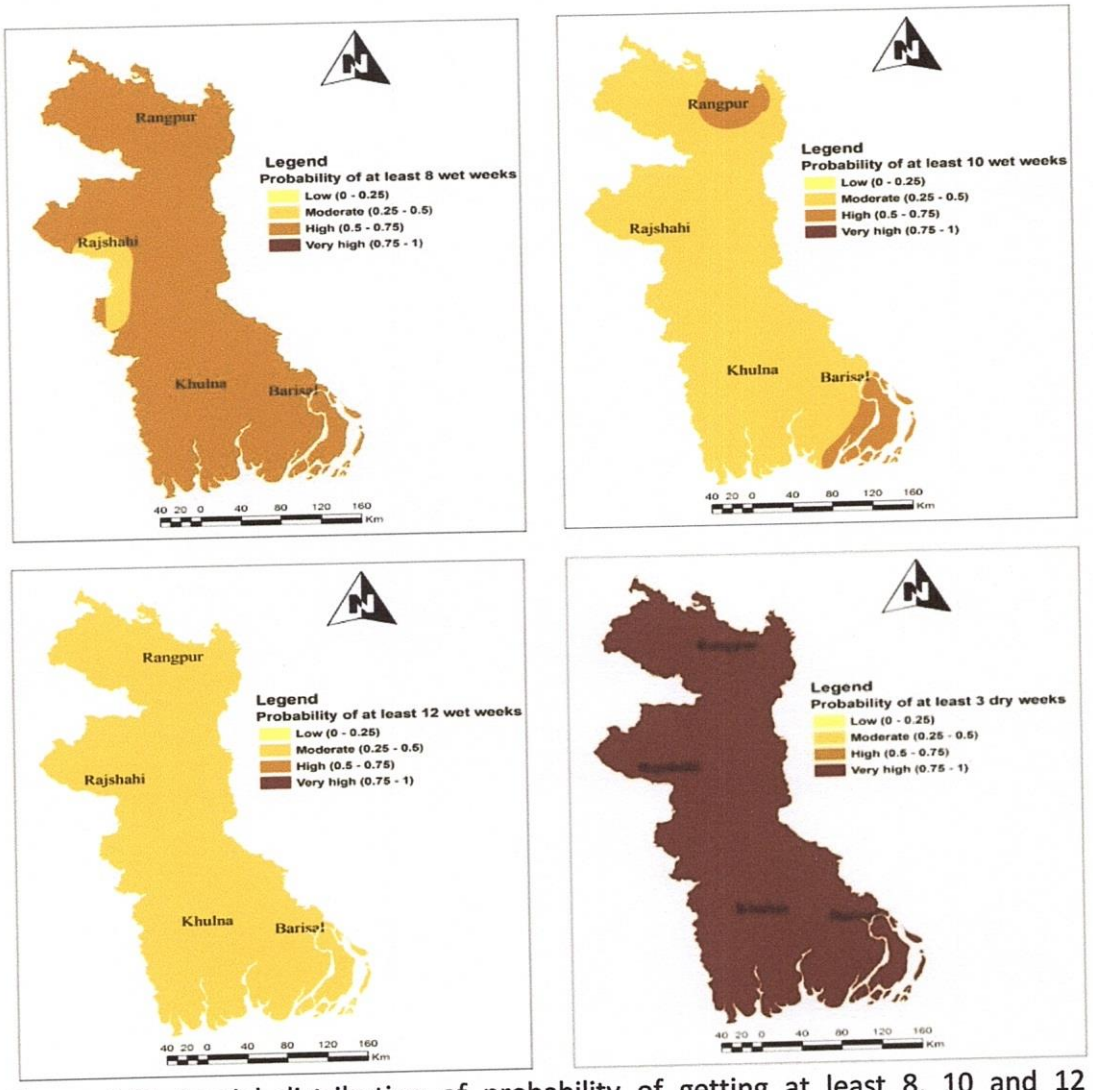


**Figure 4.35** Spatial distribution of probability of getting at least 8, 10 and 12 consecutive wet weeks and at least 3 consecutive dry weeks in Pre-Kharif season

### 4.2.6 Decade-wise Probability of Wet and Dry Weeks, and DI in Pre-Kharif Season

The decade-wise probability of at least 8, 10 and 12 consecutive wet weeks and probability of getting at least 3 consecutive dry weeks with DI for all stations in Pre-Kharif season have been estimated using suitable threshold values are shown in Appendix-XV. It reveals that, DI ranges during the decades of 1961-1971, 1971-1980, 1980-1990, 1990-2000 and 2001-2010 are 0.041-0.163, 0.045-0.182, 0.05-0.136, 0.043-0.13 and 0.049-0.189 respectively.

The ranges of the probability of getting at least 3 consecutive dry weeks during the decades of 1961-1971, 1971-1980, 1980-1990, 1990-2000 and 2001-2010 are 0.574-0.869, 0.532-0.863, 0.63-0.845, 0.633-0.867 and 0.518-0.846 respectively. The ranges of the probability of getting at least 8 consecutive wet weeks during the decades of 1961-1971, 1971-1980, 1980-1990, 1990-2000 and 2001-2010 are 0.467-0.768, 0.509-0.749, 0.496-0.836, 0.478-0.632 and 0.438-0.763 respectively. The ranges of the probability of getting at least 10 consecutive wet weeks during the decades of 1961-1971, 1971-1980, 1980-1990, 1990-2000 and 2001-2010 are 0.376-0.712, 0.42-0.689, 0.405-0.794, 0.387-0.555 and 0.346-0.707 respectively. The ranges of the probability of getting at least 12 consecutive wet weeks during the decades of 1961-1971, 1971-1980, 1980-1990, 1990-2000 and 2001-2010 are 0.303-0.661, 0.346-0.634, 0.332-0.754, 0.313-0.487 and 0.274-0.654 respectively.

The spatial distribution of agricultural drought categories during the decades (a) 1961-1970 (b) 1971-1980 (c) 1981-1990 and (d) 1991-2000 in Pre-Kharif season are shown in figure 4.36. It reveals that the study area mainly suffers from extreme agricultural drought in all decades but the south-western part of the Rajshahi division suffers from severe agricultural drought in Kharif season during 1981-1990 decade and shown in figure 4.36(c).

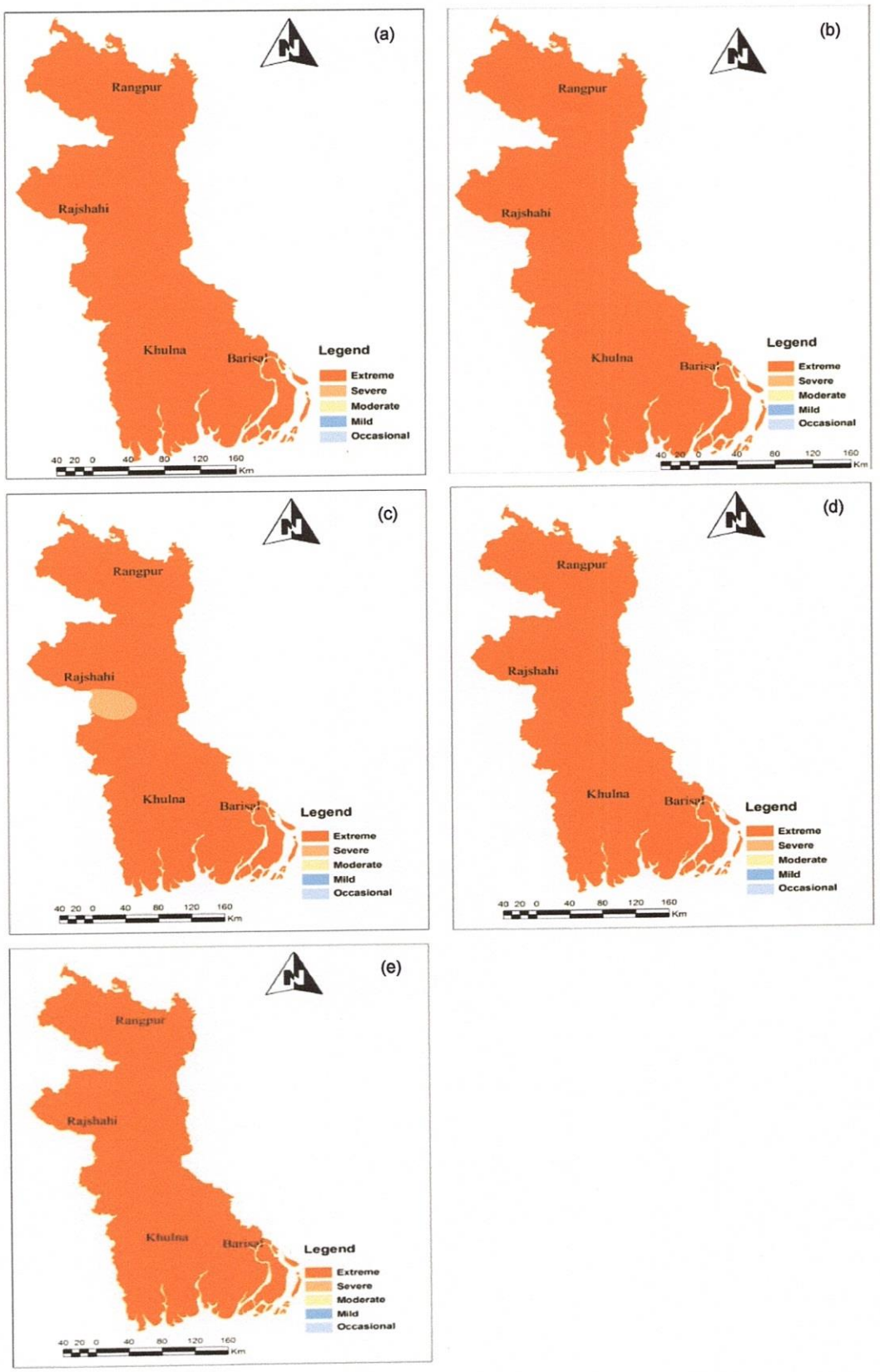


**Figure 4.36** Spatial distribution of DI during (a) 1961-1970, (b) 1971-1980, (c) 1981-1990, (d) 1991-2000, and (e) 2001-2010 in Pre-Kharif season

### 4.2.7 Year-wise Probability of Wet and Dry Weeks, and DI in Pre-Kharif Season

The year-wise probability of wet and dry weeks and DI in each station in the area with suitable threshold values are shown in Appendix-XVI to XXVII. Additionally, the year-wise line graph of DI in each station with suitable threshold values for detecting the trend of drought indexes are shown in figure 4.37 and shows that the DI values in generally increase in the study area. The maximum DI values are closed to zero line are found in Dinajpur, Rangpur, Ishwardi and Jessore areas and will become more drought proneness in comparison to other areas in recent decades.

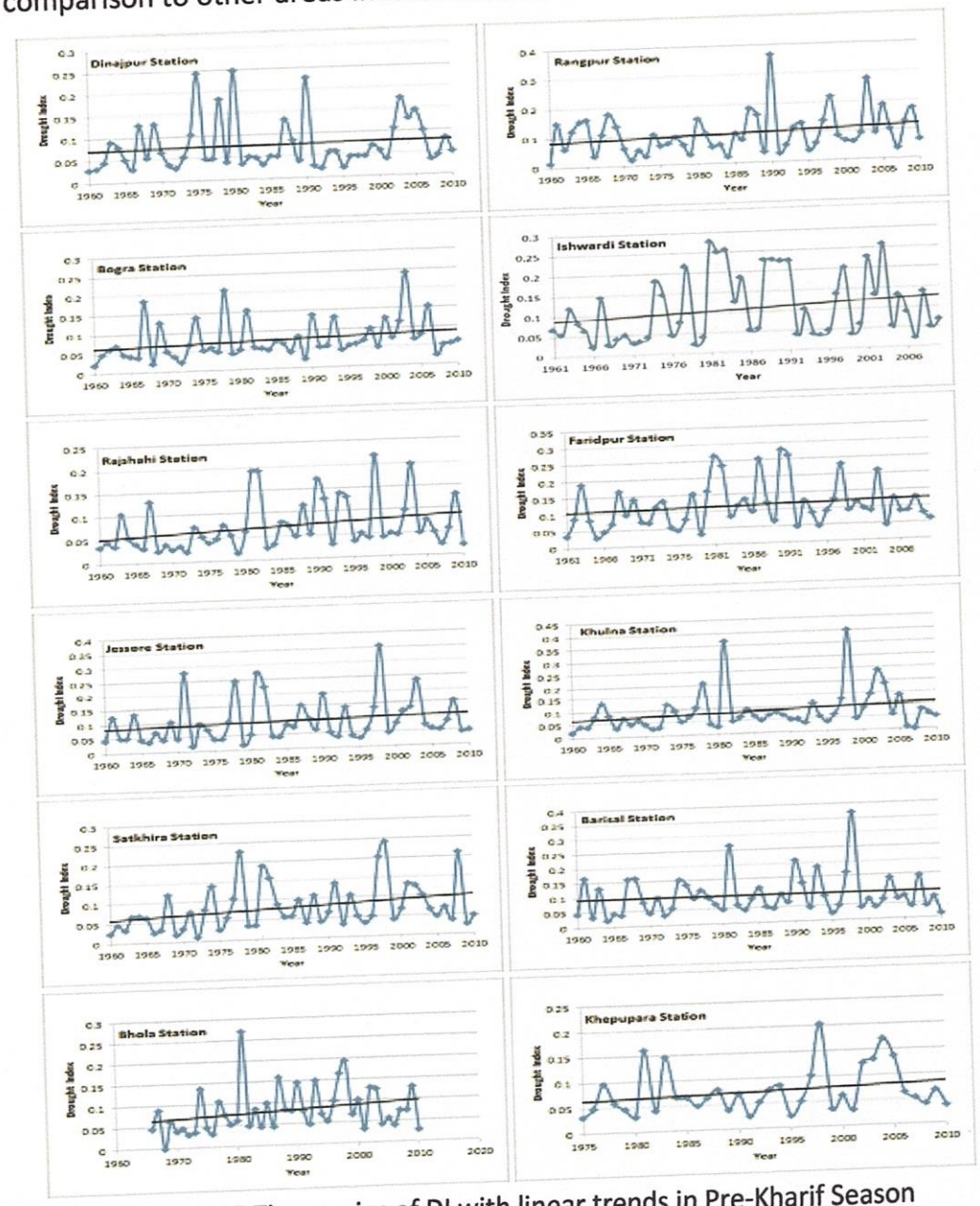


**Figure 4.37** Time series of DI with linear trends in Pre-Kharif Season

### 4.2.8 Station-wise Probability of Wet and Dry Weeks, and DI in Rabi Season

The weekly total rainfall in Rabi season have been considered to find out probability of getting at least 8, 10 and 12 consecutive wet weeks and the probability of getting at least 3 consecutive dry weeks, and DI based on the higher order constant values of $P_{01}$ and $P_{11}$ and results are shown in table 4.33. It reveals that, the extreme agricultural drought occurs in all meteorological stations where DI values range from 0.003 to 0.008 where the lowest value of DI is found in Dinajpur, Rangpur and Bogra stations (DI=0.003) and that of highest in Barisal, Bhola and Khepupara stations (DI=0.008). But no other types of drought prone areas are found in the western part of Bangladesh. The probability of getting at least 3 consecutive dry weeks is highest in Bogra station (0.990) and that of lowest in Barisal station (0.972). The probability of getting at least 8, 10 and 12 consecutive wet weeks are found high in Khepupara station (0.380, 0.288, 0.219) and low in Bogra station (0.257, 0.174, 0.118) respectively.

The spatial distribution of DI is shown in figure 4.38 and is reveals that study area suffers from extreme agricultural drought during Rabi season.

**Table 4.33** Probability of getting wet and dry weeks, and DI in Rabi season

| | Rabi season using suitable threshold values (TV) in millimeters | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|
| Station | $P$ | $P_{11}$ | $P_{01}$ | E(Y) | Probability of getting wet week at least | | | P(D>3) | TV | DI | Drought Classes |
| | | | | | 8 | 10 | 12 | | | | |
| Dinajpur | 0.026 | 0.849 | 0.004 | 0.606 | 0.318 | 0.229 | 0.165 | 0.988 | 25 | 0.003 | Extreme |
| Rangpur | 0.021 | 0.827 | 0.004 | 0.390 | 0.264 | 0.180 | 0.123 | 0.989 | 25 | 0.003 | Extreme |
| Bogra | 0.019 | 0.824 | 0.003 | 0.344 | 0.257 | 0.174 | 0.118 | 0.990 | 25 | 0.003 | Extreme |
| Ishwardi | 0.040 | 0.836 | 0.007 | 1.382 | 0.286 | 0.200 | 0.140 | 0.980 | 25 | 0.006 | Extreme |
| Rajshahi | 0.029 | 0.843 | 0.005 | 0.756 | 0.302 | 0.214 | 0.152 | 0.986 | 25 | 0.004 | Extreme |
| Faridpur | 0.049 | 0.849 | 0.008 | 2.177 | 0.317 | 0.228 | 0.165 | 0.977 | 25 | 0.007 | Extreme |
| Jessore | 0.053 | 0.857 | 0.008 | 2.530 | 0.339 | 0.249 | 0.182 | 0.976 | 25 | 0.007 | Extreme |
| Khulna | 0.050 | 0.860 | 0.007 | 2.219 | 0.348 | 0.257 | 0.190 | 0.978 | 25 | 0.006 | Extreme |
| Satkhira | 0.052 | 0.853 | 0.008 | 2.410 | 0.329 | 0.239 | 0.174 | 0.976 | 25 | 0.007 | Extreme |
| Barisal | 0.058 | 0.849 | 0.009 | 3.010 | 0.318 | 0.230 | 0.166 | 0.972 | 25 | 0.008 | Extreme |
| Bhola | 0.066 | 0.870 | 0.009 | 3.484 | 0.378 | 0.286 | 0.217 | 0.973 | 25 | 0.008 | Extreme |
| Khepupara | 0.064 | 0.871 | 0.009 | 2.593 | 0.380 | 0.288 | 0.219 | 0.974 | 25 | 0.008 | Extreme |

**Figure 4.38** Spatial distribution of DI in Rabi season

The spatial distribution of the probability of getting at least 8, 10 and 12 consecutive wet weeks and the probability of getting at least 3 consecutive dry weeks in Rabi season are shown in figure 4.39. The probability of getting at least 8 wet weeks is moderate in the area. Moreover, the probability of getting at least 10 consecutive weeks is mainly low except in the southern part of the area. The probability of at least 12 consecutive wet weeks is low in the study area. On the other hand, the probability of at least 3 consecutive dry weeks is very high in the whole area.

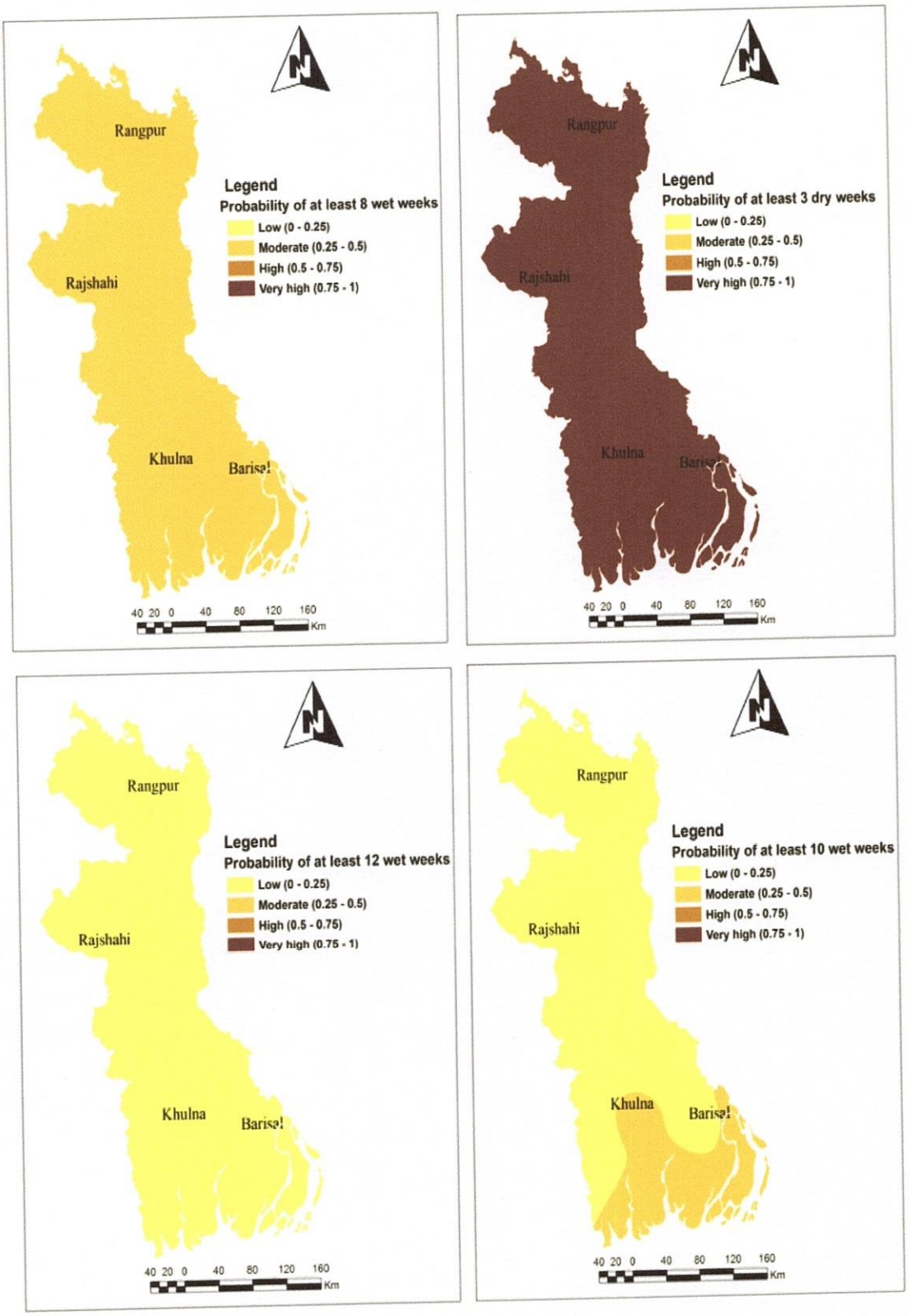


**Figure 4.39** Spatial distribution of probability of getting at least 8, 10 and 12 consecutive wet weeks and the probability of getting at least 3 consecutive dry weeks in Rabi season

### 4.2.9 Decade-wise Probability of Wet and Dry Weeks, and DI in Rabi Season

The probability of at least 8, 10 and 12 consecutive wet weeks and probability of getting at least 3 consecutive dry weeks with DI for all stations in Rabi season have been estimated using suitable threshold values are shown in Appendix-XXVIII. It reveals that the ranges of the values of DI during the decades of 1961-1971, 1971-1980, 1980-1990, 1990-2000 and 2001-2010 are 0.001-0.006, 0.003-0.01, 0.004-0.01, 0.003-0.011 and 0.001-0.008 respectively. The ranges of the probability of getting at least 3 consecutive dry weeks during the decades of 1961-1971, 1971-1980, 1980-1990, 1990-2000 and 2001-2010 are 0.979-0.995, 0.965-0.99, 0.965-0.987, 0.962-0.99 and 0.971-0.997 respectively. The ranges of the probability of getting at least 8 consecutive wet weeks during the decades of 1961-1971, 1971-1980, 1980-1990, 1990-2000 and 2001-2010 are 0.133-0.354, 0.263-0.475, 0.252-0.401, 0.195-0.397 and 0.21-0.384 respectively. The ranges of the probability of getting at least 10 consecutive wet weeks during the decades of 1961-1971, 1971-1980, 1980-1990, 1990-2000 and 2001-2010 are 0.075-0.263, 0.179-0.384, 0.170-0.309, 0.122-0.305 and 0.134-0.293 respectively. The ranges of the probability of getting at least 12 consecutive wet weeks during the decades of 1961-1971, 1971-1980, 1980-1990, 1990-2000 and 2001-2010 are 0.042-0.195, 0.122-0.31, 0.115-0.238, 0.077-0.234 and 0.086-0.223 respectively. The spatial distribution of agricultural drought categories in Rabi season during the decades of (a) 1961-1970 (b) 1971-1980 (c) 1981-1990 (d) 1991-2000 and (e) 2001-2010 are shown in figure 4.40 and it reveals that the study area suffers from extreme agricultural drought in all decades Rabi season.

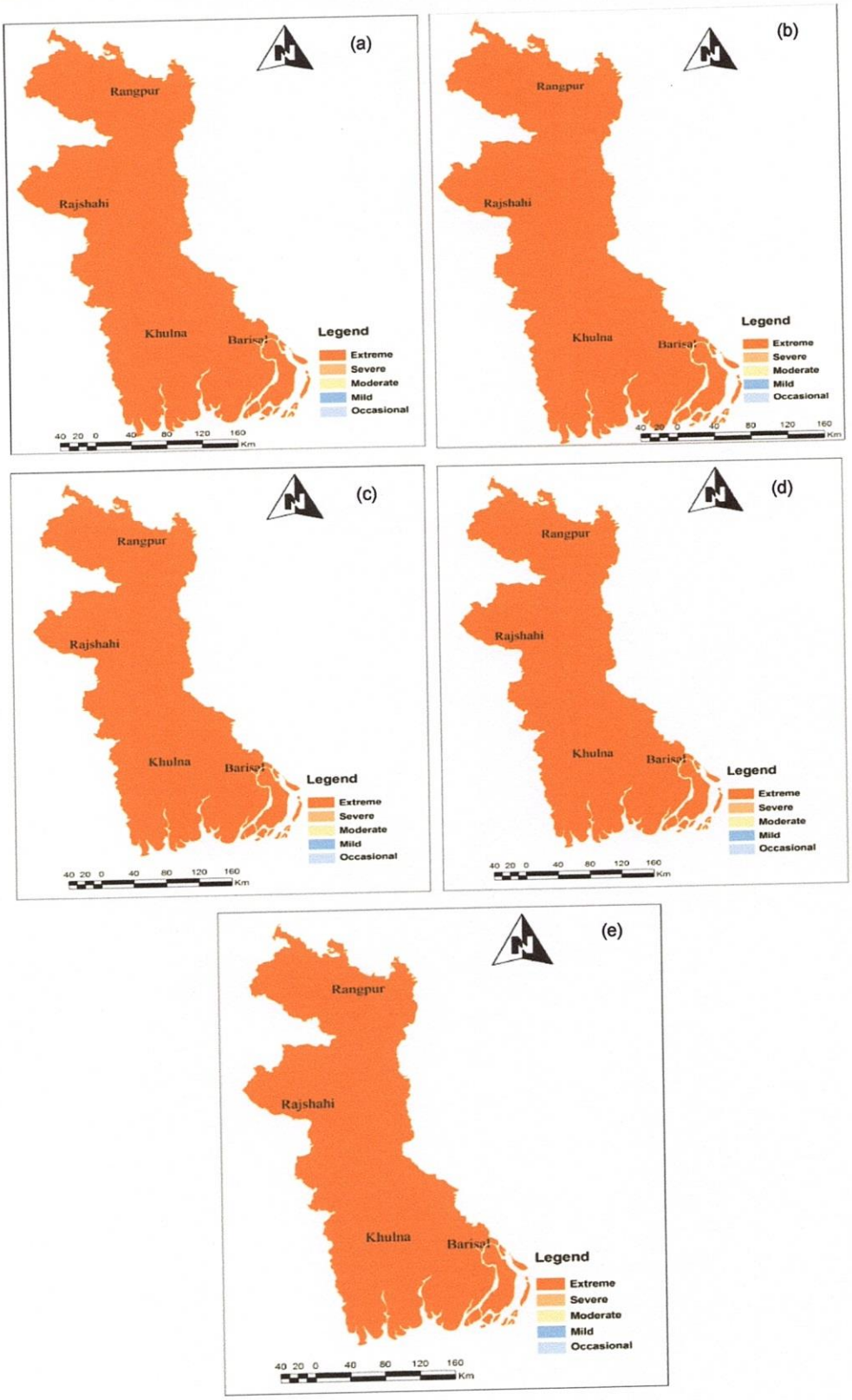


**Figure 4.40** Spatial distribution of agricultural drought during (a) 1961-1970, (b) 1971-1980, (c) 1981-1990, (d) 1991-2000, and (e) 2001-2010 in Rabi season

### 4.2.10 Seasonal Comparison of Wet and Dry Weeks Probability

The probability of getting at least 8, 10 and 12 consecutive wet weeks and probability of getting at least 3 consecutive dry weeks in different seasons are shown in figures 4.41-4.44 using line diagram. These Figures indicate that the probability of getting at least 8, 10 and 12 consecutive wet weeks are comparatively high in Kharif season and low in Rabi season and also indicate the probability of getting at least 8, 10 and 12 consecutive wet weeks are high in the southern part like Jessore, Khulna, Satkhira, Barisal and Bhola districts in comparison to the northern part. The highest probability of getting at least 8, 10 and 12 consecutive wet weeks are found in Khepupara that are 0.792, 0.741 and 0.693 respectively and lowest in Rajshahi in Kharif and Pre-Kharif seasons and that of Bogra in Rabi season.

On the other hand, the results of the probability of at least 3 consecutive dry weeks are shown in figure 4.44 and it reveals that the probability of getting at least 3 consecutive dry weeks is high in Rabi season and lowers in Kharif season. Moreover, it is also shown that, during the Pre-Kharif season the probability of getting at least 3 consecutive dry weeks varies slightly. The highest probability of at least 3 consecutive dry weeks during the Pre-Kharif season is found at Rajshahi (0.851) and that of lowest at Faridpur (0.765). In Kharif season the probability of getting at least 3 consecutive dry weeks ranges from 0.506 to 0.652 and that of for Rabi season ranges from 0.972 to 0.990.

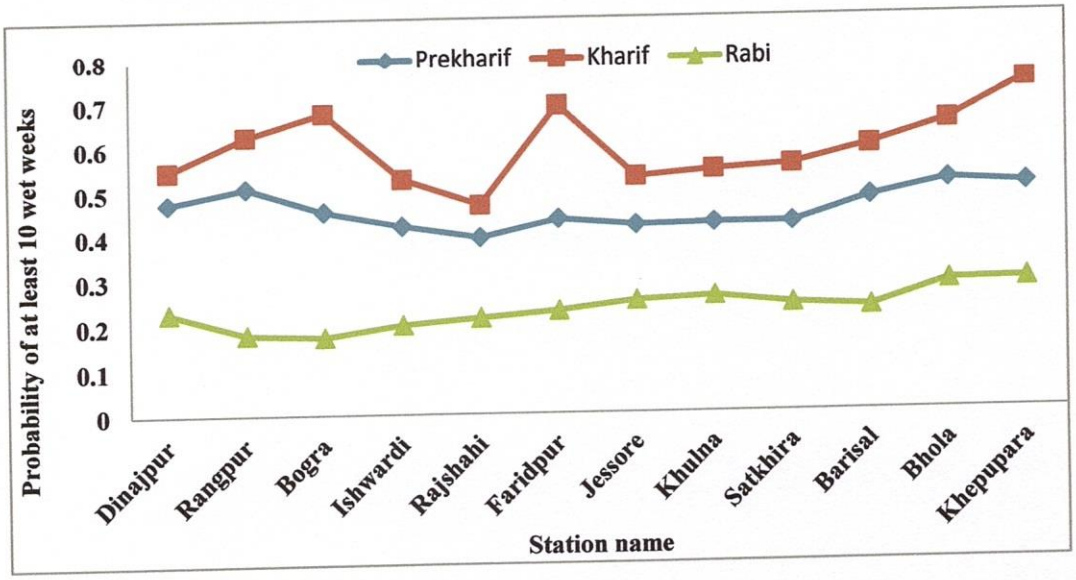


**Figure 4.41** Probability of getting at least 8 consecutive wet weeks

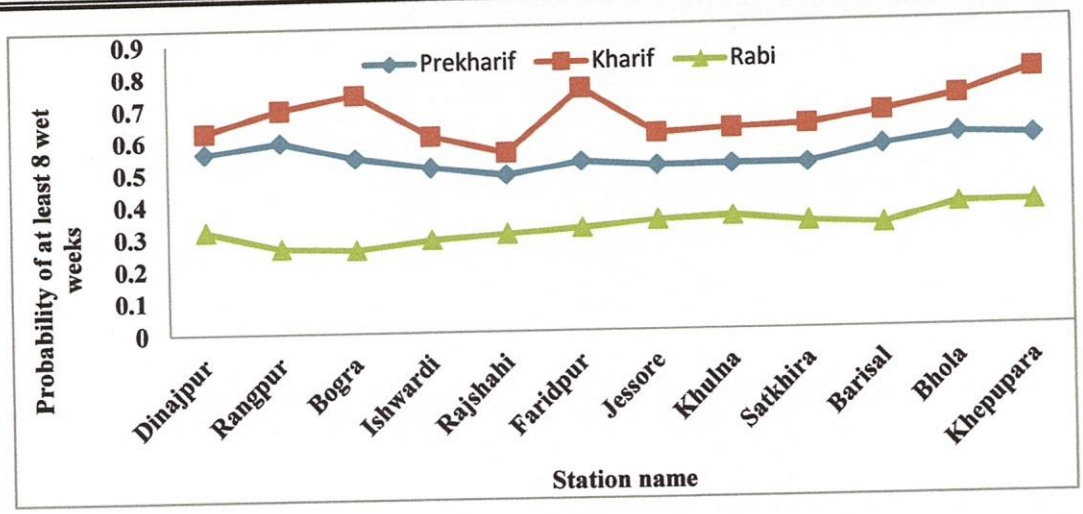


**Figure 4.42** Probability of getting at least 10 consecutive wet weeks

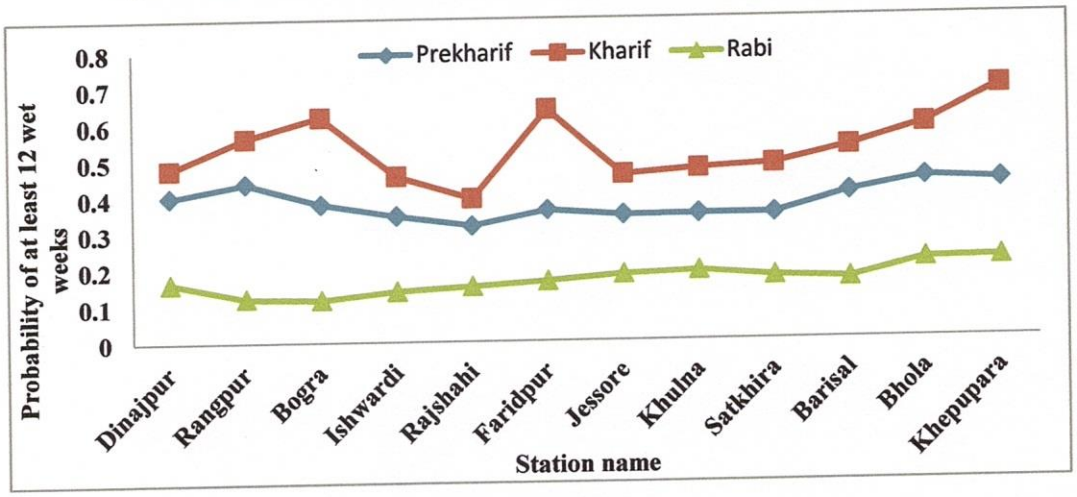


**Figure 4.43** Probability of getting at least 12 consecutive wet weeks

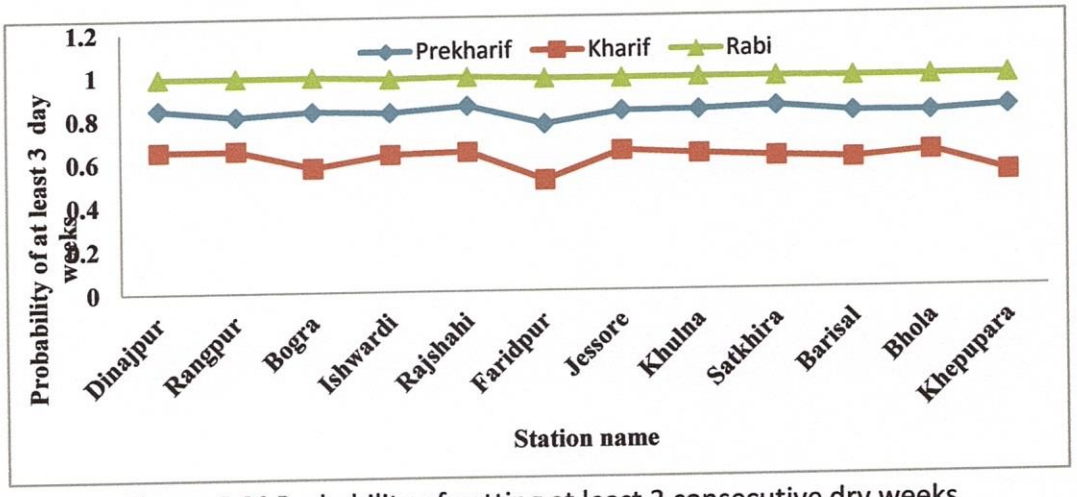


**Figure 4.44** Probability of getting at least 3 consecutive dry weeks

## 4.3 Analysis of Drought Hazard, Vulnerability and Risk

### 4.3.1 Introduction

The economy and food supply is closely linked up to the significant climate variations and catastrophes having profound effects on society. So climate can be thought as hazard, where floods, droughts and cyclones are examples and may be judged by characteristics like magnitude, frequency, velocity, area of influence, speed of onset, and duration. These characteristics influence the nature of human response (Burton et al. 1978).

Risk is the result of physically defined hazards interacting with exposed systems– taking into consideration the properties of the systems, such as their sensitivity or social vulnerability. It also can be considered as the combination of events, its likelihood and its consequences. Risk equals the probability of climate hazard multiplied by a given system's vulnerability.

Hazard is an event or physical condition that has the potential to cause fatalities, injuries, property damage, infrastructure damage, agricultural loss, and damage to the environment, interruption of business or other types of harm or loss.

Vulnerability is the degree to which a system is susceptible to, or unable to cope with adverse effects of climate change, including climate variability and extremes. It is a function of character, magnitude and rate of climate variation to which a system is exposed relative to its sensitivity and its adaptive capacity (Ramamasy and Bass, 2007).

### 4.3.2 Station-wise Drought Risk Assessment

Risk assessment involves the nature and extent of risk by analyzing potential threats and evaluating existing conditions of vulnerability that could pose a potential threat to property, livelihoods and the environment on which they depend. In this section the annual occurrence (Pa), annual percentage of probabilities (P) and average recurrence Interval in terms of year (T) have been calculated using equations 3.14, 3.15 and 3.16 respectively.

Drought hazard index (DHI), drought vulnerability index (DVI) based on socio-economic and physical vulnerability indicators, and drought risk index (DRI) have been calculated by using equations 3.17, 3.18 and 3.19 respectively.

Finally, district level drought risk map of the area has been prepared on the basis of the values of DRI obtained from the equation 3.19.

**Dinajpur Station**

From table 4.34, a total of 25 agricultural drought (2 occasional, 3 mild, 1 moderate, 7 severe and 12 extreme drought) events are found before the median year (1960 to 1984). On the other hand a total of 26 agricultural drought (1 occasional, 2 mild, 7 moderate, 2 severe and 13 extreme droughts) events are found after the median year (1986 to 2010). The annual occurrence of severe drought decreases after the median year whereas moderate and extreme drought events increase after the median year (Table 4.35). Therefore the annual probabilities of moderate and extreme agricultural drought events are increasing in the recent decades.

**Table 4.34** Agricultural drought categories during the period of 1960 to 2010 for Kharif season in Dinajpur station

| Occasional Drought | | Mild Drought | | Moderate Drought | | Severe Drought | | Extreme Drought | |
|---|---|---|---|---|---|---|---|---|---|
| 1960-1984 | 1986-2010 | 1960-1984 | 1986-2010 | 1960-1984 | 1986-2010 | 1960-1984 | 1986-2010 | 1960-1984 | 1986-2010 |
| 1973 | 1987 | 1972 | 1986 | 1966 | 1992 | 1962 | 1991 | 1960 | 1988 |
| 1977 | | 1976 | 1998 | | 1993 | 1963 | 2000 | 1961 | 1989 |
| | | 1983 | | | 1999 | 1969 | | 1964 | 1990 |
| | | | | | 2001 | 1971 | | 1965 | 1994 |
| | | | | | 2003 | 1979 | | 1967 | 1995 |
| | | | | | 2005 | 1980 | | 1968 | 1996 |
| | | | | | 2008 | 1984 | | 1970 | 1997 |
| | | | | | | | | 1974 | 2002 |
| | | | | | | | | 1975 | 2004 |
| | | | | | | | | 1978 | 2006 |
| | | | | | | | | 1981 | 2007 |
| | | | | | | | | 1982 | 2009 |
| | | | | | | | | | 2010 |

**Table 4.35** Annual occurrence (Pa), average recurrence interval in year (T) and annual percentage of probability (P) of drought classes in Dinajpur station

| Drought Severity | Annual occurrence (Pa) | | Average recurrence interval (T) | | Annual probability (P) | |
|---|---|---|---|---|---|---|
| | 1960-1984 | 1986-2010 | 1960-1984 | 1986-2010 | 1960-1984 | 1986-2010 |
| Occasional | 0.08 | 0.04 | 12.50 | 25.00 | 7.69 | 3.92 |
| Mild | 0.12 | 0.08 | 8.33 | 12.50 | 11.31 | 7.69 |
| Moderate | 0.04 | 0.28 | 26.00 | 3.57 | 3.77 | 24.42 |
| Severe | 0.28 | 0.08 | 3.57 | 13.00 | 24.42 | 7.40 |
| Extreme | 0.48 | 0.52 | 2.08 | 1.92 | 38.12 | 40.55 |

**Rangpur Station**

From Table 4.36, it is evident that the area experienced a total of 25 agricultural drought events (3 occasional, 2 mild, 2 moderate, 9 severe and 9 extreme droughts) before the median year (1960 to 1984). On the other hand, a total of 25 agricultural drought events (1 occasional, 1 mild, 6 moderate, 9 severe and 8 extreme droughts) have been identified after the median year (1986 to 2010). The annual occurrence of moderate drought events increased after the median year whereas occasional, mild and extreme drought events slightly decreased after the median year (Table 4.37). So the annual probability of moderate agricultural drought events increases in the recent decades.

**Table 4.36** Agricultural drought categories during the period of 1960 to 2010 for Kharif season in Rangpur station

| Occasional Drought | | Mild Drought | | Moderate Drought | | Severe Drought | | Extreme Drought | |
|---|---|---|---|---|---|---|---|---|---|
| 1960-1984 | 1986-2010 | 1960-1984 | 1986-2010 | 1960-1984 | 1986-2010 | 1960-1984 | 1986-2010 | 1960-1984 | 1986-2010 |
| 1964 | 1993 | 1980 | 2003 | 1977 | 1987 | 1960 | 1994 | 1961 | 1986 |
| 1972 | | 1981 | | 1984 | 1992 | 1963 | 1996 | 1962 | 1988 |
| 1973 | | | | | 1995 | 1965 | 1998 | 1966 | 1989 |
| | | | | | 2004 | 1967 | 1999 | 1969 | 1990 |
| | | | | | 2005 | 1968 | 2000 | 1974 | 1991 |
| | | | | | 2007 | 1970 | 2001 | 1976 | 1997 |
| | | | | | | 1971 | 2002 | 1978 | 2008 |
| | | | | | | 1975 | 2006 | 1979 | 2010 |
| | | | | | | 1983 | 2009 | 1982 | |

**Table 4.37** Annual occurrence (Pa), average recurrence interval in year (T) and annual percentage of probability (P) of drought classes in Rangpur station

| Drought Severity | Annual Occurrence (Pa) | | Average Recurrence Interval (T) | | Annual Probability (P) | |
|---|---|---|---|---|---|---|
| | 1960-1984 | 1986-2010 | 1960-1984 | 1986-2010 | 1960-1984 | 1986-2010 |
| Occasional | 0.12 | 0.04 | 8.33 | 25.00 | 11.31 | 3.92 |
| Mild | 0.08 | 0.04 | 12.50 | 25.00 | 7.69 | 3.92 |
| Moderate | 0.08 | 0.24 | 12.50 | 4.17 | 7.69 | 21.34 |
| Severe | 0.36 | 0.36 | 2.78 | 2.78 | 30.23 | 30.23 |
| Extreme | 0.36 | 0.32 | 2.78 | 3.13 | 30.23 | 27.39 |

**Bogra Station**

A total of 25 (Table 4.38) agricultural drought events (6 occasional, 3 moderate, 6 severe and 10 extreme drought) have been identified before the median year (1960 to 1984). On the other hand, a total of 25 agricultural drought events (4 occasional, 4 mild, 5 moderate, 6 severe and 6 extreme droughts) have been identified after the median year (1986 to 2010). The annual occurrence of mild and moderate drought events increases after the median year whereas occasional and extreme droughts increase after the median year (Table 4.39). Therefore the annual probability of mild and moderate agricultural drought events increases in the recent decades.

**Table 4.38** Agricultural drought categories during the period of 1960 to 2010 for Kharif season in Bogra station

| Occasional Drought | | Mild Drought | | Moderate Drought | | Severe Drought | | Extreme Drought | |
|---|---|---|---|---|---|---|---|---|---|
| 1960-1984 | 1986-2010 | 1960-1984 | 1986-2010 | 1960-1984 | 1986-2010 | 1960-1984 | 1986-2010 | 1960-1984 | 1986-2010 |
| 1963 | 1995 | | 1989 | 1960 | 1986 | 1961 | 1987 | 1967 | 1988 |
| 1964 | 1998 | | 2000 | 1970 | 1992 | 1962 | 1990 | 1968 | 1991 |
| 1965 | 2003 | | 2002 | 1983 | 1993 | 1971 | 1994 | 1969 | 1996 |
| 1966 | 2006 | | 2010 | | 2005 | 1972 | 1999 | 1974 | 1997 |
| 1973 | | | | | 2007 | 1976 | 2008 | 1975 | 2001 |
| 1977 | | | | | | 1979 | 2009 | 1978 | 2004 |
| | | | | | | | | 1980 | |
| | | | | | | | | 1981 | |
| | | | | | | | | 1982 | |
| | | | | | | | | 1984 | |

**Table 4.39** Annual occurrence (Pa), average recurrence interval in year (T) and annual percentage of probability (P) of drought classes in Bogra station

| Drought Severity | Annual Occurrence (Pa) | | Average Recurrence Interval (T) | | Annual Probability (P) | |
|---|---|---|---|---|---|---|
| | 1960-1984 | 1986-2010 | 1960-1984 | 1986-2010 | 1960-1984 | 1986-2010 |
| Occasional | 0.24 | 0.16 | 4.17 | 6.25 | 21.34 | 14.79 |
| Mild | 0.00 | 0.16 | Undefined | 6.25 | 0.00 | 14.79 |
| Moderate | 0.12 | 0.20 | 8.33 | 5.00 | 11.31 | 18.13 |
| Severe | 0.24 | 0.24 | 4.17 | 4.17 | 21.34 | 21.34 |
| Extreme | 0.40 | 0.24 | 2.50 | 4.17 | 32.97 | 21.34 |

**Ishwardi Station**

From Table 4.40, a total of 24 agricultural drought events (3 occasional, 2 mild, 4 moderate, 2 severe and 13 extreme droughts) have been identified before the median year (1961 to 1984). On the other hand a total of 25 agricultural drought events (5 occasional, 5 mild, 3 moderate, 2 severe and 10 extreme droughts) have been identified after the median year (1986 to 2010). The annual occurrence of occasional and mild drought events decreases after the median year whereas moderate and extreme droughts decreases after the median year (Table 4.41). Hence, the annual probability of occasional, mild and severe agricultural drought events increases in the recent decades.

**Table 4.40** Agricultural drought categories during the period of 1961 to 2010 for Kharif season in Ishwardi station

| Occasional Drought | | Mild Drought | | Moderate Drought | | Severe Drought | | Extreme Drought | |
|---|---|---|---|---|---|---|---|---|---|
| 1961-1984 | 1986-2010 | 1961-1984 | 1986-2010 | 1961-1984 | 1986-2010 | 1961-1984 | 1986-2010 | 1961-1984 | 1986-2010 |
| 1963 | 1989 | 1964 | 1991 | 1961 | 2001 | 1976 | 1996 | 1962 | 1986 |
| 1973 | 1998 | 1975 | 1992 | 1966 | 2002 | 1980 | 1999 | 1965 | 1987 |
| 1983 | 2000 | | 1993 | 1970 | 2010 | | | 1967 | 1988 |
| | 2003 | | 2005 | 1977 | | | | 1968 | 1990 |
| | 2007 | | 2008 | | | | | 1969 | 1994 |
| | | | | | | | | 1971 | 1995 |
| | | | | | | | | 1972 | 1997 |
| | | | | | | | | 1974 | 2004 |
| | | | | | | | | 1978 | 2006 |
| | | | | | | | | 1979 | 2009 |
| | | | | | | | | 1981 | |
| | | | | | | | | 1982 | |
| | | | | | | | | 1984 | |

**Table 4.41** Annual occurrence (Pa), average recurrence interval in year (T) and annual percentage of probability (P) of drought classes in Ishwardi station

| Drought Severity | Annual Occurrence (Pa) | | Average Recurrence Interval (T) | | Annual Probability (P) | |
|---|---|---|---|---|---|---|
| | 1961-1984 | 1986-2010 | 1961-1984 | 1986-2010 | 1961-1984 | 1986-2010 |
| Occasional | 0.13 | 0.20 | 8.00 | 5.00 | 11.75 | 18.13 |
| Mild | 0.08 | 0.20 | 12.00 | 5.00 | 8.00 | 18.13 |
| Moderate | 0.17 | 0.12 | 6.00 | 8.33 | 15.35 | 11.31 |
| Severe | 0.08 | 0.24 | 12.00 | 4.17 | 8.00 | 21.34 |
| Extreme | 0.40 | 0.08 | 2.50 | 12.50 | 32.97 | 7.69 |

**Rajshahi Station**

A total of 25 (Table 4.42) agricultural drought events (3 occasional, 2 mild, 4 moderate, 4 severe and 12 extreme) have been identified before the median year (1960 to 1984). On the other hand, a total of 25 agricultural drought events (1 occasional, 2 mild, 4 moderate, 7 severe and 11 extreme) events have been identified after the median year (1986 to 2010). The annual occurrence of severe and extreme drought events increases after the median year whereas occasional drought events decrease after the median year (Table 4.43). Therefore the annual probability of moderate and severe agricultural drought events increases in the recent decades.

