

Vulnerability to Climate Induced Drought SCENARIO & IMPACTS

June 2013

STUDY REPORT

Comprehensive Disaster Management Programme (CDMP II)
Ministry of Disaster Management and Relief

Vulnerability to Climate Induced Drought

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Conducted By

CEGIS

Center for Environmental and Geographic Information Services

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Comprehensive Disaster Management Programme (CDMP II)
Ministry of Disaster Management and Relief

VULNERABILITY to CLIMATE INDUCED DROUGHT
SCENARIO & IMPACTS

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Comprehensive Disaster Management Programme (CDMP II)
Department of Disaster Management Building (6th Floor)
92-93, Mohakhali C/A, Dhaka-1212, Bangladesh
Tel: (880) 2 9890937
Email: info@cdmp.org.bd
Web: www.cdmp.org.bd

Edited by

Sanjib Kumar Saha
Response and Adaptation Management Analyst

Mirza Shawkat Ali
Climate Change Adaptation Specialist

Shaila Shahid
Communications Specialist

Cover design
Irtija Wasif

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Shaurov Book Center BD Ltd.
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E-mail:info@spdbd.com, Web:www.spdbd.com

STUDY TEAM

Malik Fida A Khan
Director, Climate Change Study Division
Center for Environmental and Geographic Information Services (CEGIS)

Mohammad Shahidul Islam
Director (In charge), Remote Sensing Division
Center for Environmental and Geographic Information Services (CEGIS)

Bushra Monowar Duti
Professional, Climate Change Study Division
Center for Environmental and Geographic Information Services (CEGIS)

Rifat Quamrul Alam
Professional, Climate Change Study Division
Center for Environmental and Geographic Information Services (CEGIS)

Kamruzzaman Akand
Professional, Climate Change Study Division
Center for Environmental and Geographic Information Services (CEGIS)

Sharmin Nahar Nipa
Professional, Climate Change Study Division
Center for Environmental and Geographic Information Services (CEGIS)

Riyana Ayub
Professional, Climate Change Study Division
Center for Environmental and Geographic Information Services (CEGIS)

Tahmina Tamanna
Professional, Climate Change Study Division
Center for Environmental and Geographic Information Services (CEGIS)

Rakibul Hassan Khan
Professional, Climate Change Study Division
Center for Environmental and Geographic Information Services (CEGIS)

Md. Shahadat Hossain Choudhury
Professional, Database/ IT Division
Center for Environmental and Geographic Information Services (CEGIS)

Rakibul Islam Roni
Professional, Database/IT Division
Center for Environmental and Geographic Information Services (CEGIS)

Hasan Tawfique Imam
Professional, Water Resources Division
Center for Environmental and Geographic Information Services (CEGIS)

Md. Nasrat Jahan
Professional, Remote Sensing Division
Center for Environmental and Geographic Information Services (CEGIS)

Dr. Anil Chandra Aich
Soil and Agriculture Expert
Center for Environmental and Geographic Information Services (CEGIS)

Vulnerability to
Climate Induced Drought

SCENARIO AND IMPACTS

FOREWORD

Bangladesh is a hotspot for geophysical and climatic hazards. The country is relatively ranked very high in terms of vulnerability to natural calamities. Geographical location and geophysical configuration combined with its topography and dense population made the country prone to various disasters, including climate change, which often resulting in high loss of life and economic damage. The economic impact of disasters usually consists of direct damage e.g. infrastructure, crops, housing, loss of lives and livelihoods, and indirect damage e.g. loss of revenues, unemployment and enduring poverty. It is therefore increasingly becoming a major concern for the government, development partners, researchers and communities as well.

The country frequently experiences multiple natural hazards including floods, cyclones, droughts, salinity, water-logging, river and coastal erosion, hailstorms, tornados, tidal surge and landslides etc. Impact of climate change is increasing the threat of natural disaster and affecting the lives and livelihood of millions. In this scenario, the underpinning needs for detail technical research study in relations to disaster risk reduction and various options for climate change adaptation issues have been long due. I am very happy that the Comprehensive Disaster Management Programme (CDMP II), Ministry of Disaster Management and Relief has taken initiatives for conducting some technical research on various critically concerning areas of DRR and CCA from the country perspectives.

I hope the research study report on 'Vulnerability to Climate Induced Drought: Scenario and Impacts' will serve as a resource for understanding, analyzing and addressing the risks and vulnerability associated with disaster and climate change for the relevant stakeholders.

I encourage not only relevant researchers or development professionals but all concerned citizens to make use of the study, utilize the recommendations part and take pro-active effort to pursue the research benefits to bring positive impacts in the life of the vulnerable communities. I congratulate and convey my sincere thanks to the study team and fellow colleagues who were involved in thorough editing and publishing of the document.

Mohammad Abdul Qayyum
National Project Director
Comprehensive Disaster Management Programme (CDMP II)

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The study on ‘Vulnerability to Climate Induced Drought: Scenario and Impacts’ became possible due to the contribution made by a considerable number of people and organizations. CDMP expresses deepest indebtedness and profound gratitude to all of those who were involved in shaping the whole study, from inception to completion of the study and preparation of the report.

CDMP wishes to extend heartfelt thanks and acknowledges the hard work and sincere efforts of the study team of Center for Environmental and Geographic Information Services (CEGIS).

Special thanks and gratitude are due to the team of reviewers especially Dr. Zahurul Karim, Team Leader, FAO and Ex Secretary, GoB; Dr. M. Asaduzzaman, Economist, Bangladesh Institute of Development Studies (BIDS); Dr. Manoranjan Mondal, Collaborative Research Scientist, International Rice Research Institute (IRRI); Dr. M. Aminul Islam, Senior Advisor, UNDP; Dr. Md. Sabbir Mostafa Khan, Professor, Department of Water Resources Engineering, BUET.

The comments and suggestions received from the workshop participated by development professionals, research scientists, government officials and others have contributed a lot to improve the report.

Finally, the guidance from the Department of Disaster Management, Ministry of Disaster Management and Relief and financial contribution from the development partners, UNDP in particular, are gratefully acknowledged.

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BADC	Bangladesh Agricultural Development Corporation
BARC	Bangladesh Agricultural Research Council
BAU	Bangladesh Agricultural University
BMD	Bangladesh Meteorological Department
BRRI	Bangladesh Rice Research Institute
BWDB	Bangladesh Water Development Board
CC	Climate Change
CDMP	Comprehensive Disaster Management Programme
CEGIS	Center for Environmental and Geographic Information Services
CSM	Cropping System Model
DAE	Department of Agricultural Extension
DSSAT	Decision Support System for Agrotechnology Transfer
EROS	Earth Resources Observation Systems
FAO	Food and Agriculture Organization
GCM	Global Circulation Model
GDP	Gross Domestic Product
GIS	Geographical Information System
IPCC	Intergovernmental Panel on Climate Change
IWM	Institute of Water Modeling
MODIS	Moderate-Resolution Imaging Spectrometer
NAPA	National Adaptation Programme of Action
NDVI	Normalized Difference Vegetation Index
PET	Potential Evapo-Transpiration
RCM	Regional Climate Model
R&D	Research and Development
RS	Remote Sensing
SPI	Standard Precipitation Index
SRDI	Soil Resource Development Institute
SRES	Special Report on Emissions Scenarios
TCI	Thermal Condition Index
UNDP	United Nations Development Programme
UNFCCC	United Nations Framework Convention on Climate Change
VCI	Vegetation Condition Index

EXECUTIVE SUMMARY

INTRODUCTION

Drought is primarily an agricultural phenomenon that refers to conditions where plants are responsive to certain levels of moisture stress that affect both the vegetative growth and yield of crops. Decrease in rainfall and shortage of surface water and groundwater recharge causes depletion in soil moisture. Changes in such factors develop due to changes in local, regional and global weather and climate. Bangladesh experienced severe droughts in the year of 1951, 1957, 1961, 1972, 1976, 1979, 1986, 1989 and 1997. Most of these droughts primarily occurred in pre-monsoon and post-monsoon seasons, but in some extreme cases the pre-monsoon droughts had extended to the monsoon season due to delayed onset of monsoon rains.

The CDMP phase II took an initiative to assess the vulnerability, enumerate the spatial and temporal effects of climate change on drought, analyze drought frequency, and propose alternative adaptation options to combat the disasters to increase resilience. This is expected to make a technical contribution to the effort to strengthen the socio-economic status of the drought vulnerable population of Bangladesh. This study was conducted to assess the present condition of drought in the country considering the different climate change scenarios predicted by the IPCC with relevance to Bangladesh. The study also focused on the formulation of strategic adaptations and conceptualization of a drought monitoring protocol.

Different literatures have been reviewed to identify the link between drought and climate change. The historical trend of drought has been identified from existing literatures. Observed yields in recent years have been analyzed to find the trend of production. Though a change in temperature and rainfall is evident from historical climatic trend analysis, introduction of different types of new varieties and year to year increase in production are observed. Data on production of rice yield indicate an overall increase in yield in every year for both Aman and Boro. This is due to the fact that in recent years agriculturists and farmers have introduced cultivation of high yielding varieties along with proper irrigation, fertilizer and pesticide management. On the other hand, dependency on rainfed local variety has decreased in the competition with High Yielding Variety, both due to its high yielding capacity and its less dependency on rainfall due to irrigation availability.

The changes in the climatic parameters predicted by the IPCC have been reviewed in the context of Bangladesh. Metrological data of BMD stations have been analyzed to assess the seasonal and yearly changes of rainfall and temperature. A rise of 0.45^{O}C in winter and 0.52^{O}C in monsoon minimum temperature is observed along with a rise of 0.87^{O}C in pre-monsoon and 0.42^{O}C in post-monsoon in maximum temperature. The mean annual maximum, average and minimum temperature has also increased by 0.02^{O}C/year, 0.016^{O}C/year and 0.012^{O}C/year respectively. The projection of climate change has been analyzed by MAGICC/SCENGEN. Eight GCMs which portray Bangladesh situation better than others have been chosen for analyzing two SRES emission scenarios A2-AIM and B1-AIM. The projections have been made for the period of 2015-2045 (2030s) and 2035-2065 (2050s). MAGICC has been run to predict climate up to 2100.

Seasonal (Rabi, Kharif-I and Kharif-II) drought prone areas all over Bangladesh have been identified on upazila basis. Each of the drought vulnerable upazila has been ranked in terms of severity for each of the seasonal drought classification. Thus individual ranking of Rabi, Kharif-I and Kharif-II season has been done for all the drought-affected areas in terms of severity of a real extent. The top 213 vulnerable 'hotspot' upazilas have been identified from the combined vulnerability ranking.

The Normalized Difference Vegetation Index (NDVI) has been analyzed as a remote sensing tool to assess drought condition. NDVI MODIS 16 days composite images acquired between 2000 and 2009 have been used for this analysis. NDVI itself does not reflect drought or non-drought conditions. However, the severity of a drought may be defined as NDVI deviation from its long-term NDVI means (DEVNDVI). When DEVNDVI is negative, it indicates the below-normal vegetation condition/health and, therefore, suggests a prevailing drought situation. The greater the negative departures from long-term mean NDVI, the greater the magnitude of a drought. The Vegetation Condition Index (VCI) has also been analyzed which shows how close the NDVI of the current month is to the minimum NDVI calculated from the long-term record. The 50% VCI indicate fair vegetation conditions and the VCI values between 50% and 100% indicate optimal or above normal conditions. A number of drought indices are used to estimate the severity of drought using algorithms that incorporate recent temperature, rainfall, and soil moisture. The Standard Precipitation Index (SPI) has been used to assess the meteorological drought years with SPI value within 0(zero) to -2.00. SPI value less than -2.00 is identified as severe drought year which includes 1986, 1992, 1995-96, 1997-98. A comparative analysis has been carried out in a smaller scale between SPI and remote sensing where it is found out that these two tools are complementary to each other in assessing drought.

Decision Support System for Agro-technology Transfer (DSSAT) is a crop modeling software that simulates growth and development of a crop over time, as well as the soil water, carbon and nitrogen processes and management practices. This model is used, along with future climate projection dataset and other management data like irrigation, fertilizer, planting methods etc, to project future yield of selected rice cultivars in year 2030 and 2050. The effect of CO_2 is also considered under the environmental modification option of the model. The calibrated models have then been used for the simulation of future yield for BR 11, BR 14 and BRRI Dhan 29 considering rainfall and temperature sensitivity of future climate. The model result has been analyzed to assess for drought vulnerability for four climate scenarios. For BRRI Dhan 29 analysis has been performed considering temperature, rainfall and CO_2 sensitivity. The increase of CO_2 in different climate change scenarios is considered as 370 ppm in the base year, 450 ppm in A2 2030, 550 ppm in A2 2050, 410 ppm in B1 2030, 500 ppm in B1 2030 (IPCC 4th Assessment Report).

The model result shows that Bagerhat, Dinajpur, Gaibandha, Maulvibazar, Panchagarh, Rangpur, Sirajganj and Thakurgaon districts have high yield loss for BR 11 (Aman) i.e. greater than 30% in both A2 and B1 scenarios in years 2030 and 2050. In the case of BR 14 (Boro) 30% and more yield loss is simulated by the model in Bagerhat, Barguna, Chittagong, Cox's Bazar, Dinajpur, Faridpur, Gopalganj, Jessore, Joypurhat, Khulna, Magura, Naogaon, Nawabganj, Nilphamari, Pabna, Panchagarh, Patuakhali, Rajbari, Rajshahi, Rangpur, Sirajganj and Thakurgaon. For BRRI Dhan 29 it is seen 2050 has higher yield loss than 2030 in the TR (temperature and rainfall) change combination in both A2 and B1 scenario. Khulna, Rajshahi and Faridpur have higher yield loss in TRC (temperature, rainfall and CO_2) combination than TR (temperature and rainfall) change combination for BRRI Dhan 29 analysis. As B1 is a more optimistic scenario than A2, higher yield loss is observed for A2 scenario. Between 2030 and 2050, 2030 simulation gives higher yield loss than 2050 in most cases of BR11 and BR14. Yield loss is higher for Aman in Rangpur and Khulna divisions. Yield loss for Boro is higher in Rajshahi division, Barisal division and the south-west region. The Eastern hills and the North-East have similar yield loss condition for both the crop types.

Future production is predicted considering present irrigation, pesticide application, planting method and future weather requirement. DSSAT employs constant multipliers for daily total crop biomass under elevated CO_2, which has been equally applied to either stressed or unstressed growth conditions. The DSSAT response ratio increases from 350 to 550 ppm if CO_2 is 1.15. Hence, it is scientifically proved that CO_2 has an enhancing effect on yield, at least to an optimum level.