**Table 4.42** Agricultural drought categories during the period of 1960 to 2010 for Kharif season in Rajshahi station

| Occasional Drought | | Mild Drought | | Moderate Drought | | Severe Drought | | Extreme Drought | |
|---|---|---|---|---|---|---|---|---|---|
| 1960-1984 | 1986-2010 | 1960-1984 | 1986-2010 | 1960-1984 | 1986-2010 | 1960-1984 | 1986-2010 | 1960-1984 | 1986-2010 |
| 1963 | 1980 | 1970 | 2007 | 1960 | 1989 | 1962 | 1987 | 1965 | 1986 |
| 1964 | | 1998 | 2008 | 1961 | 2000 | 1967 | 1991 | 1966 | 1988 |
| 1973 | | | | 1972 | 2002 | 1971 | 1994 | 1968 | 1990 |
| | | | | 1976 | 2010 | 1978 | 1996 | 1969 | 1992 |
| | | | | | | | 1999 | 1974 | 1993 |
| | | | | | | | 2001 | 1975 | 1995 |
| | | | | | | | 2006 | 1977 | 1997 |
| | | | | | | | | 1979 | 2003 |
| | | | | | | | | 1981 | 2004 |
| | | | | | | | | 1982 | 2005 |
| | | | | | | | | 1983 | 2009 |
| | | | | | | | | 1984 | |

**Table 4.43** Annual occurrence (Pa), average recurrence interval in year (T) and annual percentage of probability (P) of drought classes in Rajshahi station

| Drought Severity | Annual Occurrence (Pa) | | Average Recurrence Interval (T) | | Annual Probability (P) | |
|---|---|---|---|---|---|---|
| | 1960-1984 | 1986-2010 | 1960-1984 | 1986-2010 | 1960-1984 | 1986-2010 |
| Occasional | 0.12 | 0.04 | 8.33 | 25.00 | 11.31 | 3.92 |
| Mild | 0.08 | 0.08 | 12.50 | 12.50 | 7.69 | 7.69 |
| Moderate | 0.16 | 0.16 | 6.25 | 6.25 | 14.79 | 14.79 |
| Severe | 0.16 | 0.28 | 6.25 | 3.57 | 14.79 | 24.42 |
| Extreme | 0.48 | 0.44 | 2.08 | 2.27 | 38.12 | 35.60 |

**Faridpur Station**

A total of 25 (Table 4.44) agricultural drought events (4 occasional, 4 mild, 4 moderate, 6 severe and 7 extreme) have been identified before the median year (1960 to 1984). On the other hand, a total of 25 agricultural drought events 6 occasional, 2 mild, 3 moderate, 4 severe and 10 extreme) have been identified after the median year (1986 to 2010). The annual occurrence of occasional and extreme drought events increases after the median year whereas mild, moderate and severe drought events decrease after the median year (Table 4.45). So, the annual probability of occasional and extreme agricultural drought events increases in the recent decades.

**Table 4.44** Agricultural drought categories during the period of 1960 to 2010 for Kharif season in Faridpur station

| Occasional Drought | | Mild Drought | | Moderate Drought | | Severe Drought | | Extreme Drought | |
|---|---|---|---|---|---|---|---|---|---|
| 1960-1984 | 1986-2010 | 1960-1984 | 1986-2010 | 1960-1984 | 1986-2010 | 1960-1984 | 1986-2010 | 1960-1984 | 1986-2010 |
| 1964 | 1995 | 1961 | 1987 | 1960 | 1988 | 1963 | 1992 | 1962 | 1986 |
| 1965 | 2000 | 1973 | 2007 | 1970 | 1989 | 1969 | 1996 | 1966 | 1990 |
| 1971 | 2001 | 1974 | | 1976 | 1998 | 1972 | 1999 | 1967 | 1991 |
| 1983 | 2002 | 1977 | | 1978 | | 1975 | 2005 | 1968 | 1993 |
| | 2003 | | | | | 1982 | | 1979 | 1994 |
| | 2010 | | | | | 1984 | | 1980 | 1997 |
| | | | | | | | | 1981 | 2004 |
| | | | | | | | | | 2006 |
| | | | | | | | | | 2008 |
| | | | | | | | | | 2009 |

**Table 4.45** Annual occurrence (Pa), average recurrence interval in year (T) and annual percentage of probability (P) of drought classes in Faridpur station

| Drought Severity | Annual Occurrence (Pa) | | Average Recurrence Interval (T) | | Annual Probability (P) | |
|---|---|---|---|---|---|---|
| | 1960-1984 | 1986-2010 | 1960-1984 | 1986-2010 | 1960-1984 | 1986-2010 |
| Occasional | 0.16 | 0.24 | 6.25 | 4.17 | 14.79 | 21.34 |
| Mild | 0.16 | 0.08 | 6.25 | 12.50 | 14.79 | 7.69 |
| Moderate | 0.16 | 0.12 | 6.25 | 8.33 | 14.79 | 11.31 |
| Severe | 0.24 | 0.16 | 4.17 | 6.25 | 21.34 | 14.79 |
| Extreme | 0.28 | 0.40 | 3.57 | 2.50 | 24.42 | 32.97 |

**Jessore Station**

A total of 25 (Table 4.46) agricultural drought events (5 occasional, 4 mild, 3 moderate, 2 severe and 11 extreme) have been identified before the median year (1960 to 1984). On the other hand, a total of 24 agricultural drought events (5 occasional, 4 mild, 1 moderate, 4 severe and 10 extreme) have been identified after the median years (1986 to 2010). The annual occurrence of moderate drought events decreases after the median year whereas severe and extreme drought events increase after the median year (Table 4.47). Therefore, the annual probability of severe agricultural drought events increases in the recent decades.

**Table 4.46** Agricultural drought categories during the period of 1960 to 2010 for Kharif season in Jessore station

| Occasional Drought | | Mild Drought | | Moderate Drought | | Severe Drought | | Extreme Drought | |
|---|---|---|---|---|---|---|---|---|---|
| 1960-1984 | 1986-2010 | 1960-1984 | 1986-2010 | 1960-1984 | 1986-2010 | 1960-1984 | 1986-2010 | 1960-1984 | 1986-2010 |
| 1963 | 1998 | 1961 | 1987 | 1960 | 1991 | 1968 | 1988 | 1962 | 1986 |
| 1964 | 1999 | 1966 | 1992 | 1970 | | 1976 | 1990 | 1965 | 1993 |
| 1971 | 2000 | 1973 | 1995 | 1974 | | | 2001 | 1967 | 1994 |
| 1975 | 2003 | 1978 | 2007 | | | | 2010 | 1969 | 1996 |
| 1980 | 2005 | | | | | | | 1972 | 1997 |
| | | | | | | | | 1977 | 2002 |
| | | | | | | | | 1979 | 2004 |
| | | | | | | | | 1981 | 2006 |
| | | | | | | | | 1982 | 2008 |
| | | | | | | | | 1983 | 2009 |
| | | | | | | | | 1984 | |

**Table 4.47** Annual occurrence (Pa), average recurrence interval in year (T) and annual percentage of probability (P) of drought classes in Jessore station

| Drought Severity | Annual Occurrence (Pa) | | Average Recurrence Interval (T) | | Annual Probability (P) | |
|---|---|---|---|---|---|---|
| | 1960-1984 | 1986-2010 | 1960-1984 | 1986-2010 | 1960-1984 | 1986-2010 |
| Occasional | 0.20 | 0.20 | 5.00 | 5.00 | 18.13 | 18.13 |
| Mild | 0.16 | 0.16 | 6.25 | 6.25 | 14.79 | 14.79 |
| Moderate | 0.12 | 0.04 | 8.33 | 25.00 | 11.31 | 3.92 |
| Severe | 0.08 | 0.16 | 12.50 | 6.25 | 7.69 | 14.79 |
| Extreme | 0.44 | 0.40 | 2.27 | 2.50 | 35.60 | 32.97 |

**Khulna Station**

A total of 24 (Table 4.48) agricultural drought events (4 occasional, 5 mild, 3 moderate, 5 severe and 7 extreme) events have been identified before the median year (1960 to 1984). On the other hand, a total of 25 agricultural drought events (6 occasional, 1 mild, 1 moderate, 7 severe and 10 extreme) have been identified after the median year (1986 to 2010). The annual occurrence of mild and moderate drought events decreases after the median year whereas occasional, severe and extreme drought events increase after the median year (Table 4.49). Therefore the annual probability of occasional, severe and extreme agricultural drought events increases in the recent decades.

**Table 4.48** Agricultural drought categories during the period of 1960 to 2010 for Kharif season in Khulna station

| Occasional Drought | | Mild Drought | | Moderate Drought | | Severe Drought | | Extreme Drought | |
|---|---|---|---|---|---|---|---|---|---|
| 1960-1984 | 1986-2010 | 1960-1984 | 1986-2010 | 1960-1984 | 1986-2010 | 1960-1984 | 1986-2010 | 1960-1984 | 1986-2010 |
| 1966 | 1989 | 1963 | 1988 | 1960 | 1999 | 1961 | 1992 | 1962 | 1986 |
| 1972 | 1991 | 1964 | | 1976 | | 1969 | 1995 | 1967 | 1987 |
| 1973 | 1998 | 1965 | | 1980 | | 1970 | 1996 | 1968 | 1990 |
| 1983 | 2003 | 1971 | | | | 1978 | 2000 | 1974 | 1993 |
| | 2005 | 1977 | | | | 1982 | 2001 | 1979 | 1994 |
| | 2010 | | | | | | 2007 | 1981 | 1997 |
| | | | | | | | 2009 | 1984 | 2002 |
| | | | | | | | | | 2004 |
| | | | | | | | | | 2006 |
| | | | | | | | | | 2008 |

**Table 4.49** Annual occurrence (Pa), average recurrence interval in year (T) and annual percentage of probability (P) of drought classes in Khulna station

| Drought Severity | Annual Occurrence (Pa) | | Average Recurrence Interval (T) | | Annual Probability (P) | |
|---|---|---|---|---|---|---|
| | 1960-1984 | 1986-2010 | 1960-1984 | 1986-2010 | 1960-1984 | 1986-2010 |
| Occasional | 0.16 | 0.24 | 6.25 | 4.17 | 14.79 | 21.34 |
| Mild | 0.20 | 0.04 | 5.00 | 25.00 | 18.13 | 3.92 |
| Moderate | 0.12 | 0.04 | 8.33 | 25.00 | 11.31 | 3.92 |
| Severe | 0.20 | 0.28 | 5.00 | 3.57 | 18.13 | 24.42 |
| Extreme | 0.28 | 0.40 | 3.57 | 2.50 | 24.42 | 32.97 |

**Satkhira Station**

A total of 25 (Table 4.50) agricultural drought events (8 occasional, 2 mild, 2 moderate, 6 severe and 7 extreme) have been identified before the median year (1960 to 1984). On the other hand, a total of 26 agricultural drought events (5 occasional, 2 mild, 3 moderate, 4 severe and 11 extreme) have been identified after the median year (1986 to 2010). The annual occurrence of occasional and severe drought events decreases after the median year whereas moderate and extreme droughts increase after the median year (Table 4.51). Therefore, the annual probability of moderate and extreme agricultural drought events increases in the recent decades.

**Table 4.50** Agricultural drought categories during the period of 1960 to 2010 for Kharif season in Satkhira station

| Occasional Drought | | Mild Drought | | Moderate Drought | | Severe Drought | | Extreme Drought | |
|---|---|---|---|---|---|---|---|---|---|
| 1960-1984 | 1986-2010 | 1960-1984 | 1986-2010 | 1960-1984 | 1986-2010 | 1960-1984 | 1986-2010 | 1960-1984 | 1986-2010 |
| 1963 | 1989 | 1964 | 1993 | 1970 | 1988 | 1962 | 1996 | 1960 | 1986 |
| 1971 | 1999 | 1969 | 2001 | 1980 | 1991 | 1968 | 2000 | 1961 | 1987 |
| 1972 | 2003 | | | | 1998 | 1976 | 2002 | 1965 | 1990 |
| 1973 | 2005 | | | | | 1977 | 2007 | 1966 | 1992 |
| 1974 | 2010 | | | | | 1978 | | 1967 | 1994 |
| 1975 | | | | | | 1979 | | 1981 | 1995 |
| 1983 | | | | | | | | 1982 | 1997 |
| 1984 | | | | | | | | | 2004 |
| | | | | | | | | | 2006 |
| | | | | | | | | | 2008 |
| | | | | | | | | | 2009 |

**Table 4.51** Annual occurrence (Pa), average recurrence interval in year (T) and annual percentage of probability (P) of drought classes in Satkhira station

| Drought Severity | Annual Occurrence (Pa) | | Average Recurrence Interval (T) | | Annual Probability (P) | |
|---|---|---|---|---|---|---|
| | 1960-1984 | 1986-2010 | 1960-1984 | 1986-2010 | 1960-1984 | 1986-2010 |
| Occasional | 0.32 | 0.20 | 3.13 | 5.00 | 27.39 | 18.13 |
| Mild | 0.08 | 0.08 | 12.50 | 12.50 | 7.69 | 7.69 |
| Moderate | 0.08 | 0.12 | 12.50 | 8.33 | 7.69 | 11.31 |
| Severe | 0.24 | 0.16 | 4.17 | 6.25 | 21.34 | 14.79 |
| Extreme | 0.28 | 0.44 | 3.57 | 2.27 | 24.42 | 35.60 |

**Barisal Station**

A total of 25 (Table 4.52) agricultural drought events (3 occasional, 4 mild, 6 moderate, 1 severe and 11 extreme) have been identified before the median year (1960 to 1984). On the other hand, a total of 26 agricultural drought events (7 occasional, 3 mild, 2 moderate, 5 severe and 8 extreme) have been identified after the median year (1986 to 2010). The annual occurrence of occasional and severe drought events increases after the median year whereas mild, moderate and extreme drought events decrease after the median year (Table 4.53). Therefore, the annual probability of occasional and severe agricultural drought events increases in the recent decades.

**Table 4.52** Agricultural drought categories during the period of 1960 to 2010 for Kharif season in Barisal station

| Occasional Drought | | Mild Drought | | Moderate Drought | | Severe Drought | | Extreme Drought | |
|---|---|---|---|---|---|---|---|---|---|
| 1960-1984 | 1986-2010 | 1960-1984 | 1986-2010 | 1960-1984 | 1986-2010 | 1960-1984 | 1986-2010 | 1960-1984 | 1986-2010 |
| 1964 | 1987 | 1962 | 1993 | 1960 | 1998 | 1980 | 1988 | 1967 | 1986 |
| 1973 | 1989 | 1965 | 2001 | 1961 | 2006 | | 1994 | 1969 | 1990 |
| 1975 | 1999 | 1966 | 2004 | 1963 | | | 1995 | 1970 | 1991 |
| | 2000 | 1983 | | 1968 | | | 2002 | 1971 | 1992 |
| | 2003 | | | 1974 | | | 2005 | 1972 | 1996 |
| | 2007 | | | 1977 | | | | 1976 | 1997 |
| | 2010 | | | | | | | 1978 | 2008 |
| | | | | | | | | 1979 | 2009 |
| | | | | | | | | 1981 | |
| | | | | | | | | 1982 | |
| | | | | | | | | 1984 | |

**Table 4.53** Annual occurrence (Pa), average recurrence interval in year (T) and annual percentage of probability (P) of drought classes in Barisal station

| Drought Severity | Annual Occurrence (Pa) | | Average Recurrence Interval (T) | | Annual Probability (P) | |
|---|---|---|---|---|---|---|
| | 1960-1984 | 1986-2010 | 1960-1984 | 1986-2010 | 1960-1984 | 1986-2010 |
| Occasional | 0.12 | 0.28 | 8.33 | 3.57 | 11.31 | 24.42 |
| Mild | 0.16 | 0.12 | 6.25 | 8.33 | 14.79 | 11.31 |
| Moderate | 0.24 | 0.08 | 4.17 | 12.50 | 21.34 | 7.69 |
| Severe | 0.04 | 0.20 | 25.00 | 5.00 | 3.92 | 18.13 |
| Extreme | 0.44 | 0.32 | 2.27 | 3.13 | 35.60 | 27.39 |

**Bhola Station**

A total of 21 (Table 4.54) agricultural drought events (4 occasional, 3 mild, 4 moderate, 4 severe and 6 extreme) have been identified before the median year (1966 to 1987). On the other hand, a total of 26 agricultural drought events (5 occasional, 3 mild, 2 moderate, 3 severe and 9 extreme) have been identified after the median year (1989 to 2010). The annual occurrence of moderate and severe drought events decreases after the median year whereas extreme drought events increase after the median year (Table 4.55). Therefore, the annual probability of occasional and extreme agricultural drought events increases in the recent decades.

**Table 4.54** Agricultural drought categories during the period of 1966 to 2010 for Kharif season in Bhola station

| Occasional Drought | | Mild Drought | | Moderate Drought | | Severe Drought | | Extreme Drought | |
|---|---|---|---|---|---|---|---|---|---|
| 1966-1987 | 1989-2010 | 1966-1987 | 1989-2010 | 1966-1987 | 1989-2010 | 1966-1987 | 1989-2010 | 1966-1987 | 1989-2010 |
| 1973 | 1989 | 1966 | 2002 | 1970 | 1995 | 1968 | 1996 | 1967 | 1990 |
| 1975 | 1992 | 1979 | 2003 | 1971 | 2000 | 1982 | 1998 | 1969 | 1991 |
| 1980 | 1999 | 1986 | 2005 | 1976 | | 1983 | 2001 | 1972 | 1993 |
| 1985 | 2004 | | | 1977 | | 1984 | | 1974 | 1994 |
| | 2007 | | | | | | | 1978 | 1997 |
| | | | | | | | | 1981 | 2006 |
| | | | | | | | | | 2008 |
| | | | | | | | | | 2009 |
| | | | | | | | | | 2010 |

**Table 4.55** Annual occurrence (Pa), average recurrence interval in year (T) and annual percentage of probability (P) of drought classes in Bhola station

| Drought Severity | Annual Occurrence (Pa) | | Average Recurrence Interval (T) | | Annual Probability (P) | |
|---|---|---|---|---|---|---|
| | 1966-1987 | 1989-2010 | 1966-1987 | 1989-2010 | 1966-1987 | 1989-2010 |
| Occasional | 0.18 | 0.23 | 5.50 | 4.40 | 16.62 | 20.33 |
| Mild | 0.14 | 0.14 | 7.33 | 7.33 | 12.75 | 12.75 |
| Moderate | 0.18 | 0.09 | 5.50 | 11.00 | 16.62 | 8.69 |
| Severe | 0.18 | 0.14 | 5.50 | 7.33 | 16.62 | 12.75 |
| Extreme | 0.27 | 0.41 | 3.67 | 2.44 | 23.87 | 33.57 |

**Khepupara Station**

A total of 17 (Table 4.56) agricultural drought events (4 occasional, 2 mild, 3 moderate and 8 extreme) have been identified before the median year (1975 to 1991). On the other hand, a total of 18 agricultural drought events (5 occasional, 5 mild, 1 moderate, 4 severe and 3 extreme) have been identified after the median year (1992 to 2010). The annual occurrence of mild and severe drought events increases after the median year whereas moderate and extreme droughts decrease after the median years (Table 4.57). So, the annual probability of occasional, mild and severe agricultural drought events increases in the recent decades.

**Table 4.56** Agricultural drought categories during the period of 1975 to 2010 for Kharif season in Khepupara station

| Occasional Drought | | Mild Drought | | Moderate Drought | | Severe Drought | | Extreme Drought | |
|---|---|---|---|---|---|---|---|---|---|
| 1975-1991 | 1992-2010 | 1975-1991 | 1992-2010 | 1975-1991 | 1992-2010 | 1975-1991 | 1992-2010 | 1975-1991 | 1992-2010 |
| 1979 | 1998 | 1978 | 1993 | 1975 | 2009 | | 1994 | 1977 | 1997 |
| 1983 | 1999 | 1980 | 1995 | 1976 | | | 1996 | 1981 | 2004 |
| 1989 | 2001 | | 2000 | 1987 | | | 2002 | 1982 | 2006 |
| 1991 | 2003 | | 2007 | | | | 2005 | 1984 | |
| | 2010 | | 2008 | | | | | 1985 | |
| | | | | | | | | 1986 | |
| | | | | | | | | 1988 | |
| | | | | | | | | 1990 | |

**Table 4.57** Annual occurrence (Pa), average recurrence interval in year (T) and annual percentage of probability (P) of drought classes in Khepupara station

| Drought Severity | Annual Occurrence (Pa) | | Average Recurrence Interval (T) | | Annual Probability (P) | |
|---|---|---|---|---|---|---|
| | 1975-1991 | 1992-2010 | 1975-1991 | 1992-2010 | 1975-1991 | 1992-2010 |
| Occasional | 0.22 | 0.28 | 4.50 | 3.60 | 19.93 | 24.25 |
| Mild | 0.11 | 0.28 | 9.00 | 3.60 | 10.52 | 24.25 |
| Moderate | 0.17 | 0.06 | 6.00 | 18.00 | 15.35 | 5.40 |
| Severe | 0.00 | 0.22 | Undefined | 4.50 | 0.00 | 19.93 |
| Extreme | 0.44 | 0.17 | 2.25 | 6.00 | 35.88 | 15.35 |

### 4.3.3 Drought Hazard Index and Hazard Map

Year-wise percentages of annual occurrences of drought events in Kharif season for all meteorological stations have been considered for calculating drought hazard index (DHI) by using equation 3.17 and the obtained values are given in the table 4.58. The DHI map is prepared by ordinary kriging method using geo-statistical tools in GIS environment and shown in figure 4.45. From table 4.58, it reveals that highest occurrence (50.98%) of annual extreme drought and that of lowest (5.88%) occurrence of occasional drought with the highest DHI (32) are found in Dinajpur station in comparison to other stations of the study area. Spatial distribution of DHI values in the area is shown in figure 4.45 where its value ranges from 15 to 32 with high DHI values in Thakurgaon (29.43) and Rajshahi (29.27) districts. The lower DHI values are in Borguna (17.24) and Bagerhat(17.62) districts. Figure 4.46 shows that, Panchagarh, Takurgoan, Dinajpur, Nilphamari, Nawabganj, Naogaon, Rajshahi and Natore districts belong to extreme hazardous area in comparison to other districts of the area.

**Table 4.58** Percentage of annual occurrences of drought classes and DHI for Kharif season

| Stations Name | Percentage of Annual Occurrences | | | | | DHI |
|---|---|---|---|---|---|---|
| | Occasional | Mild | Moderate | Severe | Extreme | |
| Dinajpur | 5.88 | 9.80 | 15.69 | 17.65 | 50.98 | 32 |
| Rangpur | 7.84 | 5.88 | 17.65 | 35.29 | 33.33 | 25 |
| Bogra | 19.61 | 7.84 | 15.69 | 25.49 | 31.37 | 22 |
| Ishwardi | 16.00 | 14.00 | 14.00 | 8.00 | 48.00 | 28 |
| Rajshahi | 7.84 | 7.84 | 15.69 | 21.57 | 47.06 | 31 |
| Faridpur | 19.61 | 11.76 | 13.73 | 19.61 | 35.29 | 18 |
| Jessore | 19.61 | 15.69 | 7.84 | 11.76 | 43.14 | 20 |
| Khulna | 19.61 | 11.76 | 7.84 | 23.53 | 35.29 | 17 |
| Satkhira | 25.49 | 7.84 | 9.80 | 19.61 | 37.25 | 17 |
| Barisal | 19.61 | 13.73 | 15.69 | 11.76 | 39.22 | 22 |
| Bhola | 20.00 | 13.33 | 15.56 | 15.56 | 33.33 | 21 |
| Khepupara | 25.00 | 19.44 | 11.11 | 11.11 | 33.33 | 15 |

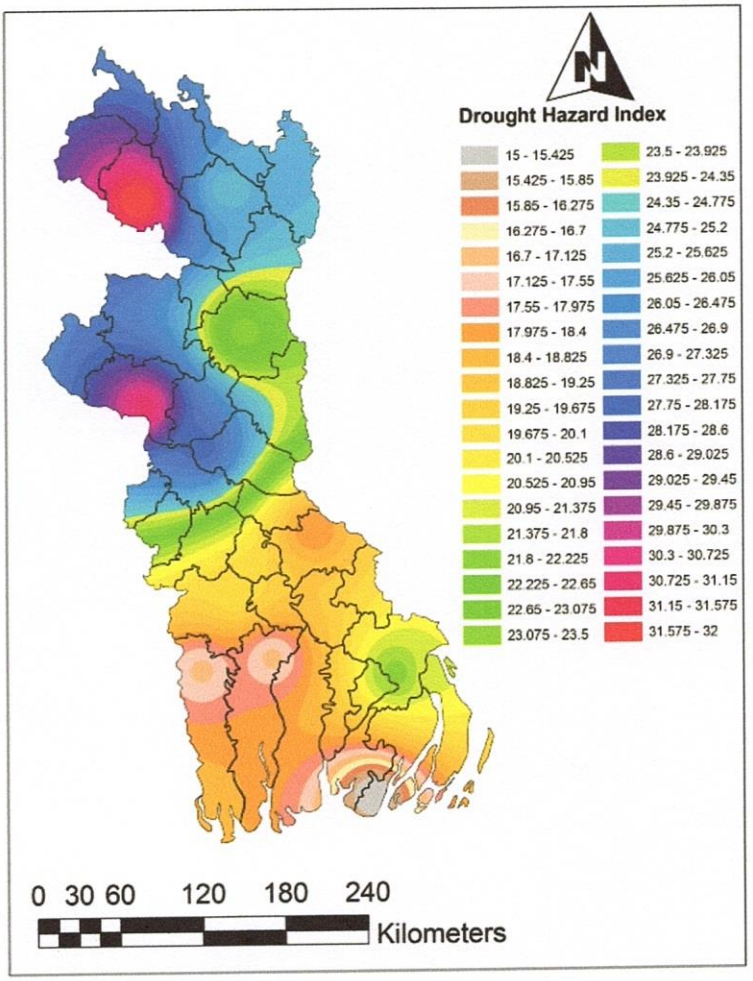


**Figure 4.45** Spatial distribution of DHI values with district boundaries

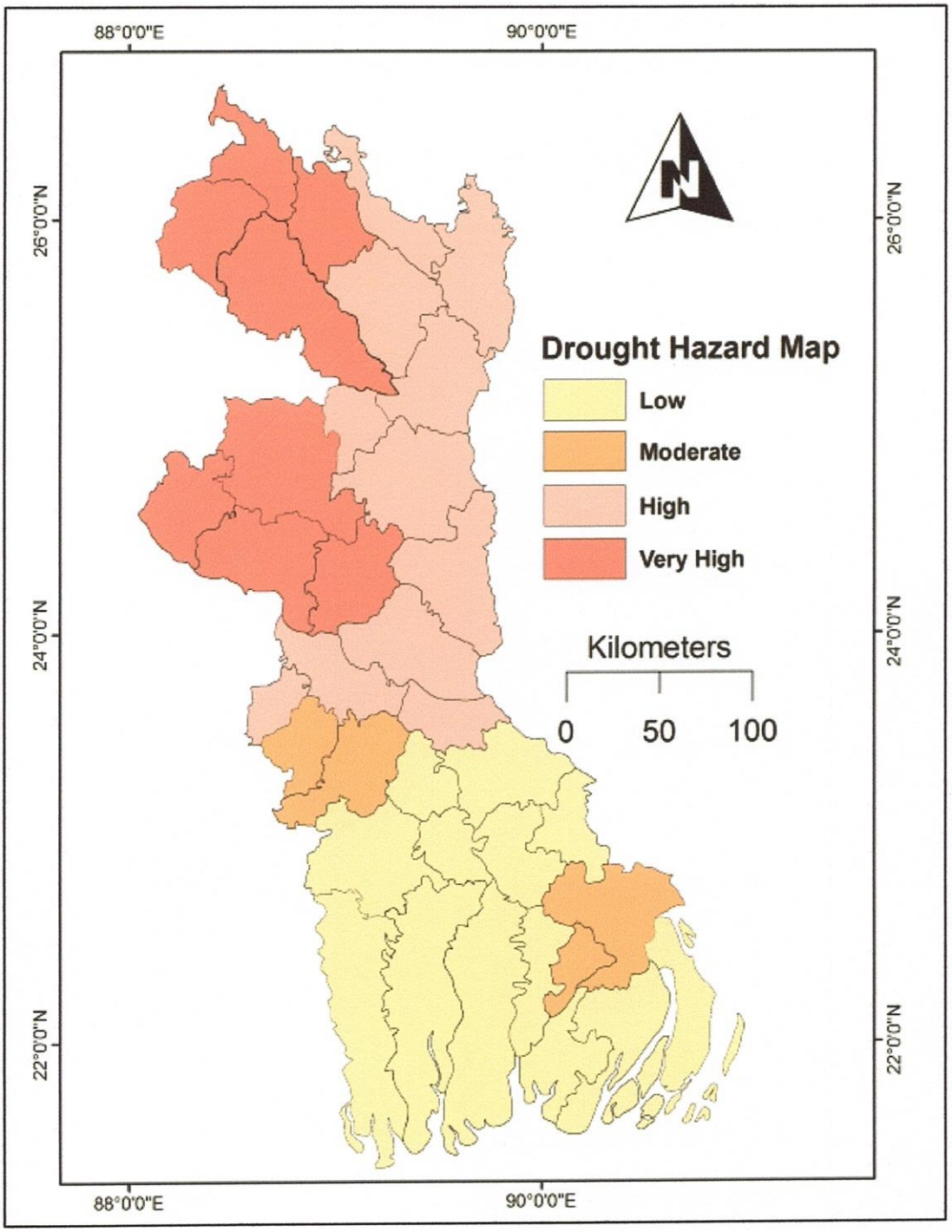


**Figure 4.46** District level drought hazard map in Kharif season

### 4.3.4 Drought Vulnerability Based on Socio-economic and Physical Indicators

Bangladesh ranks low on just about all parameters of economic development, which in combination with other factors such as geography and climate makes the country quite vulnerable to climate change. Here the total population is over 149.8 million living in a small land area with a population density of more than 1115 persons per $km^2$ where 73% of the population lives in rural areas. (Bangladesh Demographic & Health Survey Report-2011 published in 2012).

Assessment of the impacts of drought hazards and vulnerability to climate change and subsequently working out adaptation needs requires good quality of information. This information includes climate data, such as rainfall, temperature and the frequency of extreme events, and non-climatic data, such as the current situation on the ground for different sectors including water resources, agriculture and food security, human health, terrestrial ecosystems and biodiversity, and coastal zones. So climate change data including future impacts and vulnerabilities needs to be integrated with socio-economic data and analyses across a range of sectors, and the results must be tailored for policymakers and stakeholders (UNFCCC, 2007).

However, all the indicators are not readily obtainable and/or quantifiable for Bangladesh. After careful consideration of obtainable/quantifiable socio-economic and physical indicators, four individual socio-economic and two physical/structural indicators are considered to represent the vulnerability of various geographic populations to the impact of droughts (Shahid and Behrawan, 2008, Rahman, 2011).

In the present study on drought vulnerability study these socio-economic factors have been considered, because agricultural drought has adverse effects on these factors. The socio-economic indicators are population density, female to male ratio, percentage of people depending on agriculture and literacy rate. Two physical/structural indicators are: percentage of irrigated land to cultivable land and crop production per unit area. For each of the above six indicators four classes were selected, ranging from the lowest to the highest values to prepare district level vulnerability maps of the study area. The equal interval method (Slocum, 1999) is used to derive the classes.

#### 4.3.4.1 Population Density

Population density defines number of persons per square kilometer. The degree of calamity associated with a disaster will be associated with the density of population of any area. Severity of disaster is higher in densely populated area in comparison to the less populated area. Z-score map of population density factor of drought vulnerability is shown in figure 4.47, where high Z-score values represent the high impact on drought vulnerability and vice-versa and values ranges from 0.85 to 1.85 which covers 16.55% of the study area. In the district levels the Z-score of population density is found very high in Nilphamari, Rangpur, Gaibandha, Bogra, Sirajganj and Kushtia districts. About 36.19% of the total area is found under a high level impact on drought vulnerability that covers the districts like Lalmonrhat, Kurigram, Nawabganj, Rajshahi, Natore, Pabna, Faridpur, Madaripur, Chuadanga, Jhenaidah, Jessore, Satkhira and Bagerhat. The area with moderate level of impact on drought vulnerability covers 31.53% of the total study area that covers Panchagarh, Thakugaon, Dinajpur, Naogaon, Meherpur, Rajbari, Magura, Narail, Gopalganj, Barisal and Pirojpur districts. In similar way, the area of low impact of drought vulnerability is found in Khulna, Jhalokati, Patuakhali, Bhola and Borguna districts that covers small portion (10.93%) of the study area.

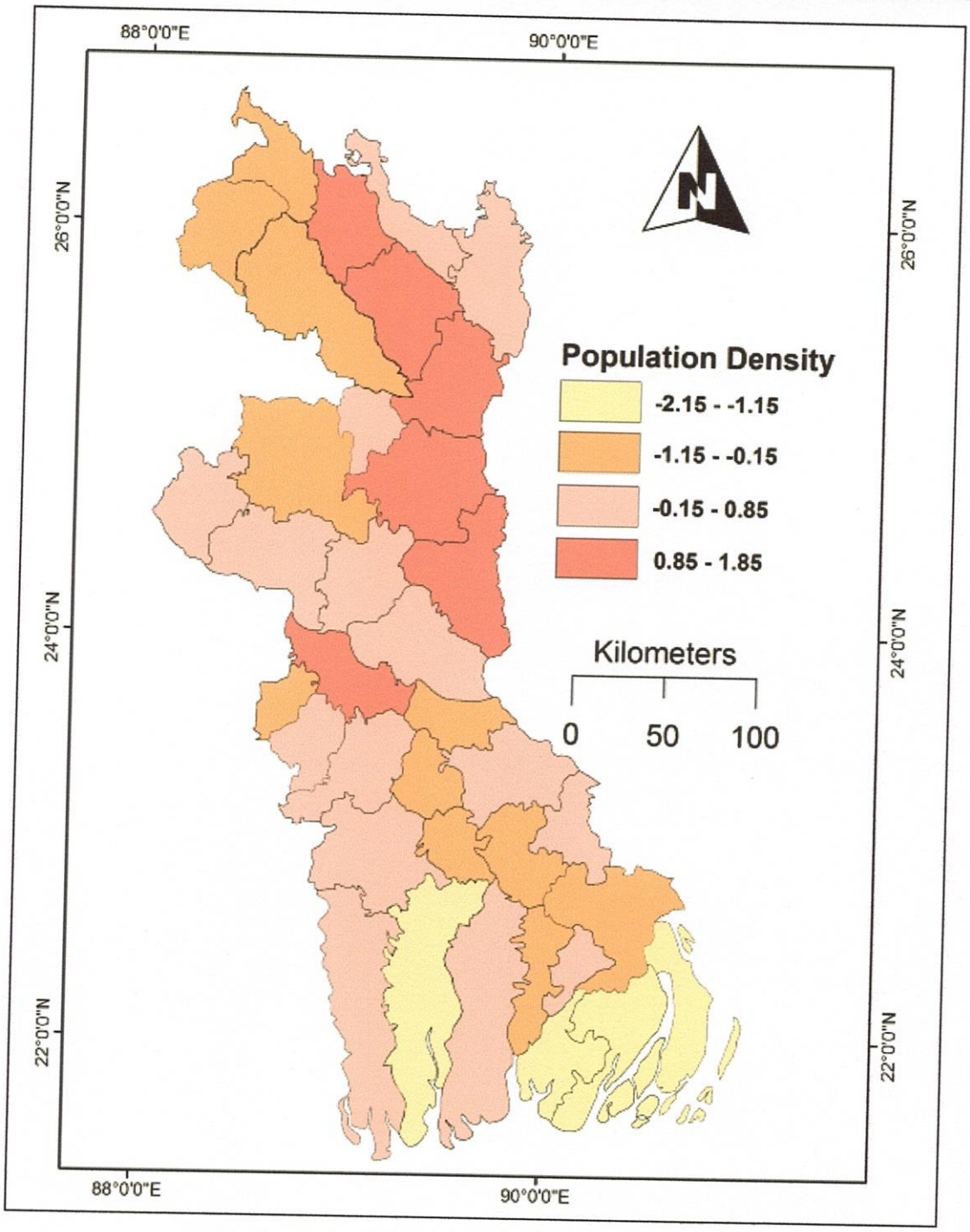


**Figure 4.47** Z-score map of population density per km$^2$

### 4.3.4.2 Female to Male Ratio

Number of women to men in an area represents female to male ratio and in widely diverse populations, women are most at risk when disaster unfolds (Vaughan, 1987). When in 1991 cyclone and floods hit Bangladesh, the death

rate for women was almost five times higher than for men (Huq and Ayers, 2007). The Z-score map of female to male ratio factor of drought vulnerability is shown in figure 4.48, where the high Z-score value ranges from (1.60-2.66) which covers 5.09% of the study area. In the district levels, the Z-score of female to male ratio is found very high in Jhalokati district. About 24.02% of the total area is found under a high level impact on drought vulnerability which includes districts like Kurigram, Gaibandha, Nawabganj, Rajbari, Faridpur, Narail, Gopalganj, Madaripur, Barisal, Pirojpur, Patuakhali and Borguna. The area of moderate level of impact on drought vulnerability covers 40.39% of total study area that includes Naogaon, Natore, Pabna, Kushtia, Meherpur, Chuadanga, Jhenaidht includes Magura, Satkhira and Bhola districts. In similar way, the area of low impact of drought vulnerability is found in Panchagarh, Thakugaon, Nilphamari, Rangpur, Dinajpur, Joypurhat, Bogra, Sirajganj, Rajshahi, Jessore, Khulna and Bagerhat districts that covers 24.44% portion of the study area.

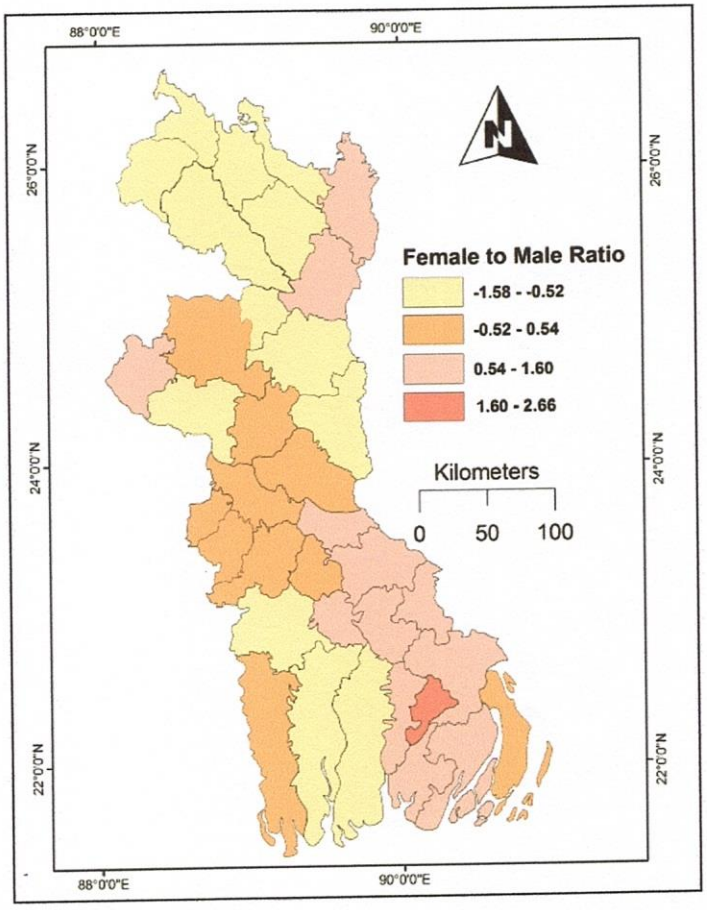


**Figure 4.48** Z-score map of female to male ratio

#### 4.3.4.3 Literacy Rate

Literacy is a major factor in creating awareness among the people in a society, as they understand easily with less effort and money (Balaji et al. 2013). Literate people can build up awareness among the people who are suffering from drought hazard through media engagement and also ensure the awareness through valuable writings regarding the drought hazard consequences in different types of social media like newspapers, magazines and pamphlets; and organize the valued seminars and symposiums. Besides these, they can also play vital role exposing the devastating effect of drought vulnerability in participating different electronic media like radio, television, documentary film and street plays etc.

The Z-score map of literacy rate factor of drought vulnerability is shown in figure 4.49, and reveals that the high values of Z–score represent the less impact of drought vulnerability and vice-versa. The high Z-score values ranges from 1.50 to 2.45 which cover 5.97% of the study area indicating low impact of drought vulnerability in Lalmonrhat, Pirojpur and Jhalokati districts. Again he Z-score values of literacy rate ranges from 0.56 to 1.50 covering 22.09 % of the study area represents moderate impact in Dinajpur, Joypurhat, Jhenaidha, Bagerhat and Patuakhali Districts. On the other hand, the Z-score values of literacy rate ranging from -0.39 to 0.56 covers 37.07 % of the study area representing high impact in Panchagarh, Thakugaon, Nilphamari, Gaibandha, Chuadanga, Jessore, Khulna, Narail, Gopalganj, Madaripur, Faridpur and Barisal districts. The Z-score values of literacy rate ranging from -1.34 to -0.39 covers 25.82 % of the study area representing very high impact in Kurigram, Rangpur, Naogaon, Bogra, Magura, Rajbari, Kushtia, Meherpur, Pabna, Sirajganj, Natore, Rajshahi and Nawabganj districts.

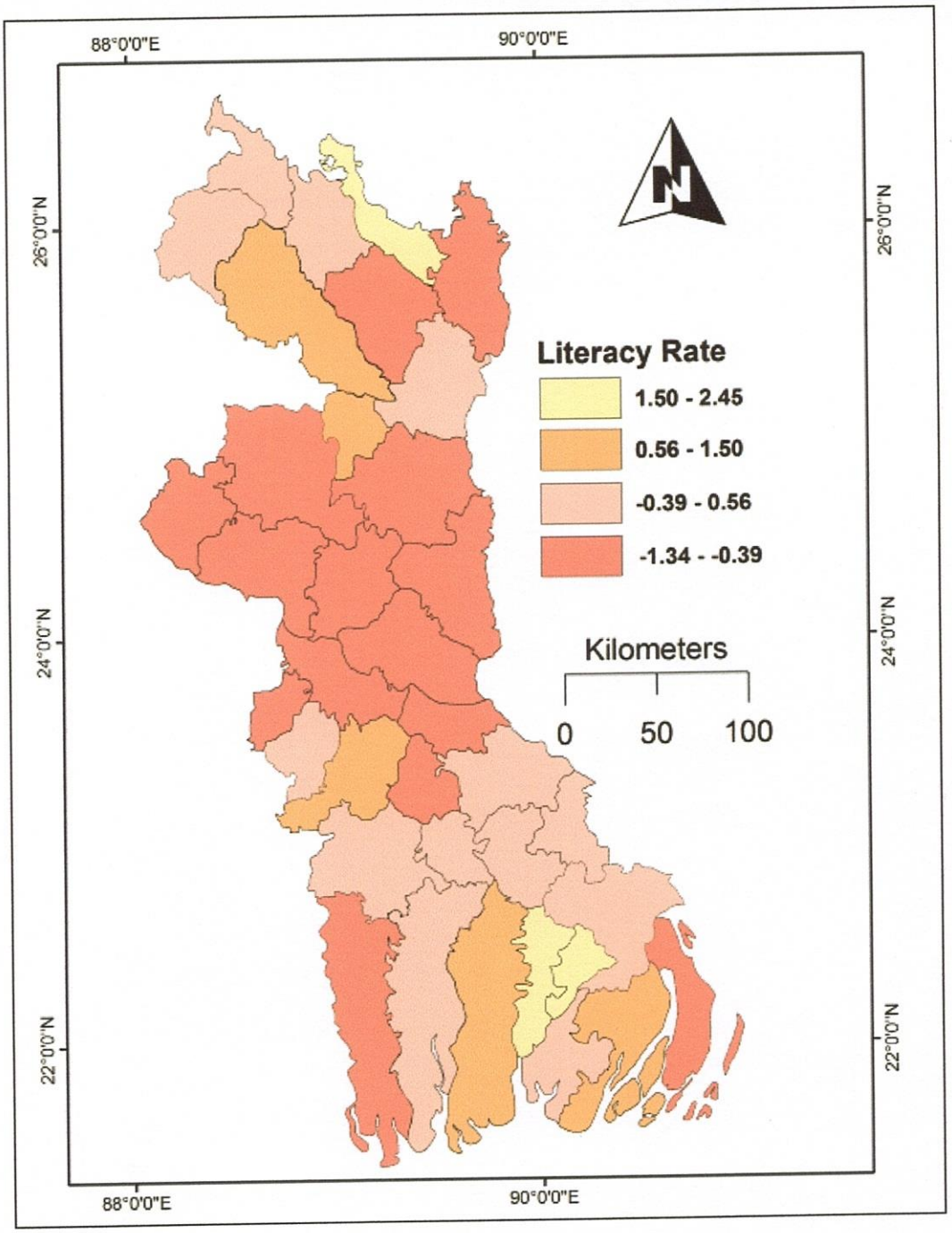


**Figure 4.49** Z-score map of literacy rate

### 4.3.4.4 People Depending on Agriculture

Percentage of people depending on agriculture includes both farmers and agricultural workers. More than 75% of the people in Bangladesh depend on agriculture (Shahid and Behrawan, 2008). Agriculture is the most affected sector by flood and drought in Bangladesh. The district level Z-score map of

the study area considering the socio-economic indicator i.e., percentage of people living on agriculture is shown in figure 4.50 and reveals that the high Z-score values ranges from 0.37 to 1.38 cover 21.19% of the study area representing very high impact of drought vulnerability in Kurigram, Lalmonrhat, Nilphamari, Panchagarh, Thakurgaon, Rangpur, Naogaon, Joypurhat, Bogra, Natore, Meherpur, Jhenaidha, Magura and Gopalganj districts. On the other hand, the Z-score values of literacy rate ranges from -0.64 to -0.37 covers 38.32 % of the area indicating high impact of drought vulnerability in Dinajpur, Gaibandha, Nawabganj, Rajshahi, Pabna, Chuadanga, Rajbari, Faridpur, Madaripur, Narail, Jessore, Satkhira, Borguna, Patuakhali and Bhola districts. Again the Z-score values of literacy rate ranging from -1.65 to -0.64 cover 21.16% of the study area representing moderate impact in Barisal and Pirojpur districts, and that of ranging from -2.66 to -1.65 covers 4.56 % of the study area indicating low impact of drought vulnerability in Kushtia, Khulna, Bagerhat and Jhalokati districts.

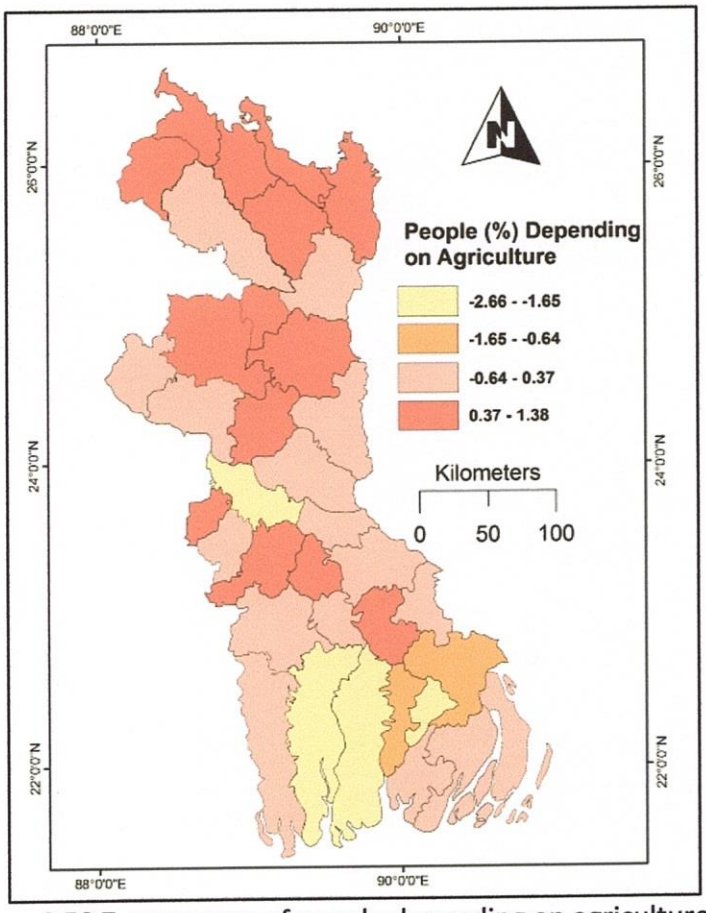


**Figure 4.50** Z-score map of people depending on agriculture (%)

#### 4.3.4.5 Irrigated Land to Cultivable Land

It represents percentage of irrigated land to cultivable land. In Bangladesh about 45.78% cultivated lands are under irrigation (BBS 2011). About 75% water for irrigation comes from groundwater and the rest comes from surface water (Bari and Anwar, 2000). Surface and groundwater availability is directly related to meteorological drought. A deficit of rainfall lowers the groundwater table as well as river water level and makes irrigation costly or sometimes impossible (Shahid and Behrawan, 2008). The district level drought vulnerability map of the study area considering the indicator of percentage of irrigated land to cultivable land is shown in figure 4.51 and reveals that the high Z-score values ranging from 0.71 to 1.53 cover 17.59% of the area indicating very high impact in Thakurgaon, Dinajpur, Rangpur, Joypurhat, Bogra, Sirajganj, Natore, Kushtia, Meherpur, Chuadanga and Jessore districts. On the other hand, the Z-score values ranging from -0.10 to 0.71 cover 22.13% of the area representing high impact of drought vulnerability in Lalmonirhat, Kurigram, Naogaon, Nawabganj, Rajshahi, Pabna, Jhenaidha and Magura districts. Again the Z-score values ranging from -0.92 to -0.10 covers 28.14% of the study area representing moderate impact of drought vulnerability in Nilphamari, Rajbari, Faridpur, Gopalganj, Barisal, Jhalokati and Bagerhat districts, and that of Z-score values ranges from -1.74 to -0.92 covering 13.79% of the area indicating low impact of drought vulnerability in Panchagarh, Narail, Satkhira, Khulna, Pirojpur, Bhola, Patuakhali and Borguna districts.

#### 4.3.4.6 Crop Production

Crop production refers to the amount of crop produced in metric ton per square kilometer. Droughts in higher crop productive area have higher negative impact on economy than that of lower crop productive area. In Bangladesh, 46% of croplands are multiple-cropped and the rest are single cropped. Multiple cropped lands produced more food than that of single-cropped lands (Shahid and Behrawan, 2008). The district level vulnerability map of the study area considering indicator like crop production per unit area is shown in figure 4.52 and reveals that the high Z-score values ranging 1.23 to 2.13 cover 9.27% of the area indicating very high impact of drought vulnerability in Dinajpur, Bogra, Pabna and Jessore districts. The Z-score values ranges from 0.34 to 1.24 cover 25.76% of the area presenting high

impact of drought vulnerability in Rangpur, Thakurgaon, Kurigram, Gaibandha, Joypurhat, Nawabganj, Rajshahi, Naogaon, Natore and Sirajganj districts. Again the Z-score values ranging from -0.56 to 0.34 cover 34.54% of the area indicating moderate impact of drought vulnerability in Nilphamari, Lalmonirhat, Rajbari, Faridpur, Gopalganj, Chuadanga, Narail, Jhalokati, Pirojpur, Kushtia and Jhenaidah districts, where that of Z-score values from -1.45 to -0.56 covers 21.42% of the area indicating low impact of drought vulnerability in Panchagarh, Bagerhat, Barisal, Madaripur, Meherpur, Magura, Satkhira, Khulna, Bhola, Patuakhali and Borguna districts.

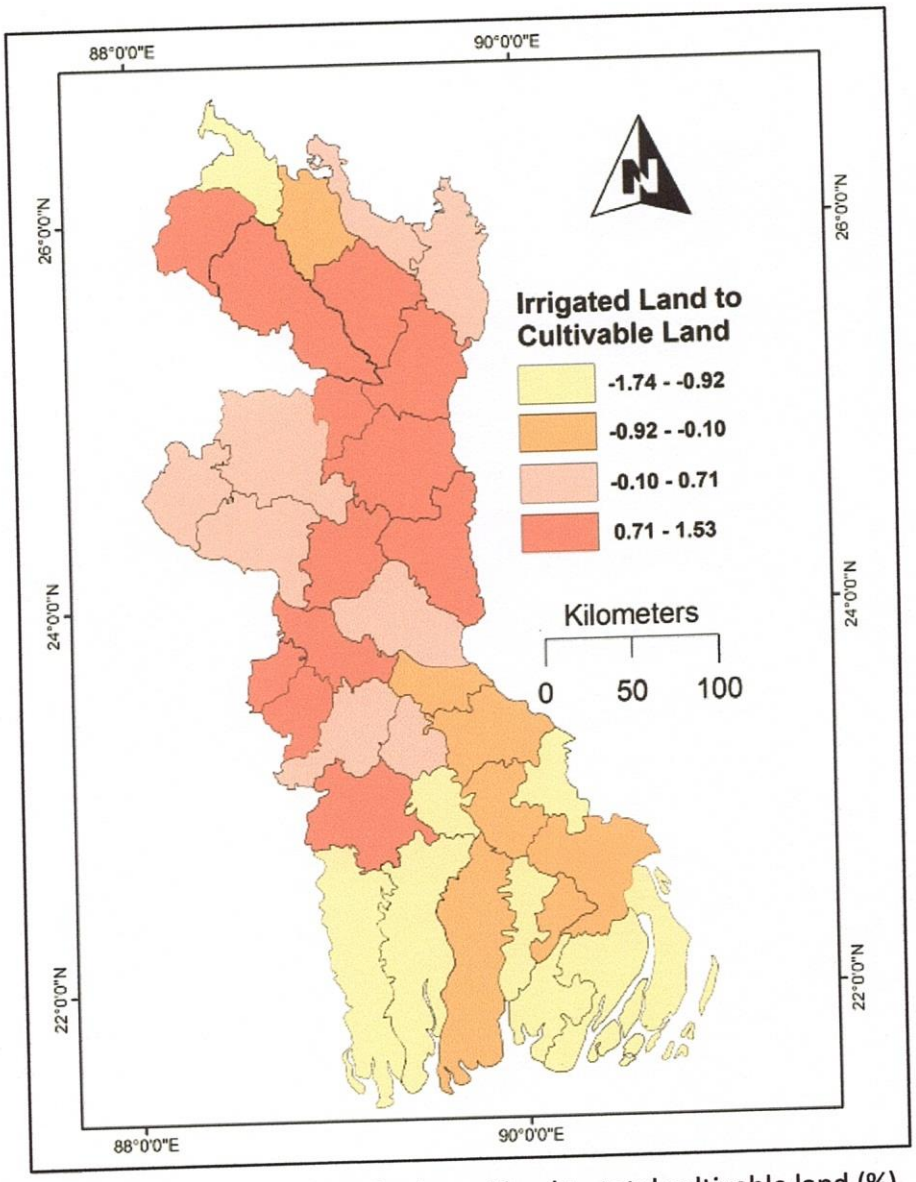


**Figure 4.51** Z-score map of irrigated land to total cultivable land (%)

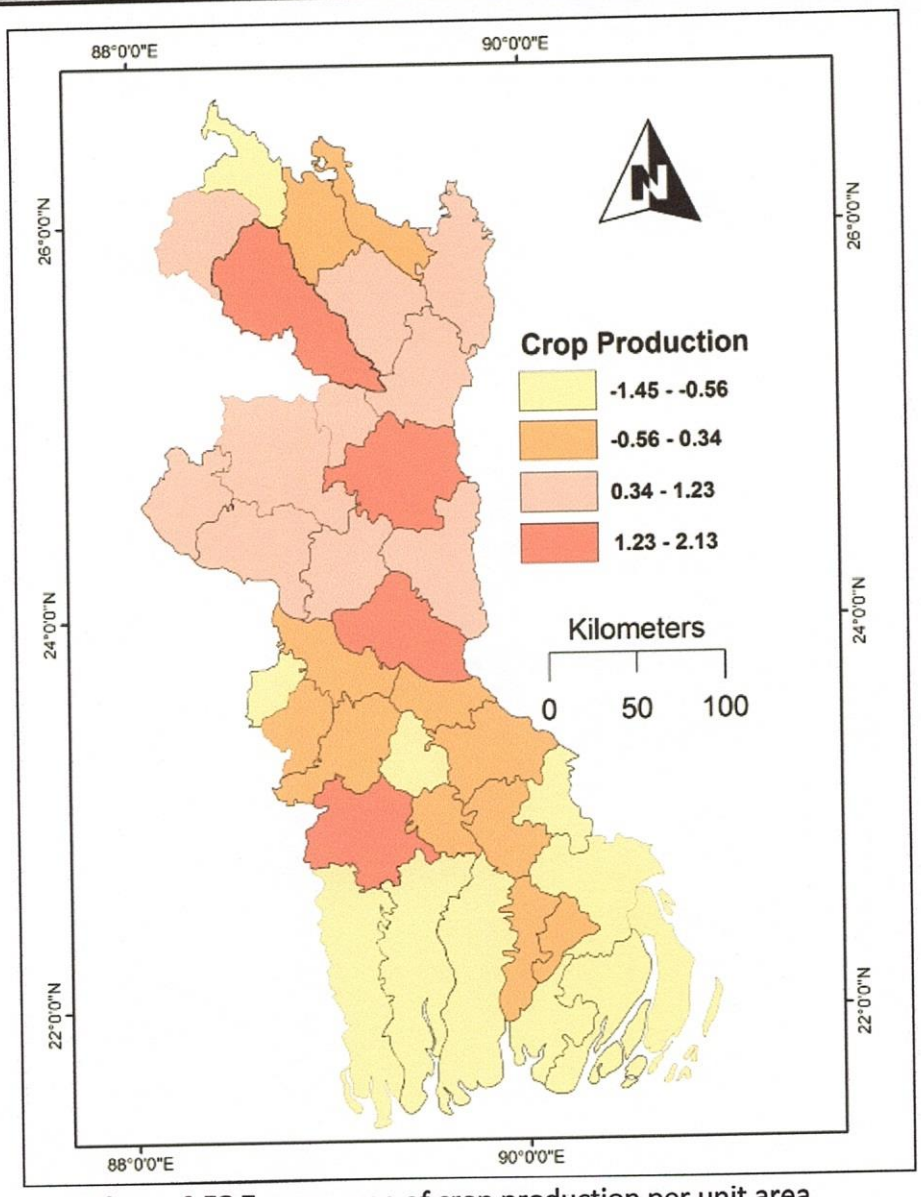


**Figure 4.52** Z-score map of crop production per unit area

### 4.3.5 Drought Vulnerability Map

A composite drought vulnerability map is prepared considering all socio-economic and physical vulnerability indicators. Beside this, the district wise integrated layer is classified according to DVI values (equation 3.17) into four classes with equal interval method to produce the composite drought vulnerability map of the study area shown in figure 4.53, and reveals that the pattern of vulnerability to drought can be separated into four zones: low vulnerability in Rangpur, Rajbari, Bhola and Satkhira districts; moderate vulnerability in Sirajganj, Chuadanga, Borguna, Bagerhat, Gopalganj and

Patuakhali district; high vulnerability in Jessore, Jhalokati, Jhenaidah, Khulna, Kushtia, Lalmonirhat, Madaripur, Magura, Meherpur, Naogaon, Narail, Panchagarh, Pirojpur, Rajshahi and Thakurgaon district; and very high in Bogra, Dinajpur, Faridpur, Gaibandha, Joypurhat, Kurigram, Natore, Nawabganj, Nilphamari and Pabna districts. In generally the highest vulnerable zones are concentrated in the north and north-eastern part of the study area where all vulnerability indicators are comparatively high except literacy rate.

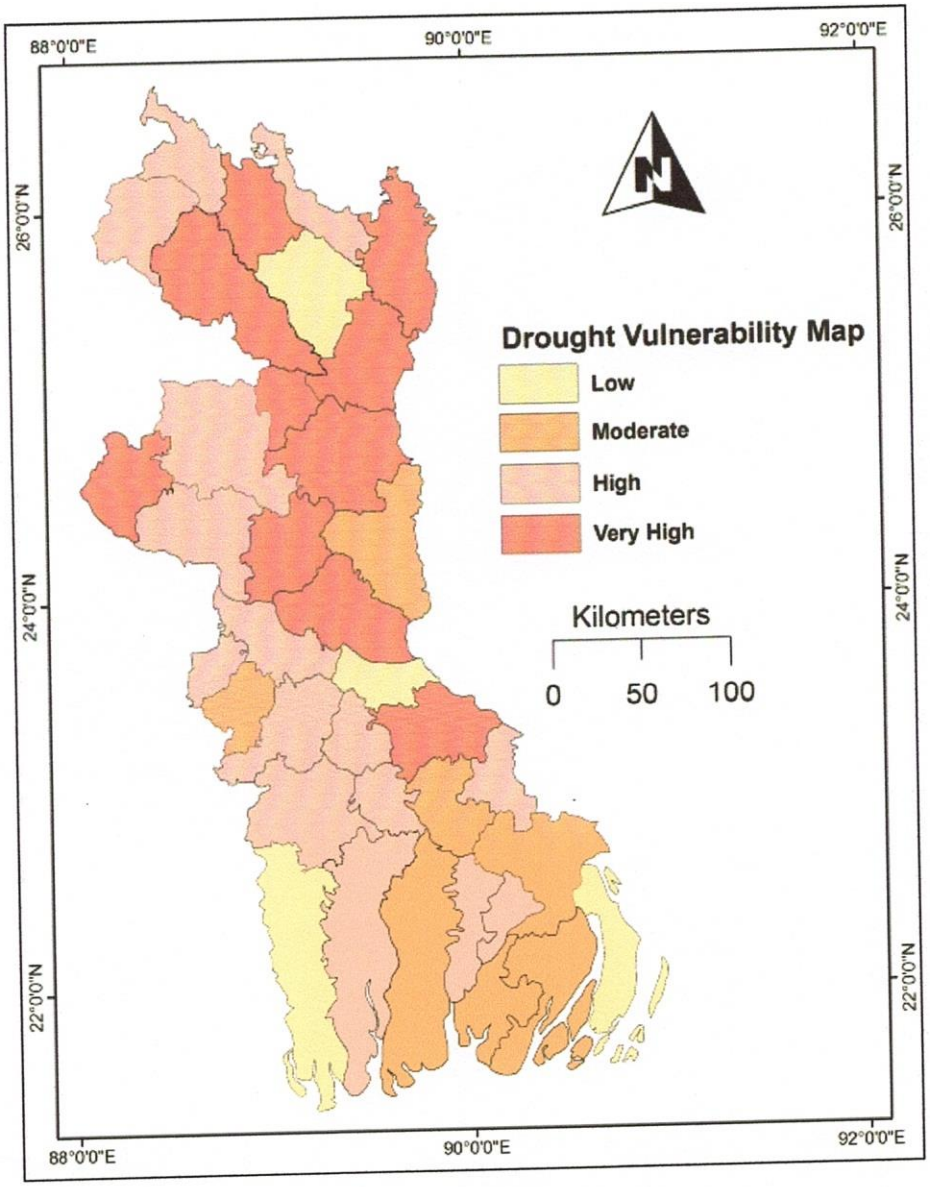


**Figure 4.53** Drought vulnerability map of the study area

### 4.3.6 Drought Risk Map

Drought hazard and drought vulnerability maps are integrated using GIS to produce drought risk map of the study area. The DRI of each district of the integrated layer is calculated using equation 3.18 and the district-wise integrated layers are then classified according to DRI values into four classes using equal interval method to produce the risk map of agricultural drought hazards assessed by Markov chain model (Figure 4.54) and indicate that agricultural droughts pose high risk to some of the northern districts, where few districts in the southern part are exposed to moderate risk. Among the three districts, in the coastal area, one in northern part and two in eastern part of the study area face less risk to droughts of this category.

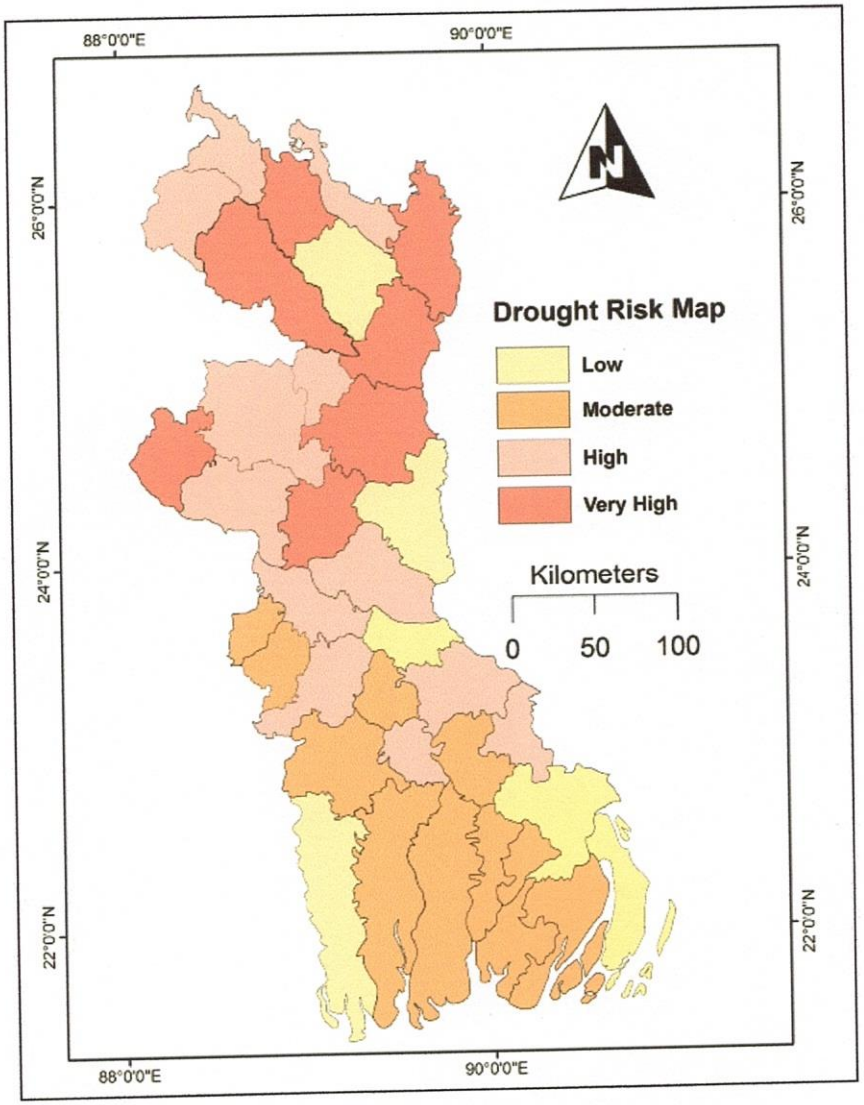


**Figure 4.54** Drought risk map of the study area

Table 4.59 shows that 21.63% of the area is exposed to very high risk, 26.54% area to high risk, 29.68% to moderate risk and 22.15% to low risk. Hence, high crop production, dependency on agriculture and irrigation alone with high variability of annual rainfall has made the northern part highly risky to droughts compared to other parts of the country. So water conservation measures are essential for reducing the drought impact in the area especially for poverty alleviation.

**Table 4.59** Area (%) under different drought risk categories

| Drought Risk | Area (%) |
|---|---|
| Very High | 21.63 |
| High | 26.54 |
| Moderate | 29.68 |
| Low | 22.15 |

## 4.4 Risk Ranking and Adaptation Based on Drought Severity and Frequency

The climate (drought) risk analysis is the prerequisite for developing viable adaptation options to manage future anticipated risks. Once the analysis is done, the next step is to identify and prioritize the local adaptation options and test them through demonstration and implementations at local level. In the present study, both the magnitude and frequency of a climate event are given qualitative measures that permit the prioritization of selected climate risks among multiple risks. Because the low frequency events may become high frequency events under climate change, they need to be given sufficient consideration.

### 4.4.1 Station-wise Risk Ranking

Station-wise drought risk ranking has been done on the basis of frequency and severity of agricultural drought events. In the present study, severity of agricultural droughts are classified as mild, moderate, sever and extreme on the basis of suitable (5, 10, 15, 20 and 25 mm) threshold values. The risk ranking diagram is flexible to consider the severity and frequency (Ramamasy and Bass, 2007). Here the minor, serious, extensive and catastrophe risks are replaced by mild, moderate, sever and extreme drought events. The risk

ranking and adaptation measures for 12 meteorological stations are discussed below:

**Dinajpur Station**

As given in table 4.60, there are 5 mild, 8 moderate, 9 severe and 25 extreme agricultural drought events have been identified at Dinajpur station. Frequency of these types of drought has been calculated by the equation 3.15 and values are given in table 4.60.

Risk ranking diagram of Dinajpur station (Figure 4.55) shows that the mild drought events have taken place in class **D** because its severity is minor and the frequency is very low *i.e.,* events that occur less than once in ten years (Table 4.60). Therefore there exists low risk condition and additional adaptation initiatives are necessary. The moderate drought events have taken place in class **C** because the severity of this types of droughts is serious and frequency is low i.e. events that occur from once in five years to ten years (Table 4.60). As a result, risk condition is sufficiently high to give consideration for further adaptation initiatives.

Severe drought has fallen in class **B** because its severity is extensive and frequency is low *i.e.,* events that occur from once in five years to ten years (Table 4.60). As a result, moderate to high risk condition is necessarily addressed by adaptation.

Extreme drought has placed in class **A**, where severity is catastrophic and frequency is high *i.e.,* events that occur less than once in three years (Table 4.60). Hence risk condition is high to give highest priority for implementing adaptation measures. From the risk ranking diagram, it is evident that highest drought risk fall in the class **A**. This indicates high risk condition and to give highest priority for implementing adaptation measures.

**Table 4.60** Drought severity and frequency of Dinajpur station

| Drought Severity | Drought Frequency (Year) |
|---|---|
| Mild drought | 17.00 |
| Moderate drought | 10.20 |
| Severe drought | 6.38 |
| Extreme drought | 5.67 |

| | | | | |
|---|---|---|---|---|
| **High** | C | B | A | **A** |
| **Moderate** | C | B | B | A |
| **Low** | D | **C** | **B** | B |
| **Very Low** | **D** | D | C | C |
| | **Mild** | **Moderate** | **Sever** | **Extreme** |

**Figure 4.55** Drought risk ranking of Dinajpur station for the period of 1960-2010 (filled-up classes indicate drought risk condition)

**Rangpur Station**

As given in table 4.61 there are 3 mild, 8 moderate, 18 severe and 17 extreme agricultural droughts have been identified in Rangpur station. Frequency (average recurrence interval) for these types of drought events is calculated by the equation 3.14 and values are given in table 4.61. The drought risk ranking diagram of Rangpur station for the period of 1960 to 2010 is shown in figure 4.56.

Risk ranking diagram of Rangpur (Figure 4.56) shows that the mild drought events have taken place in class **D** because its severity is minor and the frequency is very low *i.e.,* events that occur less than once in ten years (Table 4.61). Therefore there exists low risk condition and additional adaptation initiatives are necessary.

The moderate drought events have taken place in class **C** because its severity is serious and frequency is low i.e. events that occur from once in five years to ten years (Table 4.61). As a result, risk condition is sufficiently high to give consideration for further adaptation initiatives.

Severe drought has fallen in class **B** because its severity is extensive and frequency is low *i.e.,* events that occur from once in five years to ten years (Table 4.61). As a result, moderate to high risk condition is necessarily addressed by adaptation.

Extreme drought has placed in class **A**, where severity is catastrophic and frequency is high *i.e.,* events that occur less than once in three years (Table 4.61). Hence risk condition is high to give highest priority for implementing adaptation measures.

From the risk ranking diagram it is evident that highest drought risk fall in the class **A**. This indicates high risk condition and to give highest priority for implementing adaptation measures.

**Table 4.61** Drought severity and frequency of Rangpur station

| Drought Severity | Drought Frequency (Year) |
|---|---|
| Mild drought | 17.00 |
| Moderate drought | 5.67 |
| Severe drought | 2.83 |
| Extreme drought | 3.00 |

| | | | | |
|---|---|---|---|---|
| **High** | C | B | A | **A** |
| **Moderate** | C | B | B | A |
| **Low** | D | **C** | **B** | B |
| **Very Low** | **D** | D | C | C |
| | **Mild** | **Moderate** | **Sever** | **Extreme** |

**Figure 4.56** Drought risk ranking of Rangpur station for the period of 1960-2010

**Bogra Station**

As given in table 4.62, there are 4 mild, 8 moderate, 12 severe and 16 extreme agricultural drought events have been identified in Bogra station. Frequency (average recurrence interval) for these types of drought event is calculated by the equation 3.14 and values are given in table 4.62. The drought risk ranking diagram of Bogra station for the period of 1960 to 2010 is shown in figure 4.57.

Risk ranking diagram of Bogra (Figure 4.57) shows that the mild drought events have taken place in class **D** because its severity is minor and the frequency is very low *i.e.,* events that occur less than once in ten years (Table 4.62). Therefore low risk condition exists and additional adaptation initiatives are needed.

The moderate drought events have taken place in class **C** because its severity is serious and frequency is low i.e. events that occur from once in five to ten

years (Table 4.62). As a result, risk condition is sufficiently high to give consideration for further adaptation initiatives.

Severe drought has fallen in class **B** because its severity is extensive and frequency is moderate *i.e.,* events that occur from once in three years to five years (Table 4.62). As a result, moderate to high risk condition is necessarily addressed by adaptation.

Extreme drought has placed in class **A**, where severity is catastrophic and frequency is high *i.e.,* events that occur less than once in three years (Table 4.62). Hence risk condition is high to give highest priority for implementing adaptation measures.

From the risk ranking diagram it is evident that highest drought risk fall in the class **B**. This indicates moderate to high risk condition exists and is necessarily addressed by adaptation in the study area.

**Table 4.62** Drought severity and frequency of Bogra station

| Drought Severity | Drought Frequency (Year) |
|---|---|
| Mild drought | 12.75 |
| Moderate drought | 6.38 |
| Severe drought | 3.92 |
| Extreme drought | 3.19 |

| | | | | |
|---|---|---|---|---|
| **High** | C | B | A | A |
| **Moderate** | C | B | **B** | **A** |
| **Low** | D | **C** | B | B |
| **Very Low** | **D** | D | C | C |
| | **Mild** | **Moderate** | **Sever** | **Extreme** |

**Figure 4.57** Drought risk ranking of Bogra station for the period of 1960-2010

**Ishwardi Station**

As given in table 4.63 there are 7 mild, 7 moderate, 4 severe and 23 extreme agricultural drought events have been identified in Ishwardi. Frequency (average recurrence interval) for these types of drought event is calculated by the equation 3.14 and values are given in table 4.63. The drought risk ranking diagram of Ishwardi station for the period of 1961-2010 is shown in figure 4.58.

Risk ranking diagram of Ishwardi (Figure 4.58) shows that the mild drought events have taken place in class **D** because its severity is minor and the frequency is low *i.e.,* events that occur less than once in ten years (Table 4.63). Therefore there exists low risk condition and additional adaptation initiatives are necessary.

The moderate drought events have taken place in class **C** because the severity of this types of droughts is serious and frequency is low i.e. events that occur from once in five to ten years (Table 4.63). As a result, risk condition is sufficiently high to give consideration for further adaptation initiatives.

Severe drought has fallen in class **C** because its severity is extensive and frequency is very low *i.e.,* events that occur less than once in ten years (Table 4.63). As a result, risk condition is sufficiently high and to give consideration for further adaptation initiatives.

Extreme drought has placed in class **A**, where severity is catastrophic and frequency is high *i.e.,* events that occur less than once in three years (Table 4.63). Hence risk condition is high to give highest priority for implementing adaptation measures.

From the risk ranking diagram it is evident that highest drought risk fall in the class **B**. This indicates moderate to high risk condition exists and is necessarily addressed by adaptation in the study area.

**Table 4.63** Drought severity and frequency of Ishwardi station

| Drought Severity | Drought Frequency (Year) |
|---|---|
| Mild drought | 7.14 |
| Moderate drought | 7.14 |
| Severe drought | 12.50 |
| Extreme drought | 2.08 |

| | | | | |
|---|---|---|---|---|
| **High** | C | B | A | **A** |
| **Moderate** | C | B | B | A |
| **Low** | **D** | **C** | B | B |
| **Very Low** | D | D | **C** | C |
| | **Mild** | **Moderate** | **Sever** | **Extreme** |

**Figure 4.58** Drought risk ranking of Ishwardi station for the period of 1961-2010

**Rajshahi Station**

As given in table 4.64 there are 4 mild, 8 moderate, 11 severe and 23 extreme agricultural droughts have been identified in Rajshahi station. Frequency (average recurrence interval) for these types of drought event is calculated by the equation 3.14 and values are given in table 4.64. The drought risk ranking diagram of Rajshahi station for the period of 1960 to 2010 is shown in figure 4.59.

Risk ranking diagram of Rajshahi (Figure 4.59) shows that the mild drought has fallen in class **D** because its severity is minor and frequency is very low *i.e.,* events that occur less than once in ten years (Table 4.64). Therefore there exists low risk condition and additional adaptation initiatives are necessary.

The moderate drought event has taken place in class **C** because its severity is serious and frequency is low *i.e.,* events that occur once between 5 to 10 years (Table 4.64). Therefore there exists sufficiently high risk condition and to give consideration for further adaptation initiatives.

The severity of severe drought has taken place in class B because this type of drought is extensive and frequency is moderate *i.e.,* events that occur once

between 3 to 5 years (Table 4.64). Therefore there exists moderate to high risk condition and risk is addressed by adaptation.

Extreme agricultural drought events has fallen in class A and drought severity is catastrophic but frequency is high *i.e.,* events that occur less than once within 3 years (Table 4.4.5). However, risk condition is high and to give highest priority for implementing adaptation measures.

From the risk ranking diagram it is evident that highest drought risk fall in the class **A**. This indicates moderate to high risk condition exists and is necessarily addressed by adaptation in the study area.

**Table 4.64** Drought severity and frequency of Rajshahi station

| Drought Severity | Drought Frequency (Year) |
|---|---|
| Mild drought | 12.75 |
| Moderate drought | 6.38 |
| Severe drought | 4.64 |
| Extreme drought | 2.13 |

| | | | | |
|---|---|---|---|---|
| **High** | C | B | A | **A** |
| **Moderate** | C | B | **B** | A |
| **Low** | D | **C** | B | B |
| **Very Low** | **D** | D | C | C |
| | **Mild** | **Moderate** | **Sever** | **Extreme** |

**Figure 4.59** Drought risk ranking of Rajshahi station for the period of 1960-2010

**Faridpur Station**

As given in table 4.65 there are 6 mild, 7 moderate, 10 severe and 17 extreme agricultural drought events have been identified in Faridpur station. Frequency (average recurrence interval) for these types of drought event is calculated by the equation 3.14 and values are given in table 4.65. The drought risk ranking diagram of Faridpur station for the period of 1960 to 2010 is shown in figure 4.60.

Risk ranking diagram of Faridpur (Figure 4.60) shows that the mild drought has fallen in class **D** because its severity is minor and frequency is low *i.e.,* events that occur less than once five to ten years (Table 4.65). Therefore there exists low risk condition and additional adaptation initiatives are necessary.

The moderate drought event has taken place in class **C** because its severity is serious and frequency is low *i.e.,* events that occur once between 5 to 10 years (Table 4.65). Therefore there exists sufficiently high risk condition and to give consideration for further adaptation initiatives.

The severity of severe drought has taken place in class **B** because its severity is extensive and frequency is low *i.e.,* events that occur once between 5 to 10 years (Table 4.65). Therefore there exists moderate to high risk condition and risk is addressed by adaptation.

Extreme agricultural drought events has fallen in class **A** and drought severity is catastrophic but frequency is high *i.e.,* events that occur less than once within 3 years (Table 4.65). However, risk condition is high and to give highest priority for implementing adaptation measures.

From the risk ranking diagram it is evident that highest drought risk fall in the class **A**. This indicates that the high risk condition exists and to give highest priority for implementing adaptation measures.

**Table 4.65** Drought severity and frequency of Faridpur station

| Drought Severity | Drought Frequency (Year) |
|---|---|
| Mild drought | 8.50 |
| Moderate drought | 7.29 |
| Severe drought | 5.10 |
| Extreme drought | 2.83 |

| | | | | |
|---|---|---|---|---|
| **High** | C | B | A | **A** |
| **Moderate** | C | B | B | A |
| **Low** | **D** | **C** | **B** | B |
| **Very Low** | D | D | C | C |
| | **Mild** | **Moderate** | **Sever** | **Extreme** |

**Figure 4.60** Drought risk ranking Faridpur station for the period of 1960-2010

**Jessore Station**

As given in table 4.66 there are 8 mild, 4 moderate, 6 severe and 21 extreme agricultural drought events have been identified in Jessore station. Frequency (average recurrence interval) for these types of drought event is calculated by the equation 3.14 and values are given in table 4.66. The drought risk ranking diagram of Jessore station for the period of 1960 to 2010 is shown in figure 4.61.

Risk ranking diagram of Jessore (Figure 4.61) shows that the mild drought has fallen in class **D** because its severity is minor and frequency is low *i.e.,* events that occur less than once in between five to ten years (Table 4.66) with low risk condition needing additional adaptation initiatives.

Moderate drought event has taken place in class **D** because its severity is serious and frequency is very low *i.e.,* events that occur less than once in 10 years (Table 4.66). Therefore there exists low-risk condition and additional adaptation initiatives are needed.

The severity of severe drought has taken place in class **B** because its severity is extensive and frequency is low *i.e.,* events that occur once between 5 to 10 years (Table 4.66). Therefore there exists moderate to high risk condition and risk is addressed by adaptation.

Extreme agricultural drought events has fallen in class **A** and drought severity is catastrophic but frequency is high *i.e.,* events that occur less than once within 3 years (Table 4.66). However, risk condition is high and to give highest priority for implementing adaptation measures.

From the risk ranking diagram it is evident that highest drought risk fall in the class **A**. This indicates that the high risk condition exists and to give highest priority for implementing adaptation measures.

**Table 4.66** Drought severity and frequency of Jessore station

| Drought Severity | Drought Frequency (Year) |
|---|---|
| Mild drought | 6.38 |
| Moderate drought | 12.75 |
| Severe drought | 8.50 |
| Extreme drought | 2.32 |

| | | | | |
|---|---|---|---|---|
| **High** | C | B | A | **A** |
| **Moderate** | C | B | B | A |
| **Low** | **D** | C | **B** | B |
| **Very Low** | D | **D** | C | C |
| | **Mild** | **Moderate** | **Sever** | **Extreme** |

**Figure 4.61** Drought risk ranking of Jessore station for the period of 1960-2010

**Khulna Station**

As given in table 4.67 there are 6 mild, 4 moderate, 12 severe and 17 extreme agricultural drought events have been identified in Khulna station. Frequency (average recurrence interval) for these types of drought event is calculated by the equation 3.14 and values are given in table 4.67. The drought risk ranking diagram of Khulna station for the period of 1960 to 2010 is shown in figure 4.62.

Risk ranking diagram of Khulna (Figure 4.62) shows that the mild drought has fallen in class **D** because its severity is minor and frequency is low *i.e.,* events that occur less than once in between five to ten years (Table 4.4.8) showing low risk condition where additional adaptation initiatives are necessary. The moderate drought event has taken place in class **D** because the severity of this type of drought is serious and frequency is very low *i.e.,* events that occur less than once in 10 years (Table 4.67). Therefore there exists low-risk condition and to give additional adaptation initiatives.

The severity of severe drought has taken place in class **B** because its severity is extensive and frequency is moderate *i.e.,* events that occur once between 3 to 5 years (Table 4.67). Therefore there exists moderate to high risk condition and risk is addressed by adaptation.

Extreme agricultural drought events has fallen in class **A** and drought severity is catastrophic but frequency is high *i.e.,* events that occur less than once within 3 years (Table 4.67). However, risk condition is high and to give highest priority for implementing adaptation measures.

From the risk ranking diagram it is evident that highest drought risk fall in the class **A**. This indicates that the high risk condition exists and to give highest priority for implementing adaptation measures.

**Table 4.67** Drought severity and frequency of Khulna station

| Drought Severity | Drought Frequency (Year) |
|---|---|
| Mild drought | 8.50 |
| Moderate drought | 12.75 |
| Severe drought | 4.25 |
| Extreme drought | 2.83 |

| | | | | |
|---|---|---|---|---|
| **High** | C | B | A | **A** |
| **Moderate** | C | B | **B** | A |
| **Low** | **D** | C | B | B |
| **Very Low** | D | **D** | C | C |
| | **Mild** | **Moderate** | **Sever** | **Extreme** |

**Figure 4.62** Drought risk ranking of Khulna station for the period of 1960-2010

**Satkhira Station**

As given in table 4.68 there are 4 mild, 5 moderate, 10 severe and 18 extreme agricultural drought events have been identified in Satkhira station. Frequency (average recurrence interval) for these types of drought event is calculated by the equation 3.14 and values are given in table 4.68. The drought risk ranking

diagram of Satkhira station for the period of 1960 to 2010 is shown in figure 4.63.

Risk ranking diagram of Satkhira (Figure 4.63) shows that both mild and moderate drought events have taken place in class **D** but its severity is higher than the mild drought. On the other hand frequency of mild and moderate drought are very low *i.e.,* events that occur less than once in ten years (Table 4.4.9). Therefore there exists low risk condition and additional adaptation initiatives are necessary.

The severity of severe drought events has taken place in class **B** because its severity is extensive and frequency is low *i.e.,* events that occur once between 5 to 10 years (Table 4.68). Therefore there exists moderate to high risk condition and risk is addressed by adaptation.

Extreme agricultural drought events has fallen in class **A** and drought severity is catastrophic but frequency is high *i.e.,* events that occur less than once within 3 years (Table 4.68). However, risk condition is high and to give highest priority for implementing adaptation measures.

From the risk ranking diagram it is evident that highest drought risk fall in the class **A**. This indicates that the high risk condition exists and to give highest priority for implementing adaptation measures.

**Table 4.68** Drought severity and frequency of Satkhira station

| Drought Severity | Drought Frequency (Year) |
|---|---|
| Mild drought | 12.75 |
| Moderate drought | 10.20 |
| Severe drought | 5.10 |
| Extreme drought | 2.68 |

| | | | | |
|---|---|---|---|---|
| **High** | C | B | A | **A** |
| **Moderate** | C | B | B | A |
| **Low** | D | C | **B** | B |
| **Very Low** | **D** | **D** | C | C |
| | **Mild** | **Moderate** | **Sever** | **Extreme** |

**Figure 4.63** Drought risk ranking of Satkhira station for the period of 1960-2010

**Barisal Station**

As given in Table 4.69 there are 7 mild, 8 moderate, 6 severe and 19 extreme agricultural drought events have been identified in Barisal station. Frequency (average recurrence interval) for these types of drought event is calculated by the equation 3.14 and values are given in table 4.68. The drought risk ranking diagram of Ishwardi station for the period of 1960 to 2010 is shown in figure 4.64.

Risk ranking diagram of Barisal station (Figure 4.64) shows that the mild drought has fallen in class **D** because its severity is minor and frequency is low *i.e.,* events that occur less than once in between five to ten years (Table 4.69). Therefore there exists low risk condition and additional adaptation initiatives are necessary.

The moderate drought event has taken place in class **C** because its severity is serious and frequency is low *i.e.,* events that occur less than once in 5 to 10 years (Table 4.69). Therefore there exists low-risk condition and to give additional adaptation initiatives.

The severity of severe drought has taken place in class **B** because its severity is extensive and frequency is low *i.e.,* events that occur once between 5 to 10 years (Table 4.69). Therefore there exists moderate to high risk condition and risk is addressed by adaptation.

Extreme agricultural drought events has fallen in class **A** and drought severity is catastrophic but frequency is high *i.e.,* events that occur less than once within 3 years (Table 4.69). However, risk condition is high and to give highest priority for implementing adaptation measures.

From the risk ranking diagram it is evident that highest drought risk fall in the class **A**. This indicates that the high risk condition exists and to give highest priority for implementing adaptation measures.

**Table 4.69** Drought severity and frequency of Barisal station

| Drought Severity | Drought Frequency (Year) |
|---|---|
| Mild drought | 7.29 |
| Moderate drought | 6.38 |
| Severe drought | 8.50 |
| Extreme drought | 2.55 |

| | | | | |
|---|---|---|---|---|
| **High** | C | B | A | **A** |
| **Moderate** | C | B | B | A |
| **Low** | **D** | **C** | **B** | B |
| **Very Low** | D | D | C | C |
| | **Mild** | **Moderate** | **Sever** | **Extreme** |

**Figure 4.64** Drought risk ranking of Barisal station for the period of 1960-2010

**Bhola Station**

As given in table 4.70 there are 6 mild, 6 moderate, 7 severe and 15 extreme agricultural drought events have been identified in Bhola station. Frequency (average recurrence interval) for these types of drought event is calculated by the equation 3.14 and values are given in table 4.70. The drought risk ranking diagram of Bhola station for the period of 1966 to 2010 is shown in figure 4.65. Risk ranking diagram of Bhola station (Figure 4.65) shows that the mild drought has fallen in class **D** because the severity of this type of drought is minor and frequency is low *i.e.,* events that occur less than once in between five to ten years (Table 4.70). Therefore there exists low risk condition and additional adaptation initiatives are necessary.

The moderate drought event has taken place in class **C** because its severity is serious and frequency is low *i.e.,* events that occur less than once in 5 to 10 years (Table 4.70). Therefore there exists low-risk condition and to give additional adaptation initiatives.

The severity of severe drought has taken place in class **B** because its severity is extensive and frequency is low *i.e.,* events that occur once between 5 to 10 years (Table 4.70). Therefore there exists moderate to high risk condition and risk is addressed by adaptation.

Extreme agricultural drought events has fallen in class **A** and drought severity is catastrophic but frequency is high *i.e.,* events that occur less than once within 3 years (Table 4.70). However, risk condition is high and to give highest priority for implementing adaptation measures.

From the risk ranking diagram it is evident that highest drought risk fall in the class **A**. This indicates that the high risk condition exists and to give highest priority for implementing adaptation measures.

**Table 4.70** Drought severity and frequency of Bhola station

| Drought Severity | Drought Frequency (Year) |
|---|---|
| Mild drought | 7.50 |
| Moderate drought | 6.43 |
| Severe drought | 6.43 |
| Extreme drought | 3.00 |

| | | | | |
|---|---|---|---|---|
| **High** | C | B | A | **A** |
| **Moderate** | C | B | B | A |
| **Low** | **D** | **C** | **B** | B |
| **Very Low** | D | D | C | C |
| | **Mild** | **Moderate** | **Sever** | **Extreme** |

**Figure 4.65** Drought risk ranking of Bhola station for the period of 1966-2010

**Khepupara Station**

As given in table 4.71 there are 7 mild, 4 moderate, 4 severe and 11 extreme agricultural drought events have been identified in Khepupara. Frequency (average recurrence interval) for these types of drought event is calculated by the equation 3.14 and values are given in table 4.71. The drought risk ranking

diagram of Ishwardi station for the period of 1975 to 2010 is shown in figure 4.66.

Risk ranking diagram of Khepupara station (Figure 4.66) shows that the mild drought has fallen in class **D** because its severity is minor and frequency is low *i.e.,* events that occur less than once in between five to ten years (Table 4.71). Therefore there exists low risk condition and additional adaptation initiatives are necessary.

The moderate drought event has taken place in class **C** because its severity is serious and frequency is low *i.e.,* events that occur less than once in 5 to 10 years (Table 4.71). Therefore there exists low-risk condition and to give additional adaptation initiatives.

The severity of severe drought has taken place in class **B** because its severity is extensive and frequency is low *i.e.,* events that occur once between 5 to 10 years (Table 4.71). Therefore there exists moderate to high risk condition and risk is addressed by adaptation.

Extreme agricultural drought events has fallen in class **A** and drought severity is catastrophic but frequency is high *i.e.,* events that occur less than once within 3 years (Table 4.71). However, risk condition is high and to give highest priority for implementing adaptation measures.

From the risk ranking diagram it is evident that highest drought risk fall in the class **A**. This indicates that the high risk condition exists and to give highest priority for implementing adaptation measures.

**Table 4.71** Drought severity and frequency of Khepupara station

| Drought Severity | Drought Frequency (Year) |
|---|---|
| Mild drought | 5.14 |
| Moderate drought | 9.00 |
| Severe drought | 9.00 |
| Extreme drought | 3.00 |

| | | | | |
|---|---|---|---|---|
| **High** | C | B | A | **A** |
| **Moderate** | C | B | B | A |
| **low** | **D** | **C** | **B** | B |
| **Very Low** | D | D | C | C |
| | **Mild** | **Moderate** | **Sever** | **Extreme** |

**Figure 4.66** Drought risk ranking of Khepupara station for the period of 1975-2010

### 4.4.2 Priority for Adaptation

Adaptation responses and mitigation actions may occur simultaneously and their efficacy will depend on the patterns of realized climate change in the coming decades. The associated interactions between factor like climate change, adaptation and mitigation will frequently involve water resources. Bangladesh is highly sensitive to climate variability and change impacts on the agriculture sector. Considering its agriculture-based subsistence economy and the fact that the sector employs almost two thirds of the population, adaptation to climate change impacts will be vital to achieving sustainable development. The key risks from climate change to agriculture and allied sectors in western part of Bangladesh are related to increased drought frequencies and inadequate availability of water for irrigation. Agricultural practice depends on freshwater resources and, thus, depends on the success of adaptations in that sector.

Though the western part of Bangladesh is drought prone and future climate change could aggravate the problems, there are many positive aspects that can be considered for selection of viable adaptation options. Qualitative and objective assessment of adaptation practices through systematic methodologies yielded a viable adaptation menu. Following practices should be given priority to mitigate future drought impacts and water management, as:

- Combined use of surface and groundwater;
- Rainwater harvesting, recycling and conservation;
- Artificial recharge to improve groundwater level;
- Excavation of water control structures and mini ponds;
- Re-excavation of traditional ponds and *khari* canals;

- Improve water-use efficiency;
- Cultivation of drought-resistant varieties of rice and other crops to improve the productivity;
- Crop diversification and intensification in drought-prone areas;
- Promotion of alternative seedbed method for *T. Aman* rice to manage variability in rainfall pattern;
- Crop intensification by adopting *T. aman* – mustard/linseed/mung bean cropping system to use the residual moisture after *T. aman* rice;
- Promotion of mango cultivation to increase income and mitigate seasonal drought; and
- Establishment of model homestead gardens.

# Chapter V

# Conclusions and Policy Implications

# CHAPTER V

# CONCLUSIONS AND POLICY IMPLICATIONS

## 5.1 Conclusions

The chapter attempts to present a synopsis of findings of the study regarding various aspects of climate modeling, drought risk assessment and adaptation strategies found as stated in different chapters in accordance with the objectives of research. And the following conclusions are drawn based on the entire study findings:

- The annual average rainfall in the study area is 1925 mm where the driest (amount of rainfall 1492 mm) and wettest (amount of rainfall 2766 mm) parts are Rajshahi and Khepupara respectively. Rainfall is higher in south and north than the central part. Kharif season is the wettest season when almost 62% of rainfall occurs, while the driest Rabi season receives only 3.23% of total annual rainfall and the rest 35.20% occurs during the Pre-Kharif season.

- Both positive and negative trends are found in annual and seasonal rainfall time series data, though the trends vary spatially. The significant positive trends at 95% confidence levels in annual rainfall are observed at the rates of 8.56 and 11.15 and 13.66 mm/year at Dinajpur, Rangpur, and Khepupara stations respectively. On the other hand, two significant decreasing trends at 95% and 90% confidence levels are found at Bhola (-11.67 mm/year) and Rajshahi (-5.95 mm/year) stations respectively. During Rabi season major parts of the area show insignificant trend at 90% and 95% confidence level except a pocket area in the north-west part. In Pre-Kharif season, most of the stations (83.34%) are found to have insignificant trends at 90% and 95% confidence levels. The south-west and parts of north also show insignificant positive trends during Pre-Kharif season. The central and south-eastern parts show insignificant negative trends during this season. In Kharif season's rainfall, 75% and 25% stations have

increasing and decreasing trends respectively. The strongest significant positive trends during Kharif season are observed at the rate of 7.407, 6.157 and 12.733 mm/year at Rangpur, Khulna and Khepupara stations respectively and that in Rajshahi, Faridpur and Bhola show insignificant negative trends.

- Annual average temperature is about 25.44°C where the lowest mean annual value is in the north-east ranging from 24.18 to 24.43°C, and increases towards the south reaching its extreme in south-west along the coast of the Bay of Bengal where values range from 25.92 to 26.17°C. Rabi is the coolest season of the study area where temperature ranges from 19.15 to 21.06°C. Northern part is cooler than the south. Pre-Kharif is the climatically summer season when mean temperature ranges from 26.02 to 29.03°C. Kharif season is climatically the rainy season in the area and mean temperature ranges from 27.61 to 28.42°C. The spatial pattern of seasonal temperature is similar to the distribution of annual temperature.

- 83.33% and 16.67% of stations show rising and falling trends in annual mean temperature respectively and rising trends are found significant at 90% and 95% confidence level in north-east and insignificant in north-west of the study area. Increasing and decreasing trends in Rabi season mean temperature series are observed with MK test at 75% and 25% of the stations respectively, but most of them (about 75%) are insignificant at 90% and 95% confidence levels. Rising trends of Rabi season mean temperature are significant in the north-eastern part of the study area. The north-western and south-eastern parts show insignificant positive trends, whereas some areas in south show significant negative trends. Rising and falling trends in Pre-Kharif season (summer season) mean temperature are found at 58.53% and 41.67% of the stations respectively, but most of them (83.33%) are insignificant at 90% and 95% confidence levels. Northern part of the area shows insignificant negative trends; while southern part shows

insignificant positive trends during this season. In Kharif season (rainy season), all stations show rising trends, which are significant at 90% and 95% confidence levels except at Barisal station. Sen's Slope analysis indicates that the rate of change varies from 0.004 to 0.016°C/year with an average 0.011°C/year during this season.

- In the analysis of ARIMA model, the station wise future prediction of mean temperature varies by little amount over the years except Faridpur station. The spatial distribution of yearly mean forecasting temperature (°C) will vary as 24.47-25.97, 24.57-26.03, 24.69-26.03, 24.54-26.03 and 24.73-26.75 in 2012-2016 respectively, whereas long term annual average temperature ranges from 24.18 to 26.17°C. Therefore, predicted temperatures for all years are higher than the long term observed mean temperature. The predicted temperatures for the years 2014 and 2015 reveal that the mean temperatures in the southern part show similar results. Though temperature is rising, spatial pattern will remain same in the future as the observed mean temperature.
- The north-western region like Dinajpur, Rangpur, Ishwardi and Rajshahi are more drought prone and less crops prospect areas due to the lower values of DI, probability of getting at least 8, 10 and 12 consecutive wet weeks are comparatively low, probability of at least 3 consecutive dry weeks are comparatively high and expected number of wet weeks lies between 7 to 9. Similarly, the area under Bogra, Faridpur, Bhola and Khepupara stations are less drought prone and high crops prospect areas due to the high values of DI, probability of getting at least 8, 10 and 12 consecutive wet weeks are comparatively high, probability of at least 3 consecutive dry weeks are comparatively low and expected number of wet weeks lies between 10 to 13 but Bhola and Khepupara are low crops prospect area due to the salinity problem. Lastly, this study provides all about similar results in decade and year-wise analysis.

- Annual occurrences, frequency (average recurrence interval) and percentage of annual probability indicate that the probability of extreme drought occurrence increases in recent decades in Dinajpur, Ishwardi and Rajshahi stations, but frequency decreases i.e. drought event becomes more frequent in comparison to other parts of the study area.
- The station-wise drought hazard index (DHI) is highest in Dinajpur and lowest in Khepupara stations and ranges from 15 to 32 in the area. But within the district boundaries higher DHI values (29.43 and 29.27) cover Thakurgaon and Rajshahi districts and lower DHI values (17.24 and 17.62) cover Borguna and Bagerhat districts respectively.
- On the other hand, the spatial distribution of drought hazard index indicate that the northern districts like Panchagarh, Takurgoan, Dinajpur, Nilphamari, Nawabganj, Naogaon, Rajshahi and Natore fall in extreme hazardous area in comparison to rest of the districts.
- The study on drought vulnerability indicates that the northern part of the area is exposed to high to very high drought vulnerability as higher percentage of illiterate people, higher dependence on agricultural practices and high percentage of irrigated to cultivable land. But the southern part of the area is exposed to low to moderate vulnerability as all the values of vulnerability indicators are comparatively low.
- The drought risk analysis of the study area shows that agricultural droughts pose high risk to parts of northern districts, but few districts in the southern part are exposed to moderate risk. The three districts in the coastal area and one district in northern part and two districts in eastern part of the area are less risky to droughts. Present study also indicates that 21.63%, 26.54% and 29.68% of the area are exposed to very high, high and moderate drought risk respectively. Hence, high crop production and higher dependency of agriculture on irrigation along with high variability of annual rainfall occurrence has made the

northern part to become high drought risk area in comparison to other parts.

- According to agricultural drought hazard risk ranking based on frequency and severity classes the area falls in the extreme (A) category in all stations meaning that the agricultural drought hazard risk is high in the study area.
- Finally, hazard risk ranking based on frequency and severity of agricultural drought classes indicate even low risk areas also suffer from extreme agricultural drought due to uneven spatio-temporal nature of rainfall during cropping season.

## 5.2 Policy Implications

To minimize the adverse effect due to droughts the following steps should be considered to face the climate change impact:

- As Panchagarh, Thakurgoan, Dinajpur, Nilphamari, Nawabganj, Naogaon, Rajshahi and Natore districts are becoming more vulnerable to high drought risk hazard, hence an effective hydrological adaptation measures are to be taken into account along with traditional adapting measures;
- Accordingly priority should be given to ranking risks like timing, importance of sector and climate associated events based on the frequency and severity of impact;
- Implementing effective drought forecasting and warning system are necessary;
- Probability analysis of cropping seasonal rainfall before cropping season starts;
- Detail research works on droughts for risk management considering possible causes of droughts such as natural, structural, geomorphological features etc. have to be carried out;

- Public awareness programs about the severity of droughts and proper education about nature and frequency of droughts;
- Attention should be given to store more relief goods in godown storages to mitigate recurrent drought effects;
- Review of the drought management activities to improve the process and planning for the future;
- Socio-economic and physical factors should be included in the management policy to make effective planning like family planning program should become stronger to minimize population density per unit area. Gender inequalities must be reduced so that girls are brought up like boys from their childhood;
- Improve existing water management systems, introduce new irrigation methods, artificial recharge of groundwater etc.; and
- There should be a master plan especially for drought prone areas and also Integrated Water Resources Management (IWRM) plan for minimizing adverse effect due to drought and managing the impact of changing environment.

Therefore, urgent need to act on adaptation keeping in mind climate change features, rainfall and temperature variability, possible impacts of climate change and risk ranking to make viable adaptation measures.