A framework is proposed based on key components which will act as an effective tool for designing integrated adaptation option at national level. The National Drought Information System (NDIS) will be a complete resource for adaptation related to drought, compiling trace of every individual adaptation tool, research, and studies in agricultural field related to drought. It will also provide input and act as a catalyst for field-level demonstrations of viable adaptation options with potentials to improve the capacity of rural livelihoods to adapt to climate change. The option for adaptation can be sub-divided into farm level, system level, planning level and livelihood level options.

To bridge the gap between knowledge of climate change and research, there is a need to enhance understanding and modeling of climate changes related to drought at scales relevant to decision making. The proposed NDIS can be an effective tool and the indicative methodology for the monitoring of drought under a monitoring protocol. A number of government and non-government organizations may actively participate in the NDIS in order to utilize their existing knowledge, tools and data related to drought for successfully managing the drought phenomenon. DRAS can be used as a drought monitoring tool as it represents the drought condition by GIS interface. This tool can be incorporated successfully in the proposed NDIS. There are a number of drought indices used to estimate the severity of drought in an area using algorithms that incorporate recent temperature, rainfall, and soil moisture.

A Drought Monitoring Protocol can be established for reliable early warning system. If a component of the early warning protocol is based on hydrological indicators, it will be easy to obtain a representative spatial and temporal situation of drought that allows drought on-set identification, control and assessment of their severity. This protocol deals with the decision making process on water resources management of a river basin under drought conditions. Data dissemination at community level can be effectively performed through use of existing latest and easily available technology like the cellphone text message service. Based on the early warning component, data of drought prediction and risk will be processed in the central database of NDIS and zone specific information will be sent to community level via text message. The rationale for using a SMS-based data dissemination service refers to availability, accessibility and convenience. The required technical components for establishing this data dissemination system are a dedicated SMS gateway which also act as an area specific target group database and the NDIS database.

CHAPTER 1

Introduction

1.1 Background

Drought is perhaps the most complex natural hazard. It is a common disaster phenomenon for the north-western districts of Bangladesh. Drought is a 'prolonged absence or marked deficiency of precipitation', a 'deficiency of precipitation that results in water shortage for some activity or for some group' or a 'period of abnormally dry weather sufficiently prolonged for the lack of precipitation to cause a serious hydrological imbalance' (Heim, 2002). Drought has been defined in a number of ways. 'Agricultural drought' relates to moisture deficits in the topmost one meter or so of soil (the root zone) that impact crops, 'meteorological drought' is mainly a prolonged deficit of precipitation, and 'hydrological drought' is related to below-normal stream flow, lake and groundwater levels (IPCC, 2007c). In Bangladesh, drought condition prevails for a prolonged, continuous period of dry weather along with abnormal insufficient rainfall. It is the period when moisture content of soil is less than the required amount for satisfactory crop-growth during the normal crop-growing season.

Two critical dry periods are distinguished (Karim et al., 1990) as droughts in Bangladesh: Rabi and pre-Kharif drought (January and May), due to: (i) the cumulative effect of dry days; (ii) higher temperatures during pre-Kharif (>40 degrees Celsius in March/May); and (iii) low soil moisture availability. This drought affects all the Rabi crops, such as HYV Boro, wheat, pulses and potatoes especially where irrigation possibilities are limited. It also affects sugarcane production.

Kharif droughts in the period June/July to October, created by sub-humid and dry conditions in the highland and medium highland areas of the country (in addition to the west/northwest also the Madhupur tract is drought prone). Shortage of rainfall affects the critical reproductive stages of transplanted Aman crops in December, reducing its yield, particularly in those areas with low soil moisture holding capacity.

Initially the study was titled as 'Locating spatial and temporal distribution of drought (baseline) and their impacts and scenarios and vulnerabilities over time and space following climate change by union'. But while the study has been carried out, drought extent has been analyzed spatially and temporally (considering climate change) over selected vulnerable upazila and not union. This is due to the fact that climate change scenario projection and crop growth simulation at base scenario and future scenario at such detailed and minute extent is overly time-consuming and difficult. Yet again there are other factors that are needed to be considered in the model simulation e.g. field data, cropping practice and planting details, soil data etc, which are difficult to collect at union level but was possible to collect at upazila level. The study has also attempted to propose certain scale of adaptation strategies considering the future drought condition. Hence finally the study title was set to 'Vulnerability to Climate Induced Drought Scenario and Impacts'.

The Comprehensive Disaster Management Programme (CDMP II) engaged the consortium, the Institute of Water Modelling (IWM) through a formal contract agreement signed on 14th October, 2010 to carry out this study.

1.2 Objective

The overall aim of the study is to make significant technical contribution as a part of strengthening the socio-economic status of the drought vulnerable population of Bangladesh by assessing the vulnerability of drought, enumerating the effect of climate change on drought spatially and temporally and proposing alternative adaptation options to combat the disasters to increase resilience.

To fulfill the key objectives, following are the specific objectives:

- Define drought in the context of Bangladesh;
- Identify the drought vulnerable 'hot-spots' in Bangladesh;
- Assess the probable impact of climate change on drought in terms of spatial and temporal implications;
- Identify possible adaptation measures to combat drought and develop a drought monitoring protocol.

1.3 Methodology of the Study

The methodology of the study was formulated with an integrated focus towards identifying climate change induced drought in selected hotspots and developing strategic measures of adaptation. In short the methodology is presented below -

- Reviewing literature related to climate change and drought to conceptualize climate change induced drought
- Finding historical trend in changing climate in Bangladesh
- Future projection of climate change by climate model
- Finding historical trend of drought in Bangladesh
- Identification of drought vulnerable hotspots
- Evaluation of drought vulnerable hotspots by remote sensing and meteorological indicators
- Future assessment of drought in changing climate with cropping system model
- Formulation of adaptation strategies and development of monitoring protocol

1.4 Limitation of the Study

At the initial level of the study, it was planned to assess climate change induced drought at the union level, but due to constraints such as model parameterization and data non-availability, hotspots from the context of drought in Bangladesh have been chosen in upazila level. The climate change projection has been done for year 2030 and 2050 for selected IPCC emission scenarios, which are A2 and B1 (Refer to Chapter 3, Section 3.4). But IPCC has many other emission scenarios, i.e A1FI, A1B, A1T and B2, which are not considered in the study. Projection has not been done till year 2100 as such distant future projection has many levels of uncertainty. Models used, such as MAGIC/SCENGEN in case of climate forecast and DSSAT in case of crop model simulation have their own limitations also as these are tools that are dependent on data homogeneity and data authenticity.

CHAPTER 2

2.1 Defining Drought

Drought refers to a considerable and prolonged lack of rainfall over a wide area that significantly affects agriculture, domestic water supply and water-dependent economic activities and may lead to famine. Scientifically, drought is defined on the basis of non-availability of rainfall, leading to decrease in base flow and surface flow of water bodies and depletion of soil moisture (Nandargi, et al., 2005).

Drought is primarily an agricultural phenomenon that refers to conditions where plants are responsive to certain levels of moisture stress that affect both the vegetative growth and yield of crops. It occurs when supply of moisture stored in the soil is insufficient to meet the optimum need of a particular type of crop.

As a consequence of usual hydro-meteorological variability, drought occurs in pre-monsoon season when the potential evapo-transpiration (PET) is higher than the available moisture due to uncertainty in rainfall, while in post-monsoon season it is due to prolonged dry periods without appreciable rainfall (Karim et al., 1990). In both the seasons, due to sudden increase in temperature coupled with non-availability of rainfall causes a sharp rise in PET.

The offset of drought is slow as it is influenced by climatic fluctuations over an extended period of time. The affected area is widespread. Drought causes -

- Soil degradation
- Loss of crops
- Loss of other economic activities
- Starvation/malnutrition of human beings/grazing animals
- Spread of diseases
- Migration of people and livestock

Drought is not aridity or desertification. Aridity is a dominant feature of dry regions which refers to permanent conditions of low average precipitation or available water. Destruction and degradation of land resources processes may lead to desertification of an area which in its first place was not an arid region. Drought may lead to desertification or aridity if it prevails for a prolonged period accompanied with destructive land use practices (Nandargi, et. al., 2005). Based on (Warren, et. al., 1992), drought occurs when moisture supply is abnormally below average for period upto 2 years.

Types of drought need to be distinguished in order to understand causes and effects. The types of drought to be considered are:

- Meteorological
- Agricultural
- Seasonal
- Hydrological
- Socio-economic

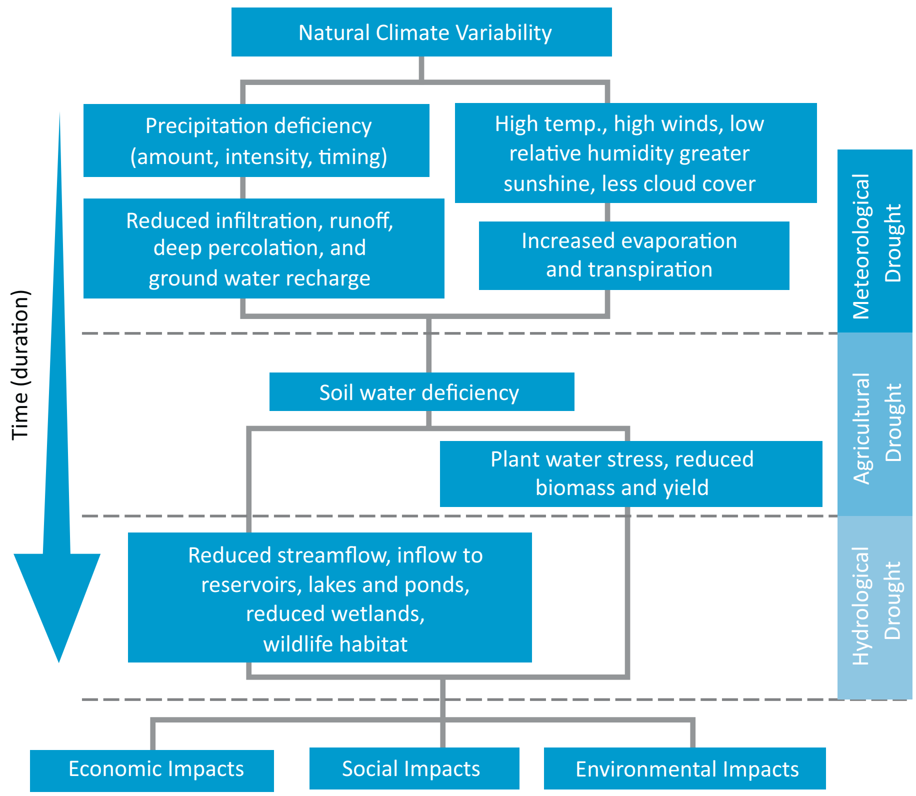


Figure2.1: Types of drought and their impacts over time (Ramamasy & Baas, 2007)

Meteorological and agricultural droughts are frequently, but erroneously, considered synonymous. Meteorological and hydrological droughts are physical events, but agricultural drought refers to the impact of the first two on agricultural production. It is necessary to distinguish between these types and clarify where and how they overlap. Both climate variability and climate change influence such aspects as time (season, intra-season), location and length of drought occurrence.

Meteorological drought occurs when the reduction in rainfall for a specified period (day, month, season or year) is below a specified amount - usually defined as some proportion of the long-term average. It is usually an expression of precipitation's departure from normal over some period of time. These definitions are region-specific and presumably based on a thorough understanding of regional climatology.

Hydrological drought refers to deficiencies in surface and subsurface water supplies based on measurements of stream flow and lake, reservoir and groundwater levels. When precipitation is reduced or deficient during an extended period of time, this shortage eventually will be reflected in declining surface and subsurface water levels. However, hydrological measurements are not the earliest indicators of drought because of the time between reduced periods of precipitation and reduced water in streams, rivers, lakes and reservoirs.

Agricultural drought occurs when there is not enough soil moisture to meet the needs of a particular crop at a particular time. Agricultural drought happens after meteorological drought but before hydrological drought. Agriculture is usually the first economic sector to be affected by drought.

Socio-economic drought occurs when physical water shortage starts to affect people, individually and collectively. In more abstract terms, most socio-economic definitions of drought are associated with its effect on the supply and demand of a product that has market value.

Seasonal drought is related to deficit soil moisture during certain periods within a season. In Bangladesh, three types of droughts are recognized during monsoon season:

Early-season droughts are due to delayed onset or early breaks in monsoon rainfall. Mid-season droughts are caused by intermittent, short or extended dry spells. Terminal-season droughts are caused by early withdrawal of monsoon rainfall. In the Barind tracts of Bangladesh, terminal droughts are more frequent and coincide with the most important growth phases of the rice crop.

One may relate to occurrence of drought with certain physical observations:

- Development of continually broken cracks on the dried up topsoil;
- Burnt-out yellowish foliage in the vegetation cover (top yellow syndrome), particularly observed in betel nut trees and bamboo groves; and
- Loosening of soil structure, ending up in the topsoil transforming into a dusty layer.

Based on literature review it can be said that there lacks a working definition of drought. Nevertheless, the different meteorological, hydrological, agro-ecological and socio-economic definitions that have been suggested can be merged into a comprehensive definition such as: On the basis of non-availability of rainfall (rainfall deficiency by more than 25% from normal long term average) for a prolonged time period over a wide area, a decreased condition in base flow and surface flow of water bodies leading to depletion of soil moisture which ultimately causes plant water stress and reduced biomass causing reduced yield can be defined as drought.

2.2 Causes of Drought

The causes of drought in Bangladesh are related to climate variability and non-availability of soil moisture leading to reduced harvest. Decrease in rainfall, shortage of surface water and groundwater recharge cause depletion in soil moisture. The immediate cause of rainfall shortage may be one or more factors including absence of moisture in the atmosphere or large-scale downward movement of air within the atmosphere which suppresses rainfall. Changes in such factors involve changes in local, regional and global weather and climate. While it may be possible to indicate the immediate cause of drought in a particular location, it is not often possible to identify an underlying cause. Some studies (e.g., Karim et. al., 1996) show that crop yields potentially increase with an increase in temperature of a few degrees celsius. Reduced precipitation in winter would have a negative effect on yields. Other changes such as effects on crop pest and disease incidence could also reduce crop yields.

Short-term drought episodes can be linked to global atmospheric and oceanic circulation features. For example, the El- Nino/ Southern Oscillation (ENSO) phenomenon, which results from the development of warm surface water off the Pacific coast of South America, affects the levels of rainfall in many parts of the world, including monsoon rainfall in Bangladesh. On a larger scale, the link between sea surface temperature and rainfall has been suggested as a possible cause of long, dry regimes. Increasing levels of carbon dioxide and other greenhouse gasses have been suggested as causes of rainfall changes, which are, in turn, attributed as climate change. There is strong evidence that climate change will alter the rainfall pattern, and as a result more frequent droughts are estimated. Among the local-level causes are human-induced changes resulting from vegetation loss due to over exploitation of resources and deforestation.