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# Appendix

# Appendix

**Appendix-I**

General computer programming for calculating parameters ($P$, $P_{11}$, $P_{01}$, E(Y), P(W>8), P(W>10), P(W>12), P(D>3) and DI of Markov chain model are as follows:

For threshold values a=5 or 10 or 15 or 20 or 25

```
TPM<-function(x){
dd<-0; ww<-0; dw<-0; wd<-0; a=?;
for(i in 1:(length(x)-1)){
if(x[i]<a & x[i+1]<a)
dd<-dd+1
else
0
if(x[i]>=a & x[i+1]>=a)
ww<-ww+1
else
0
if(x[i]<a & x[i+1]>=a)
dw<-dw+1
else
0
if(x[i]>=a & x[i+1]<a)
wd<-wd+1
else
0
}
matrix(c((dd/(dd+dw)),(wd/(wd+ww)),(dw/(dd+dw)),(ww/(wd+ww))),2,2)}

x<-
ts(read.csv(file="e:/Kharif_dinazpur/Kharif_dinazpur_1960.csv",sep=",",header=TRUE)
)
TPM(x)
```

Detail computer programming for calculating parameters ($P$, $P_{11}$, $P_{01}$, E(Y), P(W>8), P(W>10), P(W>12), P(D>3) and DI with specific threshold values for Markov chain model are as follows:

```
TPM5<-function(x){
```

```
a=5 #Change it
dd<-0; ww<-0; dw<-0; wd<-0;
for(i in 1:(length(x)-1)){
if(x[i]<a & x[i+1]<a)
dd<-dd+1
else
0
if(x[i]>=a & x[i+1]>=a)
ww<-ww+1
else
0
if(x[i]<a & x[i+1]>=a)
dw<-dw+1
else
0
if(x[i]>=a & x[i+1]<a)
wd<-wd+1
else
0
}
matrix(c((dd/(dd+dw)),(wd/(wd+ww)),(dw/(dd+dw)),(ww/(wd+ww))),2,2)}

TPM10<-function(x){
a=10 #Change it
dd<-0; ww<-0; dw<-0; wd<-0;
for(i in 1:(length(x)-1)){
if(x[i]<a & x[i+1]<a)
dd<-dd+1
else
0
if(x[i]>=a & x[i+1]>=a)
ww<-ww+1
else
0
if(x[i]<a & x[i+1]>=a)
dw<-dw+1
else
0
```

```
if(x[i]>=a & x[i+1]<a)
wd<-wd+1
else
0
}
matrix(c((dd/(dd+dw)),(wd/(wd+ww)),(dw/(dd+dw)),(ww/(wd+ww))),2,2)}

TPM15<-function(x){
a=15 #Change it
dd<-0; ww<-0; dw<-0; wd<-0;
for(i in 1:(length(x)-1)){
if(x[i]<a & x[i+1]<a)
dd<-dd+1
else
0
if(x[i]>=a & x[i+1]>=a)
ww<-ww+1
else
0
if(x[i]<a & x[i+1]>=a)
dw<-dw+1
else
0
if(x[i]>=a & x[i+1]<a)
wd<-wd+1
else
0
}
matrix(c((dd/(dd+dw)),(wd/(wd+ww)),(dw/(dd+dw)),(ww/(wd+ww))),2,2)}

TPM20<-function(x){
a=20 #Change it
dd<-0; ww<-0; dw<-0; wd<-0;
for(i in 1:(length(x)-1)){
if(x[i]<a & x[i+1]<a)
dd<-dd+1
else
0
```

```
if(x[i]>=a & x[i+1]>=a)
ww<-ww+1
else
0
if(x[i]<a & x[i+1]>=a)
dw<-dw+1
else
0
if(x[i]>=a & x[i+1]<a)
wd<-wd+1
else
0
}
matrix(c((dd/(dd+dw)),(wd/(wd+ww)),(dw/(dd+dw)),(ww/(wd+ww))),2,2)}
```

```
TPM25<-function(x){
a=25 #Change it
dd<-0; ww<-0; dw<-0; wd<-0;
for(i in 1:(length(x)-1)){
if(x[i]<a & x[i+1]<a)
dd<-dd+1
else
0
if(x[i]>=a & x[i+1]>=a)
ww<-ww+1
else
0
if(x[i]<a & x[i+1]>=a)
dw<-dw+1
else
0
if(x[i]>=a & x[i+1]<a)
wd<-wd+1
else
0
}
matrix(c((dd/(dd+dw)),(wd/(wd+ww)),(dw/(dd+dw)),(ww/(wd+ww))),2,2)}
```

```
x<-
ts(read.csv(file="e:/Kharif_dinazpur/Kharif_dinazpur_1960.csv",sep=",",header=TRUE)
)
c(TPM5(x)[,2], TPM10(x)[,2], TPM15(x)[,2],TPM20(x)[,2], TPM25(x)[,2])
```

**Appendix-II** Decade-wise analysis of probability of wet and dry weeks and index of drought proneness of 12 meteorological stations of study area for Kharif season

| | Kharif season suitable using threshold values (TV) in millimeters | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|
| Station | $P$ | $P_{11}$ | $P_{01}$ | E(Y) | Probability of getting wet week at least | | | P(D>3) | TV | DI | Drought Classes |
| | | | | | 8 | 10 | 12 | | | | |
| Dinajpur | | | | | | | | | | | |
| 1961-1970 | 0.637 | 0.922 | 0.137 | 71.916 | 0.567 | 0.482 | 0.410 | 0.643 | 20 | 0.126 | Severe |
| 1971-1980 | 0.904 | 0.980 | 0.186 | 144.064 | 0.869 | 0.835 | 0.802 | 0.540 | 5 | 0.182 | Moderate |
| 1981-1990 | 0.728 | 0.949 | 0.138 | 93.846 | 0.691 | 0.622 | 0.560 | 0.641 | 20 | 0.131 | Severe |
| 1991-2000 | 0.730 | 0.938 | 0.167 | 93.879 | 0.641 | 0.564 | 0.497 | 0.579 | 15 | 0.156 | Severe |
| 2001-2010 | 0.665 | 0.931 | 0.137 | 77.777 | 0.607 | 0.526 | 0.456 | 0.644 | 20 | 0.127 | Severe |
| Rangpur | | | | | | | | | | | |
| 1961-1970 | 0.814 | 0.967 | 0.144 | 117.080 | 0.791 | 0.740 | 0.692 | 0.627 | 5 | 0.139 | Severe |
| 1971-1980 | 0.740 | 0.953 | 0.134 | 96.777 | 0.713 | 0.647 | 0.587 | 0.649 | 15 | 0.128 | Severe |
| 1981-1990 | 0.753 | 0.955 | 0.138 | 100.216 | 0.723 | 0.659 | 0.600 | 0.640 | 15 | 0.132 | Severe |
| 1991-2000 | 0.841 | 0.964 | 0.190 | 124.282 | 0.774 | 0.719 | 0.668 | 0.532 | 5 | 0.183 | Moderate |
| 2001-2010 | 0.670 | 0.934 | 0.134 | 79.117 | 0.621 | 0.542 | 0.473 | 0.649 | 20 | 0.125 | Severe |
| Bogra | | | | | | | | | | | |
| 1961-1970 | 0.789 | 0.951 | 0.181 | 109.862 | 0.706 | 0.639 | 0.579 | 0.549 | 10 | 0.172 | Severe |
| 1971-1980 | 0.696 | 0.942 | 0.134 | 85.866 | 0.657 | 0.582 | 0.516 | 0.650 | 20 | 0.126 | Severe |
| 1981-1990 | 0.736 | 0.950 | 0.138 | 95.738 | 0.700 | 0.632 | 0.571 | 0.640 | 15 | 0.131 | Severe |
| 1991-2000 | 0.874 | 0.969 | 0.214 | 134.359 | 0.803 | 0.754 | 0.708 | 0.485 | 5 | 0.208 | Moderate |
| 2001-2010 | 0.892 | 0.968 | 0.264 | 140.133 | 0.796 | 0.746 | 0.699 | 0.399 | 5 | 0.255 | Mild |
| Ishwardi | | | | | | | | | | | |
| 1961-1970 | 0.719 | 0.933 | 0.171 | 85.508 | 0.616 | 0.537 | 0.467 | 0.571 | 20 | 0.159 | Severe |
| 1971-1980 | 0.722 | 0.946 | 0.141 | 91.797 | 0.676 | 0.605 | 0.541 | 0.633 | 15 | 0.134 | Severe |
| 1981-1990 | 0.726 | 0.948 | 0.136 | 93.216 | 0.691 | 0.621 | 0.559 | 0.644 | 15 | 0.129 | Severe |
| 1991-2000 | 0.810 | 0.955 | 0.194 | 115.526 | 0.722 | 0.658 | 0.600 | 0.524 | 10 | 0.185 | Moderate |
| 2001-2010 | 0.781 | 0.944 | 0.201 | 107.660 | 0.667 | 0.594 | 0.529 | 0.511 | 10 | 0.189 | Moderate |

| | Kharif season suitable using threshold values (TV) in millimeters | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|
| Station | $P$ | $P_{11}$ | $P_{01}$ | E(Y) | Probability of getting wet week at least | | | P(D>3) | TV | DI | Drought Classes |
| | | | | | 8 | 10 | 12 | | | | |
| Rajshahi | | | | | | | | | | | |
| 1961-1970 | 0.717 | 0.934 | 0.167 | 91.024 | 0.620 | 0.541 | 0.472 | 0.578 | 20 | 0.156 | Severe |
| 1971-1980 | 0.824 | 0.959 | 0.190 | 119.821 | 0.749 | 0.689 | 0.634 | 0.532 | 10 | 0.182 | Moderate |
| 1981-1990 | 0.834 | 0.975 | 0.128 | 123.132 | 0.836 | 0.794 | 0.754 | 0.664 | 5 | 0.124 | Extreme |
| 1991-2000 | 0.641 | 0.921 | 0.141 | 72.438 | 0.562 | 0.476 | 0.404 | 0.633 | 25 | 0.130 | Severe |
| 2001-2010 | 0.839 | 0.962 | 0.197 | 124.129 | 0.763 | 0.707 | 0.654 | 0.518 | 5 | 0.189 | Moderate |
| Faridpur | | | | | | | | | | | |
| 1961-1970 | 0.667 | 0.930 | 0.139 | 78.654 | 0.604 | 0.523 | 0.453 | 0.638 | 25 | 0.129 | Severe |
| 1971-1980 | 0.795 | 0.949 | 0.198 | 111.494 | 0.692 | 0.623 | 0.561 | 0.515 | 15 | 0.188 | Moderate |
| 1981-1990 | 0.890 | 0.976 | 0.192 | 139.717 | 0.845 | 0.805 | 0.767 | 0.527 | 5 | 0.188 | Moderate |
| 1991-2000 | 0.898 | 0.981 | 0.168 | 141.723 | 0.874 | 0.840 | 0.809 | 0.576 | 5 | 0.165 | Severe |
| 2001-2010 | 0.893 | 0.972 | 0.236 | 140.594 | 0.818 | 0.772 | 0.729 | 0.446 | 5 | 0.230 | Moderate |
| Jessore | | | | | | | | | | | |
| 1961-1970 | 0.784 | 0.947 | 0.192 | 105.682 | 0.684 | 0.614 | 0.550 | 0.527 | 15 | 0.182 | Moderate |
| 1971-1980 | 0.883 | 0.973 | 0.201 | 137.473 | 0.827 | 0.784 | 0.742 | 0.509 | 5 | 0.196 | Moderate |
| 1981-1990 | 0.720 | 0.945 | 0.142 | 91.788 | 0.671 | 0.599 | 0.535 | 0.631 | 20 | 0.135 | Severe |
| 1991-2000 | 0.882 | 0.973 | 0.201 | 136.876 | 0.826 | 0.783 | 0.741 | 0.509 | 5 | 0.196 | Moderate |
| 2001-2010 | 0.687 | 0.935 | 0.143 | 83.519 | 0.624 | 0.546 | 0.477 | 0.630 | 25 | 0.134 | Severe |
| Khulna | | | | | | | | | | | |
| 1961-1970 | 0.836 | 0.962 | 0.194 | 123.401 | 0.763 | 0.706 | 0.653 | 0.524 | 5 | 0.187 | Moderate |
| 1971-1980 | 0.894 | 0.974 | 0.215 | 140.312 | 0.834 | 0.792 | 0.752 | 0.483 | 5 | 0.210 | Moderate |
| 1981-1990 | 0.723 | 0.946 | 0.141 | 92.403 | 0.678 | 0.607 | 0.543 | 0.634 | 20 | 0.133 | Severe |
| 1991-2000 | 0.689 | 0.928 | 0.158 | 83.143 | 0.594 | 0.512 | 0.442 | 0.596 | 25 | 0.147 | Severe |
| 2001-2010 | 0.862 | 0.968 | 0.200 | 130.958 | 0.796 | 0.745 | 0.698 | 0.512 | 10 | 0.194 | Moderate |
| Satkhira | | | | | | | | | | | |
| 1961-1970 | 0.674 | 0.930 | 0.145 | 80.402 | 0.602 | 0.521 | 0.450 | 0.626 | 25 | 0.135 | Severe |
| 1971-1980 | 0.899 | 0.973 | 0.242 | 142.402 | 0.824 | 0.780 | 0.738 | 0.436 | 5 | 0.235 | Mild |
| 1981-1990 | 0.713 | 0.942 | 0.145 | 53.445 | 0.656 | 0.582 | 0.516 | 0.626 | 25 | 0.136 | Severe |
| 1991-2000 | 0.737 | 0.945 | 0.155 | 95.562 | 0.671 | 0.598 | 0.534 | 0.603 | 25 | 0.147 | Severe |
| 2001-2010 | 0.865 | 0.968 | 0.205 | 131.960 | 0.796 | 0.746 | 0.699 | 0.503 | 10 | 0.198 | Moderate |

| | Kharif season suitable using threshold values (TV) in millimeters | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|
| Station | $P$ | $P_{11}$ | $P_{01}$ | E(Y) | Probability of getting wet week at least | | | P(D>3) | TV | DI | Drought Classes |
| | | | | | 8 | 10 | 12 | | | | |
| Barisal | | | | | | | | | | | |
| 1961-1970 | 0.703 | 0.938 | 0.148 | 87.319 | 0.637 | 0.559 | 0.492 | 0.619 | 25 | 0.138 | Severe |
| 1971-1980 | 0.757 | 0.947 | 0.164 | 101.175 | 0.685 | 0.614 | 0.551 | 0.585 | 25 | 0.155 | Severe |
| 1981-1990 | 0.744 | 0.945 | 0.159 | 97.718 | 0.674 | 0.603 | 0.539 | 0.596 | 25 | 0.150 | Severe |
| 1991-2000 | 0.737 | 0.945 | 0.155 | 95.562 | 0.671 | 0.598 | 0.534 | 0.603 | 25 | 0.147 | Severe |
| 2001-2010 | 0.836 | 0.960 | 0.204 | 123.427 | 0.752 | 0.693 | 0.639 | 0.504 | 15 | 0.196 | Moderate |
| Bhola | | | | | | | | | | | |
| 1971-1980 | 0.770 | 0.958 | 0.141 | 104.812 | 0.739 | 0.678 | 0.622 | 0.633 | 25 | 0.135 | Severe |
| 1981-1990 | 0.779 | 0.953 | 0.165 | 107.120 | 0.714 | 0.648 | 0.589 | 0.581 | 25 | 0.158 | Severe |
| 1991-2000 | 0.903 | 0.980 | 0.185 | 143.271 | 0.869 | 0.834 | 0.801 | 0.542 | 5 | 0.181 | Moderate |
| 2001-2010 | 0.729 | 0.942 | 0.156 | 93.912 | 0.658 | 0.584 | 0.518 | 0.601 | 25 | 0.147 | Severe |
| Khepupara | | | | | | | | | | | |
| 1981-1990 | 0.786 | 0.959 | 0.152 | 109.318 | 0.744 | 0.684 | 0.628 | 0.609 | 25 | 0.146 | Severe |
| 1991-2000 | 0.877 | 0.965 | 0.245 | 135.111 | 0.782 | 0.729 | 0.680 | 0.430 | 15 | 0.237 | Mild |
| 2001-2010 | 0.873 | 0.970 | 0.205 | 134.451 | 0.809 | 0.761 | 0.717 | 0.502 | 15 | 0.199 | Moderate |

**Appendix-III** Year-wise analysis of probability of wet and dry weeks and index of drought proneness in Dinajpur station for Kharif season

| | Kharif season using suitable threshold values (TV) in millimeters | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|
| Year | $P$ | $P_{11}$ | $P_{01}$ | E(Y) | Probability of getting wet week at least | | | P(D>3) | TV | DI | Drought Classes |
| | | | | | 8 | 10 | 12 | | | | |
| 1960 | 0.463 | 0.935 | 0.056 | 9.714 | 4.495 | 0.627 | 0.549 | 0.480 | 25 | 0.052 | Extreme |
| 1961 | 0.336 | 0.889 | 0.056 | 7.286 | 2.451 | 0.438 | 0.346 | 0.274 | 25 | 0.050 | Extreme |
| 1962 | 0.580 | 0.887 | 0.156 | 11.000 | 6.379 | 0.433 | 0.341 | 0.268 | 20 | 0.138 | Severe |
| 1963 | 0.743 | 0.939 | 0.176 | 12.714 | 9.449 | 0.644 | 0.568 | 0.501 | 25 | 0.166 | Severe |
| 1964 | 0.752 | 0.957 | 0.130 | 14.143 | 10.636 | 0.735 | 0.673 | 0.617 | 15 | 0.125 | Extreme |
| 1965 | 0.587 | 0.962 | 0.054 | 12.143 | 7.132 | 0.763 | 0.706 | 0.653 | 25 | 0.052 | Extreme |
| 1966 | 0.917 | 0.982 | 0.200 | 16.714 | 15.333 | 0.880 | 0.849 | 0.819 | 5 | 0.196 | Moderate |
| 1967 | 0.692 | 0.954 | 0.103 | 13.286 | 9.198 | 0.719 | 0.655 | 0.596 | 10 | 0.099 | Extreme |

| | Kharif season using suitable threshold values (TV) in millimeters | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|
| Year | $P$ | $P_{11}$ | $P_{01}$ | E(Y) | Probability of getting wet week at least | | | P(D>3) | TV | DI | Drought Classes |
| | | | | | 8 | 10 | 12 | | | | |
| 1968 | 0.558 | 0.930 | 0.089 | 11.000 | 6.138 | 0.600 | 0.518 | 0.448 | 25 | 0.083 | Extreme |
| 1969 | 0.705 | 0.930 | 0.167 | 13.143 | 9.265 | 0.603 | 0.522 | 0.451 | 10 | 0.155 | Severe |
| 1970 | 0.578 | 0.940 | 0.082 | 10.429 | 6.023 | 0.650 | 0.575 | 0.508 | 25 | 0.077 | Extreme |
| 1971 | 0.361 | 0.568 | 0.244 | 6.286 | 2.267 | 0.019 | 0.006 | 0.002 | 5 | 0.138 | Severe |
| 1972 | 0.802 | 0.935 | 0.261 | 14.286 | 11.453 | 0.627 | 0.549 | 0.480 | 5 | 0.244 | Mild |
| 1973 | 0.949 | 0.973 | 0.500 | 16.857 | 16.000 | 0.827 | 0.783 | 0.742 | 5 | 0.487 | Occasional |
| 1974 | 0.914 | 0.991 | 0.100 | 16.143 | 14.751 | 0.936 | 0.918 | 0.901 | 5 | 0.099 | Extreme |
| 1975 | 0.784 | 0.969 | 0.111 | 14.857 | 11.648 | 0.804 | 0.756 | 0.710 | 15 | 0.108 | Extreme |
| 1976 | 0.864 | 0.951 | 0.308 | 15.571 | 13.450 | 0.706 | 0.639 | 0.578 | 10 | 0.293 | Mild |
| 1977 | 0.974 | 0.991 | 0.333 | 17.143 | 16.700 | 0.940 | 0.923 | 0.907 | 5 | 0.330 | Occasional |
| 1978 | 0.722 | 0.956 | 0.115 | 13.714 | 9.901 | 0.727 | 0.664 | 0.606 | 25 | 0.110 | Extreme |
| 1979 | 0.948 | 0.991 | 0.167 | 16.714 | 15.850 | 0.938 | 0.921 | 0.904 | 5 | 0.165 | Severe |
| 1980 | 0.886 | 0.982 | 0.143 | 16.429 | 14.559 | 0.878 | 0.846 | 0.816 | 10 | 0.140 | Severe |
| 1981 | 0.612 | 0.935 | 0.103 | 11.857 | 7.260 | 0.625 | 0.546 | 0.478 | 25 | 0.096 | Extreme |
| 1982 | 0.603 | 0.934 | 0.100 | 11.714 | 7.066 | 0.621 | 0.542 | 0.473 | 25 | 0.093 | Extreme |
| 1983 | 0.743 | 0.910 | 0.259 | 13.571 | 10.077 | 0.517 | 0.428 | 0.355 | 5 | 0.236 | Mild |
| 1984 | 0.818 | 0.970 | 0.133 | 15.286 | 12.501 | 0.810 | 0.762 | 0.718 | 5 | 0.129 | Severe |
| 1985 | 0.692 | 0.954 | 0.103 | 13.286 | 9.198 | 0.719 | 0.655 | 0.596 | 25 | 0.099 | Extreme |
| 1986 | 0.867 | 0.962 | 0.250 | 15.714 | 13.619 | 0.760 | 0.703 | 0.650 | 5 | 0.240 | Mild |
| 1987 | 0.899 | 0.963 | 0.333 | 16.143 | 14.515 | 0.766 | 0.710 | 0.658 | 5 | 0.321 | Occasional |
| 1988 | 0.636 | 0.964 | 0.063 | 12.857 | 8.182 | 0.775 | 0.721 | 0.670 | 25 | 0.060 | Extreme |
| 1989 | 0.719 | 0.967 | 0.083 | 14.000 | 10.062 | 0.793 | 0.742 | 0.694 | 10 | 0.081 | Extreme |
| 1990 | 0.656 | 0.965 | 0.067 | 13.143 | 8.628 | 0.780 | 0.726 | 0.677 | 25 | 0.064 | Extreme |
| 1991 | 0.836 | 0.969 | 0.158 | 14.857 | 12.424 | 0.803 | 0.754 | 0.708 | 5 | 0.153 | Severe |
| 1992 | 0.750 | 0.920 | 0.241 | 13.286 | 9.964 | 0.556 | 0.470 | 0.397 | 15 | 0.222 | Moderate |
| 1993 | 0.715 | 0.907 | 0.233 | 13.143 | 9.397 | 0.505 | 0.415 | 0.342 | 15 | 0.212 | Moderate |
| 1994 | 0.421 | 0.889 | 0.081 | 8.571 | 3.605 | 0.438 | 0.346 | 0.274 | 25 | 0.072 | Extreme |
| 1995 | 0.877 | 0.962 | 0.273 | 15.857 | 13.914 | 0.762 | 0.705 | 0.652 | 15 | 0.123 | Extreme |
| 1996 | 0.595 | 0.928 | 0.106 | 10.857 | 6.458 | 0.591 | 0.508 | 0.437 | 25 | 0.099 | Extreme |
| 1997 | 0.656 | 0.965 | 0.067 | 13.143 | 8.628 | 0.780 | 0.726 | 0.677 | 10 | 0.064 | Extreme |

| Year | Kharif season using suitable threshold values (TV) in millimeters | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|
| | $P$ | $P_{11}$ | $P_{01}$ | E(Y) | Probability of getting wet week at least | | | P(D>3) | TV | DI | Drought Classes |
| | | | | | 8 | 10 | 12 | | | | |
| 1998 | 0.843 | 0.950 | 0.267 | 15.286 | 12.892 | 0.701 | 0.633 | 0.572 | 10 | 0.253 | Mild |
| 1999 | 0.917 | 0.982 | 0.200 | 16.714 | 15.333 | 0.880 | 0.849 | 0.819 | 5 | 0.196 | Moderate |
| 2000 | 0.822 | 0.967 | 0.154 | 13.857 | 11.389 | 0.789 | 0.737 | 0.689 | 5 | 0.149 | Severe |
| 2001 | 0.793 | 0.935 | 0.250 | 14.143 | 11.217 | 0.624 | 0.545 | 0.476 | 10 | 0.234 | Moderate |
| 2002 | 0.640 | 0.924 | 0.135 | 12.143 | 7.774 | 0.575 | 0.491 | 0.419 | 25 | 0.125 | Extreme |
| 2003 | 0.888 | 0.971 | 0.231 | 15.714 | 13.953 | 0.813 | 0.766 | 0.722 | 5 | 0.224 | Moderate |
| 2004 | 0.559 | 0.914 | 0.109 | 10.857 | 6.070 | 0.534 | 0.446 | 0.373 | 25 | 0.099 | Extreme |
| 2005 | 0.784 | 0.947 | 0.190 | 14.429 | 11.305 | 0.685 | 0.615 | 0.552 | 10 | 0.180 | Moderate |
| 2006 | 0.742 | 0.957 | 0.125 | 14.000 | 10.387 | 0.733 | 0.670 | 0.613 | 5 | 0.120 | Extreme |
| 2007 | 0.841 | 0.981 | 0.100 | 16.000 | 13.460 | 0.875 | 0.842 | 0.811 | 5 | 0.098 | Extreme |
| 2008 | 0.810 | 0.947 | 0.227 | 14.429 | 11.692 | 0.682 | 0.611 | 0.548 | 5 | 0.215 | Moderate |
| 2009 | 0.575 | 0.901 | 0.133 | 11.000 | 6.324 | 0.484 | 0.393 | 0.319 | 25 | 0.120 | Extreme |
| 2010 | 0.762 | 0.969 | 0.100 | 14.571 | 11.102 | 0.801 | 0.751 | 0.705 | 5 | 0.097 | Extreme |

**Appendix-IV** Year-wise analysis of probability of wet and dry weeks and index of drought proneness in Rangpur station for Kharif season

| Year | Kharif season using suitable threshold values (TV) in millimeters | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|
| | P | $P_{11}$ | $P_{01}$ | E(Y) | Probability of getting wet week at least | | | P(D>3) | TV | DI | Drought Classes |
| | | | | | 8 | 10 | 12 | | | | |
| 1960 | 0.696 | 0.929 | 0.161 | 9.043 | 0.599 | 0.517 | 0.447 | 0.590 | 10 | 0.150 | Severe |
| 1961 | 0.517 | 0.900 | 0.107 | 4.877 | 0.478 | 0.387 | 0.314 | 0.712 | 25 | 0.096 | Extreme |
| 1962 | 0.631 | 0.937 | 0.108 | 7.659 | 0.633 | 0.555 | 0.487 | 0.709 | 15 | 0.101 | Extreme |
| 1963 | 0.783 | 0.958 | 0.150 | 11.404 | 0.742 | 0.682 | 0.626 | 0.614 | 10 | 0.144 | Severe |
| 1964 | 0.897 | 0.962 | 0.333 | 14.217 | 0.760 | 0.703 | 0.650 | 0.296 | 5 | 0.321 | Occasional |
| 1965 | 0.750 | 0.943 | 0.172 | 10.071 | 0.661 | 0.587 | 0.521 | 0.567 | 5 | 0.163 | Severe |
| 1966 | 0.548 | 0.897 | 0.125 | 5.797 | 0.467 | 0.376 | 0.303 | 0.670 | 25 | 0.112 | Extreme |
| 1967 | 0.762 | 0.957 | 0.136 | 10.888 | 0.738 | 0.676 | 0.620 | 0.644 | 5 | 0.131 | Severe |
| 1968 | 0.871 | 0.980 | 0.133 | 13.433 | 0.869 | 0.835 | 0.803 | 0.651 | 5 | 0.131 | Severe |
| 1969 | 0.744 | 0.980 | 0.059 | 11.165 | 0.867 | 0.832 | 0.799 | 0.834 | 10 | 0.058 | Extreme |
| 1970 | 0.852 | 0.971 | 0.167 | 13.396 | 0.815 | 0.768 | 0.725 | 0.579 | 5 | 0.162 | Severe |
| 1971 | 0.818 | 0.970 | 0.133 | 12.501 | 0.810 | 0.762 | 0.718 | 0.651 | 10 | 0.129 | Severe |

| | Kharif season using suitable threshold values (TV) in millimeters | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|
| Year | P | $P_{11}$ | $P_{01}$ | E(Y) | Probability of getting wet week at least | | | P(D>3) | TV | DI | Drought Classes |
| | | | | | 8 | 10 | 12 | | | | |
| 1972 | 0.922 | 0.972 | 0.333 | 15.022 | 0.819 | 0.774 | 0.731 | 0.296 | 5 | 0.324 | Occasional |
| 1973 | 0.884 | 0.952 | 0.364 | 14.021 | 0.711 | 0.645 | 0.585 | 0.258 | 5 | 0.346 | Occasional |
| 1974 | 0.914 | 0.991 | 0.100 | 14.751 | 0.936 | 0.918 | 0.901 | 0.729 | 5 | 0.099 | Extreme |
| 1975 | 0.772 | 0.958 | 0.143 | 11.144 | 0.740 | 0.679 | 0.623 | 0.630 | 10 | 0.137 | Severe |
| 1976 | 0.576 | 0.932 | 0.093 | 6.500 | 0.609 | 0.528 | 0.458 | 0.746 | 25 | 0.087 | Extreme |
| 1977 | 0.828 | 0.958 | 0.200 | 12.177 | 0.742 | 0.682 | 0.626 | 0.512 | 10 | 0.192 | Moderate |
| 1978 | 0.784 | 0.969 | 0.111 | 11.648 | 0.804 | 0.756 | 0.710 | 0.702 | 15 | 0.108 | Extreme |
| 1979 | 0.594 | 0.933 | 0.098 | 6.874 | 0.617 | 0.537 | 0.468 | 0.735 | 20 | 0.091 | Extreme |
| 1980 | 0.845 | 0.949 | 0.278 | 12.552 | 0.693 | 0.624 | 0.562 | 0.377 | 15 | 0.264 | Mild |
| 1981 | 0.845 | 0.949 | 0.278 | 12.552 | 0.693 | 0.624 | 0.562 | 0.377 | 15 | 0.264 | Mild |
| 1982 | 0.548 | 0.897 | 0.125 | 5.797 | 0.467 | 0.376 | 0.303 | 0.670 | 25 | 0.112 | Extreme |
| 1983 | 0.744 | 0.945 | 0.160 | 10.315 | 0.673 | 0.601 | 0.537 | 0.593 | 15 | 0.151 | Severe |
| 1984 | 0.845 | 0.961 | 0.214 | 13.042 | 0.756 | 0.698 | 0.644 | 0.485 | 10 | 0.206 | Moderate |
| 1985 | 0.835 | 0.960 | 0.200 | 12.759 | 0.754 | 0.695 | 0.641 | 0.512 | 5 | 0.192 | Moderate |
| 1986 | 0.625 | 0.950 | 0.083 | 7.679 | 0.698 | 0.630 | 0.569 | 0.770 | 25 | 0.079 | Extreme |
| 1987 | 0.917 | 0.982 | 0.200 | 15.333 | 0.880 | 0.849 | 0.819 | 0.512 | 5 | 0.196 | Moderate |
| 1988 | 0.740 | 0.968 | 0.091 | 10.574 | 0.797 | 0.747 | 0.700 | 0.751 | 5 | 0.088 | Extreme |
| 1989 | 0.795 | 0.970 | 0.118 | 11.928 | 0.806 | 0.758 | 0.713 | 0.687 | 5 | 0.114 | Extreme |
| 1990 | 0.827 | 0.981 | 0.091 | 13.110 | 0.874 | 0.841 | 0.809 | 0.751 | 5 | 0.089 | Extreme |
| 1991 | 0.785 | 0.980 | 0.071 | 12.105 | 0.871 | 0.837 | 0.804 | 0.801 | 5 | 0.070 | Extreme |
| 1992 | 0.759 | 0.932 | 0.214 | 10.187 | 0.610 | 0.530 | 0.460 | 0.485 | 15 | 0.200 | Moderate |
| 1993 | 0.905 | 0.953 | 0.444 | 14.607 | 0.715 | 0.650 | 0.591 | 0.171 | 5 | 0.424 | Occasional |
| 1994 | 0.724 | 0.932 | 0.179 | 9.718 | 0.610 | 0.530 | 0.460 | 0.554 | 5 | 0.166 | Severe |
| 1995 | 0.888 | 0.972 | 0.222 | 14.334 | 0.819 | 0.774 | 0.731 | 0.471 | 5 | 0.216 | Moderate |
| 1996 | 0.707 | 0.939 | 0.147 | 8.988 | 0.644 | 0.568 | 0.501 | 0.621 | 15 | 0.138 | Severe |
| 1997 | 0.480 | 0.902 | 0.091 | 4.597 | 0.484 | 0.394 | 0.320 | 0.751 | 25 | 0.082 | Extreme |
| 1998 | 0.852 | 0.971 | 0.167 | 13.396 | 0.815 | 0.768 | 0.725 | 0.579 | 5 | 0.162 | Severe |
| 1999 | 0.902 | 0.982 | 0.167 | 14.941 | 0.879 | 0.848 | 0.817 | 0.579 | 5 | 0.164 | Severe |
| 2000 | 0.759 | 0.943 | 0.179 | 10.296 | 0.664 | 0.591 | 0.525 | 0.554 | 5 | 0.168 | Severe |
| 2001 | 0.733 | 0.941 | 0.161 | 9.526 | 0.654 | 0.579 | 0.513 | 0.590 | 25 | 0.152 | Severe |
| 2002 | 0.902 | 0.982 | 0.167 | 14.941 | 0.879 | 0.848 | 0.817 | 0.579 | 5 | 0.164 | Severe |
| 2003 | 0.862 | 0.960 | 0.250 | 13.177 | 0.751 | 0.693 | 0.638 | 0.422 | 10 | 0.240 | Mild |
| 2004 | 0.793 | 0.948 | 0.200 | 11.561 | 0.688 | 0.618 | 0.555 | 0.512 | 5 | 0.190 | Moderate |
| 2005 | 0.835 | 0.960 | 0.200 | 12.759 | 0.754 | 0.695 | 0.641 | 0.512 | 10 | 0.192 | Moderate |

| Year | Kharif season using suitable threshold values (TV) in millimeters | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|
| | P | $P_{11}$ | $P_{01}$ | E(Y) | Probability of getting wet week at least | | | P(D>3) | TV | DI | Drought Classes |
| | | | | | 8 | 10 | 12 | | | | |
| 2006 | 0.725 | 0.944 | 0.148 | 9.840 | 0.667 | 0.594 | 0.529 | 0.618 | 5 | 0.140 | Severe |
| 2007 | 0.853 | 0.960 | 0.235 | 12.802 | 0.749 | 0.690 | 0.635 | 0.447 | 5 | 0.226 | Moderate |
| 2008 | 0.793 | 0.978 | 0.083 | 11.217 | 0.857 | 0.821 | 0.785 | 0.770 | 10 | 0.082 | Extreme |
| 2009 | 0.668 | 0.927 | 0.147 | 8.395 | 0.587 | 0.505 | 0.434 | 0.621 | 5 | 0.136 | Severe |
| 2010 | 0.551 | 0.944 | 0.068 | 6.140 | 0.670 | 0.598 | 0.533 | 0.809 | 25 | 0.064 | Extreme |

**Appendix-V** Year-wise analysis of probability of wet and dry weeks and index of drought proneness in the Bogra station for Kharif season

| Year | Kharif season using suitable threshold values (TV) in millimeters | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|
| | $P$ | $P_{11}$ | $P_{01}$ | E(Y) | Probability of getting wet week at least | | | P(D>3) | TV | DI | Drought Classes |
| | | | | | 8 | 10 | 12 | | | | |
| 1960 | 0.862 | 0.970 | 0.188 | 13.177 | 0.808 | 0.760 | 0.715 | 0.536 | 5 | 0.182 | Moderate |
| 1961 | 0.629 | 0.904 | 0.163 | 7.192 | 0.494 | 0.404 | 0.330 | 0.587 | 15 | 0.147 | Severe |
| 1962 | 0.578 | 0.896 | 0.143 | 6.023 | 0.462 | 0.370 | 0.297 | 0.630 | 15 | 0.128 | Severe |
| 1963 | 0.922 | 0.972 | 0.333 | 15.022 | 0.819 | 0.774 | 0.731 | 0.296 | 5 | 0.324 | Occasional |
| 1964 | 0.940 | 0.963 | 0.571 | 15.571 | 0.770 | 0.714 | 0.663 | 0.079 | 5 | 0.550 | Occasional |
| 1965 | 0.874 | 0.952 | 0.333 | 13.733 | 0.708 | 0.642 | 0.582 | 0.296 | 5 | 0.317 | Occasional |
| 1966 | 0.966 | 0.982 | 0.500 | 16.414 | 0.882 | 0.850 | 0.820 | 0.125 | 5 | 0.491 | Occasional |
| 1967 | 0.559 | 0.914 | 0.109 | 6.070 | 0.534 | 0.446 | 0.373 | 0.708 | 25 | 0.099 | Extreme |
| 1968 | 0.706 | 0.979 | 0.050 | 10.286 | 0.863 | 0.827 | 0.793 | 0.857 | 5 | 0.049 | Extreme |
| 1969 | 0.000 | 0.990 | 0.000 | 0.000 | 0.934 | 0.916 | 0.898 | 1.000 | 5 | 0.000 | Extreme |
| 1970 | 0.823 | 0.949 | 0.235 | 12.349 | 0.696 | 0.627 | 0.565 | 0.447 | 5 | 0.223 | Moderate |
| 1971 | 0.810 | 0.968 | 0.136 | 11.692 | 0.797 | 0.747 | 0.700 | 0.644 | 15 | 0.132 | Severe |
| 1972 | 0.819 | 0.968 | 0.143 | 11.933 | 0.799 | 0.749 | 0.703 | 0.630 | 5 | 0.138 | Severe |
| 1973 | 0.905 | 0.962 | 0.364 | 14.483 | 0.762 | 0.705 | 0.652 | 0.258 | 5 | 0.350 | Occasional |
| 1974 | 0.905 | 0.990 | 0.091 | 14.483 | 0.935 | 0.917 | 0.900 | 0.751 | 5 | 0.090 | Extreme |
| 1975 | 0.742 | 0.957 | 0.125 | 10.387 | 0.733 | 0.670 | 0.613 | 0.670 | 10 | 0.120 | Extreme |
| 1976 | 0.705 | 0.930 | 0.167 | 9.265 | 0.603 | 0.522 | 0.451 | 0.579 | 10 | 0.155 | Severe |
| 1977 | 0.899 | 0.963 | 0.333 | 14.515 | 0.766 | 0.710 | 0.658 | 0.296 | 10 | 0.321 | Occasional |
| 1978 | 0.612 | 0.935 | 0.103 | 7.260 | 0.625 | 0.546 | 0.478 | 0.723 | 25 | 0.096 | Extreme |
| 1979 | 0.802 | 0.968 | 0.130 | 11.453 | 0.795 | 0.744 | 0.697 | 0.658 | 15 | 0.126 | Severe |
| 1980 | 0.871 | 0.981 | 0.125 | 14.184 | 0.877 | 0.845 | 0.814 | 0.670 | 5 | 0.123 | Extreme |
| 1981 | 0.470 | 0.918 | 0.073 | 4.500 | 0.550 | 0.463 | 0.390 | 0.797 | 25 | 0.067 | Extreme |

| Year | Kharif season using suitable threshold values (TV) in millimeters | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|
| | $P$ | $P_{11}$ | $P_{01}$ | E(Y) | Probability of getting wet week at least | | | P(D>3) | TV | DI | Drought Classes |
| | | | | | 8 | 10 | 12 | | | | |
| 1982 | 0.540 | 0.896 | 0.122 | 5.627 | 0.462 | 0.370 | 0.297 | 0.676 | 25 | 0.110 | Extreme |
| 1983 | 0.784 | 0.947 | 0.190 | 11.305 | 0.685 | 0.615 | 0.552 | 0.531 | 10 | 0.180 | Moderate |
| 1984 | 0.659 | 0.939 | 0.118 | 8.280 | 0.644 | 0.568 | 0.501 | 0.687 | 25 | 0.110 | Extreme |
| 1985 | 0.852 | 0.971 | 0.167 | 13.396 | 0.815 | 0.768 | 0.725 | 0.579 | 10 | 0.162 | Severe |
| 1986 | 0.784 | 0.947 | 0.190 | 11.305 | 0.685 | 0.615 | 0.552 | 0.531 | 10 | 0.180 | Moderate |
| 1987 | 0.793 | 0.959 | 0.158 | 11.667 | 0.745 | 0.685 | 0.629 | 0.597 | 5 | 0.151 | Severe |
| 1988 | 0.480 | 0.902 | 0.091 | 4.597 | 0.484 | 0.394 | 0.320 | 0.751 | 25 | 0.082 | Extreme |
| 1989 | 0.833 | 0.950 | 0.250 | 12.619 | 0.698 | 0.630 | 0.569 | 0.422 | 5 | 0.238 | Mild |
| 1990 | 0.829 | 0.971 | 0.143 | 12.794 | 0.811 | 0.764 | 0.720 | 0.630 | 10 | 0.139 | Severe |
| 1991 | 0.812 | 0.981 | 0.083 | 12.768 | 0.873 | 0.840 | 0.808 | 0.770 | 5 | 0.082 | Extreme |
| 1992 | 0.739 | 0.921 | 0.222 | 10.024 | 0.564 | 0.478 | 0.406 | 0.471 | 5 | 0.205 | Moderate |
| 1993 | 0.856 | 0.961 | 0.231 | 13.328 | 0.758 | 0.700 | 0.647 | 0.455 | 5 | 0.222 | Moderate |
| 1994 | 0.767 | 0.944 | 0.185 | 10.522 | 0.667 | 0.594 | 0.529 | 0.541 | 5 | 0.175 | Severe |
| 1995 | 0.884 | 0.952 | 0.364 | 14.021 | 0.711 | 0.645 | 0.585 | 0.258 | 10 | 0.346 | Occasional |
| 1996 | 0.845 | 0.980 | 0.111 | 12.672 | 0.866 | 0.831 | 0.797 | 0.702 | 5 | 0.109 | Extreme |
| 1997 | 0.549 | 0.929 | 0.087 | 5.961 | 0.595 | 0.513 | 0.443 | 0.761 | 25 | 0.081 | Extreme |
| 1998 | 0.974 | 0.991 | 0.333 | 16.700 | 0.940 | 0.923 | 0.907 | 0.296 | 5 | 0.330 | Occasional |
| 1999 | 0.902 | 0.982 | 0.167 | 14.941 | 0.879 | 0.848 | 0.817 | 0.579 | 5 | 0.164 | Severe |
| 2000 | 0.862 | 0.960 | 0.250 | 13.177 | 0.751 | 0.693 | 0.638 | 0.422 | 5 | 0.240 | Mild |
| 2001 | 0.621 | 0.931 | 0.114 | 6.916 | 0.604 | 0.523 | 0.453 | 0.696 | 25 | 0.106 | Extreme |
| 2002 | 0.877 | 0.962 | 0.273 | 13.914 | 0.762 | 0.705 | 0.652 | 0.385 | 5 | 0.262 | Mild |
| 2003 | 0.922 | 0.963 | 0.444 | 15.022 | 0.766 | 0.710 | 0.658 | 0.171 | 10 | 0.428 | Occasional |
| 2004 | 0.841 | 0.981 | 0.100 | 13.460 | 0.875 | 0.842 | 0.811 | 0.729 | 5 | 0.098 | Extreme |
| 2005 | 0.845 | 0.961 | 0.214 | 13.042 | 0.756 | 0.698 | 0.644 | 0.485 | 5 | 0.206 | Moderate |
| 2006 | 0.908 | 0.944 | 0.556 | 14.663 | 0.668 | 0.595 | 0.530 | 0.088 | 5 | 0.524 | Occasional |
| 2007 | 0.888 | 0.972 | 0.222 | 14.334 | 0.819 | 0.774 | 0.731 | 0.471 | 5 | 0.216 | Moderate |
| 2008 | 0.897 | 0.981 | 0.167 | 14.217 | 0.873 | 0.840 | 0.808 | 0.579 | 5 | 0.163 | Severe |
| 2009 | 0.744 | 0.945 | 0.160 | 10.315 | 0.673 | 0.601 | 0.537 | 0.593 | 10 | 0.151 | Severe |
| 2010 | 0.819 | 0.939 | 0.278 | 12.174 | 0.643 | 0.566 | 0.499 | 0.377 | 5 | 0.261 | Mild |

**Appendix-VI** Year-wise analysis of probability of wet and dry weeks and index of drought proneness in Ishwardi station for Kharif season

| | Kharif season using suitable threshold values (TV) in millimeters | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|
| Year | P | $P_{11}$ | $P_{01}$ | E(Y) | Probability of getting wet week at least | | | P(D>3) | TV | DI | Drought Classes |
| | | | | | 8 | 10 | 12 | | | | |
| 1961 | 0.750 | 0.931 | 0.207 | 10.071 | 0.606 | 0.526 | 0.456 | 0.499 | 15 | 0.193 | Moderate |
| 1962 | 0.420 | 0.930 | 0.051 | 3.781 | 0.601 | 0.520 | 0.449 | 0.855 | 25 | 0.047 | Extreme |
| 1963 | 0.897 | 0.962 | 0.333 | 14.217 | 0.760 | 0.703 | 0.650 | 0.296 | 5 | 0.321 | Occasional |
| 1964 | 0.931 | 0.981 | 0.250 | 15.296 | 0.877 | 0.845 | 0.814 | 0.422 | 5 | 0.245 | Mild |
| 1965 | 0.758 | 0.980 | 0.063 | 11.472 | 0.868 | 0.834 | 0.801 | 0.824 | 5 | 0.061 | Extreme |
| 1966 | 0.856 | 0.961 | 0.231 | 13.328 | 0.758 | 0.700 | 0.647 | 0.455 | 5 | 0.222 | Moderate |
| 1967 | 0.795 | 0.970 | 0.118 | 11.928 | 0.806 | 0.758 | 0.713 | 0.687 | 10 | 0.114 | Extreme |
| 1968 | 0.663 | 0.952 | 0.094 | 8.526 | 0.711 | 0.645 | 0.585 | 0.744 | 25 | 0.089 | Extreme |
| 1969 | 0.771 | 0.980 | 0.067 | 11.785 | 0.869 | 0.835 | 0.803 | 0.813 | 10 | 0.065 | Extreme |
| 1970 | 0.750 | 0.931 | 0.207 | 9.964 | 0.606 | 0.526 | 0.456 | 0.499 | 25 | 0.193 | Moderate |
| 1971 | 0.645 | 0.978 | 0.040 | 8.943 | 0.856 | 0.819 | 0.783 | 0.885 | 25 | 0.039 | Extreme |
| 1972 | 0.793 | 0.967 | 0.125 | 11.217 | 0.793 | 0.742 | 0.694 | 0.670 | 5 | 0.121 | Extreme |
| 1973 | 0.931 | 0.972 | 0.375 | 15.296 | 0.821 | 0.776 | 0.734 | 0.244 | 5 | 0.365 | Occasional |
| 1974 | 0.793 | 0.967 | 0.125 | 11.217 | 0.793 | 0.742 | 0.694 | 0.670 | 10 | 0.121 | Extreme |
| 1975 | 0.877 | 0.962 | 0.273 | 13.914 | 0.762 | 0.705 | 0.652 | 0.385 | 5 | 0.262 | Mild |
| 1976 | 0.824 | 0.960 | 0.188 | 12.480 | 0.751 | 0.693 | 0.638 | 0.536 | 5 | 0.180 | Severe |
| 1977 | 0.876 | 0.972 | 0.200 | 14.017 | 0.818 | 0.772 | 0.729 | 0.512 | 5 | 0.194 | Moderate |
| 1978 | 0.552 | 0.922 | 0.096 | 5.517 | 0.566 | 0.481 | 0.409 | 0.738 | 25 | 0.089 | Extreme |
| 1979 | 0.585 | 0.932 | 0.095 | 6.685 | 0.613 | 0.533 | 0.463 | 0.741 | 25 | 0.089 | Extreme |
| 1980 | 0.603 | 0.900 | 0.152 | 6.638 | 0.478 | 0.387 | 0.314 | 0.609 | 20 | 0.137 | Severe |
| 1981 | 0.560 | 0.945 | 0.070 | 6.321 | 0.674 | 0.602 | 0.538 | 0.805 | 25 | 0.066 | Extreme |
| 1982 | 0.534 | 0.935 | 0.074 | 5.192 | 0.627 | 0.549 | 0.480 | 0.794 | 25 | 0.069 | Extreme |
| 1983 | 0.983 | 0.991 | 0.500 | 16.988 | 0.940 | 0.924 | 0.908 | 0.125 | 5 | 0.496 | Occasional |
| 1984 | 0.773 | 0.969 | 0.105 | 11.373 | 0.803 | 0.754 | 0.708 | 0.716 | 10 | 0.102 | Extreme |
| 1985 | 0.773 | 0.969 | 0.105 | 11.373 | 0.803 | 0.754 | 0.708 | 0.716 | 10 | 0.102 | Extreme |
| 1986 | 0.751 | 0.968 | 0.095 | 10.836 | 0.799 | 0.749 | 0.703 | 0.741 | 5 | 0.092 | Extreme |
| 1987 | 0.577 | 0.917 | 0.114 | 6.429 | 0.544 | 0.457 | 0.384 | 0.696 | 25 | 0.104 | Extreme |
| 1988 | 0.795 | 0.970 | 0.118 | 11.928 | 0.806 | 0.758 | 0.713 | 0.687 | 5 | 0.114 | Extreme |
| 1989 | 0.921 | 0.963 | 0.429 | 15.133 | 0.770 | 0.714 | 0.663 | 0.187 | 5 | 0.413 | Occasional |

| | Kharif season using suitable threshold values (TV) in millimeters | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|
| Year | P | $P_{11}$ | $P_{01}$ | E(Y) | Probability of getting wet week at least | | | P(D>3) | TV | DI | Drought Classes |
| | | | | | 8 | 10 | 12 | | | | |
| 1990 | 0.771 | 0.980 | 0.067 | 11.785 | 0.869 | 0.835 | 0.803 | 0.813 | 15 | 0.065 | Extreme |
| 1991 | 0.833 | 0.950 | 0.250 | 12.619 | 0.698 | 0.630 | 0.569 | 0.422 | 10 | 0.238 | Mild |
| 1992 | 0.839 | 0.940 | 0.313 | 12.704 | 0.648 | 0.573 | 0.506 | 0.325 | 5 | 0.294 | Mild |
| 1993 | 0.877 | 0.962 | 0.273 | 13.914 | 0.762 | 0.705 | 0.652 | 0.385 | 5 | 0.262 | Mild |
| 1994 | 0.474 | 0.909 | 0.082 | 4.132 | 0.513 | 0.424 | 0.350 | 0.774 | 25 | 0.075 | Extreme |
| 1995 | 0.585 | 0.932 | 0.095 | 6.685 | 0.613 | 0.533 | 0.463 | 0.741 | 25 | 0.089 | Extreme |
| 1996 | 0.853 | 0.970 | 0.176 | 12.924 | 0.806 | 0.758 | 0.713 | 0.559 | 5 | 0.171 | Severe |
| 1997 | 0.795 | 0.970 | 0.118 | 11.928 | 0.806 | 0.758 | 0.713 | 0.687 | 15 | 0.114 | Extreme |
| 1998 | 0.922 | 0.953 | 0.556 | 15.022 | 0.715 | 0.650 | 0.591 | 0.088 | 10 | 0.530 | Occasional |
| 1999 | 0.886 | 0.982 | 0.143 | 14.559 | 0.878 | 0.846 | 0.816 | 0.630 | 5 | 0.140 | Severe |
| 2000 | 0.841 | 0.937 | 0.333 | 12.250 | 0.633 | 0.556 | 0.488 | 0.296 | 15 | 0.312 | Occasional |
| 2001 | 0.813 | 0.949 | 0.222 | 12.083 | 0.693 | 0.624 | 0.562 | 0.471 | 5 | 0.211 | Moderate |
| 2002 | 0.876 | 0.972 | 0.200 | 14.017 | 0.818 | 0.772 | 0.729 | 0.512 | 5 | 0.194 | Moderate |
| 2003 | 0.836 | 0.907 | 0.474 | 12.424 | 0.506 | 0.416 | 0.343 | 0.146 | 10 | 0.430 | Occasional |
| 2004 | 0.692 | 0.954 | 0.103 | 9.198 | 0.719 | 0.655 | 0.596 | 0.721 | 10 | 0.099 | Extreme |
| 2005 | 0.843 | 0.950 | 0.267 | 12.892 | 0.701 | 0.633 | 0.572 | 0.394 | 10 | 0.253 | Mild |
| 2006 | 0.578 | 0.910 | 0.122 | 6.023 | 0.519 | 0.430 | 0.356 | 0.676 | 25 | 0.111 | Extreme |
| 2007 | 0.874 | 0.952 | 0.333 | 13.733 | 0.708 | 0.642 | 0.582 | 0.296 | 5 | 0.317 | Occasional |
| 2008 | 0.845 | 0.949 | 0.278 | 12.672 | 0.693 | 0.624 | 0.562 | 0.377 | 5 | 0.264 | Mild |
| 2009 | 0.762 | 0.969 | 0.100 | 11.102 | 0.801 | 0.751 | 0.705 | 0.729 | 5 | 0.097 | Extreme |
| 2010 | 0.793 | 0.948 | 0.200 | 11.561 | 0.688 | 0.618 | 0.555 | 0.512 | 5 | 0.190 | Moderate |