2.3 Drought in Bangladesh

Bangladesh experienced severe droughts in the years 1951, 1957, 1961, 1972, 1976, 1979, 1986, 1989 and 1997. Most of these droughts primarily occurred in pre-monsoon and post-monsoon seasons, but in some extreme cases the pre-monsoon droughts had extended into the monsoon season due to delayed onset of the monsoon rains. e.g. the 1979 drought (Choudhury, et al., 2003).
The dry zone in Bangladesh is located in the (greater) districts along the country's western border, together with some

adjoining parts of Bogra, Pabna and Faridpur districts. The mean annual rainfall in this area is 1,250-1,750 mm, falling mainly in 4-5 wet months between May-June and September-October. This dry zone includes the following agro-ecological regions:

- The Barind Tract, especially the High Barind in the west;
- The southern part of the Old Himalayan Piedmont Plain;
- The high western part of the Ganges River Floodplain;
- The western part of the Ganges Tidal Floodplain in Khulna District.

Some soils in other agro-ecological regions have a low moisture-holding capacity which provides similar problems to those occurring in the dry western districts. These drought prone soils include the following:

- Most deep and shallow terrace and valley soils on the Madhupur Tract;
- Most soils in the Northern and Eastern Hills, especially those on south-facing slopes;
- The high western part of the Ganges River Floodplain;
- The western part of the Ganges Tidal Floodplain in Khulna District.

Some soils in other agro-ecological regions have a low moisture-holding capacity which provides similar problems to those occurring in the dry western districts. These drought-prone soils include the following:

- Most deep and shallow terrace and valley soils on the Madhupur Tract;
- Most soils in the Northern and Eastern Hills, especially those on south-facing slopes;
- Sandy soils on the highest parts of floodplain ridges, especially in the north-western part of the Teesta Floodplain, the south-eastern part of the Karatoya-Bangali;
- Floodplain, the Old Brahmaputra Floodplain (e.g., in Narsingdi District), the Middle;
- Meghna Floodplain, and the Northern and Eastern Piedmont Plains;
- Sandy alluvium on river char land; and
- Many silty and clay floodplain and terrace soils whose topsoils have been puddled for the cultivation of transplanted aman paddy.

Kharif drought prevails intermittently on highland and medium highland soils from June through October. The T. Aman crops grown on these lands are affected by drought.

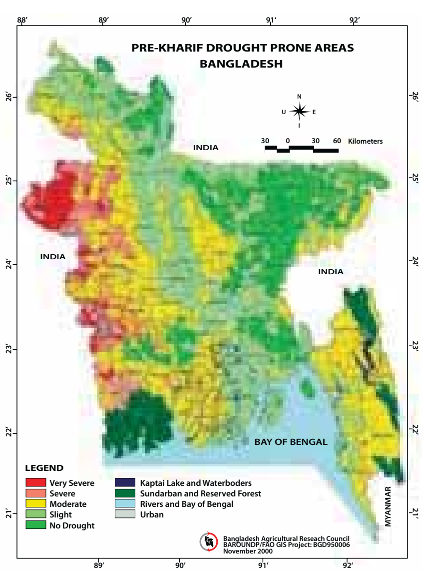


Figure 2.2: Pre-Kharif drought-prone areas

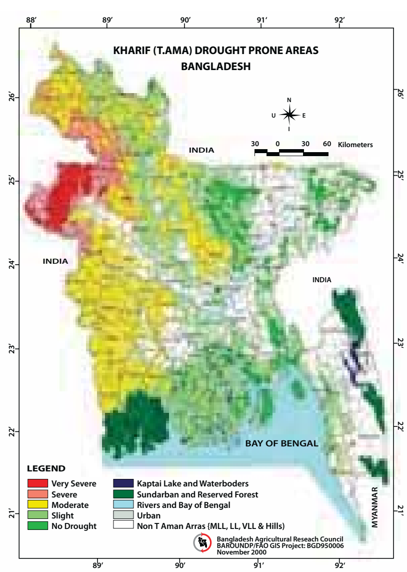


Figure 2.3: Kharif (Aman) drought-prone areas

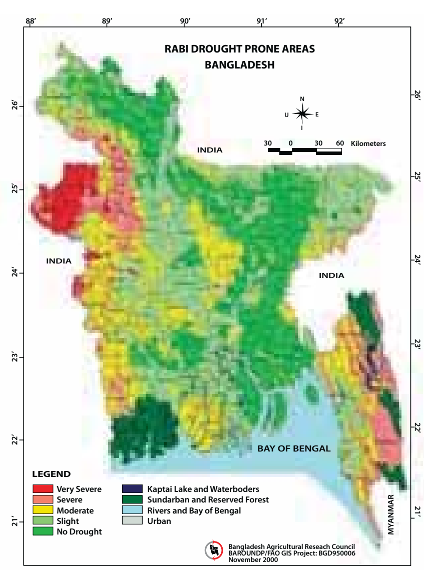


Figure 2.4: Rabi drought-prone areas

Source of maps: BARC/UNDP/FAO GIS Project: BGD/95/006

Table 2.1: Historical details of different droughts that occurred in Bangladesh

Year	Description
1865 , 1866, 1872, 1874	Reported to occur in Dhaka, Bogra and Sundarbans. Crop suffered greatly in most cases.
1951	Severe drought in north-west Bangladesh substantially reduced rice production.
1973	Drought responsible for the 1974 famine in northern Bangladesh.
1975	Drought affected 47 % of the country and more than half of the total population.
1978 -79	Widespread damage to crops reducing rice production by about 2 million tonnes, directly affecting about 42 percent of the cultivated land and 44 percent of the population.
1981	Severe drought adversely affected crop production.
1982	Drought caused a loss of rice production of about 53,000 tonnes.
1989	Drought dried up most of the rivers in Northwest Bangladesh in several districts, including Naogaon, Nawabganj, Nilpahamari and Thakurgaon.
1994, 1995, 1996	Immense crop damage, especially to rice, jute and bamboo clumps.
	No comprehensive study has been done on the droughts that was occurred after 1995-96

Source: Modified from Banglapedia, 2006

2.4 Drought Management Practices

Drought management for agriculture crops is generally performed through soil and water management. Soil management may be defined as caring for the soil to maintain fertility, preserving topsoil, and providing a media for plants to penetrate with roots so as to obtain water and nutrients needed for their growth. Agricultural water management, in simple terms, is the management of the earth surface or soil to get water into the soil, remove unwanted water, and control the loss of water by runoff. The drier regions of the country are normally concerned with preserving water in the soil and adding additional water to it as needed by crops. This is accomplished by some form of irrigation, usually from a limited supply of water.

In Bangladesh, the farmers follow traditional farming practices to control moisture loss from soil surface during the dry season. Immediately after the harvest of monsoon crops, farmers plough the land and keep it fallow for the next Rabi crops. The tilled layer acts as a barrier against moisture loss from the sub-soils. The farmers utilize the residual moisture of the soils for the following dry land Rabi crops. Mulching is also another practice adopted by the farmers. There are crops which have high water requirements and are usually grown with the help of irrigation. However, in many places, farmers grow potatoes and various types of vegetables under soil mulching. Mulching greatly retards the evaporation, so that more of the available water can be used by the crops. In addition to this practice, farmers add organic matters to their cropland to raise the moisture retention capacity of the soils.

Prior to 1960, irrigation in Bangladesh had been largely by traditional methods abstracting water from low-lying water bodies and perennial rivers and streams. Agriculture of the country was then totally dependent on the monsoon and subservient to its unpredictability. The common traditional methods were Dhoon, Swing Basket and Dug-well. The operation of these methods was entirely done by manual means and these have low lifting capacity. In modern times much advancement in the irrigation technology has been achieved. Towards the late 60s irrigation became an important concern and minor irrigation started getting attention in the official policies. The area irrigated reached to about 1.90 million hectares by 1989/90. About 87 percent of that area is irrigated by modem methods including low lift pumps (LLP), shallow tubewells (STW), deep tubewells (DTW), manually operated shallow tubewells and major canal irrigation schemes of BWDB e.g. Ganges-Kabadak (G-K) Project, Chandpur Irrigation Project (CIP), Teesta irrigation project (TIP), Karnafuli Irrigation Project (KIP) and Barisal Irrigation Project (BIP). Irrigation by traditional means declined very slowly until about

1980 when this trend began to accelerate (BANCID, 1992). Of the total irrigated area, shallow tubewell constitutes to 65.46%, low lift pump 16.59%, deep tubewell 14.85%, gravity flow 2.81% and traditional method 0.29% e.g. don, dug well, hand tubewell etc. in the year 2006-07 (MoA, 2007).

Bangladesh Water Development Board (BWDB) plays the pivotal role in expanding surface water irrigation facility in Bangladesh. Since 1985, Barind Multipurpose Development Authority (BMDA) has been working for drought management in the north-western region of Bangladesh. It provides irrigation to more than 500,000 hactors of cultivated land, takes afforestation programme for combating desertification and provide water management training to the farmers. Besides this, Local Government Engineering Department through its Small Scale Water Resources Development Sector Projects (SSWRDSP) and BADC through its minor irrigation projects contributed significantly in drought management.

2.5 Rice Production and Future Needs

As different types of new varieties have been introduced, year-to-year increase in production is observed though a change in temperature and rainfall is evident from historical trend analysis. This is due to the fact that in recent times, agriculturists and farmers have introduced cultivation of high-yield varieties along with proper irrigation, fertilizer and pesticide management, which has ultimately lead to increase in production. Yet again dependency on rained local variety has decreased in the competition with HYV, both from the aspect of its high-yielding capacity and less dependency on rainfall due to introduction of irrigation.

Table 2.2: Production of Rice from 1990-91 to 2009-10 (Figures in million metric tons)

Year	Aus	Aman	Boro	Total
1990-91	2.26	9.17	6.36	17.79
1991-92	2.18	9.27	6.81	18.26
1992-93	2.08	9.68	6.59	18.34
1993-94	1.85	9.42	6.77	18.04
1994-95	1.79	8.50	6.54	16.83
1995-96	1.68	8.79	7.22	17.69
1996-97	1.87	9.55	7.46	18.88
1997-98	1.88	8.85	8.14	18.86
1998-99	1.62	7.74	10.55	19.91
1999-00	1.73	10.31	11.03	23.07
2000-01	1.92	11.25	11.92	25.09
2001-02	1.81	10.73	11.77	24.30
2002-03	1.85	11.12	12.22	25.19
2003-04	1.83	11.52	12.84	26.19
2004-05	1.50	9.85	13.84	25.18
2005-06	1.75	10.81	13.98	26.53
2006-07	1.51	10.84	14.97	27.32
2007-08	1.51	9.66	17.76	28.93
2008-09	1.90	11.61	17.81	31.32

Source: BBS (2001-2010)

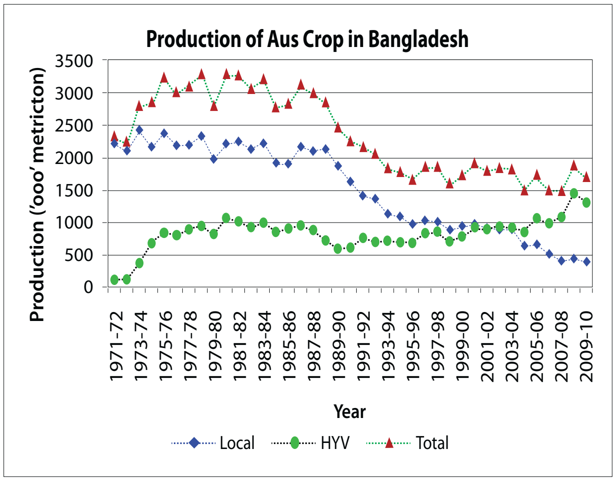


Figure 2.5: Total production of Aus crop from 1971-72 to 2009-10

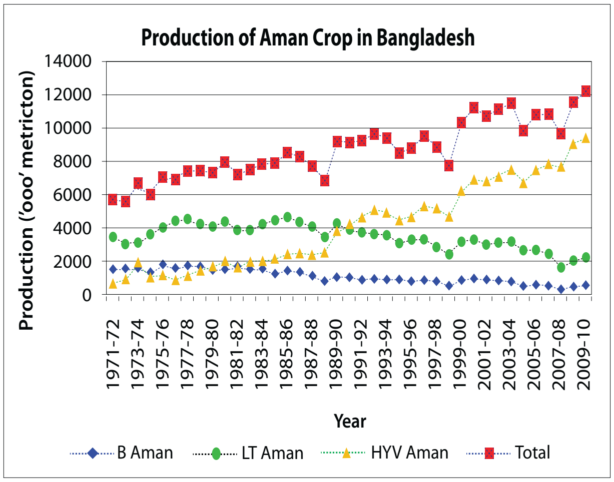


Figure 2.6: Total production of Aman crop from 1971-72 to 2009-10

Rice is still the most important agricultural crop in Bangladesh both from the point of demand (consumption) and production. Rice dominates all crops in terms of both value added as well as area. In terms of area, the share of rice/ paddy has in fact gone up. Only potato has, to an extent, shown a similar trend. It should be also noted that the area under pulses (a source of vegetable protein and also nitrogen-fixing in soil) has fallen, as has that of wheat. The relative area under oil seeds has also fallen with adverse nutritional implications.