**Appendix-VII** Year-wise analysis of probability of wet and dry weeks and index of drought proneness in Rajshahi station for Kharif season

| | Kharif season using suitable threshold values (TV) in millimeters | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|
| Year | P | $P_{11}$ | $P_{01}$ | E(Y) | Probability of getting wet week at least | | | P(D>3) | TV | DI | Drought Classes |
| | | | | | 8 | 10 | 12 | | | | |
| 1960 | 0.879 | 0.971 | 0.214 | 13.692 | 0.811 | 0.764 | 0.720 | 0.485 | 5 | 0.208 | Moderate |
| 1961 | 0.828 | 0.958 | 0.200 | 12.177 | 0.742 | 0.682 | 0.626 | 0.512 | 5 | 0.192 | Moderate |
| 1962 | 0.802 | 0.968 | 0.130 | 11.453 | 0.795 | 0.744 | 0.697 | 0.658 | 5 | 0.126 | Severe |

| Year | Kharif season using suitable threshold values (TV) in millimeters | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|
| | P | $P_{11}$ | $P_{01}$ | E(Y) | Probability of getting wet week at least | | | P(D>3) | TV | DI | Drought Classes |
| | | | | | 8 | 10 | 12 | | | | |
| 1963 | 0.905 | 0.962 | 0.364 | 14.483 | 0.762 | 0.705 | 0.652 | 0.258 | 15 | 0.350 | Occasional |
| 1964 | 0.922 | 0.972 | 0.333 | 15.022 | 0.819 | 0.774 | 0.731 | 0.296 | 10 | 0.324 | Occasional |
| 1965 | 0.752 | 0.957 | 0.130 | 10.636 | 0.735 | 0.673 | 0.617 | 0.658 | 5 | 0.125 | Extreme |
| 1966 | 0.744 | 0.980 | 0.059 | 11.165 | 0.867 | 0.832 | 0.799 | 0.834 | 15 | 0.058 | Extreme |
| 1967 | 0.725 | 0.944 | 0.148 | 9.840 | 0.667 | 0.594 | 0.529 | 0.618 | 10 | 0.140 | Severe |
| 1968 | 0.613 | 0.921 | 0.125 | 7.180 | 0.562 | 0.477 | 0.405 | 0.670 | 25 | 0.115 | Extreme |
| 1969 | 0.795 | 0.970 | 0.118 | 11.928 | 0.806 | 0.758 | 0.713 | 0.687 | 15 | 0.114 | Extreme |
| 1970 | 0.897 | 0.971 | 0.250 | 14.217 | 0.815 | 0.768 | 0.725 | 0.422 | 5 | 0.243 | Mild |
| 1971 | 0.845 | 0.969 | 0.167 | 12.672 | 0.804 | 0.756 | 0.710 | 0.579 | 5 | 0.162 | Severe |
| 1972 | 0.819 | 0.947 | 0.238 | 11.933 | 0.685 | 0.615 | 0.552 | 0.442 | 5 | 0.226 | Moderate |
| 1973 | 0.924 | 0.973 | 0.333 | 15.318 | 0.824 | 0.780 | 0.738 | 0.296 | 5 | 0.324 | Occasional |
| 1974 | 0.905 | 0.990 | 0.091 | 14.483 | 0.935 | 0.917 | 0.900 | 0.751 | 5 | 0.090 | Extreme |
| 1975 | 0.000 | 0.991 | 0.000 | 0.000 | 0.939 | 0.922 | 0.905 | 1.000 | 10 | 0.000 | Extreme |
| 1976 | 0.720 | 0.920 | 0.207 | 9.566 | 0.556 | 0.470 | 0.397 | 0.499 | 10 | 0.190 | Moderate |
| 1977 | 0.622 | 0.978 | 0.037 | 8.447 | 0.853 | 0.815 | 0.779 | 0.893 | 10 | 0.036 | Extreme |
| 1978 | 0.818 | 0.970 | 0.133 | 12.501 | 0.810 | 0.762 | 0.718 | 0.651 | 5 | 0.129 | Severe |
| 1979 | 0.762 | 0.969 | 0.100 | 11.102 | 0.801 | 0.751 | 0.705 | 0.729 | 5 | 0.097 | Extreme |
| 1980 | 0.833 | 0.929 | 0.353 | 12.496 | 0.599 | 0.517 | 0.446 | 0.271 | 10 | 0.328 | Occasional |
| 1981 | 0.531 | 0.959 | 0.047 | 5.992 | 0.745 | 0.685 | 0.630 | 0.867 | 25 | 0.045 | Extreme |
| 1982 | 0.631 | 0.923 | 0.132 | 7.573 | 0.571 | 0.487 | 0.415 | 0.655 | 5 | 0.121 | Extreme |
| 1983 | 0.758 | 0.980 | 0.063 | 11.472 | 0.868 | 0.834 | 0.801 | 0.824 | 15 | 0.061 | Extreme |
| 1984 | 0.758 | 0.980 | 0.063 | 11.472 | 0.868 | 0.834 | 0.801 | 0.824 | 15 | 0.061 | Extreme |
| 1985 | 0.795 | 0.970 | 0.118 | 11.928 | 0.806 | 0.758 | 0.713 | 0.687 | 5 | 0.114 | Extreme |
| 1986 | 0.000 | 0.991 | 0.000 | 0.000 | 0.936 | 0.919 | 0.902 | 1.000 | 5 | 0.000 | Extreme |
| 1987 | 0.696 | 0.929 | 0.161 | 9.043 | 0.599 | 0.517 | 0.447 | 0.590 | 25 | 0.150 | Severe |
| 1988 | 0.441 | 0.855 | 0.115 | 3.843 | 0.333 | 0.243 | 0.177 | 0.694 | 25 | 0.098 | Extreme |
| 1989 | 0.638 | 0.868 | 0.233 | 3.280 | 0.371 | 0.279 | 0.211 | 0.452 | 5 | 0.202 | Moderate |
| 1990 | 0.000 | 0.991 | 0.000 | 0.000 | 0.937 | 0.920 | 0.903 | 1.000 | 5 | 0.000 | Extreme |
| 1991 | 0.852 | 0.971 | 0.167 | 13.396 | 0.815 | 0.768 | 0.725 | 0.579 | 5 | 0.162 | Severe |
| 1992 | 0.472 | 0.900 | 0.089 | 4.447 | 0.478 | 0.387 | 0.314 | 0.755 | 25 | 0.080 | Extreme |

| | Kharif season using suitable threshold values (TV) in millimeters | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|
| Year | P | $P_{11}$ | $P_{01}$ | E(Y) | Probability of getting wet week at least | | | P(D>3) | TV | DI | Drought Classes |
| | | | | | 8 | 10 | 12 | | | | |
| 1993 | 0.784 | 0.969 | 0.111 | 11.648 | 0.804 | 0.756 | 0.710 | 0.702 | 10 | 0.108 | Extreme |
| 1994 | 0.659 | 0.926 | 0.143 | 8.185 | 0.583 | 0.500 | 0.429 | 0.630 | 5 | 0.132 | Severe |
| 1995 | 0.625 | 0.950 | 0.083 | 7.679 | 0.698 | 0.630 | 0.569 | 0.770 | 25 | 0.079 | Extreme |
| 1996 | 0.560 | 0.877 | 0.157 | 5.764 | 0.399 | 0.307 | 0.236 | 0.599 | 20 | 0.138 | Severe |
| 1997 | 0.663 | 0.952 | 0.094 | 8.526 | 0.711 | 0.645 | 0.585 | 0.744 | 5 | 0.089 | Extreme |
| 1998 | 0.931 | 0.981 | 0.250 | 15.296 | 0.877 | 0.845 | 0.814 | 0.422 | 5 | 0.245 | Mild |
| 1999 | 0.902 | 0.982 | 0.167 | 14.941 | 0.879 | 0.848 | 0.817 | 0.579 | 5 | 0.164 | Severe |
| 2000 | 0.836 | 0.959 | 0.211 | 12.424 | 0.745 | 0.685 | 0.629 | 0.492 | 10 | 0.202 | Moderate |
| 2001 | 0.553 | 0.882 | 0.146 | 5.851 | 0.416 | 0.324 | 0.252 | 0.623 | 25 | 0.129 | Severe |
| 2002 | 0.793 | 0.948 | 0.200 | 11.561 | 0.688 | 0.618 | 0.555 | 0.512 | 5 | 0.190 | Moderate |
| 2003 | 0.595 | 0.919 | 0.119 | 6.798 | 0.553 | 0.467 | 0.395 | 0.684 | 15 | 0.109 | Extreme |
| 2004 | 0.000 | 0.990 | 0.000 | 0.000 | 0.932 | 0.914 | 0.895 | 1.000 | 5 | 0.000 | Extreme |
| 2005 | 0.506 | 0.906 | 0.096 | 5.063 | 0.502 | 0.412 | 0.339 | 0.738 | 20 | 0.087 | Extreme |
| 2006 | 0.783 | 0.958 | 0.150 | 11.404 | 0.742 | 0.682 | 0.626 | 0.614 | 5 | 0.144 | Severe |
| 2007 | 0.833 | 0.950 | 0.250 | 12.619 | 0.698 | 0.630 | 0.569 | 0.422 | 5 | 0.238 | Mild |
| 2008 | 0.862 | 0.960 | 0.250 | 13.177 | 0.751 | 0.693 | 0.638 | 0.422 | 5 | 0.240 | Mild |
| 2009 | 0.586 | 0.918 | 0.116 | 6.612 | 0.549 | 0.462 | 0.389 | 0.690 | 25 | 0.107 | Extreme |
| 2010 | 0.776 | 0.933 | 0.231 | 10.640 | 0.617 | 0.537 | 0.468 | 0.455 | 5 | 0.215 | Moderate |

**Appendix-VIII** Year-wise analysis of probability of wet and dry weeks and index of drought proneness in Faridpur station for Kharif season

| | Kharif season using suitable threshold values (TV) in millimeters | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|
| Year | P | $P_{11}$ | $P_{01}$ | E(Y) | Probability of getting wet week at least | | | P(D>3) | TV | DI | Drought Classes |
| | | | | | 8 | 10 | 12 | | | | |
| 1960 | 0.871 | 0.970 | 0.200 | 13.433 | 0.810 | 0.762 | 0.718 | 0.512 | 5 | 0.194 | Moderate |
| 1961 | 0.828 | 0.948 | 0.250 | 12.177 | 0.688 | 0.618 | 0.555 | 0.422 | 10 | 0.237 | Mild |
| 1962 | 0.828 | 0.979 | 0.100 | 12.177 | 0.863 | 0.827 | 0.793 | 0.729 | 5 | 0.098 | Extreme |
| 1963 | 0.853 | 0.970 | 0.176 | 12.924 | 0.806 | 0.758 | 0.713 | 0.559 | 5 | 0.171 | Severe |

| | Kharif season using suitable threshold values (TV) in millimeters | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|
| Year | P | $P_{11}$ | $P_{01}$ | E(Y) | Probability of getting wet week at least | | | P(D>3) | TV | DI | Drought Classes |
| | | | | | 8 | 10 | 12 | | | | |
| 1964 | 0.957 | 0.982 | 0.400 | 16.131 | 0.880 | 0.849 | 0.819 | 0.216 | 5 | 0.393 | Occasional |
| 1965 | 0.957 | 0.982 | 0.400 | 16.131 | 0.880 | 0.849 | 0.819 | 0.216 | 5 | 0.393 | Occasional |
| 1966 | 0.558 | 0.930 | 0.089 | 6.138 | 0.600 | 0.518 | 0.448 | 0.756 | 25 | 0.083 | Extreme |
| 1967 | 0.585 | 0.932 | 0.095 | 6.685 | 0.613 | 0.533 | 0.463 | 0.741 | 25 | 0.089 | Extreme |
| 1968 | 0.741 | 0.965 | 0.100 | 9.850 | 0.780 | 0.726 | 0.677 | 0.729 | 5 | 0.097 | Extreme |
| 1969 | 0.725 | 0.944 | 0.148 | 9.840 | 0.667 | 0.594 | 0.529 | 0.618 | 15 | 0.140 | Severe |
| 1970 | 0.876 | 0.972 | 0.200 | 14.017 | 0.818 | 0.772 | 0.729 | 0.512 | 15 | 0.194 | Moderate |
| 1971 | 0.940 | 0.972 | 0.429 | 15.571 | 0.823 | 0.778 | 0.736 | 0.187 | 5 | 0.417 | Occasional |
| 1972 | 0.886 | 0.982 | 0.143 | 14.559 | 0.878 | 0.846 | 0.816 | 0.630 | 5 | 0.140 | Severe |
| 1973 | 0.899 | 0.972 | 0.250 | 14.258 | 0.819 | 0.774 | 0.731 | 0.422 | 5 | 0.243 | Mild |
| 1974 | 0.871 | 0.960 | 0.267 | 13.433 | 0.754 | 0.695 | 0.641 | 0.394 | 5 | 0.256 | Mild |
| 1975 | 0.902 | 0.982 | 0.167 | 14.941 | 0.879 | 0.848 | 0.817 | 0.579 | 5 | 0.164 | Severe |
| 1976 | 0.715 | 0.907 | 0.233 | 9.397 | 0.505 | 0.415 | 0.342 | 0.451 | 15 | 0.212 | Moderate |
| 1977 | 0.761 | 0.912 | 0.280 | 10.546 | 0.525 | 0.437 | 0.363 | 0.373 | 10 | 0.255 | Mild |
| 1978 | 0.888 | 0.972 | 0.222 | 14.334 | 0.819 | 0.774 | 0.731 | 0.471 | 5 | 0.216 | Moderate |
| 1979 | 0.762 | 0.969 | 0.100 | 11.102 | 0.801 | 0.751 | 0.705 | 0.729 | 5 | 0.097 | Extreme |
| 1980 | 0.000 | 0.991 | 0.000 | 0.000 | 0.940 | 0.924 | 0.908 | 1.000 | 5 | 0.000 | Extreme |
| 1981 | 0.634 | 0.951 | 0.086 | 7.885 | 0.702 | 0.634 | 0.573 | 0.764 | 25 | 0.081 | Extreme |
| 1982 | 0.715 | 0.943 | 0.143 | 9.607 | 0.664 | 0.591 | 0.525 | 0.630 | 15 | 0.135 | Severe |
| 1983 | 0.910 | 0.963 | 0.375 | 14.822 | 0.768 | 0.712 | 0.660 | 0.244 | 10 | 0.361 | Occasional |
| 1984 | 0.836 | 0.969 | 0.158 | 12.304 | 0.803 | 0.754 | 0.708 | 0.597 | 20 | 0.153 | Severe |
| 1985 | 0.771 | 0.980 | 0.067 | 11.785 | 0.869 | 0.835 | 0.803 | 0.813 | 5 | 0.065 | Extreme |
| 1986 | 0.841 | 0.981 | 0.100 | 13.460 | 0.875 | 0.842 | 0.811 | 0.729 | 10 | 0.098 | Extreme |
| 1987 | 0.867 | 0.962 | 0.250 | 13.619 | 0.760 | 0.703 | 0.650 | 0.422 | 5 | 0.240 | Mild |

| | Kharif season using suitable threshold values (TV) in millimeters | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|
| Year | P | $P_{11}$ | $P_{01}$ | E(Y) | Probability of getting wet week at least | | | P(D>3) | TV | DI | Drought Classes |
| | | | | | 8 | 10 | 12 | | | | |
| 1988 | 0.876 | 0.972 | 0.200 | 14.017 | 0.818 | 0.772 | 0.729 | 0.512 | 5 | 0.194 | Moderate |
| 1989 | 0.876 | 0.972 | 0.200 | 14.017 | 0.818 | 0.772 | 0.729 | 0.512 | 5 | 0.194 | Moderate |
| 1990 | 0.559 | 0.914 | 0.109 | 6.070 | 0.534 | 0.446 | 0.373 | 0.708 | 25 | 0.099 | Extreme |
| 1991 | 0.931 | 0.991 | 0.125 | 15.296 | 0.937 | 0.920 | 0.903 | 0.670 | 5 | 0.124 | Extreme |
| 1992 | 0.902 | 0.982 | 0.167 | 14.941 | 0.879 | 0.848 | 0.817 | 0.579 | 5 | 0.164 | Severe |
| 1993 | 0.000 | 0.991 | 0.000 | 0.000 | 0.938 | 0.921 | 0.904 | 1.000 | 10 | 0.000 | Extreme |
| 1994 | 0.514 | 0.924 | 0.080 | 5.283 | 0.576 | 0.492 | 0.420 | 0.779 | 25 | 0.074 | Extreme |
| 1995 | 0.922 | 0.963 | 0.444 | 15.022 | 0.766 | 0.710 | 0.658 | 0.171 | 5 | 0.428 | Occasional |
| 1996 | 0.767 | 0.955 | 0.148 | 10.522 | 0.725 | 0.661 | 0.603 | 0.618 | 5 | 0.141 | Severe |
| 1997 | 0.795 | 0.970 | 0.118 | 11.928 | 0.806 | 0.758 | 0.713 | 0.687 | 5 | 0.114 | Extreme |
| 1998 | 0.876 | 0.972 | 0.200 | 14.017 | 0.818 | 0.772 | 0.729 | 0.512 | 5 | 0.194 | Moderate |
| 1999 | 0.886 | 0.982 | 0.143 | 14.559 | 0.878 | 0.846 | 0.816 | 0.630 | 5 | 0.140 | Severe |
| 2000 | 0.834 | 0.905 | 0.476 | 12.154 | 0.498 | 0.408 | 0.335 | 0.144 | 25 | 0.431 | Occasional |
| 2001 | 0.879 | 0.941 | 0.429 | 14.948 | 0.654 | 0.579 | 0.513 | 0.187 | 10 | 0.403 | Occasional |
| 2002 | 0.922 | 0.972 | 0.333 | 15.022 | 0.819 | 0.774 | 0.731 | 0.296 | 10 | 0.324 | Occasional |
| 2003 | 0.819 | 0.916 | 0.381 | 11.933 | 0.540 | 0.453 | 0.380 | 0.237 | 10 | 0.349 | Occasional |
| 2004 | 0.827 | 0.981 | 0.091 | 13.110 | 0.874 | 0.841 | 0.809 | 0.751 | 10 | 0.089 | Extreme |
| 2005 | 0.829 | 0.971 | 0.143 | 12.794 | 0.811 | 0.764 | 0.720 | 0.630 | 10 | 0.139 | Severe |
| 2006 | 0.827 | 0.981 | 0.091 | 13.110 | 0.874 | 0.841 | 0.809 | 0.751 | 5 | 0.089 | Extreme |
| 2007 | 0.900 | 0.972 | 0.250 | 14.657 | 0.821 | 0.776 | 0.734 | 0.422 | 5 | 0.243 | Mild |
| 2008 | 0.853 | 0.980 | 0.118 | 12.924 | 0.867 | 0.832 | 0.799 | 0.687 | 5 | 0.115 | Extreme |
| 2009 | 0.612 | 0.935 | 0.103 | 7.260 | 0.625 | 0.546 | 0.478 | 0.723 | 25 | 0.096 | Extreme |
| 2010 | 0.817 | 0.918 | 0.368 | 12.023 | 0.547 | 0.461 | 0.388 | 0.252 | 10 | 0.338 | Occasional |

**Appendix-IX** Year-wise analysis of probability of wet and dry weeks and index of drought proneness in Jessore station for Kharif season

| | Kharif season using suitable threshold values (TV) in millimeters | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|
| Year | P | $P_{11}$ | $P_{01}$ | E(Y) | Probability of getting wet week at least | | | P(D>3) | TV | DI | Drought Classes |
| | | | | | 8 | 10 | 12 | | | | |
| 1960 | 0.862 | 0.970 | 0.188 | 13.177 | 0.808 | 0.760 | 0.715 | 0.536 | 10 | 0.182 | Moderate |
| 1961 | 0.888 | 0.961 | 0.308 | 13.953 | 0.758 | 0.700 | 0.647 | 0.332 | 5 | 0.296 | Mild |
| 1962 | 0.879 | 0.990 | 0.071 | 13.692 | 0.933 | 0.915 | 0.897 | 0.801 | 5 | 0.071 | Extreme |
| 1963 | 0.948 | 0.982 | 0.333 | 15.850 | 0.879 | 0.848 | 0.817 | 0.296 | 5 | 0.327 | Occasional |
| 1964 | 0.931 | 0.972 | 0.375 | 15.296 | 0.821 | 0.776 | 0.734 | 0.244 | 5 | 0.365 | Occasional |
| 1965 | 0.771 | 0.980 | 0.067 | 11.785 | 0.869 | 0.835 | 0.803 | 0.813 | 5 | 0.065 | Extreme |
| 1966 | 0.888 | 0.962 | 0.300 | 14.212 | 0.764 | 0.707 | 0.655 | 0.343 | 5 | 0.289 | Mild |
| 1967 | 0.762 | 0.969 | 0.100 | 11.102 | 0.801 | 0.751 | 0.705 | 0.729 | 20 | 0.097 | Extreme |
| 1968 | 0.871 | 0.980 | 0.133 | 13.433 | 0.869 | 0.835 | 0.803 | 0.651 | 5 | 0.131 | Severe |
| 1969 | 0.731 | 0.980 | 0.056 | 10.866 | 0.866 | 0.831 | 0.797 | 0.842 | 10 | 0.054 | Extreme |
| 1970 | 0.888 | 0.972 | 0.222 | 14.334 | 0.819 | 0.774 | 0.731 | 0.471 | 5 | 0.216 | Moderate |
| 1971 | 0.922 | 0.972 | 0.333 | 15.022 | 0.819 | 0.774 | 0.731 | 0.296 | 10 | 0.324 | Occasional |
| 1972 | 0.742 | 0.957 | 0.125 | 10.387 | 0.733 | 0.670 | 0.613 | 0.670 | 5 | 0.120 | Extreme |
| 1973 | 0.829 | 0.939 | 0.294 | 12.437 | 0.646 | 0.570 | 0.503 | 0.352 | 15 | 0.276 | Mild |
| 1974 | 0.922 | 0.981 | 0.222 | 15.022 | 0.876 | 0.844 | 0.813 | 0.471 | 5 | 0.218 | Moderate |
| 1975 | 0.983 | 0.982 | 1.000 | 16.988 | 0.883 | 0.853 | 0.823 | 0.000 | 5 | 0.982 | Occasional |
| 1976 | 0.824 | 0.960 | 0.188 | 12.480 | 0.751 | 0.693 | 0.638 | 0.536 | 5 | 0.180 | Severe |
| 1977 | 0.677 | 0.940 | 0.125 | 8.710 | 0.651 | 0.576 | 0.509 | 0.670 | 15 | 0.118 | Extreme |
| 1978 | 0.933 | 0.982 | 0.250 | 15.733 | 0.882 | 0.850 | 0.820 | 0.422 | 5 | 0.246 | Mild |
| 1979 | 0.569 | 0.946 | 0.071 | 6.505 | 0.678 | 0.606 | 0.543 | 0.801 | 25 | 0.068 | Extreme |
| 1980 | 0.899 | 0.963 | 0.333 | 14.515 | 0.766 | 0.710 | 0.658 | 0.296 | 5 | 0.321 | Occasional |
| 1981 | 0.560 | 0.945 | 0.070 | 6.321 | 0.674 | 0.602 | 0.538 | 0.805 | 25 | 0.066 | Extreme |
| 1982 | 0.578 | 0.925 | 0.102 | 6.023 | 0.581 | 0.498 | 0.426 | 0.724 | 25 | 0.094 | Extreme |
| 1983 | 0.914 | 0.991 | 0.100 | 14.621 | 0.936 | 0.918 | 0.901 | 0.729 | 10 | 0.099 | Extreme |
| 1984 | 0.729 | 0.968 | 0.087 | 10.316 | 0.795 | 0.744 | 0.697 | 0.761 | 15 | 0.084 | Extreme |

| | Kharif season using suitable threshold values (TV) in millimeters | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|
| Year | P | $P_{11}$ | $P_{01}$ | E(Y) | Probability of getting wet week at least | | | P(D>3) | TV | DI | Drought Classes |
| | | | | | 8 | 10 | 12 | | | | |
| 1985 | 0.762 | 0.969 | 0.100 | 11.102 | 0.801 | 0.751 | 0.705 | 0.729 | 15 | 0.097 | Extreme |
| 1986 | 0.856 | 0.981 | 0.111 | 13.818 | 0.876 | 0.844 | 0.813 | 0.702 | 5 | 0.109 | Extreme |
| 1987 | 0.829 | 0.939 | 0.294 | 12.437 | 0.646 | 0.570 | 0.503 | 0.352 | 15 | 0.276 | Mild |
| 1988 | 0.783 | 0.958 | 0.150 | 11.404 | 0.742 | 0.682 | 0.626 | 0.614 | 5 | 0.144 | Severe |
| 1989 | #VAL | 1.000 | NaN | #VAL! | 1.000 | 1.000 | 1.000 | #VAL! | | #VAL | #VAL! |
| 1990 | 0.864 | 0.971 | 0.182 | 13.704 | 0.816 | 0.770 | 0.727 | 0.548 | 5 | 0.177 | Severe |
| 1991 | 0.706 | 0.906 | 0.226 | 9.176 | 0.501 | 0.411 | 0.337 | 0.464 | 20 | 0.205 | Moderate |
| 1992 | 0.854 | 0.951 | 0.286 | 13.169 | 0.703 | 0.636 | 0.575 | 0.364 | 5 | 0.272 | Mild |
| 1993 | 0.841 | 0.981 | 0.100 | 13.460 | 0.875 | 0.842 | 0.811 | 0.729 | 5 | 0.098 | Extreme |
| 1994 | 0.533 | 0.910 | 0.102 | 5.554 | 0.519 | 0.430 | 0.356 | 0.724 | 25 | 0.093 | Extreme |
| 1995 | 0.833 | 0.950 | 0.250 | 12.619 | 0.698 | 0.630 | 0.569 | 0.422 | 25 | 0.238 | Mild |
| 1996 | 0.828 | 0.979 | 0.100 | 12.177 | 0.863 | 0.827 | 0.793 | 0.729 | 10 | 0.098 | Extreme |
| 1997 | 0.617 | 0.963 | 0.059 | 7.751 | 0.770 | 0.715 | 0.664 | 0.834 | 25 | 0.057 | Extreme |
| 1998 | 0.897 | 0.962 | 0.333 | 14.217 | 0.760 | 0.703 | 0.650 | 0.296 | 5 | 0.321 | Occasional |
| 1999 | 0.910 | 0.963 | 0.375 | 14.822 | 0.768 | 0.712 | 0.660 | 0.244 | 10 | 0.361 | Occasional |
| 2000 | 0.978 | 0.991 | 0.400 | 16.486 | 0.939 | 0.922 | 0.905 | 0.216 | 5 | 0.396 | Occasional |
| 2001 | 0.759 | 0.955 | 0.143 | 10.296 | 0.722 | 0.658 | 0.599 | 0.630 | 5 | 0.136 | Severe |
| 2002 | 0.744 | 0.980 | 0.059 | 11.165 | 0.867 | 0.832 | 0.799 | 0.834 | 5 | 0.058 | Extreme |
| 2003 | 0.845 | 0.939 | 0.333 | 12.672 | 0.643 | 0.566 | 0.499 | 0.296 | 20 | 0.313 | Occasional |
| 2004 | 0.798 | 0.981 | 0.077 | 12.433 | 0.872 | 0.838 | 0.806 | 0.787 | 5 | 0.075 | Extreme |
| 2005 | 0.955 | 0.964 | 0.750 | 16.091 | 0.775 | 0.721 | 0.670 | 0.016 | 5 | 0.723 | Occasional |
| 2006 | 0.677 | 0.966 | 0.071 | 9.090 | 0.784 | 0.732 | 0.683 | 0.801 | 25 | 0.069 | Extreme |
| 2007 | 0.867 | 0.962 | 0.250 | 13.619 | 0.760 | 0.703 | 0.650 | 0.422 | 5 | 0.240 | Mild |
| 2008 | 0.897 | 0.990 | 0.083 | 14.217 | 0.935 | 0.917 | 0.899 | 0.770 | 10 | 0.083 | Extreme |
| 2009 | 0.719 | 0.967 | 0.083 | 10.062 | 0.793 | 0.742 | 0.694 | 0.770 | 20 | 0.081 | Extreme |
| 2010 | 0.586 | 0.882 | 0.167 | 6.197 | 0.416 | 0.324 | 0.252 | 0.579 | 25 | 0.147 | Severe |

**Appendix-X** Year-wise analysis of probability of wet and dry weeks and index of drought proneness in Khulna station for Kharif season

| | Kharif season using suitable threshold values (TV) in millimeters | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|
| Year | P | $P_{11}$ | $P_{01}$ | E(Y) | Probability of getting wet week at least | | | P(D>3) | TV | DI | Drought Classes |
| | | | | | 8 | 10 | 12 | | | | |
| 1960 | 0.879 | 0.971 | 0.214 | 13.692 | 0.811 | 0.764 | 0.720 | 0.485 | 10 | 0.208 | Moderate |
| 1961 | 0.598 | 0.890 | 0.163 | 6.745 | 0.444 | 0.352 | 0.279 | 0.587 | 15 | 0.145 | Severe |
| 1962 | 0.845 | 0.980 | 0.111 | 12.672 | 0.866 | 0.831 | 0.797 | 0.702 | 5 | 0.109 | Extreme |
| 1963 | 0.897 | 0.971 | 0.250 | 14.217 | 0.815 | 0.768 | 0.725 | 0.422 | 5 | 0.243 | Mild |
| 1964 | 0.912 | 0.972 | 0.286 | 14.985 | 0.823 | 0.778 | 0.736 | 0.364 | 5 | 0.278 | Mild |
| 1965 | 0.843 | 0.950 | 0.267 | 12.892 | 0.701 | 0.633 | 0.572 | 0.394 | 5 | 0.253 | Mild |
| 1966 | 0.884 | 0.952 | 0.364 | 14.021 | 0.711 | 0.645 | 0.585 | 0.258 | 5 | 0.346 | Occasional |
| 1967 | 0.740 | 0.968 | 0.091 | 10.574 | 0.797 | 0.747 | 0.700 | 0.751 | 25 | 0.088 | Extreme |
| 1968 | 0.345 | 0.900 | 0.053 | 2.266 | 0.478 | 0.387 | 0.314 | 0.850 | 25 | 0.047 | Extreme |
| 1969 | 0.686 | 0.929 | 0.156 | 8.824 | 0.595 | 0.513 | 0.443 | 0.601 | 5 | 0.145 | Severe |
| 1970 | 0.793 | 0.959 | 0.158 | 11.667 | 0.745 | 0.685 | 0.629 | 0.597 | 5 | 0.151 | Severe |
| 1971 | 0.821 | 0.946 | 0.250 | 11.617 | 0.676 | 0.605 | 0.541 | 0.422 | 5 | 0.236 | Mild |
| 1972 | 0.899 | 0.963 | 0.333 | 14.515 | 0.766 | 0.710 | 0.658 | 0.296 | 5 | 0.321 | Occasional |
| 1973 | 0.940 | 0.972 | 0.429 | 15.571 | 0.823 | 0.778 | 0.736 | 0.187 | 10 | 0.417 | Occasional |
| 1974 | 0.931 | 0.991 | 0.125 | 15.296 | 0.937 | 0.920 | 0.903 | 0.670 | 10 | 0.124 | Extreme |
| 1975 | #VAL | 1.000 | NaN | #VAL! | 1.000 | 1.000 | 1.000 | #VAL! | | #VAE! | #VAL! |
| 1976 | 0.876 | 0.972 | 0.200 | 14.017 | 0.818 | 0.772 | 0.729 | 0.512 | 5 | 0.194 | Moderate |
| 1977 | 0.897 | 0.971 | 0.250 | 14.217 | 0.815 | 0.768 | 0.725 | 0.422 | 5 | 0.243 | Mild |
| 1978 | 0.814 | 0.960 | 0.176 | 12.205 | 0.749 | 0.690 | 0.635 | 0.559 | 15 | 0.169 | Severe |
| 1979 | 0.594 | 0.933 | 0.098 | 6.874 | 0.617 | 0.537 | 0.468 | 0.735 | 25 | 0.091 | Extreme |
| 1980 | 0.876 | 0.972 | 0.200 | 14.017 | 0.818 | 0.772 | 0.729 | 0.512 | 5 | 0.194 | Moderate |
| 1981 | 0.722 | 0.956 | 0.115 | 9.901 | 0.727 | 0.664 | 0.606 | 0.692 | 10 | 0.110 | Extreme |
| 1982 | 0.802 | 0.968 | 0.130 | 11.339 | 0.795 | 0.744 | 0.697 | 0.658 | 5 | 0.126 | Severe |
| 1983 | 0.914 | 0.962 | 0.400 | 14.751 | 0.764 | 0.707 | 0.655 | 0.216 | 15 | 0.385 | Occasional |
| 1984 | 0.607 | 0.963 | 0.057 | 7.541 | 0.768 | 0.712 | 0.660 | 0.838 | 25 | 0.055 | Extreme |
| 1985 | 0.744 | 0.980 | 0.059 | 11.165 | 0.867 | 0.832 | 0.799 | 0.834 | 10 | 0.058 | Extreme |

| | Kharif season using suitable threshold values (TV) in millimeters | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|
| Year | P | $P_{11}$ | $P_{01}$ | E(Y) | Probability of getting wet week at least | | | P(D>3) | TV | DI | Drought Classes |
| | | | | | 8 | 10 | 12 | | | | |
| 1986 | 0.773 | 0.969 | 0.105 | 11.373 | 0.803 | 0.754 | 0.708 | 0.716 | 20 | 0.102 | Extreme |
| 1987 | 0.558 | 0.930 | 0.089 | 6.138 | 0.600 | 0.518 | 0.448 | 0.756 | 25 | 0.083 | Extreme |
| 1988 | 0.867 | 0.962 | 0.250 | 13.619 | 0.760 | 0.703 | 0.650 | 0.422 | 10 | 0.240 | Mild |
| 1989 | 0.914 | 0.953 | 0.500 | 14.751 | 0.713 | 0.647 | 0.588 | 0.125 | 10 | 0.476 | Occasional |
| 1990 | 0.000 | 0.990 | 0.000 | 0.000 | 0.933 | 0.914 | 0.896 | 1.000 | 15 | 0.000 | Extreme |
| 1991 | 0.915 | 0.962 | 0.417 | 14.517 | 0.760 | 0.703 | 0.650 | 0.198 | 10 | 0.401 | Occasional |
| 1992 | 0.818 | 0.970 | 0.133 | 12.501 | 0.810 | 0.762 | 0.718 | 0.651 | 5 | 0.129 | Severe |
| 1993 | 0.000 | 0.991 | 0.000 | 0.000 | 0.938 | 0.921 | 0.904 | 1.000 | 10 | 0.000 | Extreme |
| 1994 | 0.649 | 0.938 | 0.114 | 8.070 | 0.640 | 0.564 | 0.496 | 0.695 | 15 | 0.107 | Extreme |
| 1995 | 0.852 | 0.971 | 0.167 | 13.396 | 0.815 | 0.768 | 0.725 | 0.579 | 5 | 0.162 | Severe |
| 1996 | 0.621 | 0.903 | 0.159 | 7.005 | 0.489 | 0.398 | 0.325 | 0.595 | 20 | 0.144 | Severe |
| 1997 | 0.636 | 0.964 | 0.063 | 8.182 | 0.775 | 0.721 | 0.670 | 0.824 | 20 | 0.060 | Extreme |
| 1998 | 0.966 | 0.982 | 0.500 | 16.414 | 0.882 | 0.850 | 0.820 | 0.125 | 5 | 0.491 | Occasional |
| 1999 | 0.957 | 0.991 | 0.200 | 16.131 | 0.939 | 0.922 | 0.905 | 0.512 | 5 | 0.198 | Moderate |
| 2000 | 0.782 | 0.953 | 0.167 | 10.387 | 0.716 | 0.651 | 0.592 | 0.579 | 10 | 0.159 | Severe |
| 2001 | 0.783 | 0.958 | 0.150 | 11.404 | 0.742 | 0.682 | 0.626 | 0.614 | 10 | 0.144 | Severe |
| 2002 | 0.673 | 0.953 | 0.097 | 8.747 | 0.714 | 0.648 | 0.588 | 0.737 | 25 | 0.092 | Extreme |
| 2003 | 0.974 | 0.991 | 0.333 | 16.700 | 0.940 | 0.923 | 0.907 | 0.296 | 5 | 0.330 | Occasional |
| 2004 | 0.729 | 0.968 | 0.087 | 10.316 | 0.795 | 0.744 | 0.697 | 0.761 | 25 | 0.084 | Extreme |
| 2005 | 0.962 | 0.973 | 0.667 | 16.349 | 0.828 | 0.785 | 0.744 | 0.037 | 5 | 0.649 | Occasional |
| 2006 | 0.871 | 0.981 | 0.125 | 14.184 | 0.877 | 0.845 | 0.814 | 0.670 | 5 | 0.123 | Extreme |
| 2007 | 0.902 | 0.982 | 0.167 | 14.941 | 0.879 | 0.848 | 0.817 | 0.579 | 5 | 0.164 | Severe |
| 2008 | 0.681 | 0.949 | 0.108 | 8.367 | 0.695 | 0.626 | 0.565 | 0.709 | 25 | 0.103 | Extreme |
| 2009 | 0.793 | 0.959 | 0.158 | 11.667 | 0.745 | 0.685 | 0.629 | 0.597 | 20 | 0.151 | Severe |
| 2010 | 0.910 | 0.963 | 0.375 | 14.822 | 0.768 | 0.712 | 0.660 | 0.244 | 5 | 0.361 | Occasional |

**Appendix-XI** Year-wise analysis of probability of wet and dry weeks and index of drought proneness in Satkhira station for Kharif season

| | Kharif season using suitable threshold values (TV) in millimeters | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|
| Year | $P$ | $P_{11}$ | $P_{01}$ | E(Y) | Probability of getting wet week at least | | | P(D>3) | TV | DI | Drought Classes |
| | | | | | 8 | 10 | 12 | | | | |
| 1960 | 0.827 | 0.981 | 0.091 | 13.110 | 0.874 | 0.841 | 0.809 | 0.751 | 10 | 0.089 | Extreme |
| 1961 | 0.856 | 0.981 | 0.111 | 13.818 | 0.876 | 0.844 | 0.813 | 0.702 | 5 | 0.109 | Extreme |
| 1962 | 0.815 | 0.966 | 0.148 | 11.172 | 0.787 | 0.734 | 0.686 | 0.618 | 5 | 0.143 | Severe |
| 1963 | 0.957 | 0.982 | 0.400 | 16.131 | 0.880 | 0.849 | 0.819 | 0.216 | 5 | 0.393 | Occasional |
| 1964 | 0.867 | 0.962 | 0.250 | 13.619 | 0.760 | 0.703 | 0.650 | 0.422 | 10 | 0.240 | Mild |
| 1965 | 0.862 | 0.980 | 0.125 | 13.177 | 0.868 | 0.834 | 0.801 | 0.670 | 10 | 0.123 | Extreme |
| 1966 | 0.371 | 0.884 | 0.068 | 2.595 | 0.421 | 0.329 | 0.257 | 0.808 | 25 | 0.061 | Extreme |
| 1967 | 0.742 | 0.957 | 0.125 | 10.387 | 0.733 | 0.670 | 0.613 | 0.670 | 25 | 0.120 | Extreme |
| 1968 | 0.871 | 0.980 | 0.133 | 13.433 | 0.869 | 0.835 | 0.803 | 0.651 | 5 | 0.131 | Severe |
| 1969 | 0.867 | 0.962 | 0.250 | 13.619 | 0.760 | 0.703 | 0.650 | 0.422 | 5 | 0.240 | Mild |
| 1970 | 0.876 | 0.972 | 0.200 | 14.017 | 0.818 | 0.772 | 0.729 | 0.512 | 10 | 0.194 | Moderate |
| 1971 | 0.897 | 0.962 | 0.333 | 14.217 | 0.760 | 0.703 | 0.650 | 0.296 | 15 | 0.321 | Occasional |
| 1972 | 0.922 | 0.972 | 0.333 | 15.022 | 0.819 | 0.774 | 0.731 | 0.296 | 20 | 0.324 | Occasional |
| 1973 | 0.922 | 0.972 | 0.333 | 15.022 | 0.819 | 0.774 | 0.731 | 0.296 | 20 | 0.324l | Occasional |
| 1974 | 0.940 | 0.963 | 0.571 | 15.571 | 0.770 | 0.714 | 0.663 | 0.079 | 5 | 0.550 | Occasional |
| 1975 | 0.983 | 0.982 | 1.000 | 16.988 | 0.883 | 0.853 | 0.823 | 0.000 | 5 | 0.982 | Occasional |
| 1976 | 0.886 | 0.982 | 0.143 | 14.559 | 0.878 | 0.846 | 0.816 | 0.630 | 5 | 0.140 | Severe |
| 1977 | 0.828 | 0.969 | 0.150 | 12.177 | 0.801 | 0.751 | 0.705 | 0.614 | 5 | 0.145 | Severe |
| 1978 | 0.829 | 0.971 | 0.143 | 12.794 | 0.811 | 0.764 | 0.720 | 0.630 | 5 | 0.139 | Severe |
| 1979 | 0.750 | 0.954 | 0.138 | 10.071 | 0.719 | 0.655 | 0.596 | 0.641 | 10 | 0.132 | Severe |
| 1980 | 0.856 | 0.961 | 0.231 | 13.328 | 0.758 | 0.700 | 0.647 | 0.455 | 5 | 0.222 | Moderate |
| 1981 | 0.617 | 0.963 | 0.059 | 7.751 | 0.770 | 0.715 | 0.664 | 0.834 | 25 | 0.057 | Extreme |
| 1982 | 0.664 | 0.961 | 0.077 | 7.871 | 0.757 | 0.699 | 0.646 | 0.787 | 25 | 0.074 | Extreme |
| 1983 | 0.940 | 0.972 | 0.429 | 15.571 | 0.823 | 0.778 | 0.736 | 0.187 | 5 | 0.417 | Occasional |
| 1984 | 0.905 | 0.953 | 0.444 | 14.607 | 0.715 | 0.650 | 0.591 | 0.171 | 5 | 0.424 | Occasional |
| 1985 | 0.000 | 0.991 | 0.000 | 0.000 | 0.938 | 0.920 | 0.904 | 1.000 | 5 | 0.000 | Extreme |
| 1986 | 0.841 | 0.981 | 0.100 | 13.460 | 0.875 | 0.842 | 0.811 | 0.729 | 25 | 0.098 | Extreme |
| 1987 | 0.731 | 0.980 | 0.056 | 10.866 | 0.866 | 0.831 | 0.797 | 0.842 | 5 | 0.054 | Extreme |
| 1988 | 0.803 | 0.948 | 0.211 | 11.820 | 0.690 | 0.621 | 0.559 | 0.492 | 5 | 0.200 | Moderate |
| 1989 | 0.897 | 0.962 | 0.333 | 14.217 | 0.760 | 0.703 | 0.650 | 0.296 | 20 | 0.321 | Occasional |
| 1990 | 0.758 | 0.980 | 0.063 | 11.472 | 0.868 | 0.834 | 0.801 | 0.824 | 20 | 0.061 | Extreme |
| 1991 | 0.871 | 0.970 | 0.200 | 13.433 | 0.810 | 0.762 | 0.718 | 0.512 | 10 | 0.194 | Moderate |
| 1992 | 0.000 | 0.991 | 0.000 | 0.000 | 0.940 | 0.923 | 0.907 | 1.000 | 5 | 0.000 | Extreme |
| 1993 | 0.933 | 0.982 | 0.250 | 15.733 | 0.882 | 0.850 | 0.820 | 0.422 | 10 | 0.246 | Mild |
| 1994 | 0.636 | 0.964 | 0.063 | 8.182 | 0.775 | 0.721 | 0.670 | 0.824 | 25 | 0.060 | Extreme |
| 1995 | 0.480 | 0.902 | 0.091 | 4.597 | 0.484 | 0.394 | 0.320 | 0.751 | 25 | 0.082 | Extreme |
| 1996 | 0.638 | 0.892 | 0.190 | 7.382 | 0.449 | 0.357 | 0.284 | 0.531 | 25 | 0.170 | Severe |

| Year | Kharif season using suitable threshold values (TV) in millimeters | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|
| | $P$ | $P_{11}$ | $P_{01}$ | E(Y) | Probability of getting wet week at least | | | P(D>3) | TV | DI | Drought Classes |
| | | | | | 8 | 10 | 12 | | | | |
| 1997 | 0.744 | 0.980 | 0.059 | 11.165 | 0.867 | 0.832 | 0.799 | 0.834 | 25 | 0.058 | Extreme |
| 1998 | 0.733 | 0.918 | 0.226 | 9.631 | 0.548 | 0.461 | 0.389 | 0.464 | 25 | 0.207 | Moderate |
| 1999 | 0.962 | 0.973 | 0.667 | 16.349 | 0.828 | 0.785 | 0.744 | 0.037 | 5 | 0.649 | Occasional |
| 2000 | 0.735 | 0.950 | 0.139 | 9.139 | 0.698 | 0.630 | 0.569 | 0.639 | 10 | 0.132 | Severe |
| 2001 | 0.940 | 0.982 | 0.286 | 15.571 | 0.878 | 0.846 | 0.816 | 0.364 | 5 | 0.280 | Mild |
| 2002 | 0.818 | 0.970 | 0.133 | 12.501 | 0.810 | 0.762 | 0.718 | 0.651 | 5 | 0.129 | Severe |
| 2003 | 0.888 | 0.951 | 0.385 | 13.953 | 0.706 | 0.639 | 0.578 | 0.233 | 15 | 0.366 | Occasional |
| 2004 | 0.646 | 0.965 | 0.065 | 8.403 | 0.778 | 0.724 | 0.674 | 0.819 | 25 | 0.062 | Extreme |
| 2005 | 0.974 | 0.974 | 1.000 | 16.703 | 0.830 | 0.787 | 0.746 | 0.000 | 5 | 0.974 | Occasional |
| 2006 | 0.856 | 0.981 | 0.111 | 13.818 | 0.876 | 0.844 | 0.813 | 0.702 | 5 | 0.109 | Extreme |
| 2007 | 0.824 | 0.960 | 0.188 | 12.480 | 0.751 | 0.693 | 0.638 | 0.536 | 5 | 0.180 | Severe |
| 2008 | 0.914 | 0.991 | 0.100 | 14.751 | 0.936 | 0.918 | 0.901 | 0.729 | 10 | 0.099 | Extreme |
| 2009 | 0.722 | 0.956 | 0.115 | 9.901 | 0.727 | 0.664 | 0.606 | 0.692 | 20 | 0.110 | Extreme |
| 2010 | 0.926 | 0.954 | 0.571 | 15.208 | 0.720 | 0.655 | 0.597 | 0.079 | 10 | 0.545 | Occasional |