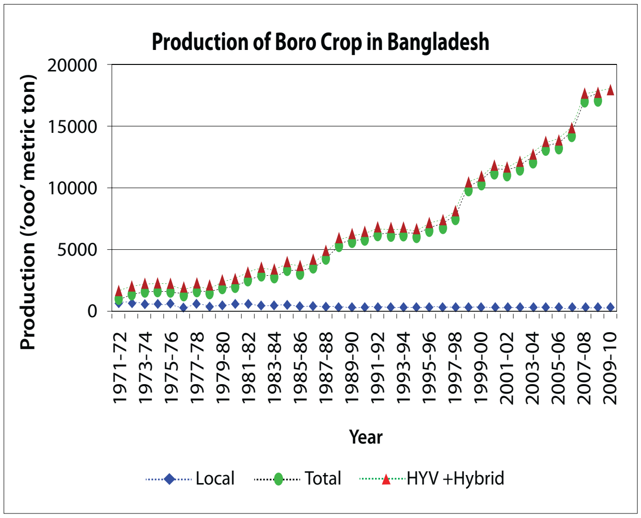


Figure 2.7: Total production of Boro crop in Bangladesh from 1971-72 to 2009-10

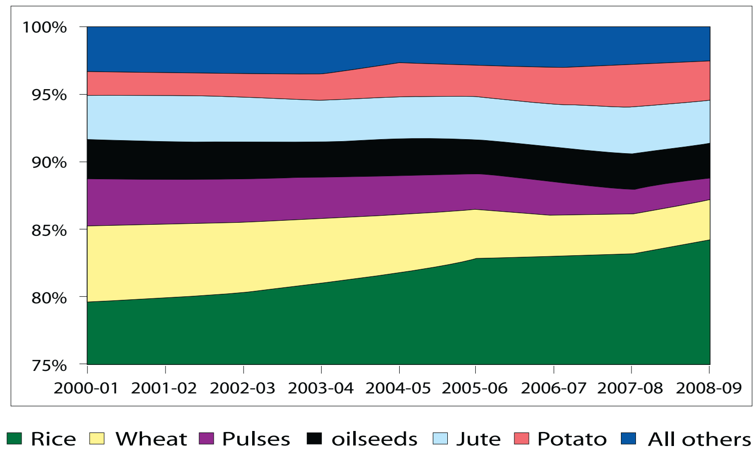


Figure 2.8: Percentage share of various crops in total cropped area

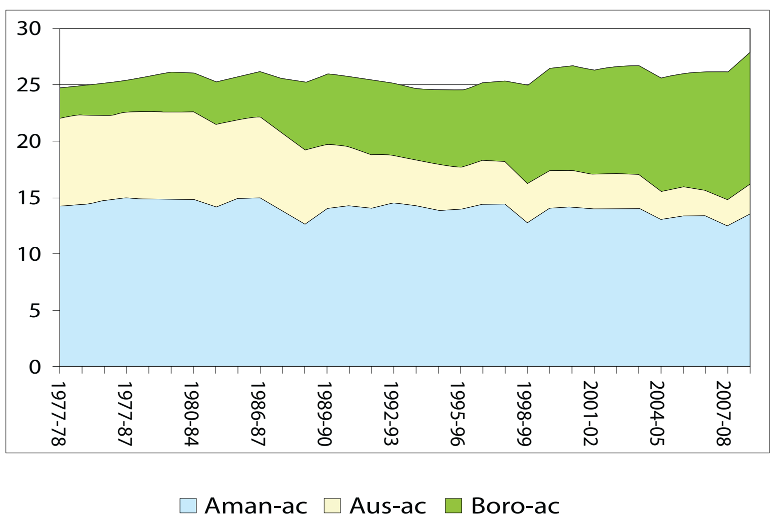


Figure 2.9: Distribution of Rice Acreage under Different Season

CHAPTER 3

Climate Change in Bangladesh

3.1 Defining Climate Change

World Meteorological Organization (WMO) defined “climate change” as the change in climate attributed directly or indirectly to human activity, which, in addition to natural climate variability, is observed over comparable time periods (WMO, 2002). According to WMO, climate variability represents the variations in the mean state and other statistics (such as standard deviations, the occurrence of extremes, etc.) of the climate on all temporal and spatial scales beyond that of individual weather events. A key difference between climate variability and change is in persistence of “anomalous” conditions. In other words, events that used to be rare, occur more frequently now, like summertime maximum air temperatures increasingly break records each year, or reversely the duration and thickness of dry seasonal rainfall decreasing with time.

The United Nations Framework Convention on Climate Change (UNFCCC) defines climate change as a change of climate which is attributed directly or indirectly to human activity that alters the composition of the global atmosphere and which is in addition to natural climate variability observed over comparable time periods. One of the established generalizations about global change is that atmospheric CO_2 concentration has increased as a result of anthropogenic emissions principally from the burning of fossil fuels, and clearing and burning of forest (Fitter, et. al., 2002).

According to IPCC, climate change may be due to natural internal processes or external forcing, or to persistent anthropogenic changes in the composition of atmosphere or in land use (IPCC, 2001).

According to the fourth IPCC assessment report, continued greenhouse gas emissions at or above current rates causes further warming and induces many changes in the global climate system during the 21st century, which would very likely be more severe than those observed during the 20th century (IPCC, 2007c). The figure below shows the scenarios of GHG emissions from 2000 to 2100 along with projections of surface temperature.

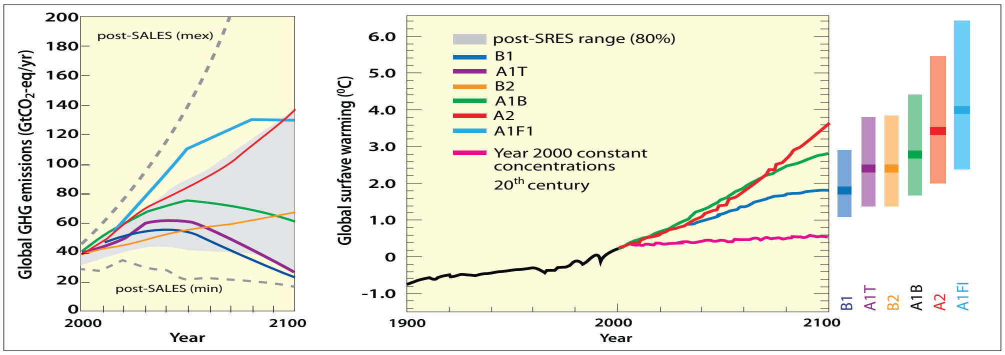


Figure 3.1: Scenarios for GHG emissions from 2000 to 2100 and global surface warming

Source: IPCC 4th Assessment Report

3.2 Climate Change Impacts on Agriculture

The impact of climate change on food production is of global concern, and also very important for Bangladesh. 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 (Ahmed, et. al., 2000). Bangladesh needs to increase the rice yield in order to meet the growing demand for food emanating from population growth. Irrigated rice or Boro rice is a potential area for increasing rice yield, which currently accounts for about 50% of total rice production in the country (BRRI, 2006). However, climate change is a potential threat towards attaining this objective. It is therefore very important to understand the effect of climate change on rice production (NIDOS, 2009).

Under the IPCC emissions scenarios, higher temperatures are projected to affect all aspects of the hydrological cycle in upcoming years. More frequent and severe droughts and floods are already apparent, and their impacts increase as a growing population becomes more dependent upon a set of atmospheric and hydrological circulations. Climate change will impact the extent and productivity of both irrigated and rain fed agriculture across the globe. Reductions in river run off and aquifer recharge are expected in the Mediterranean basin and in the semi-arid areas of the Americas, Australia and southern Africa, affecting water availability in regions that are already water-stressed. In Asia, the large contiguous areas of irrigated land that rely on snowmelt and high mountain glaciers for water will be affected by changes in runoff patterns, while highly populated deltas are at risk from a combination of reduced river inflows, increased salinity and rising sea levels. Everywhere, rising temperatures will translate into increased crop water demand (FAO, 2011).

According to IPCC 2007 report, more intense and longer droughts have been observed over wider areas since the 1970s, particularly in the tropics and subtropics. The report declares increased drying linked with higher temperatures and decreased precipitation has contributed to changes in drought. According to IPCC estimates, by 2050, increasing temperature and changing rainfall pattern along with flooding, drought and salinity Bangladesh might face a decline in crop production. Against the 1990 base year, the declines predicted are 8% in rice and 32% in wheat (MOEF, 2009). (Hussain, 2008) predicts reduction in Aus production by 1.5-25.8%, reduction in Aman production by 0.4-5.3% and increase in Boro production by 1.2-9.5% for 2050 using different models, assuming the threshold temperature not exceeding 35^{o}C.

Elevated CO_2 alone increases plant photosynthesis, and thus increases crop yields (Kimball, 1983, Tubiello, et. al., 2000). But the predicted changes in temperature and precipitation might further affect crop yields, by hastening plant development, and by altering the water and nutrient budget in the fields, and modifying plant stress (Long, 1991, Tubiello, et. al, 1999). Several studies using temperature gradient tunnels (TGTs), crop simulation models, and field experiments have been conducted to evaluate the effects of climate change particularly to temperature increase, and/or doubled CO_2 concentration on crop (rice) growth and development (Lansigan, 2001). Yoshino, et. al., (1988) predicted the effect of climate change on lowland rice yield in Japan while Solomon and Leemans (1990) in a worldwide study, used a very simple model and long-term monthly-average climatic data to predict the effect of climate change in rice yield for current growing environment. Since the western and north-western parts of Bangladesh experience high temperature which leads to high evapo-transpiration and characteristically have lower soil moisture holding capacity, drought occurs in pre-monsoon season (Choudhury, et. al., 2003 and Lansiganand, et. al., 2007).

It is already mentioned in several literatures that under climate change scenario evapo-transpiration will increase significantly, especially during the post-monsoon and pre-monsoon seasons, in the backdrop of diminishing rainfall in the winter and the already erratic rainfall variability over time and space (Karim, et. al., 1998). As a consequence, severity of moisture stress, particularly in the north-western districts mentioned in earlier sections, will increase leading to drought conditions. An earlier estimate suggests that the area severely affected by drought in Rabi season could increase from 4,000 km^2 to 12,000 km^2 under severe climate change scenario (Huq, et. al., 1996).

Rising Temperatures

Rising Temperature is predicted in future by IPCC that will result in higher evaporation rates; shorter crop seasons in mid and low latitudes, but longer crop seasons in the higher latitudes. There will be potential to increase the number of cropped seasons per year at all latitudes, where sufficient rainfall or water resources permit, although yield potentials for most crops in the mid and low latitudes will decline due to shorter seasons, higher respiration rates, and increased evaporative demand. There will be corresponding declines in potential water productivity, with and without CO_2 fertilization, for which the prospects of mitigating loss of yield potential seem to be diminishing (Long, et. al., 2005; USDA, 2008).

Change in Precipitation

Less clearly understood and more spatially variable changes in precipitation will affect agriculture. The general trends in precipitation predicted by IPCC 4th Assessment Reportare gradually being confirmed by analyses of trends in some areas e.g. declines in northern Africa and southern Europe (The Copenhagen Diagnosis, 2009). However, there remains strong disagreement in the directions, extents and spatial patterns of changes in precipitation. The fundamental reasons for this are that most GCMs used so far do not couple land use and land surface interactions that dominate weather at regional and local scales - topography, physiography, elevation and land cover (IPCC 2007c; The Copenhagen Diagnosis, 2009). GCM models predict intensification of the hydrologic cycle, with more extreme behaviour around the mean (more intense storms and longer dry periods in between) for both net reductions and increases in annual rainfall. Any meaningful assessment of the agricultural impacts of changed precipitation regimes requires more precise temporal and spatial prediction, which should be made with a higher level of certainty than is the norm at present (FAO, 2011).

Impacts on Water Sector

Climate change impacts on water resources will reflect changes in water balance brought about by increased evaporation rates and changes in precipitation. Where rainfalls decline there will be much larger corresponding reductions in surface runoff (CSIRO 2007; Milly et. al., 2005). In all cases where rainfall, runoff and groundwater recharge declines, current tensions between agricultural and environmental allocation of water will be magnified. It is becoming clear that allocation policy in the future will face considerably tougher dilemmas in balancing environmental flow allocations with those in agriculture (DSE, 2007). Where surface runoff declines, groundwater recharge is also likely to decline (FAO, 2011).

Where rivers depend on glacier-melt, short-term increase in runoff and retreat of glaciers will be replaced by long-term declines in yield (Barnett, et. al., 2005, Kulkarni, et. al., 2007). Quantification of such changes is as yet poor, resulting from the variable contribution of snow-melt to total annual flow. It is likely that low flows in pre-monsoon will fall, and the timing of seasonal flows will move from spring to winter flows. There is also an improving understanding of the complexity of mountain hydrology and the spatial extents of different runoff processes within large mountain areas (Fowler and Archer, 2005).

As rainfall regimes are expected to become more extreme, with more intense rainfalls and more frequent high-intensity rainfall, offset by longer periods of drought between rains, the following can be anticipated: reduction in base flows; increased frequency and severity of flooding, groundwater recharge may be stabilized or enhanced; increased frequency and severity of within-season, seasonal and annual droughts.

Needs to adapt agricultural water management to those different time scales must be considered. Where rainfall increases, the frequency of flooding and high flow events is expected to increase (FAO, 2011).

Climate change and corresponding impacts are given here in tabular format

Table 3.1 Impacts and vulnerabilities to climate change in South Asia in agriculture sector

Impacts	Agriculture Sectoral Vulnerabilities
Temperature Increase • Warming above the global mean in southern Asia • Fewer very cold days in South Asia **Precipitation Increase** • Increase in precipitation in most of Asia • Increase in the frequency of intense precipitation events in parts of South Asia **Extreme Events Increase** • Increasing frequency and intensity of extreme events particularly droughts during the summer months • Increase in extreme rainfall and winds associated with tropical cyclones in South Asia • Intense rainfall events causing landslides and severe floods • Heat waves/ hot spells in summer of longer duration	• Decreases in crop yield for many parts of Asia putting many millions of people at risk from hunger • Reduced soil moisture and evapo-transpiration may increase land degradation and desertification

Source: Modified from UNFCCC, 2007

3.3 Climate in Bangladesh: Historical Trend

Bangladesh has a tropical monsoon climate. In general, it is characterized by high temperature, heavy rainfall, often excessive humidity during monsoon (June to September) and marked inter and intra seasonal variation. Bangladesh is one of the country's most vulnerable to the impacts of global warming and climate change. This is due to its geographic location, dominance of river floodplains, low elevation, high population density, high level of poverty, and overwhelming dependence on nature and its resources and services which are sensitive to climate variability and climate change. The country has a history of extreme climatic events claiming millions of lives and destroying past development gains. The mass people and social system have knowledge and experiences of coping with the effects of such events to some degree and extent.

3.3.1 Temperature

The mean annual temperature is about 25^{o}C within the country while mean monthly temperatures range between 18^{o}C in January and 30^{o}C from April to May (MoEF, 2008). Figures 3.2 and Fig. 3.3 show the annual mean maximum and minimum temperatures in different locations of Bangladesh. These indicate that the northern and western parts of the country are in general hotter during summer and cooler during winter. The mean annual temperature, mean maximum temperature and mean minimum temperature has risen respectively by 0.016^{o}C/year, 0.02^{o}C/year and 0.012^{o}C/year during the 32-year period from 1977 to 2008. The observed data indicates that the significance of the trends is regionally widespread. Thus, 19 out of 31 stations exhibited statistically significant rising trend in mean annual temperature. Significant rise in minimum temperature is found valid in observations from 17 out of 31 stations while for rising maximum temperature 17 stations out of 31 showed significant results (CEGIS, 2011).

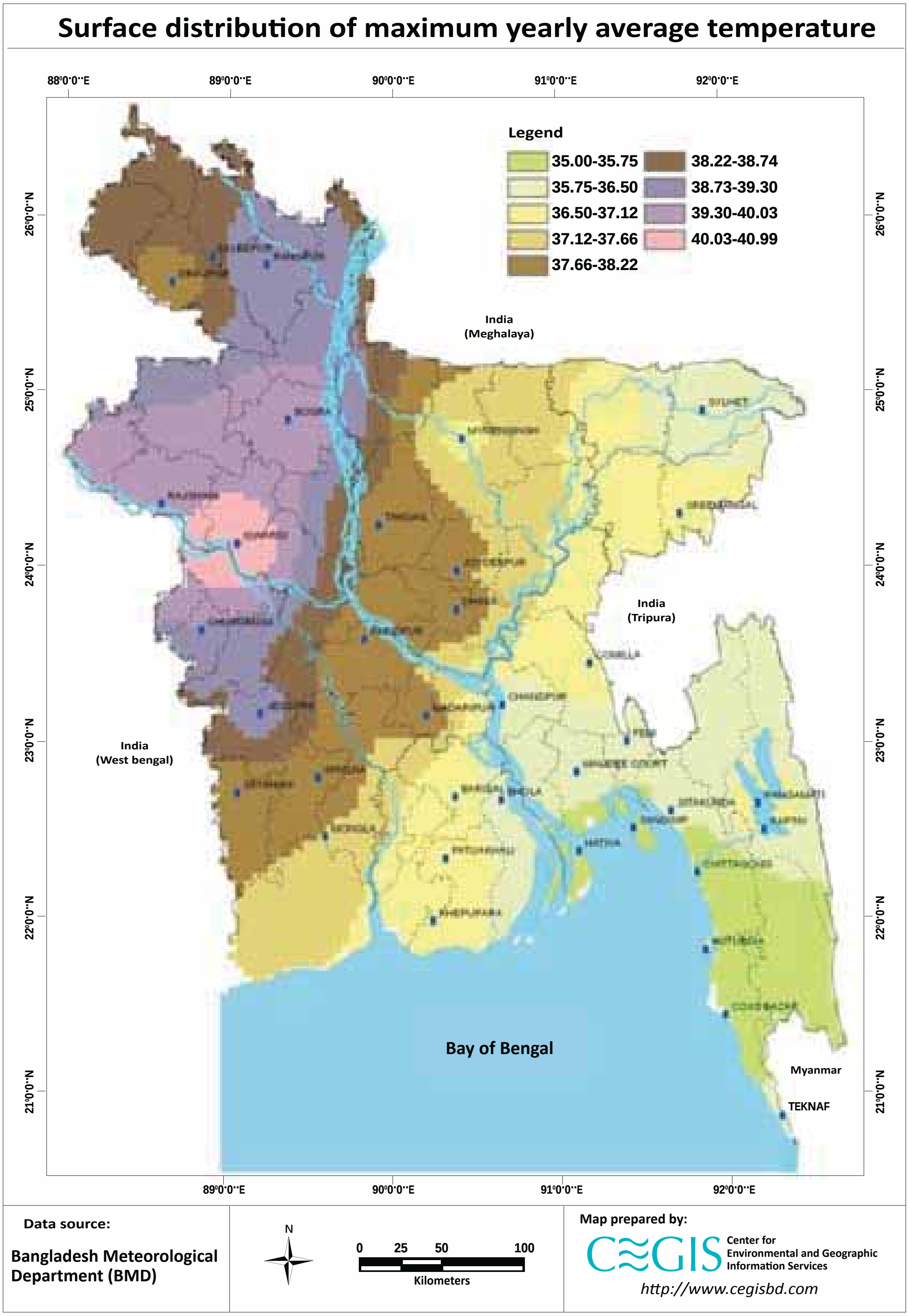


Figure 3.2: Distribution of Yearly Average of Maximum Temperature

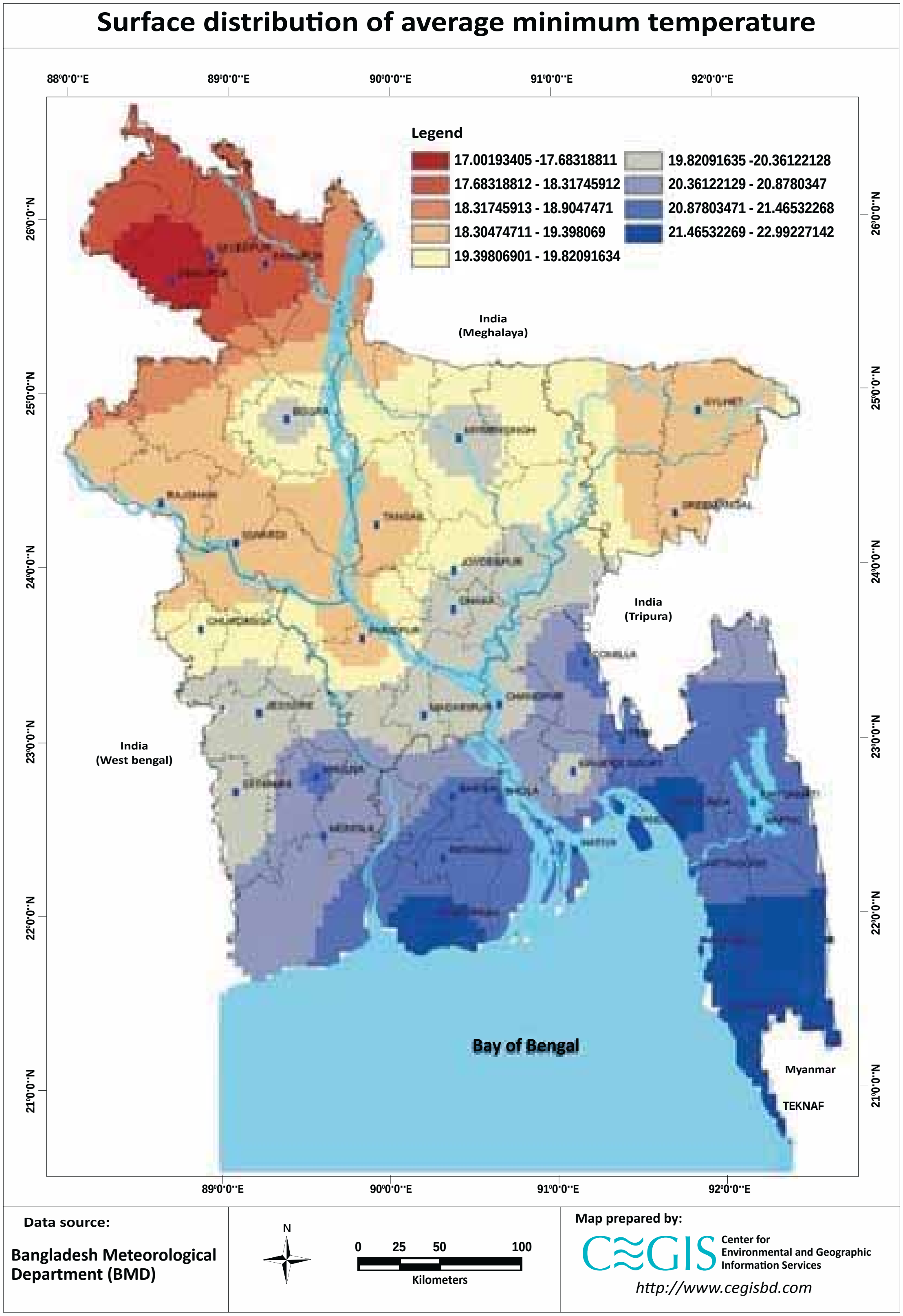


Figure 3.3: Distribution of Yearly Average of Maximum Temperature

Over the past few decades, warmer winters and hotter summers have been observed. A rise in the minimum temperature by 0.45°C and 0.52°C is observed during the winter (December-January-February) and monsoon (June-July-August) seasons respectively. Maximum temperature is also observed to have increased during the pre-monsoon (March-April-May) and post-monsoon (September-October-November) month by 0.87°C and 0.42°C respectively (CEGIS, 2011).

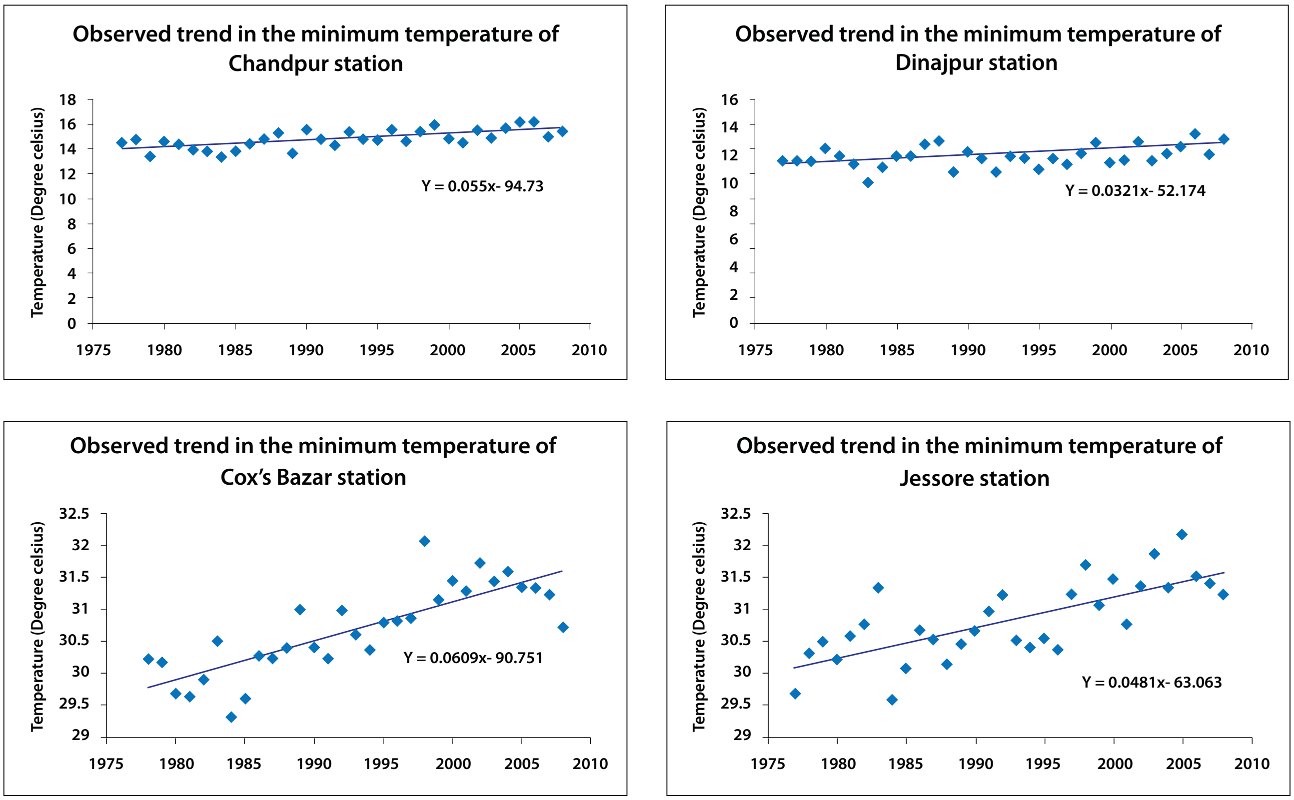


Figure 3.4: Observed trends in yearly maximum and minimum temperatures

Statistically significant rise in the minimum temperature during the winter season (December-January-February) is observed in 25 out of 34 climate observatories (BMD stations). A rise in the maximum temperature during the summer months of (June-July-August) is observed in all the stations (except one) (CEGIS, 2011). Climate variability in terms of annual count of summer days is found statistically to be significantly increasing in 13 out of 28 meteorological observatories (Mukherjee et. al., 2010). This is a proof of the fact that not only temperature is increasing, but also count of summer days is also increasing leading to the deduction that global warming and climate change is occurring regionally.

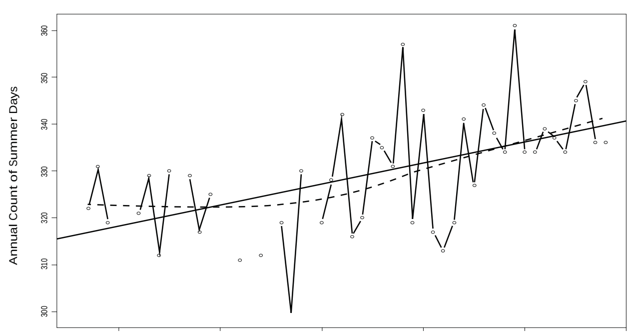


Figure 3.5: Trend in the annual count of summer days in Sylhet station

3.3.2 Rainfall

Rainfall within the country is mainly caused by the south-westerly trade winds known as the 'monsoon', during the months of June to September. The two other sources of rainfall are the western depressions of winter, which cause rainfall mainly from the end of January to the end of February, and the nor'westers (early summer thunderstorms), which cause rains mainly within the first week of May. The average annual rainfall in the country is about 2,200 mm. About 80% of the rainfall occurs from May to September. The isohyets pattern of the average rainfall is shown in Figures 3.7. The mean annual rainfall is the lowest (1,400 mm) in the Rajshahi zone near the western border. The advancement of isohyets is towards the north, east and south reaching more than 2,500 mm in the extreme north-westnear and within the northern and eastern hills and near the coasts, and exceeding 5,500 mm near the border in the north-east. There is a wide variability of rainfall from year to year and between seasons. While monsoon rainfall is high to very high, rainfall during the winter season is negligible.