**Appendix-XII** Year-wise analysis of probability of wet and dry weeks and index of drought proneness in Barisal station for Kharif season

| Year | Kharif season using suitable threshold values(TV) in millimeters | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|
| | $P$ | $P_{11}$ | $P_{01}$ | E(Y) | Probability of getting wet week at least | | | P(D>3) | TV | DI | Drought Classes |
| | | | | | 8 | 10 | 12 | | | | |
| 1960 | 0.845 | 0.959 | 0.222 | 12.672 | 0.747 | 0.687 | 0.632 | 0.471 | 15 | 0.213 | Moderate |
| 1961 | 0.957 | 0.991 | 0.200 | 16.131 | 0.939 | 0.922 | 0.905 | 0.512 | 5 | 0.198 | Moderate |
| 1962 | 0.871 | 0.960 | 0.267 | 13.433 | 0.754 | 0.695 | 0.641 | 0.394 | 5 | 0.256 | Mild |
| 1963 | 0.879 | 0.969 | 0.222 | 13.184 | 0.804 | 0.756 | 0.710 | 0.471 | 15 | 0.215 | Moderate |
| 1964 | 0.000 | 0.991 | 0.000 | 0.000 | 0.941 | 0.924 | 0.908 | 1.000 | 5 | 0.000 | Extreme |
| 1965 | 0.784 | 0.969 | 0.111 | 11.648 | 0.804 | 0.756 | 0.710 | 0.702 | 10 | 0.108 | Extreme |
| 1966 | 0.000 | 0.991 | 0.000 | 0.000 | 0.936 | 0.919 | 0.902 | 1.000 | 15 | 0.000 | Extreme |
| 1967 | 0.785 | 0.980 | 0.071 | 12.105 | 0.871 | 0.837 | 0.804 | 0.801 | 10 | 0.070 | Extreme |
| 1968 | 0.845 | 0.959 | 0.222 | 12.672 | 0.747 | 0.687 | 0.632 | 0.471 | 5 | 0.213 | Moderate |
| 1969 | 0.649 | 0.938 | 0.114 | 7.977 | 0.640 | 0.564 | 0.496 | 0.695 | 25 | 0.107 | Extreme |
| 1970 | 0.841 | 0.981 | 0.100 | 13.460 | 0.875 | 0.842 | 0.811 | 0.729 | 10 | 0.098 | Extreme |
| 1971 | 0.845 | 0.980 | 0.111 | 12.672 | 0.866 | 0.831 | 0.797 | 0.702 | 5 | 0.109 | Extreme |
| 1972 | 0.752 | 0.957 | 0.130 | 10.636 | 0.735 | 0.673 | 0.617 | 0.658 | 5 | 0.125 | Extreme |
| 1973 | 0.973 | 0.991 | 0.333 | 16.271 | 0.938 | 0.921 | 0.904 | 0.296 | 5 | 0.330 | Occasional |
| 1974 | 0.888 | 0.971 | 0.231 | 13.953 | 0.813 | 0.766 | 0.722 | 0.455 | 15 | 0.224 | Moderate |
| 1975 | 0.966 | 0.982 | 0.500 | 16.414 | 0.882 | 0.850 | 0.820 | 0.125 | 5 | 0.491 | Occasional |
| 1976 | 0.871 | 0.981 | 0.125 | 14.184 | 0.877 | 0.845 | 0.814 | 0.670 | 5 | 0.123 | Extreme |
| 1977 | 0.888 | 0.971 | 0.231 | 13.953 | 0.813 | 0.766 | 0.722 | 0.455 | 5 | 0.224 | Moderate |

| | Kharif season using suitable threshold values(TV) in millimeters | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|
| Year | $P$ | $P_{11}$ | $P_{01}$ | E(Y) | Probability of getting wet week at least | | | P(D>3) | TV | DI | Drought Classes |
| | | | | | 8 | 10 | 12 | | | | |
| 1978 | 0.758 | 0.980 | 0.063 | 11.364 | 0.868 | 0.834 | 0.801 | 0.824 | 25 | 0.061 | Extreme |
| 1979 | 0.762 | 0.969 | 0.100 | 11.102 | 0.801 | 0.751 | 0.705 | 0.729 | 10 | 0.097 | Extreme |
| 1980 | 0.886 | 0.982 | 0.143 | 14.559 | 0.878 | 0.846 | 0.816 | 0.630 | 5 | 0.140 | Severe |
| 1981 | 0.762 | 0.969 | 0.100 | 11.102 | 0.801 | 0.751 | 0.705 | 0.729 | 10 | 0.097 | Extreme |
| 1982 | 0.621 | 0.931 | 0.114 | 6.828 | 0.604 | 0.523 | 0.453 | 0.696 | 25 | 0.106 | Extreme |
| 1983 | 0.912 | 0.972 | 0.286 | 14.985 | 0.823 | 0.778 | 0.736 | 0.364 | 5 | 0.278 | Mild |
| 1984 | 0.758 | 0.980 | 0.063 | 11.364 | 0.868 | 0.834 | 0.801 | 0.824 | 20 | 0.061 | Extreme |
| 1985 | 0.827 | 0.981 | 0.091 | 13.110 | 0.874 | 0.841 | 0.809 | 0.751 | 5 | 0.089 | Extreme |
| 1986 | 0.732 | 0.956 | 0.120 | 10.038 | 0.730 | 0.667 | 0.610 | 0.681 | 20 | 0.115 | Extreme |
| 1987 | 0.827 | 0.981 | 0.091 | 13.110 | 0.874 | 0.841 | 0.809 | 0.751 | 5 | 0.089 | Extreme |
| 1988 | 0.829 | 0.971 | 0.143 | 12.794 | 0.811 | 0.764 | 0.720 | 0.630 | 10 | 0.139 | Severe |
| 1989 | 0.793 | 0.905 | 0.364 | 11.220 | 0.498 | 0.408 | 0.335 | 0.258 | 25 | 0.329 | Occasional |
| 1990 | 0.806 | 0.970 | 0.125 | 12.212 | 0.808 | 0.760 | 0.715 | 0.670 | 15 | 0.121 | Extreme |
| 1991 | 0.931 | 0.991 | 0.125 | 15.296 | 0.937 | 0.920 | 0.903 | 0.670 | 5 | 0.124 | Extreme |
| 1992 | 0.751 | 0.968 | 0.095 | 10.728 | 0.799 | 0.749 | 0.703 | 0.741 | 20 | 0.092 | Extreme |
| 1993 | 0.933 | 0.982 | 0.250 | 15.733 | 0.882 | 0.850 | 0.820 | 0.422 | 5 | 0.246 | Mild |
| 1994 | 0.793 | 0.959 | 0.158 | 11.667 | 0.745 | 0.685 | 0.629 | 0.597 | 5 | 0.151 | Severe |
| 1995 | 0.864 | 0.971 | 0.182 | 13.704 | 0.816 | 0.770 | 0.727 | 0.548 | 10 | 0.177 | Severe |
| 1996 | 0.862 | 0.990 | 0.063 | 13.177 | 0.932 | 0.914 | 0.895 | 0.824 | 5 | 0.062 | Extreme |
| 1997 | 0.673 | 0.953 | 0.097 | 8.651 | 0.714 | 0.648 | 0.588 | 0.737 | 25 | 0.092 | Extreme |
| 1998 | 0.914 | 0.981 | 0.200 | 14.751 | 0.875 | 0.842 | 0.811 | 0.512 | 5 | 0.196 | Moderate |
| 1999 | 0.957 | 0.973 | 0.600 | 16.131 | 0.825 | 0.781 | 0.740 | 0.064 | 5 | 0.584 | Occasional |
| 2000 | 0.920 | 0.971 | 0.333 | 14.594 | 0.815 | 0.768 | 0.725 | 0.296 | 5 | 0.324 | Occasional |
| 2001 | 0.862 | 0.960 | 0.250 | 13.177 | 0.751 | 0.693 | 0.638 | 0.422 | 10 | 0.240 | Mild |
| 2002 | 0.886 | 0.982 | 0.143 | 14.559 | 0.878 | 0.846 | 0.816 | 0.630 | 5 | 0.140 | Severe |
| 2003 | 0.812 | 0.913 | 0.375 | 11.481 | 0.529 | 0.441 | 0.368 | 0.244 | 15 | 0.342 | Occasional |
| 2004 | 0.000 | 0.991 | 0.000 | 0.000 | 0.936 | 0.919 | 0.902 | 1.000 | 10 | 0.000 | Extreme |
| 2005 | 0.841 | 0.971 | 0.154 | 13.093 | 0.813 | 0.766 | 0.722 | 0.606 | 15 | 0.149 | Severe |
| 2006 | 0.835 | 0.960 | 0.200 | 12.759 | 0.754 | 0.695 | 0.641 | 0.512 | 5 | 0.192 | Moderate |
| 2007 | 0.856 | 0.981 | 0.111 | 13.818 | 0.876 | 0.844 | 0.813 | 0.702 | 5 | 0.109 | Extreme |
| 2008 | 0.905 | 0.990 | 0.091 | 14.483 | 0.935 | 0.917 | 0.900 | 0.751 | 15 | 0.090 | Extreme |
| 2009 | 0.827 | 0.981 | 0.091 | 13.110 | 0.874 | 0.841 | 0.809 | 0.751 | 5 | 0.089 | Extreme |
| 2010 | 0.948 | 0.964 | 0.667 | 15.850 | 0.772 | 0.717 | 0.665 | 0.037 | 5 | 0.642 | Occasional |

**Appendix-XIII** Year-wise analysis of probability of wet and dry weeks and index of drought proneness in the Bhola station for Kharif season

| | Kharif season using suitable threshold values (TV) in millimeters | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|
| Year | $P$ | $P_{11}$ | $P_{01}$ | E(Y) | Probability of getting wet week at least | | | P(D>3) | TV | DI | Drought Classes |
| | | | | | 8 | 10 | 12 | | | | |
| 1966 | 1.000 | 1.000 | 0.250 | 17.000 | 1.000 | 1.000 | 1.000 | 0.422 | 25 | 0.250 | Mild |
| 1967 | 0.740 | 0.968 | 0.091 | 10.574 | 0.797 | 0.747 | 0.700 | 0.751 | 25 | 0.088 | Extreme |
| 1968 | 0.828 | 0.969 | 0.150 | 12.177 | 0.801 | 0.751 | 0.705 | 0.614 | 5 | 0.145 | Severe |
| 1969 | 0.712 | 0.955 | 0.111 | 9.663 | 0.725 | 0.661 | 0.603 | 0.702 | 25 | 0.106 | Extreme |
| 1970 | 0.876 | 0.972 | 0.200 | 14.017 | 0.818 | 0.772 | 0.729 | 0.512 | 5 | 0.194 | Moderate |
| 1971 | 0.845 | 0.959 | 0.222 | 12.672 | 0.747 | 0.687 | 0.632 | 0.471 | 5 | 0.213 | Moderate |
| 1972 | 0.524 | 0.942 | 0.064 | 5.615 | 0.658 | 0.584 | 0.518 | 0.820 | 25 | 0.060 | Extreme |
| 1973 | 1.000 | 1.000 | 0.333 | 17.143 | 1.000 | 1.000 | 1.000 | 0.296 | 5 | 0.333 | Occasional |
| 1974 | 0.798 | 0.981 | 0.077 | 12.433 | 0.872 | 0.838 | 0.806 | 0.787 | 15 | 0.075 | Extreme |
| 1975 | 0.884 | 0.952 | 0.364 | 14.021 | 0.711 | 0.645 | 0.585 | 0.258 | 20 | 0.346 | Occasional |
| 1976 | 0.711 | 0.919 | 0.200 | 9.341 | 0.552 | 0.466 | 0.393 | 0.512 | 20 | 0.184 | Moderate |
| 1977 | 0.879 | 0.971 | 0.214 | 13.692 | 0.811 | 0.764 | 0.720 | 0.485 | 10 | 0.208 | Moderate |
| 1978 | 0.845 | 0.990 | 0.056 | 12.672 | 0.931 | 0.912 | 0.893 | 0.842 | 5 | 0.055 | Extreme |
| 1979 | 0.933 | 0.982 | 0.250 | 15.733 | 0.882 | 0.850 | 0.820 | 0.422 | 15 | 0.246 | Mild |
| 1980 | 0.940 | 0.972 | 0.429 | 15.571 | 0.823 | 0.778 | 0.736 | 0.187 | 10 | 0.417 | Occasional |
| 1981 | 0.587 | 0.962 | 0.054 | 7.132 | 0.763 | 0.706 | 0.653 | 0.846 | 25 | 0.052 | Extreme |
| 1982 | 0.764 | 0.946 | 0.174 | 10.803 | 0.679 | 0.608 | 0.544 | 0.564 | 5 | 0.165 | Severe |
| 1983 | 0.864 | 0.971 | 0.182 | 13.704 | 0.816 | 0.770 | 0.727 | 0.548 | 15 | 0.177 | Severe |
| 1984 | 0.886 | 0.982 | 0.143 | 14.559 | 0.878 | 0.846 | 0.816 | 0.630 | 5 | 0.140 | Severe |
| 1985 | 0.974 | 0.982 | 0.667 | 16.700 | 0.882 | 0.852 | 0.822 | 0.037 | 10 | 0.655 | Occasional |
| 1986 | 0.845 | 0.949 | 0.278 | 12.672 | 0.693 | 0.624 | 0.562 | 0.377 | 25 | 0.264 | Mild |
| 1987 | 0.829 | 0.971 | 0.143 | 12.794 | 0.811 | 0.764 | 0.720 | 0.630 | 5 | 0.139 | Severe |
| 1988 | 0.876 | 0.972 | 0.200 | 14.017 | 0.818 | 0.772 | 0.729 | 0.512 | 5 | 0.194 | Moderate |
| 1989 | 0.931 | 0.963 | 0.500 | 15.296 | 0.768 | 0.712 | 0.660 | 0.125 | 25 | 0.481 | Occasional |
| 1990 | 0.762 | 0.969 | 0.100 | 11.102 | 0.801 | 0.751 | 0.705 | 0.729 | 15 | 0.097 | Extreme |
| 1991 | 0.931 | 0.991 | 0.125 | 15.296 | 0.937 | 0.920 | 0.903 | 0.670 | 5 | 0.124 | Extreme |
| 1992 | 0.950 | 0.982 | 0.333 | 16.143 | 0.882 | 0.852 | 0.822 | 0.296 | 5 | 0.327 | Occasional |
| 1993 | 0.841 | 0.981 | 0.100 | 13.460 | 0.875 | 0.842 | 0.811 | 0.729 | 10 | 0.098 | Extreme |
| 1994 | 0.516 | 0.975 | 0.027 | 6.270 | 0.836 | 0.794 | 0.754 | 0.921 | 25 | 0.026 | Extreme |
| 1995 | 0.888 | 0.972 | 0.222 | 14.334 | 0.819 | 0.774 | 0.731 | 0.471 | 5 | 0.216 | Moderate |

| Year | Kharif season using suitable threshold values (TV) in millimeters | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|
| | $P$ | $P_{11}$ | $P_{01}$ | E(Y) | Probability of getting wet week at least | | | P(D>3) | TV | DI | Drought Classes |
| | | | | | 8 | 10 | 12 | | | | |
| 1996 | 0.759 | 0.943 | 0.179 | 10.296 | 0.664 | 0.591 | 0.525 | 0.554 | 15 | 0.168 | Severe |
| 1997 | 0.702 | 0.955 | 0.107 | 9.429 | 0.722 | 0.658 | 0.599 | 0.712 | 20 | 0.102 | Extreme |
| 1998 | 0.902 | 0.982 | 0.167 | 14.941 | 0.879 | 0.848 | 0.817 | 0.579 | 5 | 0.164 | Severe |
| 1999 | 0.948 | 0.982 | 0.333 | 15.850 | 0.879 | 0.848 | 0.817 | 0.296 | 5 | 0.327 | Occasional |
| 2000 | 0.888 | 0.971 | 0.231 | 13.953 | 0.813 | 0.766 | 0.722 | 0.455 | 5 | 0.224 | Moderate |
| 2001 | 0.948 | 0.991 | 0.167 | 15.850 | 0.938 | 0.921 | 0.904 | 0.579 | 5 | 0.165 | Severe |
| 2002 | 0.900 | 0.972 | 0.250 | 14.657 | 0.821 | 0.776 | 0.734 | 0.422 | 20 | 0.243 | Mild |
| 2003 | 0.879 | 0.961 | 0.286 | 13.692 | 0.756 | 0.698 | 0.644 | 0.364 | 5 | 0.275 | Mild |
| 2004 | 0.991 | 0.991 | 1.000 | 17.278 | 0.941 | 0.924 | 0.908 | 0.000 | 5 | 0.991 | Occasional |
| 2005 | 0.867 | 0.962 | 0.250 | 13.619 | 0.760 | 0.703 | 0.650 | 0.422 | 15 | 0.240 | Mild |
| 2006 | 0.773 | 0.969 | 0.105 | 11.373 | 0.803 | 0.754 | 0.708 | 0.716 | 15 | 0.102 | Extreme |
| 2007 | 0.957 | 0.964 | 0.800 | 16.131 | 0.773 | 0.719 | 0.668 | 0.008 | 5 | 0.771 | Occasional |
| 2008 | 0.897 | 0.990 | 0.083 | 14.217 | 0.935 | 0.917 | 0.899 | 0.770 | 10 | 0.083 | Extreme |
| 2009 | 0.712 | 0.955 | 0.111 | 9.663 | 0.725 | 0.661 | 0.603 | 0.702 | 25 | 0.106 | Extreme |
| 2010 | 0.752 | 0.957 | 0.130 | 10.636 | 0.735 | 0.673 | 0.617 | 0.658 | 10 | 0.125 | Extreme |

**Appendix-XIV** Year-wise analysis of probability of wet and dry weeks and index of drought proneness in Khepupara station for Kharif season

| Year | Kharif season using suitable threshold values (TV) in millimeters | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|
| | $P$ | $P_{11}$ | $P_{01}$ | E(Y) | Probability of getting wet week at least | | | P(D>3) | TV | DI | Drought Classes |
| | | | | | 8 | 10 | 12 | | | | |
| 1975 | 0.711 | 0.919 | 0.200 | 9.341 | 0.552 | 0.466 | 0.393 | 0.512 | 25 | 0.184 | Moderate |
| 1976 | 0.845 | 0.961 | 0.214 | 13.042 | 0.756 | 0.698 | 0.644 | 0.485 | 5 | 0.206 | Moderate |
| 1977 | 0.793 | 0.978 | 0.083 | 11.217 | 0.857 | 0.821 | 0.785 | 0.770 | 15 | 0.082 | Extreme |
| 1978 | 0.931 | 0.981 | 0.250 | 15.296 | 0.877 | 0.845 | 0.814 | 0.422 | 5 | 0.245 | Mild |
| 1979 | 0.974 | 0.982 | 0.667 | 16.700 | 0.882 | 0.852 | 0.822 | 0.037 | 20 | 0.655 | Occasional |
| 1980 | 0.854 | 0.951 | 0.286 | 13.169 | 0.703 | 0.636 | 0.575 | 0.364 | 15 | 0.272 | Mild |
| 1981 | 0.617 | 0.963 | 0.059 | 7.751 | 0.770 | 0.715 | 0.664 | 0.834 | 25 | 0.057 | Extreme |
| 1982 | 0.649 | 0.938 | 0.114 | 8.070 | 0.640 | 0.564 | 0.496 | 0.695 | 15 | 0.107 | Extreme |
| 1983 | 0.931 | 0.972 | 0.375 | 15.296 | 0.821 | 0.776 | 0.734 | 0.244 | 10 | 0.365 | Occasional |

| Year | Kharif season using suitable threshold values (TV) in millimeters | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|
| | $P$ | $P_{11}$ | $P_{01}$ | E(Y) | Probability of getting wet week at least | | | P(D>3) | TV | DI | Drought Classes |
| | | | | | 8 | 10 | 12 | | | | |
| 1984 | 0.708 | 0.967 | 0.080 | 9.813 | 0.791 | 0.740 | 0.692 | 0.779 | 25 | 0.077 | Extreme |
| 1985 | 0.812 | 0.981 | 0.083 | 12.768 | 0.873 | 0.840 | 0.808 | 0.770 | 15 | 0.082 | Extreme |
| 1986 | 0.795 | 0.970 | 0.118 | 11.928 | 0.806 | 0.758 | 0.713 | 0.687 | 15 | 0.114 | Extreme |
| 1987 | 0.876 | 0.972 | 0.200 | 14.017 | 0.818 | 0.772 | 0.729 | 0.512 | 5 | 0.194 | Moderate |
| 1988 | 0.000 | 0.991 | 0.000 | 0.000 | 0.939 | 0.922 | 0.906 | 1.000 | 5 | 0.000 | Extreme |
| 1989 | 0.991 | 0.991 | 1.000 | 17.278 | 0.941 | 0.924 | 0.908 | 0.000 | 10 | 0.991 | Occasional |
| 1990 | 0.758 | 0.980 | 0.063 | 11.472 | 0.868 | 0.834 | 0.801 | 0.824 | 15 | 0.061 | Extreme |
| 1991 | 0.922 | 0.972 | 0.333 | 15.022 | 0.819 | 0.774 | 0.731 | 0.296 | 15 | 0.324 | Occasional |
| 1992 | 0.000 | 0.991 | 0.000 | 0.000 | 0.940 | 0.924 | 0.908 | 1.000 | 15 | 0.000 | Extreme |
| 1993 | 0.933 | 0.982 | 0.250 | 15.733 | 0.882 | 0.850 | 0.820 | 0.422 | 10 | 0.246 | Mild |
| 1994 | 0.841 | 0.971 | 0.154 | 13.093 | 0.813 | 0.766 | 0.722 | 0.606 | 5 | 0.149 | Severe |
| 1995 | 0.854 | 0.951 | 0.286 | 13.169 | 0.703 | 0.636 | 0.575 | 0.364 | 15 | 0.272 | Mild |
| 1996 | 0.879 | 0.980 | 0.143 | 13.692 | 0.871 | 0.837 | 0.804 | 0.630 | 5 | 0.140 | Severe |
| 1997 | 0.773 | 0.969 | 0.105 | 11.373 | 0.803 | 0.754 | 0.708 | 0.716 | 10 | 0.102 | Extreme |
| 1998 | 0.948 | 0.973 | 0.500 | 15.850 | 0.824 | 0.780 | 0.738 | 0.125 | 5 | 0.486 | Occasional |
| 1999 | 0.974 | 0.982 | 0.667 | 16.700 | 0.882 | 0.852 | 0.822 | 0.037 | 25 | 0.655 | Occasional |
| 2000 | 0.914 | 0.972 | 0.300 | 14.751 | 0.818 | 0.772 | 0.729 | 0.343 | 5 | 0.292 | Mild |
| 2001 | 0.897 | 0.962 | 0.333 | 14.217 | 0.760 | 0.703 | 0.650 | 0.296 | 25 | 0.321 | Occasional |
| 2002 | 0.852 | 0.971 | 0.167 | 13.396 | 0.815 | 0.768 | 0.725 | 0.579 | 5 | 0.162 | Severe |
| 2003 | 0.828 | 0.927 | 0.350 | 12.177 | 0.589 | 0.506 | 0.435 | 0.275 | 15 | 0.324 | Occasional |
| 2004 | 0.827 | 0.981 | 0.091 | 13.110 | 0.874 | 0.841 | 0.809 | 0.751 | 20 | 0.089 | Extreme |
| 2005 | 0.940 | 0.991 | 0.143 | 15.571 | 0.938 | 0.920 | 0.904 | 0.630 | 5 | 0.142 | Severe |
| 2006 | 0.785 | 0.980 | 0.071 | 12.105 | 0.871 | 0.837 | 0.804 | 0.801 | 5 | 0.070 | Extreme |
| 2007 | 0.914 | 0.972 | 0.300 | 14.751 | 0.818 | 0.772 | 0.729 | 0.343 | 5 | 0.292 | Mild |
| 2008 | 0.897 | 0.971 | 0.250 | 14.217 | 0.815 | 0.768 | 0.725 | 0.422 | 5 | 0.243 | Mild |
| 2009 | 0.957 | 0.991 | 0.200 | 16.131 | 0.939 | 0.922 | 0.905 | 0.512 | 5 | 0.198 | Moderate |
| 2010 | 0.878 | 0.942 | 0.417 | 13.803 | 0.660 | 0.586 | 0.520 | 0.198 | 20 | 0.393 | Occasional |

**Appendix-XV** Decade-wise analysis of probability of wet and dry weeks and index of drought proneness in the 12 meteorological stations for Pre-Kharif season

| | Pre-Kharif season using suitable threshold values (TV) in millimeters | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|
| Decade | $P$ | $P_{11}$ | $P_{01}$ | E(Y) | Probability of getting wet week at least | | | P(D>3) | TV | DI | Drought Classes |
| | | | | | 8 | 10 | 12 | | | | |
| **Dinajpur** | | | | | | | | | | | |
| 1961-1970 | 0.394 | 0.907 | 0.061 | 26.880 | 0.503 | 0.414 | 0.340 | 0.829 | 25 | 0.055 | Extreme |
| 1971-1980 | 0.440 | 0.939 | 0.048 | 33.343 | 0.643 | 0.567 | 0.500 | 0.863 | 25 | 0.045 | Extreme |
| 1981-1990 | 0.410 | 0.922 | 0.054 | 29.442 | 0.564 | 0.479 | 0.407 | 0.845 | 25 | 0.050 | Extreme |
| 1991-2000 | 0.380 | 0.924 | 0.047 | 25.355 | 0.575 | 0.491 | 0.420 | 0.867 | 25 | 0.043 | Extreme |
| 2000-2010 | 0.483 | 0.917 | 0.077 | 40.528 | 0.546 | 0.460 | 0.387 | 0.785 | 25 | 0.071 | Extreme |
| **Rangpur** | | | | | | | | | | | |
| 1961-1970 | 0.414 | 0.906 | 0.066 | 30.034 | 0.503 | 0.413 | 0.339 | 0.815 | 25 | 0.060 | Extreme |
| 1971-1980 | 0.473 | 0.933 | 0.060 | 38.725 | 0.615 | 0.535 | 0.466 | 0.830 | 25 | 0.056 | Extreme |
| 1981-1990 | 0.501 | 0.932 | 0.069 | 43.415 | 0.609 | 0.529 | 0.459 | 0.808 | 25 | 0.064 | Extreme |
| 1991-2000 | 0.502 | 0.931 | 0.070 | 44.110 | 0.606 | 0.526 | 0.456 | 0.806 | 25 | 0.065 | Extreme |
| 2000-2010 | 0.583 | 0.934 | 0.092 | 58.981 | 0.622 | 0.543 | 0.474 | 0.749 | 25 | 0.086 | Extreme |
| **Bogra** | | | | | | | | | | | |
| 1961-1970 | 0.355 | 0.910 | 0.049 | 21.785 | 0.517 | 0.429 | 0.355 | 0.859 | 25 | 0.045 | Extreme |
| 1971-1980 | 0.480 | 0.936 | 0.059 | 39.828 | 0.627 | 0.549 | 0.480 | 0.832 | 25 | 0.056 | Extreme |
| 1981-1990 | 0.542 | 0.932 | 0.081 | 51.456 | 0.609 | 0.529 | 0.459 | 0.776 | 25 | 0.076 | Extreme |
| 1991-2000 | 0.412 | 0.902 | 0.069 | 29.796 | 0.486 | 0.395 | 0.322 | 0.808 | 25 | 0.062 | Extreme |
| 2000-2010 | 0.454 | 0.912 | 0.073 | 35.833 | 0.524 | 0.436 | 0.363 | 0.796 | 25 | 0.067 | Extreme |
| **Ishwardi** | | | | | | | | | | | |
| 1961-1970 | 0.381 | 0.923 | 0.047 | 25.085 | 0.570 | 0.486 | 0.414 | 0.864 | 25 | 0.044 | Extreme |
| 1971-1980 | 0.439 | 0.928 | 0.057 | 33.379 | 0.591 | 0.509 | 0.438 | 0.839 | 25 | 0.053 | Extreme |
| 1981-1990 | 0.713 | 0.943 | 0.143 | 89.241 | 0.661 | 0.587 | 0.521 | 0.630 | 5 | 0.135 | Severe |
| 1991-2000 | 0.403 | 0.900 | 0.068 | 28.507 | 0.478 | 0.387 | 0.313 | 0.810 | 25 | 0.061 | Extreme |
| 2000-2010 | 0.383 | 0.889 | 0.069 | 25.495 | 0.438 | 0.346 | 0.274 | 0.807 | 25 | 0.061 | Extreme |
| **Rajshahi** | | | | | | | | | | | |
| 1961-1970 | 0.820 | 0.963 | 0.169 | 69.844 | 0.768 | 0.712 | 0.661 | 0.574 | 10 | 0.163 | Severe |
| 1971-1980 | 0.824 | 0.959 | 0.190 | 71.681 | 0.749 | 0.689 | 0.634 | 0.532 | 10 | 0.182 | Moderate |
| 1981-1990 | 0.834 | 0.975 | 0.128 | 89.637 | 0.836 | 0.794 | 0.754 | 0.664 | 5 | 0.124 | Extreme |
| 1991-2000 | 0.641 | 0.921 | 0.141 | 36.723 | 0.562 | 0.476 | 0.404 | 0.633 | 25 | 0.130 | Severe |

| Decade | Pre-Kharif season using suitable threshold values (TV) in millimeters | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|
| | $P$ | $P_{11}$ | $P_{01}$ | E(Y) | Probability of getting wet week at least | | | P(D>3) | TV | DI | Drought Classes |
| | | | | | 8 | 10 | 12 | | | | |
| 2000-2010 | 0.839 | 0.962 | 0.197 | 91.299 | 0.763 | 0.707 | 0.654 | 0.518 | 5 | 0.189 | Moderate |
| **Faridpur** | | | | | | | | | | | |
| 1961-1970 | 0.445 | 0.897 | 0.082 | 34.367 | 0.467 | 0.376 | 0.303 | 0.772 | 25 | 0.074 | Extreme |
| 1971-1980 | 0.514 | 0.920 | 0.085 | 46.298 | 0.557 | 0.472 | 0.399 | 0.766 | 25 | 0.078 | Extreme |
| 1981-1990 | 0.562 | 0.920 | 0.103 | 55.623 | 0.558 | 0.472 | 0.399 | 0.723 | 25 | 0.094 | Extreme |
| 1991-2000 | 0.503 | 0.906 | 0.095 | 43.986 | 0.500 | 0.410 | 0.337 | 0.740 | 25 | 0.086 | Extreme |
| 2000-2010 | 0.466 | 0.911 | 0.078 | 37.660 | 0.519 | 0.430 | 0.357 | 0.784 | 25 | 0.071 | Extreme |
| **Jessore** | | | | | | | | | | | |
| 1961-1970 | 0.376 | 0.906 | 0.056 | 24.472 | 0.503 | 0.413 | 0.339 | 0.840 | 25 | 0.051 | Extreme |
| 1971-1980 | 0.407 | 0.920 | 0.055 | 28.647 | 0.557 | 0.471 | 0.398 | 0.844 | 25 | 0.051 | Extreme |
| 1981-1990 | 0.464 | 0.918 | 0.071 | 37.794 | 0.551 | 0.464 | 0.392 | 0.802 | 25 | 0.065 | Extreme |
| 1991-2000 | 0.410 | 0.906 | 0.065 | 29.167 | 0.502 | 0.413 | 0.339 | 0.817 | 25 | 0.059 | Extreme |
| 2000-2010 | 0.413 | 0.901 | 0.070 | 29.616 | 0.482 | 0.391 | 0.318 | 0.805 | 25 | 0.063 | Extreme |
| **Khulna** | | | | | | | | | | | |
| 1961-1970 | 0.373 | 0.904 | 0.057 | 24.141 | 0.492 | 0.402 | 0.328 | 0.838 | 25 | 0.052 | Extreme |
| 1971-1980 | 0.445 | 0.911 | 0.071 | 34.667 | 0.522 | 0.433 | 0.360 | 0.801 | 25 | 0.065 | Extreme |
| 1981-1990 | 0.460 | 0.917 | 0.071 | 36.767 | 0.544 | 0.457 | 0.384 | 0.801 | 25 | 0.065 | Extreme |
| 1991-2000 | 0.414 | 0.903 | 0.068 | 29.741 | 0.490 | 0.400 | 0.326 | 0.809 | 25 | 0.062 | Extreme |
| 2000-2010 | 0.381 | 0.912 | 0.054 | 25.140 | 0.525 | 0.437 | 0.363 | 0.846 | 25 | 0.049 | Extreme |
| **Satkhira** | | | | | | | | | | | |
| 1961-1970 | 0.323 | 0.904 | 0.046 | 18.099 | 0.493 | 0.403 | 0.329 | 0.869 | 25 | 0.041 | Extreme |
| 1971-1980 | 0.368 | 0.908 | 0.053 | 23.742 | 0.509 | 0.420 | 0.346 | 0.848 | 25 | 0.049 | Extreme |
| 1981-1990 | 0.420 | 0.905 | 0.069 | 30.577 | 0.496 | 0.405 | 0.332 | 0.807 | 25 | 0.062 | Extreme |
| 1991-2000 | 0.452 | 0.919 | 0.067 | 35.480 | 0.553 | 0.467 | 0.394 | 0.812 | 25 | 0.062 | Extreme |
| 2000-2010 | 0.389 | 0.908 | 0.059 | 26.216 | 0.507 | 0.418 | 0.344 | 0.834 | 25 | 0.053 | Extreme |
| **Barisal** | | | | | | | | | | | |
| 1961-1970 | 0.421 | 0.915 | 0.062 | 30.740 | 0.536 | 0.448 | 0.375 | 0.825 | 25 | 0.057 | Extreme |
| 1971-1980 | 0.519 | 0.921 | 0.085 | 46.827 | 0.564 | 0.479 | 0.407 | 0.766 | 25 | 0.078 | Extreme |
| 1981-1990 | 0.511 | 0.931 | 0.072 | 45.281 | 0.608 | 0.528 | 0.458 | 0.800 | 25 | 0.067 | Extreme |
| 1991-2000 | 0.482 | 0.927 | 0.068 | 40.313 | 0.590 | 0.507 | 0.436 | 0.810 | 25 | 0.063 | Extreme |

| | Pre-Kharif season using suitable threshold values (TV) in millimeters | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|
| Decade | $P$ | $P_{11}$ | $P_{01}$ | E(Y) | Probability of getting wet week at least | | | P(D>3) | TV | DI | Drought Classes |
| | | | | | 8 | 10 | 12 | | | | |
| 2000-2010 | 0.433 | 0.919 | 0.062 | 32.461 | 0.553 | 0.467 | 0.395 | 0.826 | 25 | 0.057 | Extreme |
| Bhola | | | | | | | | | | | |
| 1971-1980 | 0.542 | 0.942 | 0.069 | 50.900 | 0.656 | 0.581 | 0.515 | 0.806 | 25 | 0.065 | Extreme |
| 1981-1990 | 0.535 | 0.929 | 0.082 | 50.064 | 0.598 | 0.516 | 0.445 | 0.775 | 25 | 0.076 | Extreme |
| 1991-2000 | 0.541 | 0.926 | 0.087 | 50.775 | 0.584 | 0.501 | 0.430 | 0.761 | 25 | 0.081 | Extreme |
| 2001-2010 | 0.449 | 0.926 | 0.061 | 34.879 | 0.582 | 0.498 | 0.427 | 0.829 | 25 | 0.056 | Extreme |
| Khepupara | | | | | | | | | | | |
| 1981-1990 | 0.446 | 0.926 | 0.060 | 34.852 | 0.584 | 0.501 | 0.430 | 0.832 | 25 | 0.055 | Extreme |
| 1991-2000 | 0.488 | 0.937 | 0.060 | 41.211 | 0.632 | 0.555 | 0.487 | 0.829 | 25 | 0.057 | Extreme |
| 2000-2010 | 0.452 | 0.917 | 0.069 | 35.470 | 0.545 | 0.458 | 0.385 | 0.808 | 25 | 0.063 | Extreme |

**Appendix-XVI** Year-wise analysis of probability of wet and dry weeks and index of drought proneness in the Dinajpur station for Pre-Kharif season

| | Pre-Kharif season using suitable threshold values (TV) in millimeters | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|
| Year | $P$ | $P_{11}$ | $P_{01}$ | E(Y) | Probability of getting wet week at least | | | P(D>3) | TV | DI | Drought Classes |
| | | | | | 8 | 10 | 12 | | | | |
| 1960 | 0.226 | 0.885 | 0.034 | 1.034 | 0.424 | 0.332 | 0.260 | 0.902 | 25 | 0.030 | Extreme |
| 1961 | 0.356 | 0.935 | 0.036 | 1.934 | 0.627 | 0.549 | 0.480 | 0.897 | 25 | 0.033 | Extreme |
| 1962 | 0.359 | 0.912 | 0.049 | 2.102 | 0.524 | 0.435 | 0.362 | 0.859 | 25 | 0.045 | Extreme |
| 1963 | 0.487 | 0.893 | 0.102 | 4.313 | 0.452 | 0.361 | 0.287 | 0.725 | 25 | 0.091 | Extreme |
| 1964 | 0.551 | 0.930 | 0.086 | 5.040 | 0.601 | 0.520 | 0.449 | 0.763 | 25 | 0.080 | Extreme |
| 1965 | 0.434 | 0.929 | 0.055 | 3.039 | 0.595 | 0.513 | 0.443 | 0.844 | 25 | 0.051 | Extreme |
| 1966 | 0.262 | 0.909 | 0.032 | 1.085 | 0.513 | 0.424 | 0.350 | 0.906 | 25 | 0.029 | Extreme |
| 1967 | 0.626 | 0.917 | 0.140 | 6.976 | 0.544 | 0.457 | 0.384 | 0.637 | 10 | 0.128 | Severe |
| 1968 | 0.354 | 0.886 | 0.063 | 2.121 | 0.428 | 0.335 | 0.263 | 0.824 | 25 | 0.055 | Extreme |
| 1969 | 0.668 | 0.931 | 0.140 | 7.535 | 0.604 | 0.523 | 0.453 | 0.637 | 15 | 0.130 | Severe |
| 1970 | 0.464 | 0.915 | 0.074 | 3.576 | 0.537 | 0.449 | 0.376 | 0.795 | 25 | 0.067 | Extreme |
| 1971 | 0.435 | 0.949 | 0.039 | 2.858 | 0.692 | 0.623 | 0.560 | 0.886 | 25 | 0.037 | Extreme |
| 1972 | 0.209 | 0.875 | 0.033 | 0.894 | 0.393 | 0.301 | 0.230 | 0.904 | 25 | 0.029 | Extreme |
| 1973 | 0.629 | 0.967 | 0.056 | 6.109 | 0.792 | 0.741 | 0.693 | 0.842 | 25 | 0.054 | Extreme |
| 1974 | 0.823 | 0.977 | 0.107 | 11.056 | 0.850 | 0.811 | 0.774 | 0.712 | 5 | 0.105 | Extreme |
| 1975 | 0.800 | 0.935 | 0.261 | 11.314 | 0.624 | 0.545 | 0.476 | 0.404 | 5 | 0.244 | Mild |
| 1976 | 0.579 | 0.964 | 0.050 | 5.128 | 0.772 | 0.717 | 0.665 | 0.857 | 25 | 0.048 | Extreme |
| 1977 | 0.783 | 0.986 | 0.049 | 9.061 | 0.909 | 0.885 | 0.861 | 0.861 | 25 | 0.048 | Extreme |

| | Pre-Kharif season using suitable threshold values (TV) in millimeters | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|
| Year | $P$ | $P_{11}$ | $P_{01}$ | E(Y) | Probability of getting wet week at least | | | P(D>3) | TV | DI | Drought Classes |
| | | | | | 8 | 10 | 12 | | | | |
| 1978 | 0.903 | 0.980 | 0.188 | 13.670 | 0.867 | 0.832 | 0.799 | 0.536 | 5 | 0.184 | Moderate |
| 1979 | 0.235 | 0.852 | 0.045 | 1.107 | 0.325 | 0.236 | 0.171 | 0.870 | 25 | 0.039 | Extreme |
| 1980 | 0.835 | 0.948 | 0.263 | 12.283 | 0.688 | 0.618 | 0.555 | 0.400 | 5 | 0.249 | Mild |
| 1981 | 0.416 | 0.946 | 0.038 | 2.613 | 0.678 | 0.606 | 0.543 | 0.889 | 25 | 0.036 | Extreme |
| 1982 | 0.452 | 0.932 | 0.056 | 3.296 | 0.610 | 0.530 | 0.460 | 0.840 | 25 | 0.052 | Extreme |
| 1983 | 0.416 | 0.925 | 0.053 | 2.790 | 0.579 | 0.496 | 0.424 | 0.848 | 25 | 0.049 | Extreme |
| 1984 | 0.478 | 0.964 | 0.033 | 4.168 | 0.772 | 0.717 | 0.665 | 0.903 | 25 | 0.032 | Extreme |
| 1985 | 0.452 | 0.932 | 0.056 | 3.296 | 0.610 | 0.530 | 0.460 | 0.840 | 25 | 0.052 | Extreme |
| 1986 | 0.425 | 0.927 | 0.054 | 2.913 | 0.587 | 0.505 | 0.434 | 0.846 | 25 | 0.050 | Extreme |
| 1987 | 0.620 | 0.910 | 0.146 | 6.550 | 0.519 | 0.430 | 0.356 | 0.623 | 15 | 0.133 | Severe |
| 1988 | 0.498 | 0.904 | 0.095 | 4.194 | 0.493 | 0.403 | 0.329 | 0.741 | 25 | 0.086 | Extreme |
| 1989 | 0.374 | 0.930 | 0.042 | 2.617 | 0.603 | 0.522 | 0.451 | 0.880 | 25 | 0.039 | Extreme |
| 1990 | 0.848 | 0.957 | 0.238 | 12.241 | 0.738 | 0.676 | 0.620 | 0.442 | 5 | 0.228 | Moderate |
| 1991 | 0.365 | 0.952 | 0.027 | 2.504 | 0.711 | 0.645 | 0.585 | 0.920 | 25 | 0.026 | Extreme |
| 1992 | 0.235 | 0.926 | 0.023 | 1.107 | 0.583 | 0.500 | 0.429 | 0.933 | 25 | 0.021 | Extreme |
| 1993 | 0.382 | 0.895 | 0.065 | 2.453 | 0.459 | 0.368 | 0.294 | 0.818 | 25 | 0.058 | Extreme |
| 1994 | 0.382 | 0.895 | 0.065 | 2.453 | 0.459 | 0.368 | 0.294 | 0.818 | 25 | 0.058 | Extreme |
| 1995 | 0.200 | 0.913 | 0.022 | 0.829 | 0.529 | 0.441 | 0.368 | 0.936 | 25 | 0.020 | Extreme |
| 1996 | 0.378 | 0.917 | 0.051 | 2.322 | 0.544 | 0.457 | 0.384 | 0.856 | 25 | 0.046 | Extreme |
| 1997 | 0.378 | 0.917 | 0.051 | 2.322 | 0.544 | 0.457 | 0.384 | 0.856 | 25 | 0.046 | Extreme |
| 1998 | 0.359 | 0.912 | 0.049 | 2.102 | 0.524 | 0.435 | 0.362 | 0.859 | 25 | 0.045 | Extreme |
| 1999 | 0.593 | 0.950 | 0.073 | 5.672 | 0.698 | 0.630 | 0.569 | 0.797 | 25 | 0.069 | Extreme |
| 2000 | 0.653 | 0.969 | 0.059 | 6.624 | 0.801 | 0.751 | 0.705 | 0.834 | 25 | 0.057 | Extreme |
| 2001 | 0.365 | 0.929 | 0.041 | 2.504 | 0.595 | 0.513 | 0.443 | 0.882 | 25 | 0.038 | Extreme |
| 2002 | 0.592 | 0.921 | 0.115 | 5.925 | 0.561 | 0.475 | 0.403 | 0.692 | 25 | 0.106 | Extreme |
| 2003 | 0.849 | 0.968 | 0.182 | 12.133 | 0.795 | 0.744 | 0.697 | 0.548 | 5 | 0.176 | Severe |
| 2004 | 0.791 | 0.965 | 0.133 | 10.392 | 0.778 | 0.724 | 0.674 | 0.651 | 5 | 0.129 | Severe |
| 2005 | 0.653 | 0.915 | 0.159 | 7.277 | 0.539 | 0.452 | 0.379 | 0.595 | 20 | 0.146 | Severe |
| 2006 | 0.730 | 0.961 | 0.105 | 8.758 | 0.757 | 0.699 | 0.646 | 0.716 | 5 | 0.101 | Extreme |
| 2007 | 0.322 | 0.919 | 0.038 | 1.976 | 0.553 | 0.467 | 0.395 | 0.889 | 25 | 0.035 | Extreme |
| 2008 | 0.536 | 0.960 | 0.046 | 4.362 | 0.751 | 0.693 | 0.638 | 0.868 | 25 | 0.044 | Extreme |
| 2009 | 0.471 | 0.898 | 0.091 | 3.769 | 0.471 | 0.380 | 0.306 | 0.751 | 25 | 0.082 | Extreme |
| 2010 | 0.443 | 0.930 | 0.056 | 3.166 | 0.603 | 0.522 | 0.451 | 0.842 | 25 | 0.052 | Extreme |
| 2011 | 0.722 | 0.961 | 0.103 | 8.562 | 0.754 | 0.696 | 0.642 | 0.723 | 15 | 0.099 | Extreme |

**Appendix-XVII** Year-wise analysis of probability of wet and dry weeks and index of drought proneness in the Rangpur station for Pre-Kharif season

| | Pre-Kharif season using suitable threshold values (TV) in millimeters | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|
| Year | $P$ | $P_{11}$ | $P_{01}$ | E(Y) | Probability of getting wet week at least | | | P(D>3) | TV | DI | Drought Classes |
| | | | | | 8 | 10 | 12 | | | | |
| 1960 | 0.217 | 0.951 | 0.014 | 1.457 | 0.705 | 0.638 | 0.577 | 0.960 | 25 | 0.013 | Extreme |
| 1961 | 0.709 | 0.935 | 0.158 | 8.503 | 0.625 | 0.546 | 0.478 | 0.597 | 5 | 0.148 | Severe |
| 1962 | 0.541 | 0.944 | 0.066 | 4.718 | 0.670 | 0.598 | 0.533 | 0.816 | 25 | 0.062 | Extreme |
| 1963 | 0.791 | 0.967 | 0.125 | 11.078 | 0.791 | 0.740 | 0.692 | 0.670 | 5 | 0.121 | Extreme |
| 1964 | 0.717 | 0.936 | 0.162 | 8.703 | 0.629 | 0.551 | 0.483 | 0.588 | 5 | 0.152 | Severe |
| 1965 | 0.780 | 0.953 | 0.167 | 10.249 | 0.714 | 0.648 | 0.588 | 0.579 | 5 | 0.159 | Severe |
| 1966 | 0.330 | 0.921 | 0.039 | 2.077 | 0.562 | 0.477 | 0.405 | 0.888 | 25 | 0.036 | Extreme |
| 1967 | 0.504 | 0.879 | 0.123 | 4.611 | 0.406 | 0.314 | 0.243 | 0.675 | 25 | 0.108 | Extreme |
| 1968 | 0.803 | 0.955 | 0.185 | 10.897 | 0.722 | 0.658 | 0.599 | 0.541 | 5 | 0.177 | Severe |
| 1969 | 0.684 | 0.932 | 0.146 | 7.916 | 0.613 | 0.533 | 0.463 | 0.622 | 15 | 0.136 | Severe |
| 1970 | 0.400 | 0.900 | 0.067 | 2.686 | 0.478 | 0.387 | 0.314 | 0.813 | 25 | 0.060 | Extreme |
| 1971 | 0.191 | 0.909 | 0.022 | 0.765 | 0.513 | 0.424 | 0.350 | 0.937 | 25 | 0.020 | Extreme |
| 1972 | 0.409 | 0.915 | 0.059 | 3.094 | 0.537 | 0.449 | 0.376 | 0.834 | 25 | 0.054 | Extreme |
| 1973 | 0.614 | 0.980 | 0.031 | 5.091 | 0.871 | 0.837 | 0.804 | 0.909 | 25 | 0.031 | Extreme |
| 1974 | 0.823 | 0.977 | 0.107 | 11.056 | 0.850 | 0.811 | 0.774 | 0.712 | 5 | 0.105 | Extreme |
| 1975 | 0.513 | 0.932 | 0.071 | 4.764 | 0.612 | 0.532 | 0.462 | 0.801 | 25 | 0.067 | Extreme |
| 1976 | 0.618 | 0.952 | 0.077 | 6.176 | 0.711 | 0.645 | 0.585 | 0.787 | 25 | 0.073 | Extreme |
| 1977 | 0.643 | 0.946 | 0.098 | 7.354 | 0.678 | 0.606 | 0.543 | 0.735 | 25 | 0.092 | Extreme |
| 1978 | 0.576 | 0.948 | 0.070 | 5.346 | 0.690 | 0.620 | 0.558 | 0.804 | 25 | 0.067 | Extreme |
| 1979 | 0.304 | 0.914 | 0.038 | 1.783 | 0.534 | 0.446 | 0.373 | 0.892 | 25 | 0.034 | Extreme |
| 1980 | 0.730 | 0.940 | 0.161 | 9.496 | 0.651 | 0.576 | 0.509 | 0.590 | 5 | 0.152 | Severe |
| 1981 | 0.584 | 0.919 | 0.113 | 5.756 | 0.555 | 0.469 | 0.397 | 0.697 | 25 | 0.104 | Extreme |
| 1982 | 0.497 | 0.939 | 0.061 | 3.980 | 0.643 | 0.566 | 0.499 | 0.829 | 25 | 0.057 | Extreme |
| 1983 | 0.567 | 0.947 | 0.069 | 5.186 | 0.685 | 0.615 | 0.552 | 0.807 | 25 | 0.065 | Extreme |
| 1984 | 1.000 | 1.000 | 0.022 | 10.857 | 1.000 | 1.000 | 1.000 | 0.936 | 25 | 0.022 | Extreme |
| 1985 | 0.644 | 0.941 | 0.106 | 6.899 | 0.654 | 0.579 | 0.513 | 0.714 | 25 | 0.100 | Extreme |
| 1986 | 0.462 | 0.896 | 0.090 | 3.632 | 0.463 | 0.372 | 0.298 | 0.755 | 25 | 0.080 | Extreme |
| 1987 | 0.811 | 0.955 | 0.192 | 11.116 | 0.725 | 0.661 | 0.603 | 0.527 | 5 | 0.184 | Moderate |
| 1988 | 0.733 | 0.938 | 0.171 | 9.108 | 0.637 | 0.559 | 0.492 | 0.569 | 5 | 0.161 | Severe |

| | Pre-Kharif season using suitable threshold values (TV) in millimeters | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|
| Year | $P$ | $P_{11}$ | $P_{01}$ | E(Y) | Probability of getting wet week at least | | | P(D>3) | TV | DI | Drought Classes |
| | | | | | 8 | 10 | 12 | | | | |
| 1989 | 0.330 | 0.921 | 0.039 | 2.077 | 0.562 | 0.477 | 0.405 | 0.888 | 25 | 0.036 | Extreme |
| 1990 | 0.953 | 0.981 | 0.375 | #VAL | 0.876 | 0.844 | 0.813 | 0.244 | 5 | 0.368 | Occasional |
| 1991 | 0.563 | 0.978 | 0.029 | 4.179 | 0.854 | 0.817 | 0.781 | 0.917 | 25 | 0.028 | Extreme |
| 1992 | 0.480 | 0.936 | 0.059 | 3.700 | 0.630 | 0.552 | 0.484 | 0.834 | 25 | 0.055 | Extreme |
| 1993 | 0.693 | 0.946 | 0.122 | 8.018 | 0.678 | 0.606 | 0.543 | 0.677 | 15 | 0.115 | Extreme |
| 1994 | 0.725 | 0.949 | 0.135 | 8.802 | 0.692 | 0.623 | 0.560 | 0.647 | 10 | 0.128 | Severe |
| 1995 | 0.396 | 0.943 | 0.038 | 2.377 | 0.662 | 0.589 | 0.523 | 0.892 | 25 | 0.035 | Extreme |
| 1996 | 0.524 | 0.942 | 0.063 | 4.416 | 0.660 | 0.586 | 0.520 | 0.821 | 25 | 0.060 | Extreme |
| 1997 | 0.684 | 0.932 | 0.146 | 7.916 | 0.613 | 0.533 | 0.463 | 0.622 | 10 | 0.136 | Severe |
| 1998 | 0.804 | 0.944 | 0.231 | 11.029 | 0.667 | 0.594 | 0.529 | 0.455 | 5 | 0.218 | Moderate |
| 1999 | 0.667 | 0.957 | 0.087 | 7.238 | 0.733 | 0.670 | 0.613 | 0.761 | 25 | 0.083 | Extreme |
| 2000 | 0.708 | 0.972 | 0.068 | 7.885 | 0.819 | 0.773 | 0.730 | 0.809 | 25 | 0.066 | Extreme |
| 2001 | 0.478 | 0.927 | 0.067 | 4.168 | 0.589 | 0.507 | 0.436 | 0.813 | 25 | 0.062 | Extreme |
| 2002 | 0.894 | 0.989 | 0.091 | 12.775 | 0.927 | 0.907 | 0.888 | 0.751 | 10 | 0.090 | Extreme |
| 2003 | 0.906 | 0.970 | 0.286 | 13.976 | 0.810 | 0.762 | 0.718 | 0.364 | 5 | 0.277 | Mild |
| 2004 | 0.699 | 0.959 | 0.095 | 7.984 | 0.745 | 0.685 | 0.630 | 0.741 | 25 | 0.091 | Extreme |
| 2005 | 0.903 | 0.980 | 0.188 | 13.670 | 0.867 | 0.832 | 0.799 | 0.536 | 5 | 0.184 | Moderate |
| 2006 | 0.730 | 0.961 | 0.105 | 8.758 | 0.757 | 0.699 | 0.646 | 0.716 | 5 | 0.101 | Extreme |
| 2007 | 0.322 | 0.919 | 0.038 | 1.976 | 0.553 | 0.467 | 0.395 | 0.889 | 25 | 0.035 | Extreme |
| 2008 | 0.800 | 0.967 | 0.130 | 11.314 | 0.793 | 0.742 | 0.694 | 0.658 | 5 | 0.126 | Severe |
| 2009 | 0.749 | 0.939 | 0.182 | 9.521 | 0.644 | 0.568 | 0.501 | 0.548 | 5 | 0.171 | Severe |
| 2010 | 0.700 | 0.971 | 0.067 | 7.700 | 0.816 | 0.770 | 0.727 | 0.813 | 25 | 0.065 | Extreme |
| 2011 | 0.489 | 0.938 | 0.060 | 3.839 | 0.637 | 0.559 | 0.492 | 0.831 | 25 | 0.056 | Extreme |