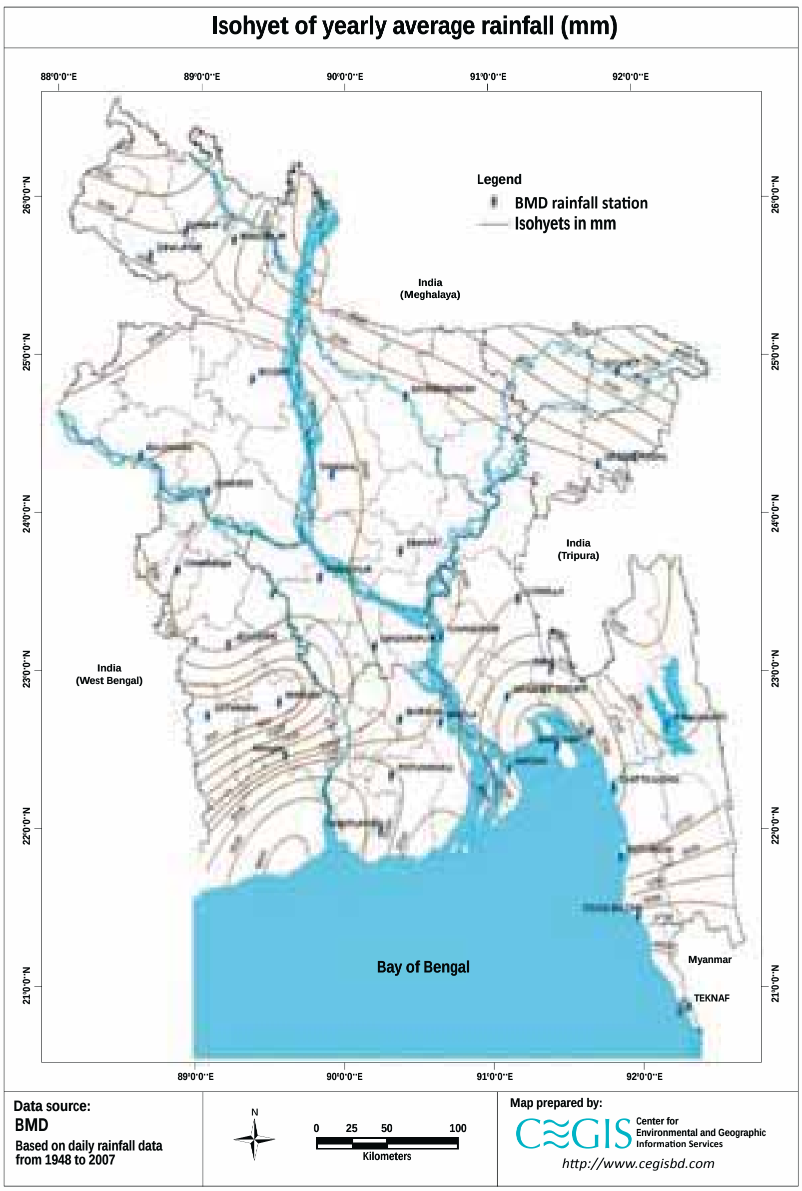


Figure 3.6: Contour map of average rainfall

The pattern of change in the rainfall is mixed and appears to indicate trend of heavier rainfall in the coastal region. Mean annual rainfall has increased statistically significantly in only 4 out of 31 observatories of the country. The dry seasonal (DJF-December-January-February) rainfall shows little change in most cases, but where it does (in 4 out of 5 stations), the trend is downwards. During the monsoon no significant trend is observed but for post monsoon seasonal rainfall, statistically significant rising trend has been observed in 11 out of 31 stations (CEGIS, 2011).

Irrespective of statistical significance, in all the seasons an overall increase in the mean seasonal rainfall is observed and found to be maximum during the pre-monsoon (MAM-March-April-May) and monsoon (JJA) season by around 100 mm. Although the winter season (DJF) experiences the minimum rainfall, it also shows a positive trend in 27 out of 32 rainfall observatories. The positive trend is comparatively prominent in the coastal regional stations. A fall in the pre-monsoon (MAM) seasonal rainfall is evident in 30 out of 32 stations of BMD (Figure 3.7). It is also significant in some of the coastal regional stations. An increase in the monsoon (JJA-June-July-August) rainfall is observed in 18 out of 32 meteorological stations, which is not statistically significant but seen to be prominent in the coastal district observatories. Post-monsoon (SON-September-October-November) rainfall is also observed to increase in 24 out of 32 meteorological stations, which is statistically significant in some of the coastal observatories(CEGIS, 2011).

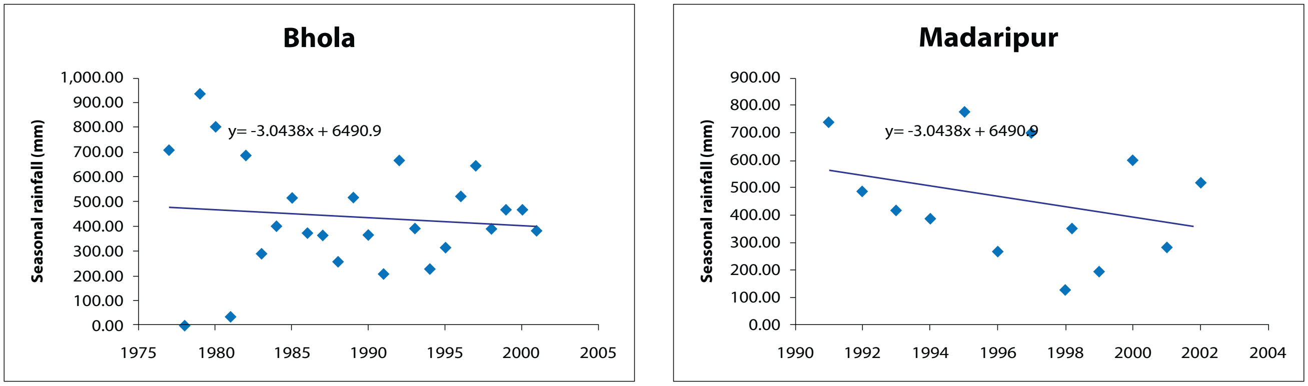


Figure 3.7: Observed trend in seasonal mean rainfall for pre-monsoon season

In terms of variability, the trend in the monthly maximum 1-day precipitation is found statistically significant only in one station, but the trend in the monthly maximum consecutive 5-day precipitation in found statistically significant in 4 out of 28 stations (Figure 3.8). The statistically significant trend during the annual count of days when precipitation is greater than 10 mm and 20 mm, has also been observed (Mukherjee et. al., 2010).

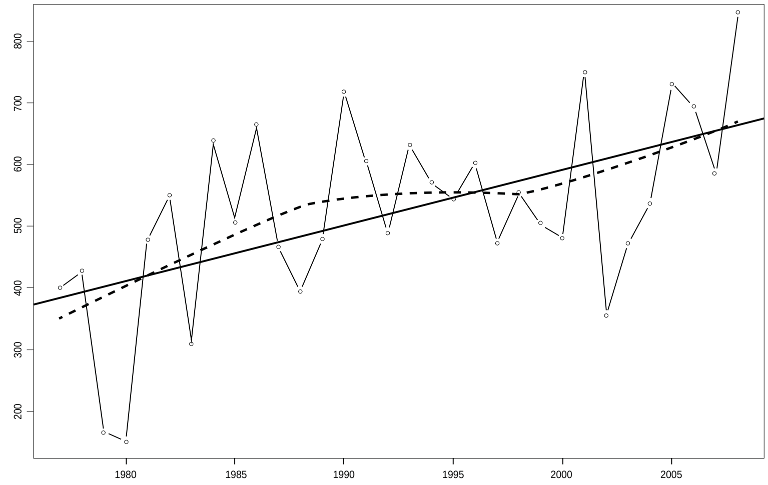


Figure 3.8: Trend in the monthly maximum consecutive 5-day precipitation in Teknaf station

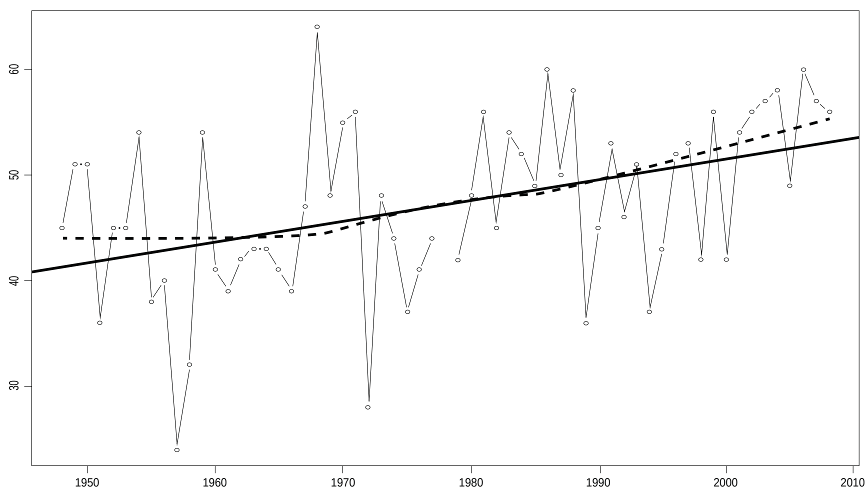


Figure 3.9: Trend in the annual count of heavy precipitation days in Jessore station (precipitation is greater than 10 mm)

From these analyses, it can be inferred that precipitation pattern is a changing. The mean annual precipitation is decreasing and dry seasonal rainfall has a decreasing pattern. Post-monsoon rainfall has an increasing pattern. Though seasonal decline in rainfall is apparent, variability in rainfall pattern is increasing. Annual count of heavy precipitation (not total precipitation) is increasing along with consecutive 5 days rainfall (continuous rain at a time).

3.4 Future Projection: Rainfall and Temperature

Several attempts have been made in climate scenario development in Bangladesh over the period using mainly GCMs and in some cases RCMs (Ahmed and Alam, 1998; Agrawala et al, 2003; Tanner et al., 2007). A general consensus from these exercises includes an over-all rise in temperature, drier dry season, and a wetter wet season. In general, change in the mean annual temperature expected to be around 10^{o}C by 2030 and 20^{o}C by 2050; change in annual rainfall is expected in the range of 0 to 2% by 2030 and 2 to 4% by 2050 with a greater variation in seasonal rainfall. Winter (December-February) rainfall is expected to decrease in most of the study results while monsoon (June-August) rainfall might increase in the future (CEGIS, 2011).

In order to estimate future climate change over Bangladesh, the 'Model for the Assessment of Greenhouse-gas Induced Climate Change' (MAGICC) and the 'SCENario GENerator' (SCENGEN) developed by the National Center for Atmospheric Research (NCAR), USA and Climatic Research Unit (CRU), University of East Anglia, UK have been used. MAGICC has a grid resolution of 2.5 degree by 2.5 degree. All model data available in MAGICC can be used to generate outputs at this resolution. Nine GCMs which portray Bangladesh situation better than others have initially been chosen. One was finally rejected based on convergence criteria. The selected models are CGCM 3.1 (T47), CCSM 3.0, CSIRO-Mk3.0, GFDL-CM 2.0 and 2.1, INM CM-3.0, MIROC 3.2 (medres) and UKMO-HadCM3 (CEGIS, 2011). SCENGEN has been used to generate changes in mean temperature and precipitation. For this analysis two SRES emission scenarios A2-AIM and B1-AIM have been selected from the family of SRES scenarios (Nakićenović and Swart, 2000). Two periods have been selected for this projection, 2015-2045 (2030s) and 2035-2065 (2050s). MAGICC has been run to predict climate up to 2100 and SCENGEN has been used to generate the annual and seasonal averages for changes in temperature and precipitation for the 2030s and 2050s under A2 and B1 emission scenarios (CEGIS, 2011).

MAGICC/ SCENGEN combines results from 20 GCMs and can represent the results as a multi-model ensemble which has been suggested by IPCC to be used in climate scenario development. Like other models, SCENGEN has its own limitations. The previous studies in climate change modeling in Bangladesh mostly were based on results of GCM data. But the grid resolution of these data is 2.5 degree or more. But in order to capture the local variations in climate, finer resolution data are needed. Regional climate models (RCM) could capture these types of variations. But as the RCM studies in Bangladesh are still in validation level and results are not yet usable. Based on these circumstances, MAGICC/ SCENGEN have been used in this study along with a simplified downscaling technique to produce outputs at 0.25° grid resolution (CEGIS, 2011).

Table 3.2 Values of Parameters used in the GCM

Parameter	Value used
Emission scenarios	A2-AIM and B1-AIM
Carbon Cycle Model	Mid
Carbon Cycle Climate Feedback	Yes
Aerosol forcing	Mid
Climate Sensitivity	3^{o}C
Thermohaline Circulation	Variable
Vertical diffusion	2.3 cm ^{2}/s
Ice melt	Mid
First year for climate model output	1990
Reference year for climate model output	1990
Last year for climate model output	2100
Scaling technique (SCENGEN)	Linear
Smoothing (SCENGEN)	No

Source: Mukherjee, et. al., 2011

It is not wise to simulate for a future condition further than 2050 as development of a country and agricultural practices might be very different than from now on 100 years ahead. Hence analysis is not done till 2100. As A2 and B1 scenarios are the most applicable in the context of Bangladesh, these scenarios have been selected for further future analysis.

A2 Scenario

The A2 scenarios are of a more divided world. The A2 family of scenarios is characterized by:

1. A world of independently operating, self-reliant nations.
2. Continuously increasing population.
3. Regionally oriented economic development.
4. Slower and more fragmented technological changes and improvements to per capita income.

B1 Scenario

The B1 scenarios are of a more integrated and more ecologically friendly world. The B1 scenarios are characterized by:

1. Rapid economic growth as in A1, but with rapid changes towards a service and information economy.
2. Population rising to 9 billion in 2050 and then declining as in A1.
3. Reductions in material intensity and introduction of clean and resource efficient technologies.
4. Emphasis on global solutions to economic, social and environmental stability

Table 3.3 presents the annual average temperature and precipitation changes that have been predicted for the 2030s and 2050s. The table indicates that the temperature may increase by 1.6^{o}C by the 2050s while precipitation may rise by 8%. Annual average changes in temperature and precipitation for A2 and B1 scenarios for various regions/divisions of the country will, of course, vary around the national mean values.