**Appendix-XVIII** Year-wise analysis of probability of wet and dry weeks and index of drought proneness in the Bogra station for Pre-Kharif season

| | Pre-Kharif season using suitable threshold values (TV) in millimeters | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|
| Year | $P$ | $P_{11}$ | $P_{01}$ | E(Y) | Probability of getting wet week at least | | | P(D>3) | TV | DI | Drought Classes |
| | | | | | 8 | 10 | 12 | | | | |
| 1960 | 0.235 | 0.926 | 0.023 | 1.107 | 0.583 | 0.500 | 0.429 | 0.933 | 25 | 0.021 | Extreme |
| 1961 | 0.348 | 0.900 | 0.053 | 2.286 | 0.478 | 0.387 | 0.314 | 0.848 | 25 | 0.048 | Extreme |
| 1962 | 0.418 | 0.905 | 0.068 | 2.928 | 0.496 | 0.406 | 0.333 | 0.808 | 25 | 0.062 | Extreme |
| 1963 | 0.481 | 0.918 | 0.076 | 3.851 | 0.551 | 0.465 | 0.392 | 0.790 | 25 | 0.070 | Extreme |
| 1964 | 0.562 | 0.962 | 0.048 | 4.816 | 0.764 | 0.707 | 0.655 | 0.862 | 25 | 0.047 | Extreme |
| 1965 | 0.300 | 0.893 | 0.046 | 1.501 | 0.452 | 0.361 | 0.287 | 0.868 | 25 | 0.041 | Extreme |
| 1966 | 0.260 | 0.875 | 0.044 | 1.152 | 0.393 | 0.301 | 0.230 | 0.874 | 25 | 0.038 | Extreme |
| 1967 | 0.811 | 0.955 | 0.192 | 11.116 | 0.725 | 0.661 | 0.603 | 0.527 | 5 | 0.184 | Moderate |
| 1968 | 0.333 | 0.957 | 0.022 | 1.429 | 0.733 | 0.670 | 0.613 | 0.936 | 25 | 0.021 | Extreme |
| 1969 | 0.725 | 0.949 | 0.135 | 8.802 | 0.692 | 0.623 | 0.560 | 0.647 | 5 | 0.128 | Severe |
| 1970 | 0.462 | 0.933 | 0.057 | 3.429 | 0.617 | 0.537 | 0.468 | 0.838 | 25 | 0.053 | Extreme |
| 1971 | 0.444 | 0.950 | 0.040 | 2.984 | 0.698 | 0.630 | 0.569 | 0.885 | 25 | 0.038 | Extreme |
| 1972 | 0.289 | 0.939 | 0.025 | 1.654 | 0.646 | 0.570 | 0.503 | 0.928 | 25 | 0.023 | Extreme |
| 1973 | 0.576 | 0.948 | 0.070 | 5.346 | 0.690 | 0.620 | 0.558 | 0.804 | 25 | 0.067 | Extreme |
| 1974 | 0.749 | 0.951 | 0.147 | 9.411 | 0.702 | 0.634 | 0.573 | 0.621 | 15 | 0.140 | Severe |
| 1975 | 0.400 | 0.913 | 0.058 | 2.971 | 0.529 | 0.441 | 0.368 | 0.836 | 25 | 0.053 | Extreme |
| 1976 | 0.391 | 0.897 | 0.066 | 2.568 | 0.469 | 0.378 | 0.304 | 0.815 | 25 | 0.059 | Extreme |
| 1977 | 0.783 | 0.986 | 0.049 | 9.061 | 0.909 | 0.885 | 0.861 | 0.861 | 25 | 0.048 | Extreme |
| 1978 | 0.833 | 0.957 | 0.217 | 11.786 | 0.733 | 0.670 | 0.613 | 0.479 | 5 | 0.208 | Moderate |
| 1979 | 0.330 | 0.903 | 0.048 | 1.790 | 0.490 | 0.400 | 0.326 | 0.864 | 25 | 0.043 | Extreme |
| 1980 | 0.621 | 0.967 | 0.055 | 5.941 | 0.789 | 0.737 | 0.689 | 0.845 | 25 | 0.053 | Extreme |
| 1981 | 0.772 | 0.952 | 0.161 | 10.037 | 0.711 | 0.645 | 0.585 | 0.590 | 5 | 0.154 | Severe |
| 1982 | 0.443 | 0.922 | 0.063 | 3.675 | 0.565 | 0.479 | 0.407 | 0.824 | 25 | 0.058 | Extreme |
| 1983 | 0.335 | 0.879 | 0.061 | 1.912 | 0.405 | 0.313 | 0.241 | 0.828 | 25 | 0.054 | Extreme |
| 1984 | 0.596 | 0.965 | 0.052 | 5.447 | 0.779 | 0.725 | 0.675 | 0.853 | 25 | 0.050 | Extreme |
| 1985 | 0.508 | 0.923 | 0.079 | 4.280 | 0.571 | 0.487 | 0.415 | 0.780 | 25 | 0.073 | Extreme |
| 1986 | 0.455 | 0.913 | 0.072 | 3.442 | 0.529 | 0.441 | 0.368 | 0.798 | 25 | 0.066 | Extreme |
| 1987 | 0.287 | 0.879 | 0.049 | 1.599 | 0.405 | 0.313 | 0.241 | 0.861 | 25 | 0.043 | Extreme |
| 1988 | 0.568 | 0.932 | 0.089 | 5.359 | 0.612 | 0.532 | 0.462 | 0.755 | 25 | 0.083 | Extreme |

| Year | Pre-Kharif season using suitable threshold values (TV) in millimeters | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|
| | $P$ | $P_{11}$ | $P_{01}$ | E(Y) | Probability of getting wet week at least | | | P(D>3) | TV | DI | Drought Classes |
| | | | | | 8 | 10 | 12 | | | | |
| 1989 | 0.296 | 0.941 | 0.025 | 1.689 | 0.654 | 0.579 | 0.513 | 0.928 | 25 | 0.023 | Extreme |
| 1990 | 0.806 | 0.966 | 0.143 | 10.817 | 0.782 | 0.729 | 0.680 | 0.630 | 5 | 0.138 | Severe |
| 1991 | 0.629 | 0.967 | 0.056 | 6.109 | 0.792 | 0.741 | 0.693 | 0.842 | 25 | 0.054 | Extreme |
| 1992 | 0.363 | 0.889 | 0.063 | 2.229 | 0.438 | 0.346 | 0.274 | 0.822 | 25 | 0.056 | Extreme |
| 1993 | 0.733 | 0.949 | 0.139 | 9.003 | 0.695 | 0.626 | 0.565 | 0.639 | 5 | 0.132 | Severe |
| 1994 | 0.340 | 0.906 | 0.048 | 1.892 | 0.502 | 0.412 | 0.339 | 0.862 | 25 | 0.044 | Extreme |
| 1995 | 0.372 | 0.892 | 0.064 | 2.340 | 0.449 | 0.357 | 0.284 | 0.820 | 25 | 0.057 | Extreme |
| 1996 | 0.391 | 0.897 | 0.066 | 2.568 | 0.469 | 0.378 | 0.304 | 0.815 | 25 | 0.059 | Extreme |
| 1997 | 0.472 | 0.917 | 0.075 | 3.712 | 0.544 | 0.457 | 0.384 | 0.792 | 25 | 0.068 | Extreme |
| 1998 | 0.491 | 0.885 | 0.111 | 4.135 | 0.424 | 0.332 | 0.260 | 0.702 | 25 | 0.098 | Extreme |
| 1999 | 0.425 | 0.927 | 0.054 | 2.913 | 0.587 | 0.505 | 0.434 | 0.846 | 25 | 0.050 | Extreme |
| 2000 | 0.717 | 0.948 | 0.132 | 8.603 | 0.688 | 0.619 | 0.556 | 0.655 | 25 | 0.125 | Extreme |
| 2001 | 0.461 | 0.906 | 0.081 | 3.884 | 0.500 | 0.410 | 0.336 | 0.777 | 25 | 0.073 | Extreme |
| 2002 | 0.693 | 0.946 | 0.122 | 8.018 | 0.678 | 0.606 | 0.543 | 0.677 | 25 | 0.115 | Extreme |
| 2003 | 0.892 | 0.970 | 0.250 | 13.506 | 0.806 | 0.758 | 0.713 | 0.422 | 5 | 0.242 | Mild |
| 2004 | 0.584 | 0.949 | 0.071 | 5.508 | 0.694 | 0.625 | 0.563 | 0.801 | 25 | 0.068 | Extreme |
| 2005 | 0.462 | 0.896 | 0.090 | 3.632 | 0.463 | 0.372 | 0.298 | 0.755 | 25 | 0.080 | Extreme |
| 2006 | 0.670 | 0.918 | 0.167 | 7.654 | 0.549 | 0.462 | 0.389 | 0.579 | 10 | 0.153 | Severe |
| 2007 | 0.330 | 0.947 | 0.026 | 2.077 | 0.685 | 0.615 | 0.552 | 0.924 | 25 | 0.025 | Extreme |
| 2008 | 0.443 | 0.930 | 0.056 | 3.166 | 0.603 | 0.522 | 0.451 | 0.842 | 25 | 0.052 | Extreme |
| 2009 | 0.337 | 0.879 | 0.062 | 1.976 | 0.405 | 0.313 | 0.241 | 0.826 | 25 | 0.054 | Extreme |
| 2010 | 0.418 | 0.905 | 0.068 | 2.928 | 0.496 | 0.406 | 0.333 | 0.808 | 25 | 0.062 | Extreme |
| 2011 | 0.541 | 0.912 | 0.103 | 4.948 | 0.526 | 0.438 | 0.364 | 0.721 | 25 | 0.094 | Extreme |

**Appendix-XIX** Year-wise analysis of probability of wet and dry weeks and index of drought proneness in the Ishwardi station for Pre-Kharif season

| | Pre-Kharif season using suitable threshold values (TV) in millimeters | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|
| Year | P | $P_{11}$ | $P_{01}$ | E(Y) | Probability of getting wet week at least | | | P(D>3) | TV | DI | Drought Classes |
| | | | | | 8 | 10 | 12 | | | | |
| 1961 | 0.464 | 0.915 | 0.074 | 3.576 | 0.537 | 0.449 | 0.376 | 0.795 | 25 | 0.067 | Extreme |
| 1962 | 0.621 | 0.967 | 0.055 | 5.941 | 0.789 | 0.737 | 0.689 | 0.845 | 25 | 0.053 | Extreme |
| 1963 | 0.844 | 0.978 | 0.120 | 11.692 | 0.854 | 0.817 | 0.781 | 0.681 | 5 | 0.117 | Extreme |
| 1964 | 0.462 | 0.896 | 0.090 | 3.632 | 0.463 | 0.372 | 0.298 | 0.755 | 25 | 0.080 | Extreme |
| 1965 | 0.427 | 0.907 | 0.069 | 3.053 | 0.505 | 0.415 | 0.342 | 0.806 | 25 | 0.063 | Extreme |
| 1966 | 0.244 | 0.938 | 0.020 | 0.803 | 0.637 | 0.559 | 0.492 | 0.941 | 25 | 0.019 | Extreme |
| 1967 | 0.813 | 0.966 | 0.148 | 11.033 | 0.784 | 0.732 | 0.683 | 0.618 | 5 | 0.143 | Severe |
| 1968 | 0.425 | 0.968 | 0.024 | 2.305 | 0.795 | 0.744 | 0.697 | 0.930 | 25 | 0.023 | Extreme |
| 1969 | 0.463 | 0.952 | 0.041 | 3.243 | 0.711 | 0.645 | 0.585 | 0.882 | 25 | 0.039 | Extreme |
| 1970 | 0.357 | 0.902 | 0.054 | 2.394 | 0.487 | 0.397 | 0.323 | 0.846 | 25 | 0.049 | Extreme |
| 1971 | 0.506 | 0.974 | 0.026 | 3.328 | 0.834 | 0.792 | 0.751 | 0.923 | 25 | 0.026 | Extreme |
| 1972 | 0.326 | 0.929 | 0.034 | 1.628 | 0.595 | 0.513 | 0.443 | 0.900 | 25 | 0.032 | Extreme |
| 1973 | 0.736 | 0.985 | 0.042 | 7.783 | 0.900 | 0.873 | 0.848 | 0.880 | 25 | 0.041 | Extreme |
| 1974 | 0.765 | 0.940 | 0.194 | 9.942 | 0.651 | 0.576 | 0.509 | 0.524 | 5 | 0.182 | Moderate |
| 1975 | 0.670 | 0.922 | 0.158 | 8.035 | 0.567 | 0.482 | 0.410 | 0.597 | 5 | 0.146 | Severe |
| 1976 | 0.527 | 0.959 | 0.045 | 4.215 | 0.747 | 0.687 | 0.632 | 0.870 | 25 | 0.044 | Extreme |
| 1977 | 0.642 | 0.955 | 0.082 | 6.699 | 0.722 | 0.658 | 0.599 | 0.775 | 25 | 0.078 | Extreme |
| 1978 | 0.841 | 0.957 | 0.227 | 12.012 | 0.735 | 0.673 | 0.617 | 0.461 | 5 | 0.217 | Moderate |
| 1979 | 0.231 | 0.933 | 0.020 | 0.725 | 0.617 | 0.537 | 0.468 | 0.941 | 25 | 0.019 | Extreme |
| 1980 | 0.383 | 0.932 | 0.042 | 2.733 | 0.610 | 0.530 | 0.460 | 0.879 | 25 | 0.039 | Extreme |
| 1981 | 0.878 | 0.960 | 0.286 | 13.550 | 0.754 | 0.695 | 0.641 | 0.364 | 5 | 0.274 | Mild |
| 1982 | 0.835 | 0.948 | 0.263 | 12.283 | 0.688 | 0.618 | 0.555 | 0.400 | 5 | 0.249 | Mild |
| 1983 | 0.809 | 0.935 | 0.273 | 11.553 | 0.627 | 0.549 | 0.480 | 0.385 | 5 | 0.255 | Mild |
| 1984 | 0.617 | 0.915 | 0.136 | 6.791 | 0.539 | 0.452 | 0.379 | 0.644 | 15 | 0.125 | Extreme |
| 1985 | 0.727 | 0.925 | 0.200 | 9.039 | 0.579 | 0.496 | 0.424 | 0.512 | 5 | 0.185 | Moderate |
| 1986 | 0.240 | 0.792 | 0.066 | 1.065 | 0.195 | 0.122 | 0.077 | 0.815 | 25 | 0.052 | Extreme |
| 1987 | 0.339 | 0.872 | 0.066 | 2.180 | 0.383 | 0.291 | 0.221 | 0.815 | 25 | 0.057 | Extreme |
| 1988 | 0.852 | 0.959 | 0.235 | 12.783 | 0.747 | 0.687 | 0.632 | 0.447 | 5 | 0.226 | Moderate |
| 1989 | 0.852 | 0.959 | 0.235 | 12.783 | 0.747 | 0.687 | 0.632 | 0.447 | 5 | 0.226 | Moderate |

| | Pre-Kharif season using suitable threshold values (TV) in millimeters | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|
| Year | P | $P_{11}$ | $P_{01}$ | E(Y) | Probability of getting wet week at least | | | P(D>3) | TV | DI | Drought Classes |
| | | | | | 8 | 10 | 12 | | | | |
| 1990 | 0.887 | 0.971 | 0.231 | 13.811 | 0.811 | 0.764 | 0.720 | 0.455 | 5 | 0.224 | Moderate |
| 1991 | 0.887 | 0.971 | 0.231 | 13.811 | 0.811 | 0.764 | 0.720 | 0.455 | 5 | 0.224 | Moderate |
| 1992 | 0.260 | 0.875 | 0.044 | 1.152 | 0.393 | 0.301 | 0.230 | 0.874 | 25 | 0.038 | Extreme |
| 1993 | 0.905 | 0.989 | 0.100 | 13.184 | 0.929 | 0.909 | 0.890 | 0.729 | 5 | 0.099 | Extreme |
| 1994 | 0.454 | 0.951 | 0.041 | 3.112 | 0.705 | 0.638 | 0.577 | 0.883 | 25 | 0.039 | Extreme |
| 1995 | 0.366 | 0.938 | 0.036 | 2.041 | 0.637 | 0.559 | 0.492 | 0.895 | 25 | 0.034 | Extreme |
| 1996 | 0.349 | 0.909 | 0.049 | 1.995 | 0.513 | 0.424 | 0.350 | 0.861 | 25 | 0.044 | Extreme |
| 1997 | 0.741 | 0.950 | 0.143 | 9.206 | 0.698 | 0.630 | 0.569 | 0.630 | 10 | 0.136 | Severe |
| 1998 | 0.789 | 0.943 | 0.214 | 10.589 | 0.661 | 0.587 | 0.521 | 0.485 | 10 | 0.202 | Moderate |
| 1999 | 0.406 | 0.944 | 0.038 | 2.494 | 0.670 | 0.598 | 0.533 | 0.890 | 25 | 0.036 | Extreme |
| 2000 | 0.661 | 0.969 | 0.060 | 6.799 | 0.804 | 0.755 | 0.709 | 0.831 | 25 | 0.058 | Extreme |
| 2001 | 0.776 | 0.930 | 0.241 | 10.307 | 0.603 | 0.522 | 0.451 | 0.437 | 5 | 0.225 | Moderate |
| 2002 | 0.635 | 0.918 | 0.143 | 7.255 | 0.549 | 0.462 | 0.389 | 0.630 | 10 | 0.131 | Severe |
| 2003 | 0.835 | 0.946 | 0.273 | 11.933 | 0.679 | 0.608 | 0.544 | 0.385 | 5 | 0.258 | Mild |
| 2004 | 0.434 | 0.929 | 0.055 | 3.039 | 0.595 | 0.513 | 0.443 | 0.844 | 25 | 0.051 | Extreme |
| 2005 | 0.659 | 0.930 | 0.136 | 7.348 | 0.600 | 0.518 | 0.448 | 0.644 | 5 | 0.127 | Severe |
| 2006 | 0.470 | 0.889 | 0.098 | 4.025 | 0.438 | 0.346 | 0.274 | 0.733 | 25 | 0.087 | Extreme |
| 2007 | 0.226 | 0.923 | 0.022 | 1.034 | 0.571 | 0.487 | 0.415 | 0.934 | 25 | 0.021 | Extreme |
| 2008 | 0.696 | 0.938 | 0.143 | 8.646 | 0.637 | 0.559 | 0.492 | 0.630 | 5 | 0.134 | Severe |
| 2009 | 0.287 | 0.857 | 0.057 | 1.434 | 0.340 | 0.250 | 0.183 | 0.837 | 25 | 0.049 | Extreme |
| 2010 | 0.282 | 0.793 | 0.081 | 1.452 | 0.197 | 0.124 | 0.078 | 0.775 | 25 | 0.065 | Extreme |
| 2011 | 0.796 | 0.943 | 0.222 | 10.808 | 0.664 | 0.591 | 0.525 | 0.471 | 5 | 0.210 | Moderate |

**Appendix-XX** Year-wise analysis of probability of wet and dry weeks and index of drought proneness in the Rajshahi station for Pre-Kharif season

| | Pre-Kharif season using suitable threshold values (TV) in millimeters | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|
| Year | P | $P_{11}$ | $P_{01}$ | E(Y) | Probability of getting wet week at least | | | P(D>3) | TV | DI | Drought Classes |
| | | | | | 8 | 10 | 12 | | | | |
| 1960 | 0.270 | 0.895 | 0.039 | 1.698 | 0.459 | 0.368 | 0.294 | 0.888 | 25 | 0.035 | Extreme |
| 1961 | 0.452 | 0.942 | 0.048 | 3.747 | 0.660 | 0.586 | 0.520 | 0.864 | 25 | 0.045 | Extreme |
| 1962 | 0.686 | 0.983 | 0.036 | 6.563 | 0.889 | 0.860 | 0.831 | 0.895 | 25 | 0.036 | Extreme |
| 1963 | 0.525 | 0.893 | 0.119 | 4.729 | 0.452 | 0.361 | 0.287 | 0.685 | 25 | 0.106 | Extreme |
| 1964 | 0.443 | 0.930 | 0.056 | 3.166 | 0.603 | 0.522 | 0.451 | 0.842 | 25 | 0.052 | Extreme |
| 1965 | 0.280 | 0.885 | 0.045 | 1.322 | 0.424 | 0.332 | 0.260 | 0.871 | 25 | 0.040 | Extreme |
| 1966 | 0.283 | 0.917 | 0.033 | 1.255 | 0.544 | 0.457 | 0.384 | 0.904 | 25 | 0.030 | Extreme |
| 1967 | 0.687 | 0.937 | 0.139 | 8.342 | 0.633 | 0.555 | 0.487 | 0.639 | 5 | 0.130 | Severe |
| 1968 | 0.278 | 0.938 | 0.024 | 1.511 | 0.637 | 0.559 | 0.492 | 0.929 | 25 | 0.023 | Extreme |
| 1969 | 0.425 | 0.947 | 0.039 | 2.735 | 0.685 | 0.615 | 0.552 | 0.888 | 25 | 0.037 | Extreme |
| 1970 | 0.506 | 0.974 | 0.026 | 3.328 | 0.834 | 0.792 | 0.751 | 0.923 | 25 | 0.026 | Extreme |
| 1971 | 0.346 | 0.933 | 0.035 | 1.830 | 0.617 | 0.537 | 0.468 | 0.898 | 25 | 0.033 | Extreme |
| 1972 | 0.321 | 0.955 | 0.022 | 1.331 | 0.722 | 0.658 | 0.599 | 0.937 | 25 | 0.021 | Extreme |
| 1973 | 0.508 | 0.923 | 0.079 | 4.280 | 0.571 | 0.487 | 0.415 | 0.780 | 25 | 0.073 | Extreme |
| 1974 | 0.296 | 0.853 | 0.062 | 1.689 | 0.328 | 0.239 | 0.174 | 0.826 | 25 | 0.053 | Extreme |
| 1975 | 0.226 | 0.846 | 0.045 | 1.034 | 0.311 | 0.222 | 0.159 | 0.871 | 25 | 0.038 | Extreme |
| 1976 | 0.387 | 0.919 | 0.051 | 2.435 | 0.553 | 0.467 | 0.395 | 0.854 | 25 | 0.047 | Extreme |
| 1977 | 0.634 | 0.954 | 0.080 | 6.523 | 0.718 | 0.654 | 0.595 | 0.779 | 25 | 0.076 | Extreme |
| 1978 | 0.471 | 0.935 | 0.058 | 3.563 | 0.624 | 0.545 | 0.476 | 0.836 | 25 | 0.054 | Extreme |
| 1979 | 0.078 | 0.778 | 0.019 | 0.168 | 0.172 | 0.104 | 0.063 | 0.944 | 25 | 0.015 | Extreme |
| 1980 | 0.470 | 0.926 | 0.066 | 4.025 | 0.583 | 0.500 | 0.429 | 0.816 | 25 | 0.061 | Extreme |
| 1981 | 0.818 | 0.956 | 0.200 | 11.338 | 0.727 | 0.664 | 0.606 | 0.512 | 5 | 0.191 | Moderate |
| 1982 | 0.748 | 0.930 | 0.207 | 9.935 | 0.603 | 0.522 | 0.451 | 0.499 | 5 | 0.192 | Moderate |
| 1983 | 0.160 | 0.846 | 0.029 | 0.459 | 0.311 | 0.222 | 0.159 | 0.914 | 25 | 0.025 | Extreme |

| | Pre-Kharif season using suitable threshold values (TV) in millimeters | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|
| Year | P | $P_{11}$ | $P_{01}$ | E(Y) | Probability of getting wet week at least | | | P(D>3) | TV | DI | Drought Classes |
| | | | | | 8 | 10 | 12 | | | | |
| 1984 | 0.336 | 0.931 | 0.035 | 1.728 | 0.606 | 0.526 | 0.456 | 0.899 | 25 | 0.032 | Extreme |
| 1985 | 0.453 | 0.894 | 0.088 | 3.497 | 0.455 | 0.363 | 0.290 | 0.758 | 25 | 0.079 | Extreme |
| 1986 | 0.408 | 0.881 | 0.082 | 2.859 | 0.412 | 0.320 | 0.248 | 0.773 | 25 | 0.072 | Extreme |
| 1987 | 0.348 | 0.900 | 0.053 | 2.286 | 0.478 | 0.387 | 0.314 | 0.848 | 25 | 0.048 | Extreme |
| 1988 | 0.560 | 0.900 | 0.127 | 5.360 | 0.478 | 0.387 | 0.314 | 0.665 | 25 | 0.115 | Extreme |
| 1989 | 0.278 | 0.844 | 0.060 | 1.511 | 0.304 | 0.217 | 0.154 | 0.830 | 25 | 0.051 | Extreme |
| 1990 | 0.795 | 0.954 | 0.179 | 10.679 | 0.719 | 0.655 | 0.596 | 0.554 | 10 | 0.170 | Severe |
| 1991 | 0.626 | 0.917 | 0.140 | 7.066 | 0.544 | 0.457 | 0.384 | 0.637 | 5 | 0.128 | Severe |
| 1992 | 0.209 | 0.875 | 0.033 | 0.894 | 0.393 | 0.301 | 0.230 | 0.904 | 25 | 0.029 | Extreme |
| 1993 | 0.636 | 0.913 | 0.152 | 6.909 | 0.529 | 0.441 | 0.368 | 0.609 | 10 | 0.139 | Severe |
| 1994 | 0.668 | 0.931 | 0.140 | 7.535 | 0.604 | 0.523 | 0.453 | 0.637 | 5 | 0.130 | Severe |
| 1995 | 0.386 | 0.941 | 0.037 | 2.263 | 0.654 | 0.579 | 0.513 | 0.893 | 25 | 0.035 | Extreme |
| 1996 | 0.434 | 0.929 | 0.055 | 3.039 | 0.595 | 0.513 | 0.443 | 0.844 | 25 | 0.051 | Extreme |
| 1997 | 0.320 | 0.900 | 0.047 | 1.691 | 0.478 | 0.387 | 0.314 | 0.865 | 25 | 0.042 | Extreme |
| 1998 | 0.703 | 0.897 | 0.243 | 8.541 | 0.469 | 0.378 | 0.304 | 0.433 | 5 | 0.218 | Moderate |
| 1999 | 0.300 | 0.893 | 0.046 | 1.501 | 0.452 | 0.361 | 0.287 | 0.868 | 25 | 0.041 | Extreme |
| 2000 | 0.596 | 0.965 | 0.052 | 5.447 | 0.779 | 0.725 | 0.675 | 0.853 | 25 | 0.050 | Extreme |
| 2001 | 0.330 | 0.895 | 0.052 | 2.077 | 0.459 | 0.368 | 0.294 | 0.852 | 25 | 0.046 | Extreme |
| 2002 | 0.558 | 0.915 | 0.107 | 5.265 | 0.538 | 0.451 | 0.378 | 0.712 | 25 | 0.098 | Extreme |
| 2003 | 0.707 | 0.910 | 0.216 | 8.581 | 0.518 | 0.429 | 0.355 | 0.481 | 10 | 0.197 | Moderate |
| 2004 | 0.406 | 0.923 | 0.053 | 2.670 | 0.571 | 0.487 | 0.415 | 0.850 | 25 | 0.049 | Extreme |
| 2005 | 0.435 | 0.889 | 0.086 | 3.235 | 0.438 | 0.346 | 0.274 | 0.764 | 25 | 0.076 | Extreme |
| 2006 | 0.365 | 0.905 | 0.055 | 2.504 | 0.496 | 0.406 | 0.333 | 0.844 | 25 | 0.050 | Extreme |
| 2007 | 0.322 | 0.946 | 0.026 | 2.022 | 0.678 | 0.606 | 0.543 | 0.925 | 25 | 0.024 | Extreme |
| 2008 | 0.339 | 0.872 | 0.066 | 2.180 | 0.383 | 0.291 | 0.221 | 0.815 | 25 | 0.057 | Extreme |

| | Pre-Kharif season using suitable threshold values (TV) in millimeters | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|
| Year | P | $P_{11}$ | $P_{01}$ | E(Y) | Probability of getting wet week at least | | | P(D>3) | TV | DI | Drought Classes |
| | | | | | 8 | 10 | 12 | | | | |
| 2009 | 0.564 | 0.885 | 0.148 | 5.474 | 0.426 | 0.334 | 0.262 | 0.618 | 5 | 0.131 | Severe |
| 2010 | 0.309 | 0.952 | 0.021 | 1.235 | 0.711 | 0.645 | 0.585 | 0.938 | 25 | 0.020 | Extreme |
| 2011 | 0.515 | 0.907 | 0.098 | 4.489 | 0.507 | 0.417 | 0.343 | 0.733 | 25 | 0.089 | Extreme |

**Appendix-XXI** Year-wise analysis of probability of wet and dry weeks and index of drought proneness in the Faridpur station for Pre-Kharif season

| | Pre-Kharif season using suitable threshold values (TV) in millimeters | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|
| Year | P | $P_{11}$ | $P_{01}$ | E(Y) | Probability of getting wet week at least | | | P(D>3) | TV | DI | Drought Classes |
| | | | | | 8 | 10 | 12 | | | | |
| 1961 | 0.396 | 0.943 | 0.038 | 2.377 | 0.662 | 0.589 | 0.523 | 0.892 | 25 | 0.035 | Extreme |
| 1962 | 0.683 | 0.958 | 0.091 | 7.607 | 0.739 | 0.678 | 0.622 | 0.751 | 20 | 0.087 | Extreme |
| 1963 | 0.818 | 0.956 | 0.200 | 11.338 | 0.727 | 0.664 | 0.606 | 0.512 | 5 | 0.191 | Moderate |
| 1964 | 0.471 | 0.898 | 0.091 | 3.769 | 0.471 | 0.380 | 0.306 | 0.751 | 25 | 0.082 | Extreme |
| 1965 | 0.251 | 0.905 | 0.032 | 1.004 | 0.496 | 0.406 | 0.333 | 0.907 | 25 | 0.029 | Extreme |
| 1966 | 0.378 | 0.917 | 0.051 | 2.322 | 0.544 | 0.457 | 0.384 | 0.856 | 25 | 0.046 | Extreme |
| 1967 | 0.390 | 0.875 | 0.080 | 2.620 | 0.393 | 0.301 | 0.230 | 0.779 | 25 | 0.070 | Extreme |
| 1968 | 0.741 | 0.938 | 0.176 | 9.314 | 0.640 | 0.564 | 0.496 | 0.559 | 5 | 0.166 | Severe |
| 1969 | 0.706 | 0.959 | 0.098 | 8.175 | 0.748 | 0.689 | 0.634 | 0.735 | 10 | 0.094 | Extreme |
| 1970 | 0.713 | 0.939 | 0.152 | 9.066 | 0.644 | 0.568 | 0.501 | 0.611 | 5 | 0.142 | Severe |
| 1971 | 0.417 | 0.884 | 0.083 | 2.982 | 0.421 | 0.329 | 0.257 | 0.770 | 25 | 0.074 | Extreme |
| 1972 | 0.435 | 0.900 | 0.077 | 3.478 | 0.478 | 0.387 | 0.314 | 0.787 | 25 | 0.069 | Extreme |
| 1973 | 0.768 | 0.963 | 0.121 | 9.766 | 0.770 | 0.715 | 0.664 | 0.679 | 20 | 0.117 | Extreme |
| 1974 | 0.676 | 0.932 | 0.143 | 7.725 | 0.609 | 0.528 | 0.458 | 0.630 | 15 | 0.133 | Severe |
| 1975 | 0.471 | 0.935 | 0.058 | 3.563 | 0.624 | 0.545 | 0.476 | 0.836 | 25 | 0.054 | Extreme |
| 1976 | 0.443 | 0.941 | 0.047 | 3.611 | 0.654 | 0.579 | 0.513 | 0.866 | 25 | 0.044 | Extreme |

| | Pre-Kharif season using suitable threshold values (TV) in millimeters | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|
| Year | P | $P_{11}$ | $P_{01}$ | E(Y) | Probability of getting wet week at least | | | P(D>3) | TV | DI | Drought Classes |
| | | | | | 8 | 10 | 12 | | | | |
| 1977 | 0.642 | 0.955 | 0.082 | 6.699 | 0.722 | 0.658 | 0.599 | 0.775 | 25 | 0.078 | Extreme |
| 1978 | 0.772 | 0.952 | 0.161 | 10.037 | 0.711 | 0.645 | 0.585 | 0.590 | 5 | 0.154 | Severe |
| 1979 | 0.294 | 0.920 | 0.033 | 1.345 | 0.558 | 0.472 | 0.400 | 0.903 | 25 | 0.031 | Extreme |
| 1980 | 0.843 | 0.969 | 0.167 | 12.532 | 0.803 | 0.754 | 0.708 | 0.579 | 5 | 0.162 | Severe |
| 1981 | 0.817 | 0.936 | 0.286 | 11.677 | 0.630 | 0.552 | 0.484 | 0.364 | 10 | 0.267 | Mild |
| 1982 | 0.826 | 0.947 | 0.250 | 12.037 | 0.685 | 0.615 | 0.552 | 0.422 | 5 | 0.237 | Mild |
| 1983 | 0.568 | 0.932 | 0.089 | 5.359 | 0.612 | 0.532 | 0.462 | 0.755 | 25 | 0.083 | Extreme |
| 1984 | 0.693 | 0.946 | 0.122 | 8.018 | 0.678 | 0.606 | 0.543 | 0.677 | 15 | 0.115 | Extreme |
| 1985 | 0.864 | 0.978 | 0.136 | 12.340 | 0.859 | 0.822 | 0.787 | 0.644 | 5 | 0.133 | Severe |
| 1986 | 0.627 | 0.939 | 0.102 | 6.543 | 0.646 | 0.570 | 0.503 | 0.724 | 25 | 0.096 | Extreme |
| 1987 | 0.809 | 0.935 | 0.273 | 11.553 | 0.627 | 0.549 | 0.480 | 0.385 | 5 | 0.255 | Mild |
| 1988 | 0.850 | 0.978 | 0.125 | 11.907 | 0.856 | 0.819 | 0.783 | 0.670 | 10 | 0.122 | Extreme |
| 1989 | 0.400 | 0.891 | 0.072 | 2.971 | 0.447 | 0.355 | 0.282 | 0.798 | 25 | 0.065 | Extreme |
| 1990 | 0.939 | 0.981 | 0.286 | 15.429 | 0.877 | 0.845 | 0.814 | 0.364 | 10 | 0.280 | Mild |
| 1991 | 0.843 | 0.948 | 0.278 | 12.532 | 0.690 | 0.621 | 0.559 | 0.377 | 5 | 0.263 | Mild |
| 1992 | 0.368 | 0.914 | 0.050 | 2.211 | 0.534 | 0.446 | 0.373 | 0.857 | 25 | 0.046 | Extreme |
| 1993 | 0.651 | 0.929 | 0.133 | 7.163 | 0.595 | 0.513 | 0.443 | 0.651 | 25 | 0.124 | Extreme |
| 1994 | 0.594 | 0.935 | 0.094 | 5.854 | 0.627 | 0.549 | 0.480 | 0.743 | 25 | 0.088 | Extreme |
| 1995 | 0.322 | 0.892 | 0.051 | 1.976 | 0.449 | 0.357 | 0.284 | 0.854 | 25 | 0.046 | Extreme |
| 1996 | 0.524 | 0.909 | 0.100 | 4.639 | 0.513 | 0.424 | 0.350 | 0.729 | 25 | 0.091 | Extreme |
| 1997 | 0.659 | 0.930 | 0.136 | 7.348 | 0.600 | 0.518 | 0.448 | 0.644 | 10 | 0.127 | Severe |
| 1998 | 0.720 | 0.900 | 0.257 | 8.949 | 0.478 | 0.387 | 0.314 | 0.410 | 25 | 0.231 | Moderate |
| 1999 | 0.532 | 0.911 | 0.102 | 4.792 | 0.520 | 0.431 | 0.357 | 0.725 | 25 | 0.093 | Extreme |
| 2000 | 0.768 | 0.963 | 0.121 | 9.766 | 0.770 | 0.715 | 0.664 | 0.679 | 25 | 0.117 | Extreme |
| 2001 | 0.661 | 0.947 | 0.103 | 7.836 | 0.685 | 0.615 | 0.552 | 0.723 | 5 | 0.097 | Extreme |

| | Pre-Kharif season using suitable threshold values (TV) in millimeters | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|
| Year | P | $P_{11}$ | $P_{01}$ | E(Y) | Probability of getting wet week at least | | | P(D>3) | TV | DI | Drought Classes |
| | | | | | 8 | 10 | 12 | | | | |
| 2002 | 0.788 | 0.976 | 0.091 | 10.025 | 0.841 | 0.801 | 0.762 | 0.751 | 20 | 0.089 | Extreme |
| 2003 | 0.796 | 0.943 | 0.222 | 10.808 | 0.664 | 0.591 | 0.525 | 0.471 | 5 | 0.210 | Moderate |
| 2004 | 0.536 | 0.960 | 0.046 | 4.362 | 0.751 | 0.693 | 0.638 | 0.868 | 25 | 0.044 | Extreme |
| 2005 | 0.603 | 0.908 | 0.140 | 6.199 | 0.508 | 0.418 | 0.345 | 0.636 | 5 | 0.127 | Severe |
| 2006 | 0.498 | 0.904 | 0.095 | 4.194 | 0.493 | 0.403 | 0.329 | 0.741 | 25 | 0.086 | Extreme |
| 2007 | 0.506 | 0.906 | 0.097 | 4.340 | 0.500 | 0.410 | 0.336 | 0.737 | 25 | 0.088 | Extreme |
| 2008 | 0.678 | 0.936 | 0.135 | 8.236 | 0.629 | 0.551 | 0.483 | 0.647 | 5 | 0.126 | Severe |
| 2009 | 0.534 | 0.927 | 0.083 | 4.730 | 0.589 | 0.507 | 0.436 | 0.770 | 25 | 0.077 | Extreme |
| 2010 | 0.524 | 0.942 | 0.063 | 4.416 | 0.660 | 0.586 | 0.520 | 0.821 | 25 | 0.060 | Extreme |
| 2011 | 0.611 | 0.909 | 0.143 | 6.373 | 0.513 | 0.424 | 0.350 | 0.630 | 15 | 0.130 | Severe |

**Appendix-XX** Year-wise analysis of probability of wet and dry weeks and index of drought proneness in the Jessore station for Pre-Kharif season

| | Pre-Kharif season using suitable threshold values (TV) in millimeters | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|
| Year | $P$ | $P_{11}$ | $P_{01}$ | E(Y) | Probability of getting wet week at least | | | P(D>3) | TV | DI | Drought Classes |
| | | | | | 8 | 10 | 12 | | | | |
| 1960 | 0.259 | 0.857 | 0.050 | 1.519 | 0.340 | 0.250 | 0.183 | 0.857 | 25 | 0.043 | Extreme |
| 1961 | 0.670 | 0.935 | 0.132 | 8.035 | 0.625 | 0.546 | 0.478 | 0.655 | 5 | 0.123 | Extreme |
| 1962 | 0.374 | 0.907 | 0.056 | 2.617 | 0.505 | 0.415 | 0.342 | 0.842 | 25 | 0.050 | Extreme |
| 1963 | 0.425 | 0.927 | 0.054 | 2.913 | 0.587 | 0.505 | 0.434 | 0.846 | 25 | 0.050 | Extreme |
| 1964 | 0.733 | 0.949 | 0.139 | 9.003 | 0.695 | 0.626 | 0.565 | 0.639 | 5 | 0.132 | Severe |
| 1965 | 0.330 | 0.903 | 0.048 | 1.790 | 0.490 | 0.400 | 0.326 | 0.864 | 25 | 0.043 | Extreme |
| 1966 | 0.406 | 0.944 | 0.038 | 2.494 | 0.670 | 0.598 | 0.533 | 0.890 | 25 | 0.036 | Extreme |
| 1967 | 0.426 | 0.898 | 0.076 | 3.348 | 0.471 | 0.380 | 0.306 | 0.790 | 25 | 0.068 | Extreme |
| 1968 | 0.509 | 0.957 | 0.044 | 3.927 | 0.738 | 0.676 | 0.620 | 0.873 | 25 | 0.042 | Extreme |
| 1969 | 0.443 | 0.843 | 0.125 | 3.611 | 0.303 | 0.215 | 0.153 | 0.670 | 25 | 0.105 | Extreme |
| 1970 | 0.283 | 0.868 | 0.052 | 1.779 | 0.372 | 0.281 | 0.212 | 0.852 | 25 | 0.045 | Extreme |

| | Pre-Kharif season using suitable threshold values (TV) in millimeters | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|
| Year | $P$ | $P_{11}$ | $P_{01}$ | E(Y) | Probability of getting wet week at least | | | P(D>3) | TV | DI | Drought Classes |
| | | | | | 8 | 10 | 12 | | | | |
| 1971 | 0.939 | 0.981 | 0.286 | 15.429 | 0.877 | 0.845 | 0.814 | 0.364 | 5 | 0.280 | Mild |
| 1972 | 0.217 | 0.929 | 0.020 | 0.651 | 0.595 | 0.513 | 0.443 | 0.942 | 25 | 0.018 | Extreme |
| 1973 | 0.611 | 0.938 | 0.098 | 6.194 | 0.637 | 0.559 | 0.492 | 0.734 | 25 | 0.092 | Extreme |
| 1974 | 0.452 | 0.904 | 0.079 | 3.747 | 0.493 | 0.403 | 0.329 | 0.780 | 25 | 0.072 | Extreme |
| 1975 | 0.280 | 0.885 | 0.045 | 1.322 | 0.424 | 0.332 | 0.260 | 0.871 | 25 | 0.040 | Extreme |
| 1976 | 0.391 | 0.933 | 0.043 | 2.851 | 0.617 | 0.537 | 0.468 | 0.877 | 25 | 0.040 | Extreme |
| 1977 | 0.722 | 0.961 | 0.103 | 8.562 | 0.754 | 0.696 | 0.642 | 0.723 | 5 | 0.099 | Extreme |
| 1978 | 0.828 | 0.946 | 0.261 | 11.704 | 0.676 | 0.605 | 0.541 | 0.404 | 5 | 0.247 | Mild |
| 1979 | 0.203 | 0.923 | 0.020 | 0.580 | 0.571 | 0.487 | 0.415 | 0.942 | 25 | 0.018 | Extreme |
| 1980 | 0.409 | 0.915 | 0.059 | 3.153 | 0.537 | 0.449 | 0.376 | 0.834 | 25 | 0.054 | Extreme |
| 1981 | 0.878 | 0.960 | 0.286 | 13.550 | 0.754 | 0.695 | 0.641 | 0.364 | 5 | 0.274 | Mild |
| 1982 | 0.817 | 0.947 | 0.238 | 11.794 | 0.682 | 0.611 | 0.548 | 0.442 | 5 | 0.225 | Moderate |
| 1983 | 0.443 | 0.941 | 0.047 | 3.675 | 0.654 | 0.579 | 0.513 | 0.866 | 25 | 0.044 | Extreme |
| 1984 | 0.491 | 0.956 | 0.043 | 3.647 | 0.727 | 0.664 | 0.606 | 0.877 | 25 | 0.041 | Extreme |
| 1985 | 0.489 | 0.902 | 0.094 | 4.050 | 0.486 | 0.395 | 0.321 | 0.744 | 25 | 0.085 | Extreme |
| 1986 | 0.517 | 0.925 | 0.081 | 4.428 | 0.577 | 0.493 | 0.422 | 0.777 | 25 | 0.075 | Extreme |
| 1987 | 0.678 | 0.923 | 0.162 | 8.236 | 0.571 | 0.487 | 0.415 | 0.588 | 5 | 0.150 | Severe |
| 1988 | 0.652 | 0.942 | 0.109 | 7.081 | 0.658 | 0.584 | 0.518 | 0.708 | 25 | 0.102 | Extreme |
| 1989 | 0.391 | 0.889 | 0.071 | 2.851 | 0.438 | 0.346 | 0.274 | 0.801 | 25 | 0.063 | Extreme |
| 1990 | 0.826 | 0.958 | 0.200 | 12.037 | 0.740 | 0.679 | 0.623 | 0.512 | 5 | 0.192 | Moderate |
| 1991 | 0.443 | 0.930 | 0.056 | 3.166 | 0.603 | 0.522 | 0.451 | 0.842 | 25 | 0.052 | Extreme |
| 1992 | 0.435 | 0.949 | 0.039 | 2.858 | 0.692 | 0.623 | 0.560 | 0.886 | 25 | 0.037 | Extreme |
| 1993 | 0.589 | 0.891 | 0.157 | 5.976 | 0.444 | 0.353 | 0.280 | 0.599 | 25 | 0.140 | Severe |
| 1994 | 0.454 | 0.951 | 0.041 | 3.112 | 0.705 | 0.638 | 0.577 | 0.883 | 25 | 0.039 | Extreme |
| 1995 | 0.226 | 0.885 | 0.034 | 1.034 | 0.424 | 0.332 | 0.260 | 0.902 | 25 | 0.030 | Extreme |
| 1996 | 0.391 | 0.897 | 0.066 | 2.568 | 0.469 | 0.378 | 0.304 | 0.815 | 25 | 0.059 | Extreme |
| 1997 | 0.741 | 0.950 | 0.143 | 9.206 | 0.698 | 0.630 | 0.569 | 0.630 | 5 | 0.136 | Severe |
| 1998 | 0.881 | 0.949 | 0.375 | 13.345 | 0.696 | 0.627 | 0.565 | 0.244 | 5 | 0.356 | Occasional |
| 1999 | 0.368 | 0.914 | 0.050 | 2.211 | 0.534 | 0.446 | 0.373 | 0.857 | 25 | 0.046 | Extreme |
| 2000 | 0.543 | 0.929 | 0.085 | 4.884 | 0.595 | 0.513 | 0.443 | 0.767 | 25 | 0.079 | Extreme |

| Year | Pre-Kharif season using suitable threshold values (TV) in millimeters | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|
| | $P$ | $P_{11}$ | $P_{01}$ | E(Y) | Probability of getting wet week at least | | | P(D>3) | TV | DI | Drought Classes |
| | | | | | 8 | 10 | 12 | | | | |
| 2001 | 0.722 | 0.952 | 0.125 | 9.280 | 0.708 | 0.641 | 0.581 | 0.670 | 5 | 0.119 | Extreme |
| 2002 | 0.798 | 0.965 | 0.138 | 10.604 | 0.780 | 0.726 | 0.677 | 0.641 | 5 | 0.133 | Severe |
| 2003 | 0.820 | 0.945 | 0.250 | 11.477 | 0.673 | 0.601 | 0.537 | 0.422 | 5 | 0.236 | Mild |
| 2004 | 0.490 | 0.920 | 0.077 | 3.992 | 0.558 | 0.472 | 0.400 | 0.787 | 25 | 0.071 | Extreme |
| 2005 | 0.382 | 0.895 | 0.065 | 2.453 | 0.459 | 0.368 | 0.294 | 0.818 | 25 | 0.058 | Extreme |
| 2006 | 0.462 | 0.933 | 0.057 | 3.429 | 0.617 | 0.537 | 0.468 | 0.838 | 25 | 0.053 | Extreme |
| 2007 | 0.411 | 0.860 | 0.097 | 2.933 | 0.349 | 0.259 | 0.191 | 0.736 | 25 | 0.084 | Extreme |
| 2008 | 0.687 | 0.924 | 0.167 | 8.440 | 0.575 | 0.491 | 0.419 | 0.579 | 10 | 0.154 | Severe |
| 2009 | 0.359 | 0.912 | 0.049 | 2.102 | 0.524 | 0.435 | 0.362 | 0.859 | 25 | 0.045 | Extreme |
| 2010 | 0.397 | 0.921 | 0.052 | 2.551 | 0.562 | 0.477 | 0.405 | 0.852 | 25 | 0.048 | Extreme |
| 2011 | 0.764 | 0.952 | 0.156 | 9.826 | 0.708 | 0.641 | 0.581 | 0.601 | 5 | 0.149 | Severe |

**Appendix-XXIII** Year-wise analysis of probability of wet and dry weeks and index of drought proneness in the Khulna station for Pre-Kharif season

| Year | Pre-Kharif season using suitable threshold values (TV) in millimeters | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|
| | $P$ | $P_{11}$ | $P_{01}$ | E(Y) | Probability of getting wet week at least | | | P(D>3) | TV | DI | Drought Classes |
| | | | | | 8 | 10 | 12 | | | | |
| 1960 | 0.217 | 0.920 | 0.022 | 0.963 | 0.558 | 0.472 | 0.400 | 0.935 | 25 | 0.020 | Extreme |
| 1961 | 0.320 | 0.900 | 0.047 | 1.691 | 0.478 | 0.387 | 0.314 | 0.865 | 25 | 0.042 | Extreme |
| 1962 | 0.473 | 0.953 | 0.042 | 3.375 | 0.716 | 0.651 | 0.592 | 0.880 | 25 | 0.040 | Extreme |
| 1963 | 0.474 | 0.907 | 0.083 | 4.128 | 0.507 | 0.417 | 0.343 | 0.770 | 25 | 0.076 | Extreme |
| 1964 | 0.676 | 0.932 | 0.143 | 7.725 | 0.609 | 0.528 | 0.458 | 0.630 | 10 | 0.133 | Severe |
| 1965 | 0.480 | 0.900 | 0.092 | 3.909 | 0.478 | 0.387 | 0.314 | 0.748 | 25 | 0.083 | Extreme |
| 1966 | 0.326 | 0.929 | 0.034 | 1.628 | 0.595 | 0.513 | 0.443 | 0.900 | 25 | 0.032 | Extreme |
| 1967 | 0.390 | 0.875 | 0.080 | 2.620 | 0.393 | 0.301 | 0.230 | 0.779 | 25 | 0.070 | Extreme |
| 1968 | 0.339 | 0.897 | 0.053 | 2.180 | 0.469 | 0.378 | 0.304 | 0.850 | 25 | 0.047 | Extreme |
| 1969 | 0.335 | 0.853 | 0.074 | 1.962 | 0.328 | 0.239 | 0.174 | 0.794 | 25 | 0.063 | Extreme |
| 1970 | 0.527 | 0.959 | 0.045 | 4.215 | 0.747 | 0.687 | 0.632 | 0.870 | 25 | 0.044 | Extreme |
| 1971 | 0.206 | 0.882 | 0.031 | 0.708 | 0.416 | 0.324 | 0.252 | 0.911 | 25 | 0.027 | Extreme |

| | Pre-Kharif season using suitable threshold values (TV) in millimeters | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|
| Year | $P$ | $P_{11}$ | $P_{01}$ | E(Y) | Probability of getting wet week at least | | | P(D>3) | TV | DI | Drought Classes |
| | | | | | 8 | 10 | 12 | | | | |
| 1972 | 0.305 | 0.923 | 0.034 | 1.436 | 0.571 | 0.487 | 0.415 | 0.902 | 25 | 0.031 | Extreme |
| 1973 | 0.643 | 0.928 | 0.130 | 6.980 | 0.591 | 0.508 | 0.437 | 0.658 | 15 | 0.121 | Extreme |
| 1974 | 0.541 | 0.912 | 0.103 | 4.948 | 0.526 | 0.438 | 0.364 | 0.721 | 25 | 0.094 | Extreme |
| 1975 | 0.462 | 0.933 | 0.057 | 3.429 | 0.617 | 0.537 | 0.468 | 0.838 | 25 | 0.053 | Extreme |
| 1976 | 0.490 | 0.920 | 0.077 | 3.992 | 0.558 | 0.472 | 0.400 | 0.787 | 25 | 0.071 | Extreme |
| 1977 | 0.584 | 0.919 | 0.113 | 5.756 | 0.555 | 0.469 | 0.397 | 0.697 | 25 | 0.104 | Extreme |
| 1978 | 0.833 | 0.957 | 0.217 | 11.786 | 0.733 | 0.670 | 0.613 | 0.479 | 5 | 0.208 | Moderate |
| 1979 | 0.280 | 0.885 | 0.045 | 1.322 | 0.424 | 0.332 | 0.260 | 0.871 | 25 | 0.040 | Extreme |
| 1980 | 0.435 | 0.960 | 0.031 | 3.540 | 0.751 | 0.693 | 0.638 | 0.911 | 25 | 0.030 | Extreme |
| 1981 | 0.907 | 0.961 | 0.385 | 14.131 | 0.756 | 0.698 | 0.644 | 0.233 | 5 | 0.370 | Occasional |
| 1982 | 0.425 | 0.927 | 0.054 | 2.913 | 0.587 | 0.505 | 0.434 | 0.846 | 25 | 0.050 | Extreme |
| 1983 | 0.496 | 0.930 | 0.069 | 4.532 | 0.601 | 0.520 | 0.449 | 0.807 | 25 | 0.064 | Extreme |
| 1984 | 0.611 | 0.938 | 0.098 | 6.194 | 0.637 | 0.559 | 0.492 | 0.734 | 25 | 0.092 | Extreme |
| 1985 | 0.472 | 0.917 | 0.075 | 3.712 | 0.544 | 0.457 | 0.384 | 0.792 | 25 | 0.068 | Extreme |
| 1986 | 0.425 | 0.927 | 0.054 | 2.913 | 0.587 | 0.505 | 0.434 | 0.846 | 25 | 0.050 | Extreme |
| 1987 | 0.390 | 0.875 | 0.080 | 2.620 | 0.393 | 0.301 | 0.230 | 0.779 | 25 | 0.070 | Extreme |
| 1988 | 0.543 | 0.929 | 0.085 | 4.884 | 0.595 | 0.513 | 0.443 | 0.767 | 25 | 0.079 | Extreme |
| 1989 | 0.431 | 0.900 | 0.076 | 3.387 | 0.478 | 0.387 | 0.314 | 0.790 | 25 | 0.068 | Extreme |
| 1990 | 0.406 | 0.923 | 0.053 | 2.670 | 0.571 | 0.487 | 0.415 | 0.850 | 25 | 0.049 | Extreme |
| 1991 | 0.406 | 0.923 | 0.053 | 2.670 | 0.571 | 0.487 | 0.415 | 0.850 | 25 | 0.049 | Extreme |
| 1992 | 0.386 | 0.941 | 0.037 | 2.263 | 0.654 | 0.579 | 0.513 | 0.893 | 25 | 0.035 | Extreme |
| 1993 | 0.830 | 0.977 | 0.111 | 11.267 | 0.851 | 0.813 | 0.777 | 0.702 | 5 | 0.109 | Extreme |
| 1994 | 0.400 | 0.900 | 0.067 | 2.686 | 0.478 | 0.387 | 0.314 | 0.813 | 25 | 0.060 | Extreme |
| 1995 | 0.425 | 0.947 | 0.039 | 2.735 | 0.685 | 0.615 | 0.552 | 0.888 | 25 | 0.037 | Extreme |
| 1996 | 0.437 | 0.909 | 0.070 | 3.180 | 0.513 | 0.424 | 0.350 | 0.803 | 25 | 0.064 | Extreme |
| 1997 | 0.783 | 0.964 | 0.129 | 10.182 | 0.775 | 0.721 | 0.670 | 0.661 | 5 | 0.124 | Extreme |
| 1998 | 0.915 | 0.961 | 0.417 | 14.375 | 0.758 | 0.700 | 0.647 | 0.198 | 5 | 0.400 | Occasional |
| 1999 | 0.378 | 0.917 | 0.051 | 2.322 | 0.544 | 0.457 | 0.384 | 0.856 | 25 | 0.046 | Extreme |
| 2000 | 0.506 | 0.906 | 0.097 | 4.340 | 0.500 | 0.410 | 0.336 | 0.737 | 25 | 0.088 | Extreme |
| 2001 | 0.722 | 0.940 | 0.156 | 9.280 | 0.647 | 0.572 | 0.505 | 0.601 | 5 | 0.147 | Severe |

| Year | Pre-Kharif season using suitable threshold values (TV) in millimeters | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|
| | $P$ | $P_{11}$ | $P_{01}$ | E(Y) | Probability of getting wet week at least | | | P(D>3) | TV | DI | Drought Classes |
| | | | | | 8 | 10 | 12 | | | | |
| 2002 | 0.856 | 0.958 | 0.250 | 12.471 | 0.740 | 0.679 | 0.623 | 0.422 | 5 | 0.239 | Mild |
| 2003 | 0.773 | 0.941 | 0.200 | 10.156 | 0.654 | 0.579 | 0.513 | 0.512 | 5 | 0.188 | Moderate |
| 2004 | 0.452 | 0.923 | 0.063 | 3.747 | 0.571 | 0.487 | 0.415 | 0.821 | 25 | 0.059 | Extreme |
| 2005 | 0.692 | 0.933 | 0.150 | 8.110 | 0.617 | 0.537 | 0.468 | 0.614 | 5 | 0.140 | Severe |
| 2006 | 0.052 | 0.167 | 0.046 | 0.089 | 0.000 | 0.000 | 0.000 | 0.869 | 25 | 0.008 | Extreme |
| 2007 | 0.052 | 0.000 | 0.055 | 0.089 | 0.000 | 0.000 | 0.000 | 0.844 | 25 | 0.000 | Extreme |
| 2008 | 0.391 | 0.867 | 0.086 | 2.851 | 0.367 | 0.276 | 0.207 | 0.764 | 25 | 0.074 | Extreme |
| 2009 | 0.391 | 0.897 | 0.066 | 2.568 | 0.469 | 0.378 | 0.304 | 0.815 | 25 | 0.059 | Extreme |
| 2010 | 0.387 | 0.919 | 0.051 | 2.435 | 0.553 | 0.467 | 0.395 | 0.854 | 25 | 0.047 | Extreme |
| 2011 | 0.425 | 0.927 | 0.054 | 2.913 | 0.587 | 0.505 | 0.434 | 0.846 | 25 | 0.050 | Extreme |

**Appendix-XXIV** Year-wise analysis of probability of wet and dry weeks and index of drought proneness in the Satkhira station for Pre-Kharif season

| Year | Pre-Kharif season using suitable threshold values (TV) in millimeters | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|
| | $P$ | $P_{11}$ | $P_{01}$ | E(Y) | Probability of getting wet week at least | | | P(D>3) | TV | DI | Drought Classes |
| | | | | | 8 | 10 | 12 | | | | |
| 1960 | 0.248 | 0.921 | 0.026 | 1.556 | 0.562 | 0.477 | 0.405 | 0.924 | 25 | 0.024 | Extreme |
| 1961 | 0.387 | 0.919 | 0.051 | 2.435 | 0.553 | 0.467 | 0.395 | 0.854 | 25 | 0.047 | Extreme |
| 1962 | 0.287 | 0.909 | 0.037 | 1.599 | 0.513 | 0.424 | 0.350 | 0.894 | 25 | 0.033 | Extreme |
| 1963 | 0.417 | 0.896 | 0.075 | 3.220 | 0.463 | 0.372 | 0.298 | 0.792 | 25 | 0.067 | Extreme |
| 1964 | 0.472 | 0.917 | 0.075 | 3.712 | 0.544 | 0.457 | 0.384 | 0.792 | 25 | 0.068 | Extreme |
| 1965 | 0.427 | 0.907 | 0.069 | 3.053 | 0.505 | 0.415 | 0.342 | 0.806 | 25 | 0.063 | Extreme |
| 1966 | 0.160 | 0.846 | 0.029 | 0.459 | 0.311 | 0.222 | 0.159 | 0.914 | 25 | 0.025 | Extreme |
| 1967 | 0.326 | 0.929 | 0.034 | 1.628 | 0.595 | 0.513 | 0.443 | 0.900 | 25 | 0.032 | Extreme |
| 1968 | 0.776 | 0.964 | 0.125 | 9.973 | 0.773 | 0.718 | 0.667 | 0.670 | 5 | 0.120 | Extreme |
| 1969 | 0.139 | 0.875 | 0.020 | 0.437 | 0.393 | 0.301 | 0.230 | 0.941 | 25 | 0.018 | Extreme |
| 1970 | 0.287 | 0.909 | 0.037 | 1.599 | 0.513 | 0.424 | 0.350 | 0.894 | 25 | 0.033 | Extreme |
| 1971 | 0.426 | 0.886 | 0.085 | 3.107 | 0.430 | 0.338 | 0.265 | 0.767 | 25 | 0.075 | Extreme |
| 1972 | 1.000 | 1.000 | 0.010 | 3.000 | 1.000 | 1.000 | 1.000 | 0.971 | 25 | 0.010 | Extreme |
| 1973 | 0.453 | 0.894 | 0.088 | 3.497 | 0.455 | 0.363 | 0.290 | 0.758 | 25 | 0.079 | Extreme |

| | Pre-Kharif season using suitable threshold values (TV) in millimeters | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|
| Year | $P$ | $P_{11}$ | $P_{01}$ | E(Y) | Probability of getting wet week at least | | | P(D>3) | TV | DI | Drought Classes |
| | | | | | 8 | 10 | 12 | | | | |
| 1974 | 0.692 | 0.933 | 0.150 | 8.110 | 0.617 | 0.537 | 0.468 | 0.614 | 5 | 0.140 | Severe |
| 1975 | 0.240 | 0.900 | 0.032 | 0.926 | 0.478 | 0.387 | 0.314 | 0.908 | 25 | 0.028 | Extreme |
| 1976 | 0.506 | 0.940 | 0.062 | 4.123 | 0.648 | 0.573 | 0.506 | 0.827 | 25 | 0.058 | Extreme |
| 1977 | 0.592 | 0.921 | 0.115 | 5.925 | 0.561 | 0.475 | 0.403 | 0.692 | 25 | 0.106 | Extreme |
| 1978 | 0.812 | 0.944 | 0.240 | 11.252 | 0.670 | 0.598 | 0.533 | 0.439 | 5 | 0.227 | Moderate |
| 1979 | 0.240 | 0.864 | 0.043 | 0.993 | 0.358 | 0.267 | 0.199 | 0.876 | 25 | 0.037 | Extreme |
| 1980 | 0.348 | 0.925 | 0.040 | 2.335 | 0.579 | 0.496 | 0.424 | 0.885 | 25 | 0.037 | Extreme |
| 1981 | 0.773 | 0.941 | 0.200 | 10.156 | 0.654 | 0.579 | 0.513 | 0.512 | 10 | 0.188 | Moderate |
| 1982 | 0.739 | 0.941 | 0.167 | 9.714 | 0.654 | 0.579 | 0.513 | 0.579 | 5 | 0.157 | Severe |
| 1983 | 0.506 | 0.906 | 0.097 | 4.340 | 0.500 | 0.410 | 0.336 | 0.737 | 25 | 0.088 | Extreme |
| 1984 | 0.497 | 0.939 | 0.061 | 3.980 | 0.643 | 0.566 | 0.499 | 0.829 | 25 | 0.057 | Extreme |
| 1985 | 0.382 | 0.895 | 0.065 | 2.453 | 0.459 | 0.368 | 0.294 | 0.818 | 25 | 0.058 | Extreme |
| 1986 | 0.491 | 0.885 | 0.111 | 4.135 | 0.424 | 0.332 | 0.260 | 0.702 | 25 | 0.098 | Extreme |
| 1987 | 0.374 | 0.930 | 0.042 | 2.617 | 0.603 | 0.522 | 0.451 | 0.880 | 25 | 0.039 | Extreme |
| 1988 | 0.534 | 0.895 | 0.121 | 4.884 | 0.459 | 0.368 | 0.294 | 0.680 | 25 | 0.108 | Extreme |
| 1989 | 0.400 | 0.935 | 0.043 | 2.971 | 0.624 | 0.545 | 0.476 | 0.875 | 25 | 0.041 | Extreme |
| 1990 | 0.496 | 0.930 | 0.069 | 4.532 | 0.601 | 0.520 | 0.449 | 0.807 | 25 | 0.064 | Extreme |
| 1991 | 0.652 | 0.920 | 0.150 | 7.640 | 0.558 | 0.472 | 0.400 | 0.614 | 5 | 0.138 | Severe |
| 1992 | 0.346 | 0.933 | 0.035 | 1.830 | 0.617 | 0.537 | 0.468 | 0.898 | 25 | 0.033 | Extreme |
| 1993 | 0.669 | 0.944 | 0.114 | 7.450 | 0.666 | 0.593 | 0.528 | 0.696 | 25 | 0.107 | Extreme |
| 1994 | 0.462 | 0.933 | 0.057 | 3.429 | 0.617 | 0.537 | 0.468 | 0.838 | 25 | 0.053 | Extreme |
| 1995 | 0.296 | 0.912 | 0.037 | 1.689 | 0.524 | 0.435 | 0.362 | 0.893 | 25 | 0.034 | Extreme |
| 1996 | 0.452 | 0.932 | 0.056 | 3.296 | 0.610 | 0.530 | 0.460 | 0.840 | 25 | 0.052 | Extreme |
| 1997 | 0.715 | 0.911 | 0.222 | 8.783 | 0.522 | 0.434 | 0.360 | 0.471 | 10 | 0.203 | Moderate |
| 1998 | 0.792 | 0.932 | 0.259 | 10.746 | 0.610 | 0.530 | 0.460 | 0.406 | 5 | 0.242 | Mild |
| 1999 | 0.491 | 0.956 | 0.043 | 3.647 | 0.727 | 0.664 | 0.606 | 0.877 | 25 | 0.041 | Extreme |
| 2000 | 0.584 | 0.949 | 0.071 | 5.508 | 0.694 | 0.625 | 0.563 | 0.801 | 25 | 0.068 | Extreme |
| 2001 | 0.733 | 0.949 | 0.139 | 9.003 | 0.695 | 0.626 | 0.565 | 0.639 | 10 | 0.132 | Severe |
| 2002 | 0.659 | 0.930 | 0.136 | 7.348 | 0.600 | 0.518 | 0.448 | 0.644 | 5 | 0.127 | Severe |
| 2003 | 0.575 | 0.918 | 0.111 | 5.590 | 0.550 | 0.463 | 0.390 | 0.702 | 25 | 0.102 | Extreme |

| Year | Pre-Kharif season using suitable threshold values (TV) in millimeters | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|
| | $P$ | $P_{11}$ | $P_{01}$ | E(Y) | Probability of getting wet week at least | | | P(D>3) | TV | DI | Drought Classes |
| | | | | | 8 | 10 | 12 | | | | |
| 2004 | 0.559 | 0.946 | 0.068 | 5.027 | 0.680 | 0.609 | 0.546 | 0.810 | 25 | 0.064 | Extreme |
| 2005 | 0.387 | 0.919 | 0.051 | 2.435 | 0.553 | 0.467 | 0.395 | 0.854 | 25 | 0.047 | Extreme |
| 2006 | 0.481 | 0.918 | 0.076 | 3.851 | 0.551 | 0.465 | 0.392 | 0.790 | 25 | 0.070 | Extreme |
| 2007 | 0.209 | 0.833 | 0.044 | 0.894 | 0.279 | 0.194 | 0.135 | 0.874 | 25 | 0.037 | Extreme |
| 2008 | 0.659 | 0.877 | 0.238 | 7.530 | 0.398 | 0.306 | 0.235 | 0.442 | 10 | 0.209 | Moderate |
| 2009 | 0.139 | 0.813 | 0.030 | 0.437 | 0.234 | 0.154 | 0.102 | 0.912 | 25 | 0.025 | Extreme |
| 2010 | 0.387 | 0.919 | 0.051 | 2.435 | 0.553 | 0.467 | 0.395 | 0.854 | 25 | 0.047 | Extreme |
| 2011 | 0.559 | 0.946 | 0.068 | 5.027 | 0.680 | 0.609 | 0.546 | 0.810 | 25 | 0.064 | Extreme |

**Appendix-XXV** Year-wise analysis of probability of wet and dry weeks and index of drought proneness in the Barisal station for Pre-Kharif season

| Year | Pre-Kharif season using suitable threshold values (TV) in millimeters | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|
| | $P$ | $P_{11}$ | $P_{01}$ | E(Y) | Probability of getting wet week at least | | | P(D>3) | TV | DI | Drought Classes |
| | | | | | 8 | 10 | 12 | | | | |
| 1960 | 0.267 | 0.861 | 0.051 | 1.603 | 0.351 | 0.260 | 0.193 | 0.856 | 25 | 0.044 | Extreme |
| 1961 | 0.741 | 0.938 | 0.176 | 9.314 | 0.640 | 0.564 | 0.496 | 0.559 | 5 | 0.166 | Severe |
| 1962 | 0.376 | 0.939 | 0.037 | 2.151 | 0.646 | 0.570 | 0.503 | 0.894 | 25 | 0.034 | Extreme |
| 1963 | 0.687 | 0.937 | 0.139 | 8.342 | 0.633 | 0.555 | 0.487 | 0.639 | 5 | 0.130 | Severe |
| 1964 | 0.333 | 0.957 | 0.022 | 1.429 | 0.733 | 0.670 | 0.613 | 0.936 | 25 | 0.021 | Extreme |
| 1965 | 0.340 | 0.906 | 0.048 | 1.892 | 0.502 | 0.412 | 0.339 | 0.862 | 25 | 0.044 | Extreme |
| 1966 | 0.444 | 0.950 | 0.040 | 2.984 | 0.698 | 0.630 | 0.569 | 0.885 | 25 | 0.038 | Extreme |
| 1967 | 0.780 | 0.953 | 0.167 | 10.249 | 0.714 | 0.648 | 0.588 | 0.579 | 10 | 0.159 | Severe |
| 1968 | 0.733 | 0.938 | 0.171 | 9.108 | 0.637 | 0.559 | 0.492 | 0.569 | 5 | 0.161 | Severe |
| 1969 | 0.551 | 0.930 | 0.086 | 5.040 | 0.601 | 0.520 | 0.449 | 0.763 | 25 | 0.080 | Extreme |
| 1970 | 0.509 | 0.957 | 0.044 | 3.927 | 0.738 | 0.676 | 0.620 | 0.873 | 25 | 0.042 | Extreme |
| 1971 | 0.619 | 0.938 | 0.100 | 6.367 | 0.641 | 0.565 | 0.497 | 0.729 | 25 | 0.094 | Extreme |
| 1972 | 0.366 | 0.938 | 0.036 | 2.041 | 0.637 | 0.559 | 0.492 | 0.895 | 25 | 0.034 | Extreme |
| 1973 | 0.565 | 0.954 | 0.060 | 5.814 | 0.718 | 0.654 | 0.595 | 0.831 | 25 | 0.057 | Extreme |
| 1974 | 0.772 | 0.952 | 0.161 | 10.037 | 0.711 | 0.645 | 0.585 | 0.590 | 15 | 0.154 | Severe |

| | Pre-Kharif season using suitable threshold values (TV) in millimeters | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|
| Year | $P$ | $P_{11}$ | $P_{01}$ | E(Y) | Probability of getting wet week at least | | | P(D>3) | TV | DI | Drought Classes |
| | | | | | 8 | 10 | 12 | | | | |
| 1975 | 0.684 | 0.932 | 0.146 | 7.916 | 0.613 | 0.533 | 0.463 | 0.622 | 15 | 0.136 | Severe |
| 1976 | 0.515 | 0.907 | 0.098 | 4.489 | 0.507 | 0.417 | 0.343 | 0.733 | 25 | 0.089 | Extreme |
| 1977 | 0.626 | 0.925 | 0.125 | 6.619 | 0.581 | 0.498 | 0.426 | 0.670 | 25 | 0.116 | Extreme |
| 1978 | 0.691 | 0.958 | 0.093 | 7.794 | 0.742 | 0.682 | 0.626 | 0.746 | 25 | 0.089 | Extreme |
| 1979 | 0.363 | 0.865 | 0.077 | 2.280 | 0.362 | 0.271 | 0.203 | 0.787 | 25 | 0.067 | Extreme |
| 1980 | 0.315 | 0.881 | 0.055 | 2.161 | 0.412 | 0.320 | 0.248 | 0.844 | 25 | 0.048 | Extreme |
| 1981 | 0.871 | 0.959 | 0.278 | 12.937 | 0.745 | 0.685 | 0.629 | 0.377 | 5 | 0.266 | Mild |
| 1982 | 0.541 | 0.944 | 0.066 | 4.718 | 0.670 | 0.598 | 0.533 | 0.816 | 25 | 0.062 | Extreme |
| 1983 | 0.540 | 0.960 | 0.047 | 4.471 | 0.751 | 0.693 | 0.638 | 0.866 | 25 | 0.045 | Extreme |
| 1984 | 0.560 | 0.931 | 0.088 | 5.199 | 0.606 | 0.526 | 0.456 | 0.759 | 25 | 0.082 | Extreme |
| 1985 | 0.635 | 0.926 | 0.128 | 6.798 | 0.586 | 0.503 | 0.432 | 0.664 | 25 | 0.118 | Extreme |
| 1986 | 0.462 | 0.933 | 0.057 | 3.429 | 0.617 | 0.537 | 0.468 | 0.838 | 25 | 0.053 | Extreme |
| 1987 | 0.339 | 0.897 | 0.053 | 2.180 | 0.469 | 0.378 | 0.304 | 0.850 | 25 | 0.047 | Extreme |
| 1988 | 0.706 | 0.959 | 0.098 | 8.175 | 0.748 | 0.689 | 0.634 | 0.735 | 25 | 0.094 | Extreme |
| 1989 | 0.455 | 0.913 | 0.072 | 3.442 | 0.529 | 0.441 | 0.368 | 0.798 | 25 | 0.066 | Extreme |
| 1990 | 0.878 | 0.970 | 0.214 | 13.550 | 0.810 | 0.762 | 0.718 | 0.485 | 5 | 0.208 | Moderate |
| 1991 | 0.668 | 0.931 | 0.140 | 7.535 | 0.604 | 0.523 | 0.453 | 0.637 | 10 | 0.130 | Severe |
| 1992 | 0.378 | 0.917 | 0.051 | 2.322 | 0.544 | 0.457 | 0.384 | 0.856 | 25 | 0.046 | Extreme |
| 1993 | 0.811 | 0.955 | 0.192 | 11.116 | 0.725 | 0.661 | 0.603 | 0.527 | 10 | 0.184 | Moderate |
| 1994 | 0.577 | 0.933 | 0.091 | 5.522 | 0.617 | 0.537 | 0.468 | 0.751 | 25 | 0.085 | Extreme |
| 1995 | 0.456 | 0.971 | 0.025 | 2.673 | 0.811 | 0.764 | 0.720 | 0.928 | 25 | 0.024 | Extreme |
| 1996 | 0.434 | 0.929 | 0.055 | 3.039 | 0.595 | 0.513 | 0.443 | 0.844 | 25 | 0.051 | Extreme |
| 1997 | 0.835 | 0.967 | 0.167 | 11.688 | 0.791 | 0.740 | 0.692 | 0.579 | 10 | 0.161 | Severe |
| 1998 | 0.907 | 0.961 | 0.385 | 14.131 | 0.756 | 0.698 | 0.644 | 0.233 | 5 | 0.370 | Occasional |
| 1999 | 0.509 | 0.957 | 0.044 | 3.927 | 0.738 | 0.676 | 0.620 | 0.873 | 25 | 0.042 | Extreme |
| 2000 | 0.593 | 0.950 | 0.073 | 5.672 | 0.698 | 0.630 | 0.569 | 0.797 | 25 | 0.069 | Extreme |
| 2001 | 0.500 | 0.957 | 0.043 | 3.786 | 0.733 | 0.670 | 0.613 | 0.875 | 25 | 0.042 | Extreme |
| 2002 | 0.708 | 0.972 | 0.068 | 7.885 | 0.819 | 0.773 | 0.730 | 0.809 | 25 | 0.066 | Extreme |
| 2003 | 0.692 | 0.933 | 0.150 | 8.110 | 0.617 | 0.537 | 0.468 | 0.614 | 10 | 0.140 | Severe |
| 2004 | 0.472 | 0.917 | 0.075 | 3.712 | 0.544 | 0.457 | 0.384 | 0.792 | 25 | 0.068 | Extreme |

| | Pre-Kharif season using suitable threshold values (TV) in millimeters | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|
| Year | $P$ | $P_{11}$ | $P_{01}$ | E(Y) | Probability of getting wet week at least | | | P(D>3) | TV | DI | Drought Classes |
| | | | | | 8 | 10 | 12 | | | | |
| 2005 | 0.365 | 0.842 | 0.091 | 2.349 | 0.300 | 0.213 | 0.151 | 0.751 | 25 | 0.077 | Extreme |
| 2006 | 0.491 | 0.956 | 0.043 | 3.647 | 0.727 | 0.664 | 0.606 | 0.877 | 25 | 0.041 | Extreme |
| 2007 | 0.700 | 0.934 | 0.154 | 8.305 | 0.621 | 0.542 | 0.473 | 0.606 | 5 | 0.144 | Severe |
| 2008 | 0.278 | 0.875 | 0.048 | 1.511 | 0.393 | 0.301 | 0.230 | 0.862 | 25 | 0.042 | Extreme |
| 2009 | 0.390 | 0.875 | 0.080 | 2.620 | 0.393 | 0.301 | 0.230 | 0.779 | 25 | 0.070 | Extreme |
| 2010 | 1.000 | 1.000 | 0.013 | 6.571 | 1.000 | 1.000 | 1.000 | 0.961 | 25 | 0.013 | Extreme |
| 2011 | 0.609 | 0.952 | 0.075 | 6.006 | 0.707 | 0.640 | 0.580 | 0.790 | 25 | 0.072 | Extreme |

**Appendix-XXVI** Year-wise analysis of probability of wet and dry weeks and index of drought proneness in the Bhola station for Pre-Kharif season

| | Pre-Kharif season using suitable threshold values (TV) in millimeters | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|
| Year | $P$ | $P_{11}$ | $P_{01}$ | E(Y) | Probability of getting wet week at least | | | P(D>3) | TV | DI | Drought Classes |
| | | | | | 8 | 10 | 12 | | | | |
| 1966 | 0.330 | 0.895 | 0.052 | 2.124 | 0.459 | 0.368 | 0.294 | 0.852 | 25 | 0.046 | Extreme |
| 1967 | 0.515 | 0.907 | 0.098 | 4.489 | 0.507 | 0.417 | 0.343 | 0.733 | 25 | 0.089 | Extreme |
| 1968 | 0.000 | 0.000 | 0.000 | 0.000 | 0.000 | 0.000 | 0.000 | 1.000 | 25 | 0.000 | Extreme |
| 1969 | 0.487 | 0.929 | 0.068 | 4.383 | 0.595 | 0.513 | 0.443 | 0.810 | 25 | 0.063 | Extreme |
| 1970 | 0.454 | 0.951 | 0.041 | 3.112 | 0.705 | 0.638 | 0.577 | 0.883 | 25 | 0.039 | Extreme |
| 1971 | 0.553 | 0.962 | 0.048 | 4.663 | 0.760 | 0.703 | 0.650 | 0.864 | 25 | 0.046 | Extreme |
| 1972 | 0.489 | 0.034 | 0.923 | 2.303 | 0.000 | 0.000 | 0.000 | 0.000 | 25 | 0.031 | Extreme |
| 1973 | 0.548 | 0.968 | 0.038 | 5.478 | 0.798 | 0.748 | 0.701 | 0.889 | 25 | 0.037 | Extreme |
| 1974 | 0.806 | 0.966 | 0.143 | 10.817 | 0.782 | 0.729 | 0.680 | 0.630 | 5 | 0.138 | Severe |
| 1975 | 0.378 | 0.917 | 0.051 | 2.322 | 0.544 | 0.457 | 0.384 | 0.856 | 25 | 0.046 | Extreme |
| 1976 | 0.336 | 0.931 | 0.035 | 1.728 | 0.606 | 0.526 | 0.456 | 0.899 | 25 | 0.032 | Extreme |
| 1977 | 0.745 | 0.962 | 0.111 | 9.156 | 0.763 | 0.706 | 0.653 | 0.702 | 25 | 0.107 | Extreme |
| 1978 | 0.634 | 0.954 | 0.080 | 6.523 | 0.718 | 0.654 | 0.595 | 0.779 | 25 | 0.076 | Extreme |
| 1979 | 1.000 | 1.000 | 0.053 | 14.714 | 1.000 | 1.000 | 1.000 | 0.850 | 20 | 0.053 | Extreme |
| 1980 | 0.591 | 0.956 | 0.064 | 6.335 | 0.729 | 0.666 | 0.609 | 0.820 | 25 | 0.061 | Extreme |
| 1981 | 0.816 | 0.934 | 0.292 | 11.419 | 0.620 | 0.541 | 0.472 | 0.355 | 10 | 0.272 | Mild |

| | Pre-Kharif season using suitable threshold values (TV) in millimeters | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|
| Year | $P$ | $P_{11}$ | $P_{01}$ | E(Y) | Probability of getting wet week at least | | | P(D>3) | TV | DI | Drought Classes |
| | | | | | 8 | 10 | 12 | | | | |
| 1982 | 0.579 | 0.964 | 0.050 | 5.128 | 0.772 | 0.717 | 0.665 | 0.857 | 25 | 0.048 | Extreme |
| 1983 | 0.683 | 0.958 | 0.091 | 7.607 | 0.739 | 0.678 | 0.622 | 0.751 | 25 | 0.087 | Extreme |
| 1984 | 0.536 | 0.960 | 0.046 | 4.362 | 0.751 | 0.693 | 0.638 | 0.868 | 25 | 0.044 | Extreme |
| 1985 | 0.722 | 0.961 | 0.103 | 8.562 | 0.754 | 0.696 | 0.642 | 0.723 | 20 | 0.099 | Extreme |
| 1986 | 0.544 | 0.961 | 0.047 | 4.511 | 0.756 | 0.698 | 0.644 | 0.866 | 25 | 0.045 | Extreme |
| 1987 | 0.780 | 0.953 | 0.167 | 10.249 | 0.714 | 0.648 | 0.588 | 0.579 | 5 | 0.159 | Severe |
| 1988 | 0.675 | 0.957 | 0.089 | 7.422 | 0.736 | 0.674 | 0.618 | 0.756 | 25 | 0.085 | Extreme |
| 1989 | 0.435 | 0.880 | 0.092 | 3.478 | 0.409 | 0.316 | 0.245 | 0.748 | 25 | 0.081 | Extreme |
| 1990 | 0.774 | 0.955 | 0.154 | 10.614 | 0.725 | 0.661 | 0.603 | 0.606 | 10 | 0.147 | Severe |
| 1991 | 0.591 | 0.941 | 0.085 | 6.251 | 0.654 | 0.579 | 0.513 | 0.766 | 25 | 0.080 | Extreme |
| 1992 | 0.397 | 0.921 | 0.052 | 2.551 | 0.562 | 0.477 | 0.405 | 0.852 | 25 | 0.048 | Extreme |
| 1993 | 0.764 | 0.952 | 0.156 | 9.826 | 0.708 | 0.641 | 0.581 | 0.601 | 25 | 0.149 | Severe |
| 1994 | 0.609 | 0.952 | 0.075 | 6.006 | 0.707 | 0.640 | 0.580 | 0.790 | 25 | 0.072 | Extreme |
| 1995 | 0.480 | 0.936 | 0.059 | 3.700 | 0.630 | 0.552 | 0.484 | 0.834 | 25 | 0.055 | Extreme |
| 1996 | 0.508 | 0.889 | 0.115 | 4.427 | 0.438 | 0.346 | 0.274 | 0.694 | 25 | 0.102 | Extreme |
| 1997 | 0.648 | 0.901 | 0.182 | 7.225 | 0.484 | 0.393 | 0.319 | 0.548 | 25 | 0.164 | Severe |
| 1998 | 0.781 | 0.942 | 0.207 | 10.371 | 0.658 | 0.583 | 0.517 | 0.499 | 10 | 0.195 | Moderate |
| 1999 | 0.584 | 0.949 | 0.071 | 5.508 | 0.694 | 0.625 | 0.563 | 0.801 | 25 | 0.068 | Extreme |
| 2000 | 0.652 | 0.942 | 0.109 | 7.081 | 0.658 | 0.584 | 0.518 | 0.708 | 25 | 0.102 | Extreme |
| 2001 | 0.655 | 0.982 | 0.034 | 5.895 | 0.882 | 0.850 | 0.820 | 0.902 | 25 | 0.033 | Extreme |
| 2002 | 0.791 | 0.965 | 0.133 | 10.392 | 0.778 | 0.724 | 0.674 | 0.651 | 5 | 0.129 | Severe |
| 2003 | 0.659 | 0.930 | 0.136 | 7.348 | 0.600 | 0.518 | 0.448 | 0.644 | 5 | 0.127 | Severe |
| 2004 | 0.518 | 0.958 | 0.045 | 4.070 | 0.742 | 0.682 | 0.626 | 0.872 | 25 | 0.043 | Extreme |
| 2005 | 0.372 | 0.892 | 0.064 | 2.340 | 0.449 | 0.357 | 0.284 | 0.820 | 25 | 0.057 | Extreme |
| 2006 | 0.473 | 0.953 | 0.042 | 3.375 | 0.716 | 0.651 | 0.592 | 0.880 | 25 | 0.040 | Extreme |
| 2007 | 0.517 | 0.925 | 0.081 | 4.428 | 0.577 | 0.493 | 0.422 | 0.777 | 25 | 0.075 | Extreme |
| 2008 | 0.517 | 0.925 | 0.081 | 4.428 | 0.577 | 0.493 | 0.422 | 0.777 | 25 | 0.075 | Extreme |
| 2009 | 0.668 | 0.931 | 0.140 | 7.535 | 0.604 | 0.523 | 0.453 | 0.637 | 5 | 0.130 | Severe |
| 2010 | 0.571 | 0.978 | 0.029 | 4.327 | 0.857 | 0.821 | 0.785 | 0.916 | 25 | 0.028 | Extreme |
| 2011 | 0.655 | 0.982 | 0.034 | 5.895 | 0.882 | 0.850 | 0.820 | 0.902 | 25 | 0.033 | Extreme |

**Appendix-XXVII** Year-wise analysis of probability of wet and dry weeks and index of drought proneness in the Khepupara station for Pre-Kharif season

| | Pre-Kharif season using suitable threshold values (TV) in millimeters | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|
| Year | $P$ | $P_{11}$ | $P_{01}$ | E(Y) | Probability of getting wet week at least | | | P(D>3) | TV | DI | Drought Classes |
| | | | | | 8 | 10 | 12 | | | | |
| 1975 | 0.336 | 0.931 | 0.035 | 1.728 | 0.606 | 0.526 | 0.456 | 0.899 | 25 | 0.032 | Extreme |
| 1976 | 0.416 | 0.925 | 0.053 | 2.790 | 0.579 | 0.496 | 0.424 | 0.848 | 25 | 0.049 | Extreme |
| 1977 | 0.627 | 0.939 | 0.102 | 6.543 | 0.646 | 0.570 | 0.503 | 0.724 | 25 | 0.096 | Extreme |
| 1978 | 0.506 | 0.940 | 0.062 | 4.123 | 0.648 | 0.573 | 0.506 | 0.827 | 25 | 0.058 | Extreme |
| 1979 | 0.368 | 0.914 | 0.050 | 2.211 | 0.534 | 0.446 | 0.373 | 0.857 | 25 | 0.046 | Extreme |
| 1980 | 0.371 | 0.944 | 0.033 | 3.181 | 0.670 | 0.598 | 0.533 | 0.905 | 25 | 0.031 | Extreme |
| 1981 | 0.733 | 0.938 | 0.171 | 9.108 | 0.637 | 0.559 | 0.492 | 0.569 | 15 | 0.161 | Severe |
| 1982 | 0.509 | 0.957 | 0.044 | 3.927 | 0.738 | 0.676 | 0.620 | 0.873 | 25 | 0.042 | Extreme |
| 1983 | 0.670 | 0.922 | 0.158 | 8.035 | 0.567 | 0.482 | 0.410 | 0.597 | 10 | 0.146 | Severe |
| 1984 | 0.455 | 0.913 | 0.072 | 3.442 | 0.529 | 0.441 | 0.368 | 0.798 | 25 | 0.066 | Extreme |
| 1985 | 0.567 | 0.947 | 0.069 | 5.186 | 0.685 | 0.615 | 0.552 | 0.807 | 25 | 0.065 | Extreme |
| 1986 | 0.397 | 0.921 | 0.052 | 2.551 | 0.562 | 0.477 | 0.405 | 0.852 | 25 | 0.048 | Extreme |
| 1987 | 0.496 | 0.930 | 0.069 | 4.461 | 0.601 | 0.520 | 0.449 | 0.807 | 25 | 0.064 | Extreme |
| 1988 | 0.543 | 0.929 | 0.085 | 4.884 | 0.595 | 0.513 | 0.443 | 0.767 | 25 | 0.079 | Extreme |
| 1989 | 0.448 | 0.950 | 0.041 | 3.070 | 0.698 | 0.630 | 0.569 | 0.883 | 25 | 0.039 | Extreme |
| 1990 | 0.530 | 0.934 | 0.074 | 5.153 | 0.622 | 0.543 | 0.474 | 0.794 | 25 | 0.069 | Extreme |
| 1991 | 0.348 | 0.950 | 0.027 | 2.286 | 0.698 | 0.630 | 0.569 | 0.922 | 25 | 0.025 | Extreme |
| 1992 | 0.452 | 0.932 | 0.056 | 3.296 | 0.610 | 0.530 | 0.460 | 0.840 | 25 | 0.052 | Extreme |
| 1993 | 0.634 | 0.954 | 0.080 | 6.523 | 0.718 | 0.654 | 0.595 | 0.779 | 25 | 0.076 | Extreme |
| 1994 | 0.568 | 0.932 | 0.089 | 5.359 | 0.612 | 0.532 | 0.462 | 0.755 | 25 | 0.083 | Extreme |
| 1995 | 0.467 | 0.971 | 0.025 | 2.800 | 0.816 | 0.770 | 0.727 | 0.927 | 25 | 0.024 | Extreme |
| 1996 | 0.434 | 0.929 | 0.055 | 3.039 | 0.595 | 0.513 | 0.443 | 0.844 | 25 | 0.051 | Extreme |
| 1997 | 0.730 | 0.961 | 0.105 | 8.758 | 0.757 | 0.699 | 0.646 | 0.716 | 10 | 0.101 | Extreme |
| 1998 | 0.789 | 0.943 | 0.214 | 10.589 | 0.661 | 0.587 | 0.521 | 0.485 | 5 | 0.202 | Moderate |
| 1999 | 0.671 | 0.983 | 0.035 | 6.226 | 0.885 | 0.855 | 0.826 | 0.898 | 25 | 0.034 | Extreme |
| 2000 | 0.677 | 0.970 | 0.063 | 7.154 | 0.809 | 0.761 | 0.717 | 0.824 | 25 | 0.061 | Extreme |
| 2001 | 0.631 | 0.981 | 0.032 | 5.408 | 0.875 | 0.842 | 0.811 | 0.906 | 25 | 0.032 | Extreme |
| 2002 | 0.783 | 0.964 | 0.129 | 10.182 | 0.775 | 0.721 | 0.670 | 0.661 | 10 | 0.124 | Extreme |
| 2003 | 0.668 | 0.931 | 0.140 | 7.535 | 0.604 | 0.523 | 0.453 | 0.637 | 10 | 0.130 | Severe |

| | Pre-Kharif season using suitable threshold values (TV) in millimeters | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|
| Year | $P$ | $P_{11}$ | $P_{01}$ | E(Y) | Probability of getting wet week at least | | | P(D>3) | TV | DI | Drought Classes |
| | | | | | 8 | 10 | 12 | | | | |
| 2004 | 0.703 | 0.922 | 0.184 | 8.433 | 0.567 | 0.482 | 0.410 | 0.543 | 5 | 0.170 | Severe |
| 2005 | 0.628 | 0.912 | 0.149 | 6.728 | 0.524 | 0.435 | 0.362 | 0.616 | 5 | 0.136 | Severe |
| 2006 | 0.550 | 0.945 | 0.067 | 4.871 | 0.675 | 0.604 | 0.540 | 0.813 | 25 | 0.063 | Extreme |
| 2007 | 0.443 | 0.930 | 0.056 | 3.166 | 0.603 | 0.522 | 0.451 | 0.842 | 25 | 0.052 | Extreme |
| 2008 | 0.473 | 0.953 | 0.042 | 3.375 | 0.716 | 0.651 | 0.592 | 0.880 | 25 | 0.040 | Extreme |
| 2009 | 0.292 | 0.800 | 0.082 | 1.542 | 0.210 | 0.134 | 0.086 | 0.773 | 25 | 0.066 | Extreme |
| 2010 | 0.406 | 0.944 | 0.038 | 2.494 | 0.670 | 0.598 | 0.533 | 0.890 | 25 | 0.036 | Extreme |
| 2011 | 0.803 | 0.976 | 0.097 | 10.433 | 0.845 | 0.805 | 0.767 | 0.737 | 10 | 0.094 | Extreme |

**Appendix-XXVIII** Decade-wise analysis of probability of wet and dry weeks and index of drought proneness in the 12 stations for Rabi season

| | Rabi season using suitable threshold values (TV) in millimeters | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|
| Decade | $P$ | $P_{11}$ | $P_{01}$ | E(Y) | Probability of getting wet week at least | | | P(D>3) | TV | DI | Drought Classes |
| | | | | | 8 | 10 | 12 | | | | |
| **Dinajpur** | | | | | | | | | | | |
| **1961-1970** | 0.012 | 0.857 | 0.002 | 0.035 | 0.340 | 0.250 | 0.183 | 0.995 | 25 | 0.001 | Extreme |
| **1971-1980** | 0.019 | 0.826 | 0.003 | 0.080 | 0.263 | 0.179 | 0.122 | 0.990 | 25 | 0.003 | Extreme |
| **1981-1990** | 0.040 | 0.854 | 0.006 | 0.316 | 0.332 | 0.242 | 0.177 | 0.982 | 25 | 0.005 | Extreme |
| **1991-2000** | 0.025 | 0.829 | 0.004 | 0.144 | 0.268 | 0.184 | 0.126 | 0.987 | 25 | 0.004 | Extreme |
| **2000-2010** | 0.023 | 0.857 | 0.003 | 0.117 | 0.340 | 0.250 | 0.183 | 0.990 | 25 | 0.003 | Extreme |
| **Rangpur** | | | | | | | | | | | |
| **1961-1970** | 0.010 | 0.750 | 0.003 | 0.027 | 0.133 | 0.075 | 0.042 | 0.992 | 25 | 0.002 | Extreme |
| **1971-1980** | 0.021 | 0.840 | 0.003 | 0.093 | 0.295 | 0.208 | 0.147 | 0.990 | 25 | 0.003 | Extreme |
| **1981-1990** | 0.040 | 0.833 | 0.007 | 0.316 | 0.279 | 0.194 | 0.135 | 0.979 | 25 | 0.006 | Extreme |
| **1991-2000** | 0.016 | 0.792 | 0.003 | 0.069 | 0.195 | 0.122 | 0.077 | 0.990 | 25 | 0.003 | Extreme |
| **2000-2010** | 0.012 | 0.857 | 0.002 | 0.035 | 0.340 | 0.250 | 0.183 | 0.995 | 25 | 0.001 | Extreme |
| **Bogra** | | | | | | | | | | | |
| **1961-1970** | 0.018 | 0.810 | 0.003 | 0.070 | 0.228 | 0.149 | 0.098 | 0.990 | 25 | 0.003 | Extreme |
| **1971-1980** | 0.028 | 0.853 | 0.004 | 0.162 | 0.328 | 0.239 | 0.174 | 0.987 | 25 | 0.004 | Extreme |
| **1981-1990** | 0.023 | 0.821 | 0.004 | 0.117 | 0.252 | 0.170 | 0.115 | 0.987 | 25 | 0.004 | Extreme |

| Decade | Rabi season using suitable threshold values (TV) in millimeters | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|
| | $P$ | $P_{11}$ | $P_{01}$ | E(Y) | Probability of getting wet week at least | | | P(D>3) | TV | DI | Drought Classes |
| | | | | | 8 | 10 | 12 | | | | |
| 1991-2000 | 0.026 | 0.806 | 0.005 | 0.137 | 0.222 | 0.144 | 0.094 | 0.985 | 25 | 0.004 | Extreme |
| 2000-2010 | 0.004 | 0.800 | 0.001 | 0.007 | 0.210 | 0.134 | 0.086 | 0.997 | 25 | 0.001 | Extreme |
| Ishwardi | | | | | | | | | | | |
| 1961-1970 | 0.023 | 0.846 | 0.004 | 0.301 | 0.311 | 0.222 | 0.159 | 0.989 | 25 | 0.003 | Extreme |
| 1971-1980 | 0.049 | 0.831 | 0.009 | 0.458 | 0.273 | 0.188 | 0.130 | 0.974 | 25 | 0.007 | Extreme |
| 1981-1990 | 0.067 | 0.850 | 0.011 | 0.822 | 0.321 | 0.232 | 0.167 | 0.968 | 25 | 0.009 | Extreme |
| 1991-2000 | 0.040 | 0.833 | 0.007 | 0.310 | 0.279 | 0.194 | 0.135 | 0.979 | 25 | 0.006 | Extreme |
| 2000-2010 | 0.021 | 0.800 | 0.004 | 0.096 | 0.210 | 0.134 | 0.086 | 0.987 | 25 | 0.003 | Extreme |
| Rajshahi | | | | | | | | | | | |
| 1961-1970 | 0.018 | 0.810 | 0.003 | 0.070 | 0.228 | 0.149 | 0.098 | 0.990 | 25 | 0.003 | Extreme |
| 1971-1980 | 0.071 | 0.875 | 0.010 | 11.095 | 0.393 | 0.301 | 0.230 | 0.972 | 25 | 0.008 | Extreme |
| 1981-1990 | 0.038 | 0.826 | 0.007 | 0.291 | 0.263 | 0.179 | 0.122 | 0.979 | 25 | 0.006 | Extreme |
| 1991-2000 | 0.048 | 0.860 | 0.007 | 0.429 | 0.347 | 0.256 | 0.189 | 0.979 | 25 | 0.006 | Extreme |
| 2000-2010 | 0.010 | 0.833 | 0.002 | 0.027 | 0.279 | 0.194 | 0.135 | 0.995 | 25 | 0.001 | Extreme |
| Faridpur | | | | | | | | | | | |
| 1961-1970 | 0.038 | 0.844 | 0.006 | 0.280 | 0.306 | 0.218 | 0.156 | 0.982 | 25 | 0.005 | Extreme |
| 1971-1980 | 0.045 | 0.833 | 0.008 | 0.387 | 0.279 | 0.194 | 0.135 | 0.977 | 25 | 0.007 | Extreme |
| 1981-1990 | 0.059 | 0.857 | 0.009 | 0.644 | 0.340 | 0.250 | 0.183 | 0.974 | 25 | 0.008 | Extreme |
| 1991-2000 | 0.057 | 0.853 | 0.009 | 0.601 | 0.328 | 0.239 | 0.174 | 0.974 | 25 | 0.008 | Extreme |
| 2000-2010 | 0.056 | 0.851 | 0.009 | 0.593 | 0.323 | 0.233 | 0.169 | 0.974 | 25 | 0.008 | Extreme |
| Jessore | | | | | | | | | | | |
| 1961-1970 | 0.042 | 0.860 | 0.006 | 0.341 | 0.348 | 0.257 | 0.190 | 0.982 | 25 | 0.005 | Extreme |
| 1971-1980 | 0.048 | 0.862 | 0.007 | 0.443 | 0.354 | 0.263 | 0.195 | 0.979 | 25 | 0.006 | Extreme |
| 1981-1990 | 0.076 | 0.857 | 0.012 | 1.066 | 0.340 | 0.250 | 0.183 | 0.965 | 25 | 0.010 | Extreme |
| 1991-2000 | 0.058 | 0.841 | 0.010 | 0.618 | 0.297 | 0.210 | 0.148 | 0.971 | 25 | 0.008 | Extreme |
| 2000-2010 | 0.050 | 0.867 | 0.007 | 0.473 | 0.367 | 0.276 | 0.207 | 0.979 | 25 | 0.006 | Extreme |
| Khulna | | | | | | | | | | | |
| 1961-1970 | 0.012 | 0.857 | 0.002 | 0.035 | 0.340 | 0.250 | 0.183 | 0.995 | 25 | 0.001 | Extreme |
| 1971-1980 | 0.039 | 0.830 | 0.007 | 0.298 | 0.271 | 0.187 | 0.128 | 0.979 | 25 | 0.006 | Extreme |
| 1981-1990 | 0.077 | 0.859 | 0.012 | 1.089 | 0.344 | 0.254 | 0.187 | 0.965 | 25 | 0.010 | Extreme |

| Decade | Rabi season using suitable threshold values (TV) in millimeters | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|
| | $P$ | $P_{11}$ | $P_{01}$ | E(Y) | Probability of getting wet week at least | | | P(D>3) | TV | DI | Drought Classes |
| | | | | | 8 | 10 | 12 | | | | |
| 1991-2000 | 0.090 | 0.876 | 0.012 | 2.887 | 0.397 | 0.305 | 0.234 | 0.964 | 25 | 0.011 | Extreme |
| 2000-2010 | 0.038 | 0.860 | 0.006 | -0.347 | 0.348 | 0.257 | 0.190 | 0.984 | 25 | 0.005 | Extreme |
| **Satkhira** | | | | | | | | | | | |
| 1961-1970 | 0.023 | 0.857 | 0.003 | 0.117 | 0.340 | 0.250 | 0.183 | 0.990 | 25 | 0.003 | Extreme |
| 1971-1980 | 0.058 | 0.855 | 0.009 | 0.618 | 0.334 | 0.244 | 0.179 | 0.974 | 25 | 0.008 | Extreme |
| 1981-1990 | 0.059 | 0.843 | 0.010 | 0.644 | 0.302 | 0.215 | 0.153 | 0.971 | 25 | 0.008 | Extreme |
| 1991-2000 | 0.075 | 0.844 | 0.013 | 1.098 | 0.304 | 0.217 | 0.154 | 0.962 | 25 | 0.011 | Extreme |
| 2000-2010 | 0.044 | 0.868 | 0.006 | 0.380 | 0.371 | 0.279 | 0.211 | 0.982 | 25 | 0.005 | Extreme |
| **Barisal** | | | | | | | | | | | |
| 1961-1970 | 0.049 | 0.862 | 0.007 | 0.451 | 0.354 | 0.263 | 0.195 | 0.979 | 25 | 0.006 | Extreme |
| 1971-1980 | 0.072 | 0.849 | 0.012 | 0.945 | 0.318 | 0.229 | 0.165 | 0.965 | 25 | 0.010 | Extreme |
| 1981-1990 | 0.069 | 0.854 | 0.011 | 0.872 | 0.330 | 0.241 | 0.175 | 0.968 | 25 | 0.009 | Extreme |
| 1991-2000 | 0.059 | 0.831 | 0.011 | 0.653 | 0.274 | 0.189 | 0.130 | 0.968 | 25 | 0.009 | Extreme |
| 2000-2010 | 0.045 | 0.852 | 0.007 | 0.394 | 0.325 | 0.236 | 0.171 | 0.979 | 25 | 0.006 | Extreme |
| **Bhola** | | | | | | | | | | | |
| 1971-1980 | 0.091 | 0.899 | 0.010 | 0.703 | 0.475 | 0.384 | 0.310 | 0.970 | 25 | 0.009 | Extreme |
| 1981-1990 | 0.069 | 0.867 | 0.010 | 1.141 | 0.367 | 0.276 | 0.207 | 0.970 | 25 | 0.009 | Extreme |
| 1991-2000 | 0.078 | 0.849 | 0.013 | 1.078 | 0.319 | 0.230 | 0.166 | 0.962 | 25 | 0.011 | Extreme |
| 2000-2010 | 0.039 | 0.872 | 0.005 | 0.556 | 0.384 | 0.293 | 0.223 | 0.984 | 25 | 0.005 | Extreme |
| **Khepupara** | | | | | | | | | | | |
| 1981-1990 | 0.076 | 0.878 | 0.010 | 1.135 | 0.401 | 0.309 | 0.238 | 0.970 | 25 | 0.009 | Extreme |
| 1990-2000 | 0.064 | 0.870 | 0.009 | 0.763 | 0.378 | 0.286 | 0.216 | 0.973 | 25 | 0.008 | Extreme |
| 2000-2010 | 0.064 | 0.855 | 0.010 | 0.754 | 0.335 | 0.245 | 0.179 | 0.971 | 25 | 0.008 | Extreme |

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