Table 3.3: Annual average changes in temperature and precipitation

Emission Scenario	Temperature Change (°C)		Precipitation (% change)	
	2030s	2050s	2030s	2050s
A2	0.73	1.32	4.9	8.1
B1	0.78	1.62	6.3	8.4

Source: CEGIS, 2011

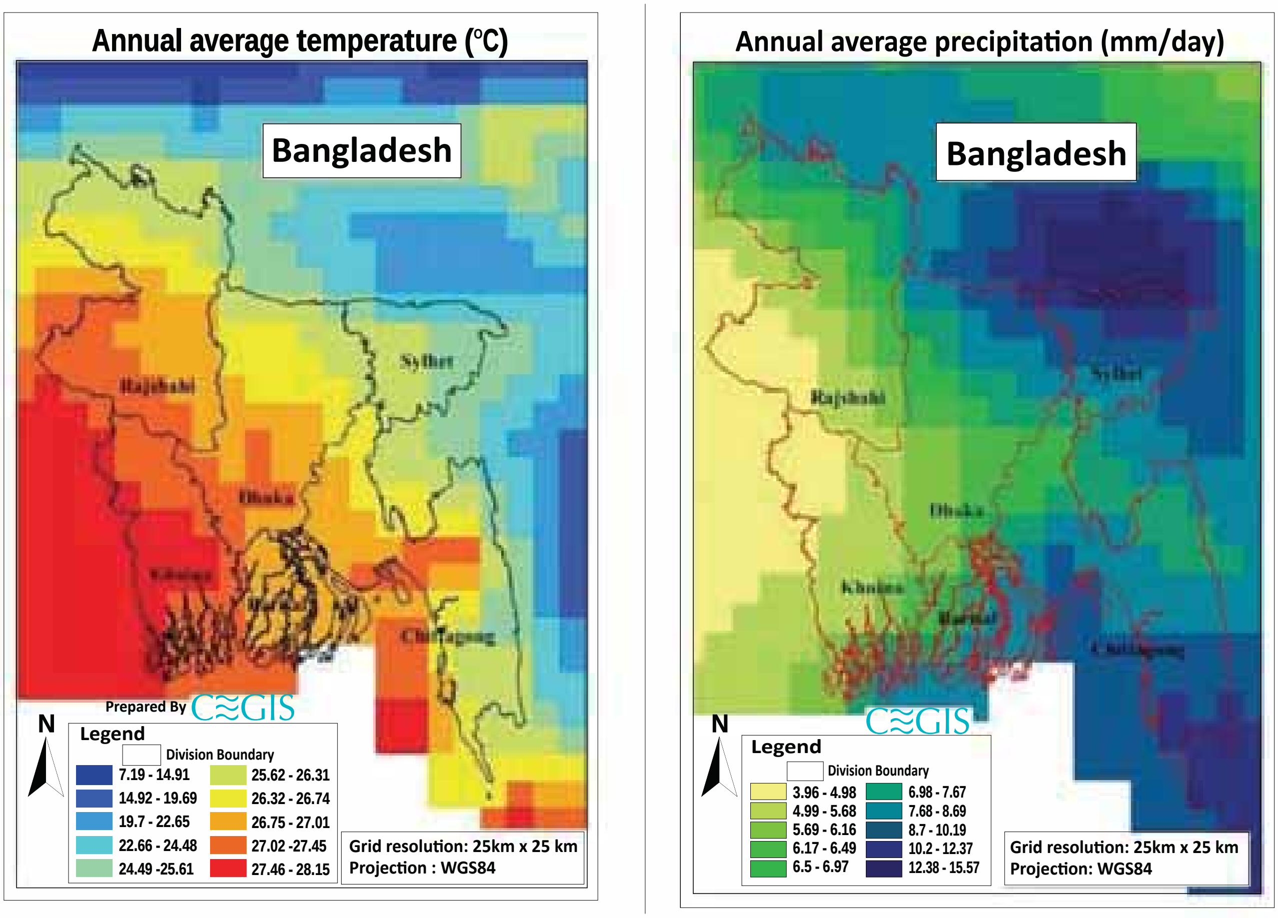


Figure 3.10: Annual average changes in tem nd precipitation (A2 scenario, 2050s)

Table 3.4: Temperature change (^{O}C): A2 scenario

Season	DJF		MAM		JJA		SON		Annual	
Division	2030s	2050s	2030s	2050s	2030s	2050s	2030s	2050s	2030s	2050s
Barisal	1.03	1.72	0.76	1.37	0.42	0.82	0.55	1.02	0.70	1.23
Chittagong	1.12	1.87	0.77	1.39	0.44	0.85	0.58	1.06	0.73	1.29
Dhaka	1.19	2.00	0.77	1.42	0.44	0.88	0.60	1.10	0.75	1.35
Khulna	1.09	1.83	0.72	1.31	0.36	0.74	0.54	0.99	0.68	1.21
Rajshahi	1.25	2.14	0.77	1.47	0.41	0.84	0.64	1.16	0.76	1.39
Sylhet	1.14	1.90	0.75	1.38	0.46	0.90	0.59	1.09	0.74	1.33
National	1.16	1.96	0.76	1.41	0.42	0.84	0.59	1.09	0.73	1.32

Source: Hassan, et. al. 2010

Note: *DJF = December-January-February; MAM = March-April-May; JJA = June-July-August; SON = September-October-November*

3.5: Temperature change (^{O}C): B1 scenario

Season	DJF		MAM		JJA		SON		Annual	
Division	2030s	2050s	2030s	2050s	2030s	2050s	2030s	2050s	2030s	2050s
Barisal	1.17	1.93	0.88	1.70	0.32	1.00	0.57	1.35	0.74	1.49
Chittagong	1.27	2.07	0.90	1.76	0.33	1.03	0.60	1.40	0.77	1.56
Dhaka	1.35	2.22	0.92	1.86	0.32	1.08	0.61	1.43	0.80	1.65
Khulna	1.23	2.07	0.84	1.68	0.24	0.93	0.53	1.25	0.71	1.48
Rajshahi	1.44	2.47	0.96	2.07	0.26	1.07	0.64	1.46	0.82	1.75
Sylhet	1.28	2.08	0.90	1.79	0.35	1.09	0.61	1.42	0.79	1.60
National	1.32	2.20	0.91	1.85	0.30	1.04	0.60	1.40	0.78	1.62

Source: Hassan, et. al. 2010

Table 3.6: Precipitation change (%): A2 scenario

Season	DJF		MAM		JJA		SON		Annual	
Division	2030s	2050s	2030s	2050s	2030s	2050s	2030s	2050s	2030s	2050s
Barisal	-32.26	-42.40	15.78	21.74	8.18	11.24	-6.11	-6.30	3.15	5.35
Chittagong	-29.32	-39.09	15.20	20.93	10.01	13.91	-6.74	-7.27	3.79	6.35
Dhaka	-26.92	-36.86	25.36	34.43	8.97	12.58	-3.88	-2.80	4.72	7.77
Khulna	-28.73	-39.12	30.01	40.30	8.73	11.76	-0.87	2.17	4.47	7.51
Rajshahi	-19.96	-27.88	28.20	38.25	9.68	14.02	2.46	6.62	6.55	10.62
Sylhet	-43.70	-59.59	24.81	33.91	10.72	15.08	-7.03	-7.37	5.07	8.35
National	-27.68	-37.67	24.00	32.61	9.47	13.29	-2.81	-1.18	4.92	8.10

Source: Hassan, et. al. 2010

Table 3.7: Precipitation change (%): B1 scenario

Season	DJF		MAM		JJA		SON		Annual	
Division	2030s	2050s	2030s	2050s	2030s	2050s	2030s	2050s	2030s	2050s
Barisal	-63.13	-54.74	13.09	6.41	10.87	9.83	-5.27	0.15	4.29	6.10
Chittagong	-57.34	-51.36	12.79	6.37	13.00	11.94	-5.81	-0.44	5.02	6.92
Dhaka	-56.16	-54.88	20.65	7.89	12.27	11.66	-3.17	2.95	6.07	8.07
Khulna	-63.25	-62.71	23.22	6.44	13.17	11.99	-0.46	6.92	6.02	8.47
Rajshahi	-47.72	-50.25	22.92	7.55	13.86	14.34	2.39	8.68	8.02	10.30
Sylhet	-87.12	-82.85	20.85	9.49	13.92	13.11	-5.98	0.15	6.52	8.63
National	-58.40	-56.56	19.52	7.34	13.05	12.51	-2.26	3.88	6.30	8.41

Source: Hassan, et. al. 2010

Drought Vulnerable Hotspots

4.1 Analysis of Past Trends

Seasonal (Rabi, Kharif-I and Kharif-II) drought prone areas all over Bangladesh have been identified on upazila basis from BARC drought maps (2000). Each of the drought vulnerable upazila has been ranked in terms of severity for each of the seasonal drought classification. The ranking is done e.g. by ranking the upazila as 'Rank 1' which has the highest severity in a specific season. Hence the minimum order of rank (Rank 1) would pronounce the hotspot with the highest vulnerability to drought. Thus individual ranking of Rabi, Kharif-I and Kharif-II season has been done for all the drought-affected areas. Then combined drought vulnerability index have been calculated from the sum of the three individual ranks for an area. Top 213 vulnerable "hot-spots" have been identified from the combined vulnerability ranking. The ranking is given in Annexure A. The first 20 most vulnerable hotspots are given below in Table 4.1 (detailed 213 hotspot in Annex A).

Table 4.1 Most vulnerable hotspots considering drought (Rank 1 to 20)

District	Upazila	Vulnerability ranking			Combined rank	Severity ranking
		Rabi	Kharif-I	Khari-II		
Naogaon	Niamatpur	7	5	3	15	1
Rajshahi	Tanore	6	2	11	19	2
Nawabganj	Nachole	9	7	4	20	3
Naogaon	Porsha	4	3	16	23	4
Naogaon	Sapahar	5	4	17	26	5
Thakurgaon	Baliadangi			30	30	6
Dinajpur	Hakimpur	18		12	30	7
Naogaon	Patnitala	12	18	1	31	8
Nawabganj	Shibganj	11	8	14	33	9
Joypurhat	Panchbibi	36		2	38	10
Rangpur	Badarganj			39	39	11
Rajshahi	Godagari	13	11	15	39	12
Naogaon	Mahadebpur	8	31	6	45	13
Nawabganj	Gomastapur	16	9	22	47	14
Rajshahi	Shah Makhdum	25	13	10	48	15
Rajbari	Goalanda			50	50	16
Rangpur	Mitha Pukur			51	51	17
Panchagarh	Tentulia			53	53	18
Thakurgaon	Thakurgaon Sadar			54	54	19
Rajshahi	Durgapur		29	25	54	20

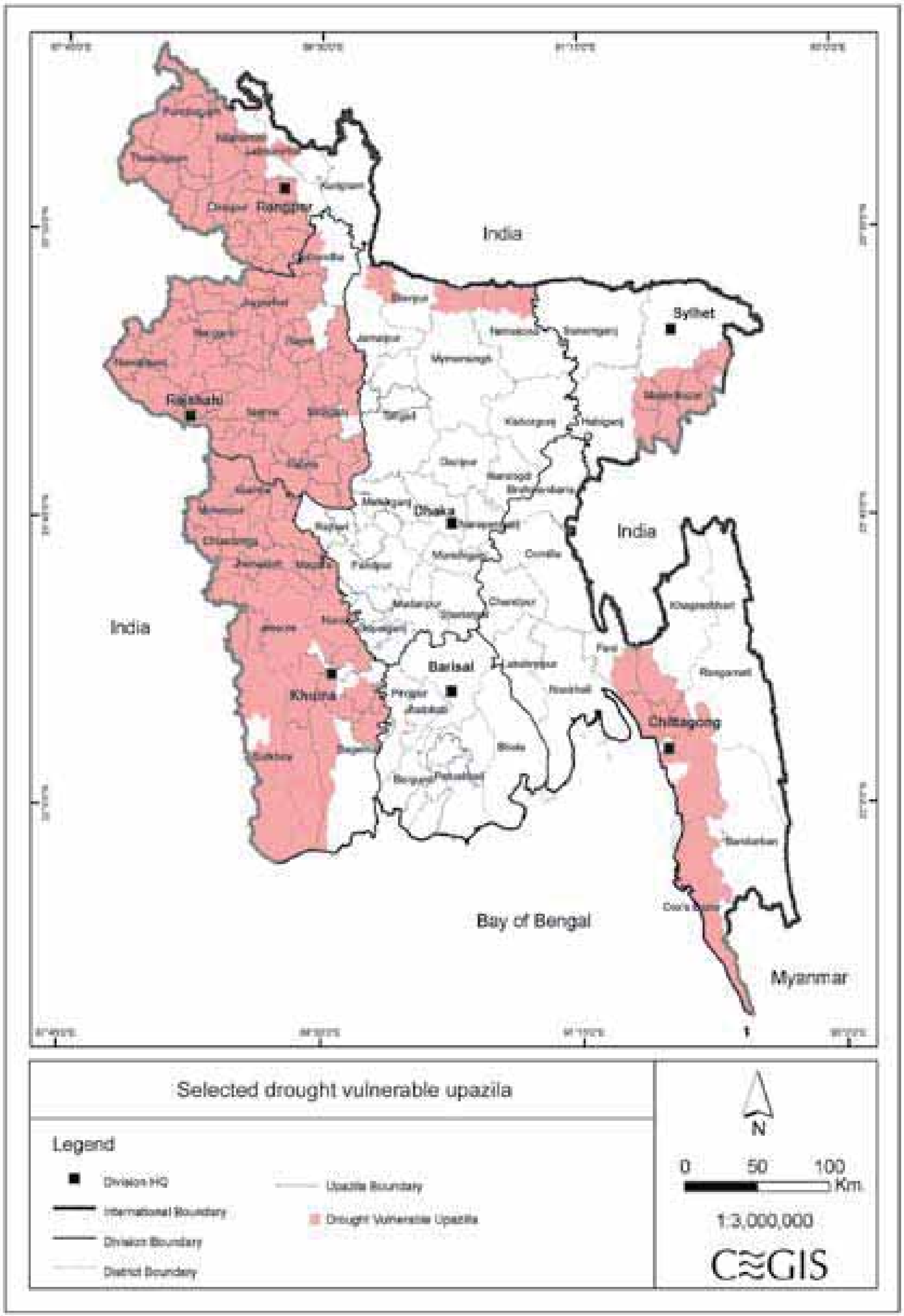


Figure 4.1: Selected drought vulnerable hotspots (upazila basis)

4.2 Remote Sensing Analysis

Satellite image data can be used to detect the onset of agricultural drought, its duration and magnitude. International Water Management Institute (IWMI) carried out a study on drought assessment and monitoring in Southwest Asia using remote sensing data. In this study three remote-sensing indices named long-term deviation mean (DEV*NDVI*) of Normalized Difference Vegetation Index (NDVI), Vegetation Condition Index (VCI) and Thermal Condition Index (TCI) were used for drought monitoring and assessment.

4.2.1 Selection of Indices

Out of the three remote-sensing indices used, DEVNDVI and VCI are complementary and were found to be sensitive indicators for drought conditions. However, TCI was found to be an unreliable indicator for drought assessment and is not recommended for future drought monitoring. Following this study, the DEVNDVI of the NDVI and VCI were selected for drought monitoring and assessment under this current study.

4.2.1.1 Normalized Difference Vegetation Index (NDVI)

Normalized Difference Vegetation Index (NDVI) is widely used in drought studies (e.g., Johnson et al. 1993). It is generally used as an index of vegetation health and density.

$$NDVI = (\lambda_{nir} - \lambda_{red}) / (\lambda_{nir} + \lambda_{red})$$

Where, λ_{nir} and λ_{red} are the reflectance in the near infrared and red bands, respectively. It reflects vegetation intensity, Leaf Area Index (LAI) and biomass. It varies in a range between -1 and + 1. NDVI itself does not reflect drought or non-drought conditions. But the severity of a drought may be defined as NDVI deviation from its long-term NDVI means (DEV_{NDVI}). This deviation is calculated as the difference between the NDVI for the current time step (e.g., January 2001) and a long-term mean NDVI for that month (e.g., an 10-year long mean NDVI of all Januaries from 2000 to 2009 for each pixel) :

$$DEV_{NDVI} = NDVIi - NDVI_{mean,m}$$

Where, NDVIi is the NDVI value for month i and $NDVI_{mean,m}$ is the long-term mean NDVI for the same month m. When DEVNDVI is negative, it indicates the below-normal vegetation condition/health and, therefore, suggests a prevailing drought situation. The greater the negative departure from long term means NDVI, the greater the magnitude of a drought. In addition the departure from the long-term mean NDVI also reflects the conditions of health of vegetation in normal and wet months/years.

4.2.1.2 Vegetation Condition Index (VCI)

VCI shows how close the NDVI of the current month is to the minimum NDVI calculated from the long-term record.

$$VCI = (NDVI_J - NDVI_{min}) / (NDVI_{max} - NDVI_{min}) * 100$$

Where, $NDVI_{max}$ and $NDVI_{min}$ are calculated from the long-term record (e.g., 10 years) for that month and j is the index of the current month or week. The 50% VCI indicate fair vegetation conditions and the VCI values between 50 and 100% indicate optimal or above normal conditions. Kogan (1995) illustrated that the VCI threshold of 35% may be used to identify extreme drought conditions. The VCI value close to zero percent reflects an extremely dry month, when the NDVI value is close to its long-term minimum. Low VCI values over several consecutive time intervals point to drought development.

4.2.2 Satellite Images Collection and Processing

Under this study "Terra"Moderate-Resolution Imaging Spectrometer (MODIS) data were used to derive drought indicators. Terra is an advanced narrowband width sensor. The MODIS instrument is operating on both the Terra and Aqua spacecraft. It has a viewing swath width of 2,330 km and views the entire surface of the Earth every one to two days. Its detectors measure 36 spectral bands between 0.405 and 14.385 µm, and it acquires data at three spatial resolutions -- 250m, 500m, and 1,000m. Normalized Difference Vegetation Index data (MOD13A1) are derived from MODIS data and it is available through the Earth Resources Observation Systems (EROS) data center. MOD13A1 data are provided every 16 days at 500-meter spatial resolution.

NDVI MODIS 16 days composite images acquired between 2000 and 2009 were downloaded through the Earth Resources Observation Systems (EROS) data center. Analysis was done from NDVI MODIS 16 days composite data of images acquired between 2nd February 2009 and 17th February 2009. For each year, 23 images are available except 2000. Between 2000 and 2009, a total of 227 images were downloaded.

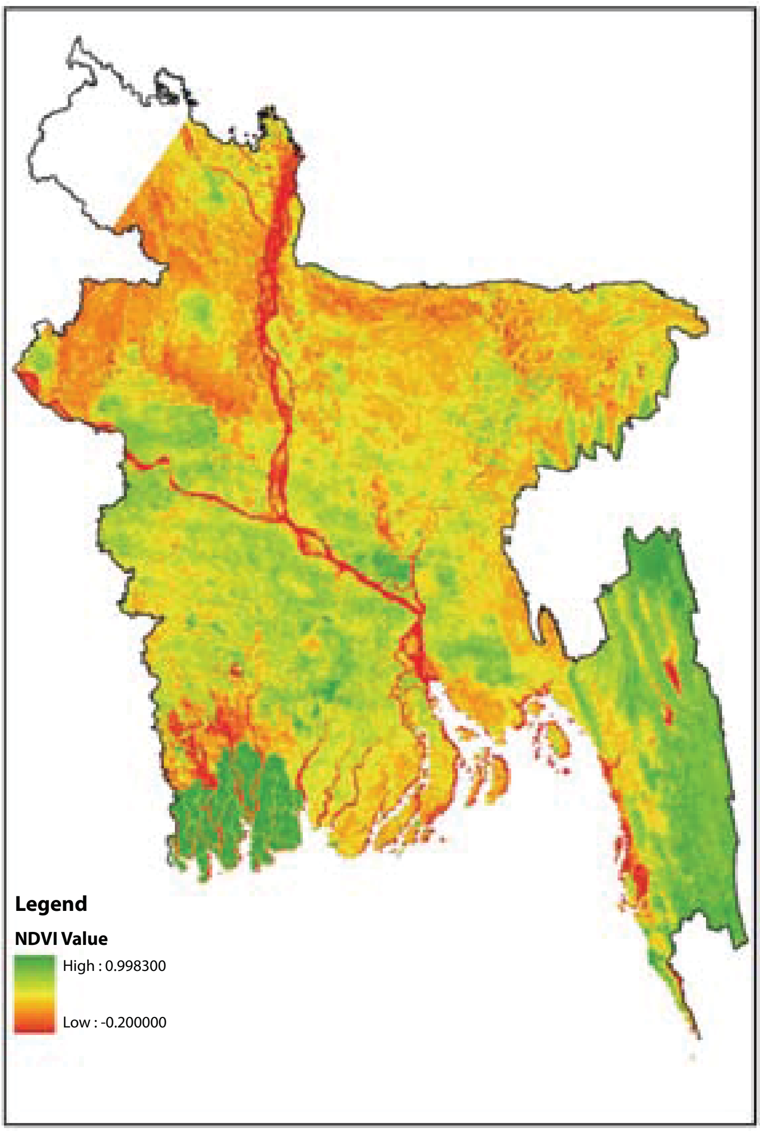


Figure 4.2: NDVI MODIS 16 days composite Image (2nd Feb - 17th Feb 2009)

After downloading, all images had been geo-referenced into BTM (Bangladesh Transverse Mercator) coordinate system. The image data that are covered by the Bangladesh boundary were finally selected for drought monitoring and assessment. Time series of MODIS imagery provide near real-time and continuous data, on which the assessment of drought development and severity could be based.

MODIS is more sensitive to changes in vegetation dynamics (Huete et al. 2002) and was found to be a more accurate and versatile instrument to monitor the global vegetation conditions than the AVHRR (Gitelson et al 1998; Justice et al. 2002). The narrower MODIS spectral bands eliminate the water absorption region in the near infrared (NIR) and also render the red band more sensitive to chlorophyll absorption (Huete et al. 2002). Atmospherically corrected NDVI MODIS generally exhibits a higher dynamic range than atmospherically corrected NDVI AVHRR.

4.2.3 Analysis of Images

Due to high cloud coverage during monsoon season drought was monitored and assessed only for dry seasons (January to May) using satellite images. The extent of negative deviation of NDVI from its long-term mean (10 Years) and the duration of continuous negative deviations are indicators of drought magnitude and persistence. Figure 4.3 shows the long-term mean NDVI conditions (green line) for dry season (January to May) and relative to it, the mean NDVI conditions of 2001, 2006, 2007, 2008 and 2009.

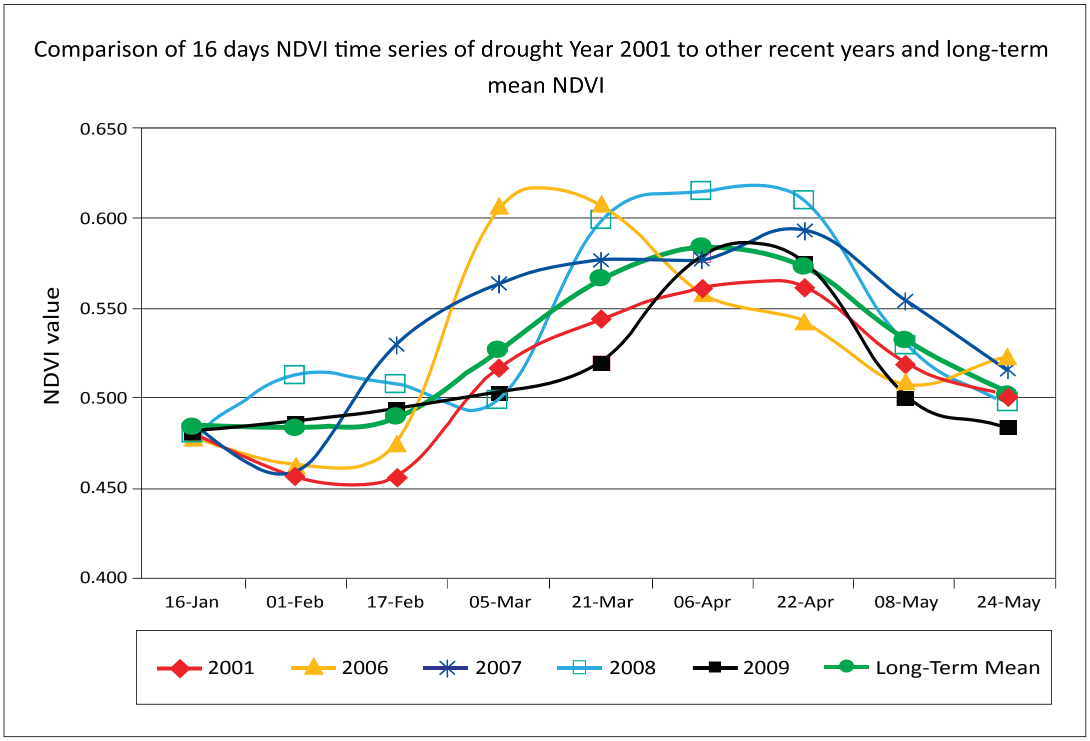


Figure 4.3: 16 days NDVI time series for drought year 2001 compared to long-term mean NDVI

Averaging NDVI values over the entire study area was done despite the spatial variability of wetness or dryness throughout the region in all selected years. The figure 4.3 shows that the mean NDVI values of 2001 were always below the long-term mean NDVI values from January to May. During this period the year 2001 was the driest period. The mean NDVI values of other years were sometimes above the long-term mean NDVI values and sometimes below the long-term mean NDVI values during January to May. In 2009, a drought was also observed during March.

Vegetation Condition Index (VCI) maps were also prepared to identify extreme drought condition. The condition (health) of vegetation presented by VCI is estimated in percent and it serves as an approximate measure of how dry the current month is. The poor vegetation condition, which is close or equal to zero, indicates an extremely dry month. The VCI of 50% reflects a fair vegetation condition. Figure 4.4 shows the VCI map of 17 February 2001 when the 16 days mean NDVI values were extremely below the long term mean NDVI values. The different shades of yellow shows the prevailing drought condition in that period.

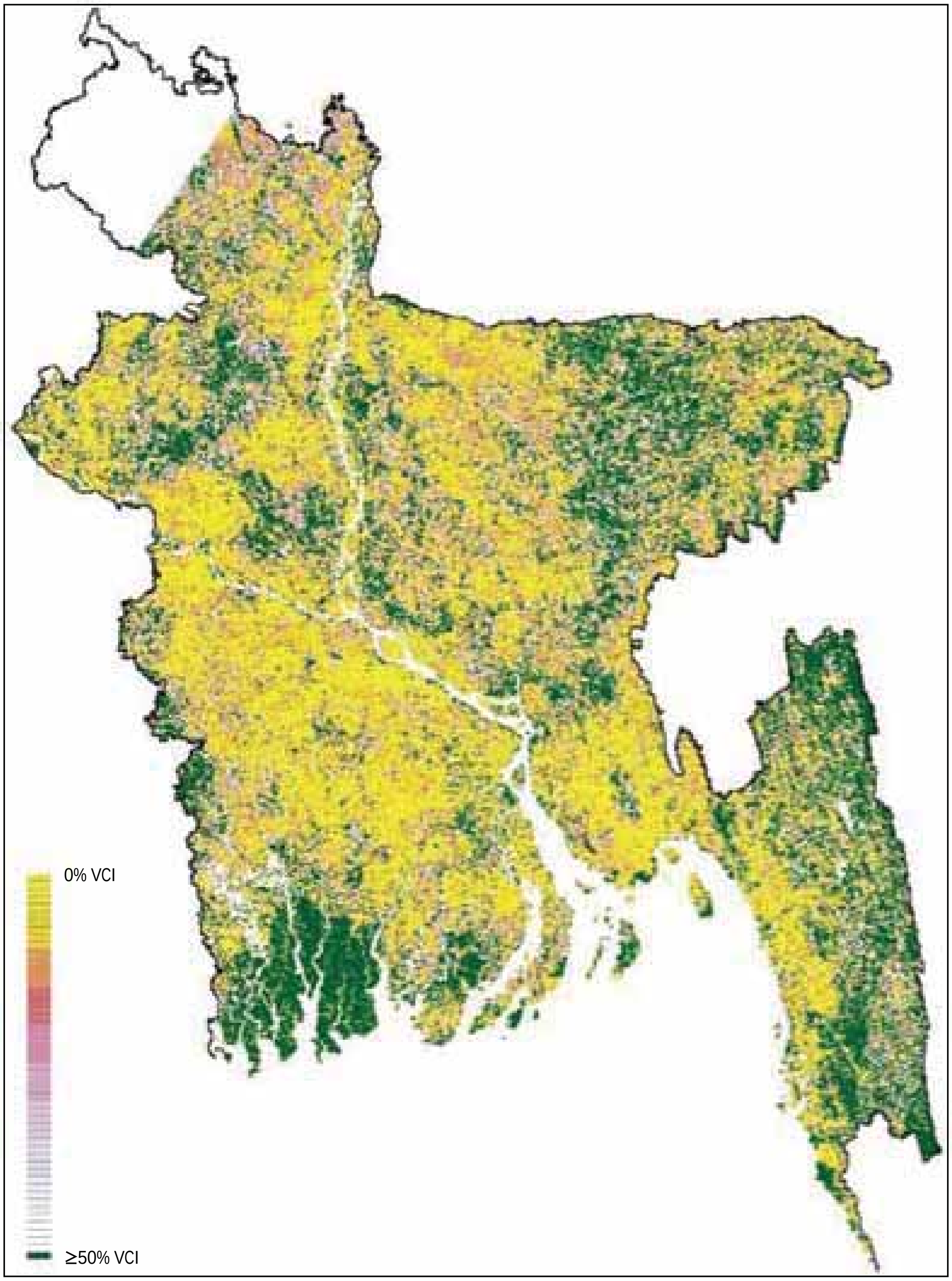


Figure 4.4: Vegetation Condition Index (VCI) Map, 17 February 2001

A 16 days-interval spatial distribution of DEVNDVI in the study area during the dry year of 2001 is given in Figure 4.5 where areas in different shades of yellow are “drought-affected” and areas in different shades of blue and red are those with denser, and healthy vegetation. The shades of yellow are the indicative of the negative deviation from the NDVI mean. It shows how drought affected areas develop between February and April 2001.

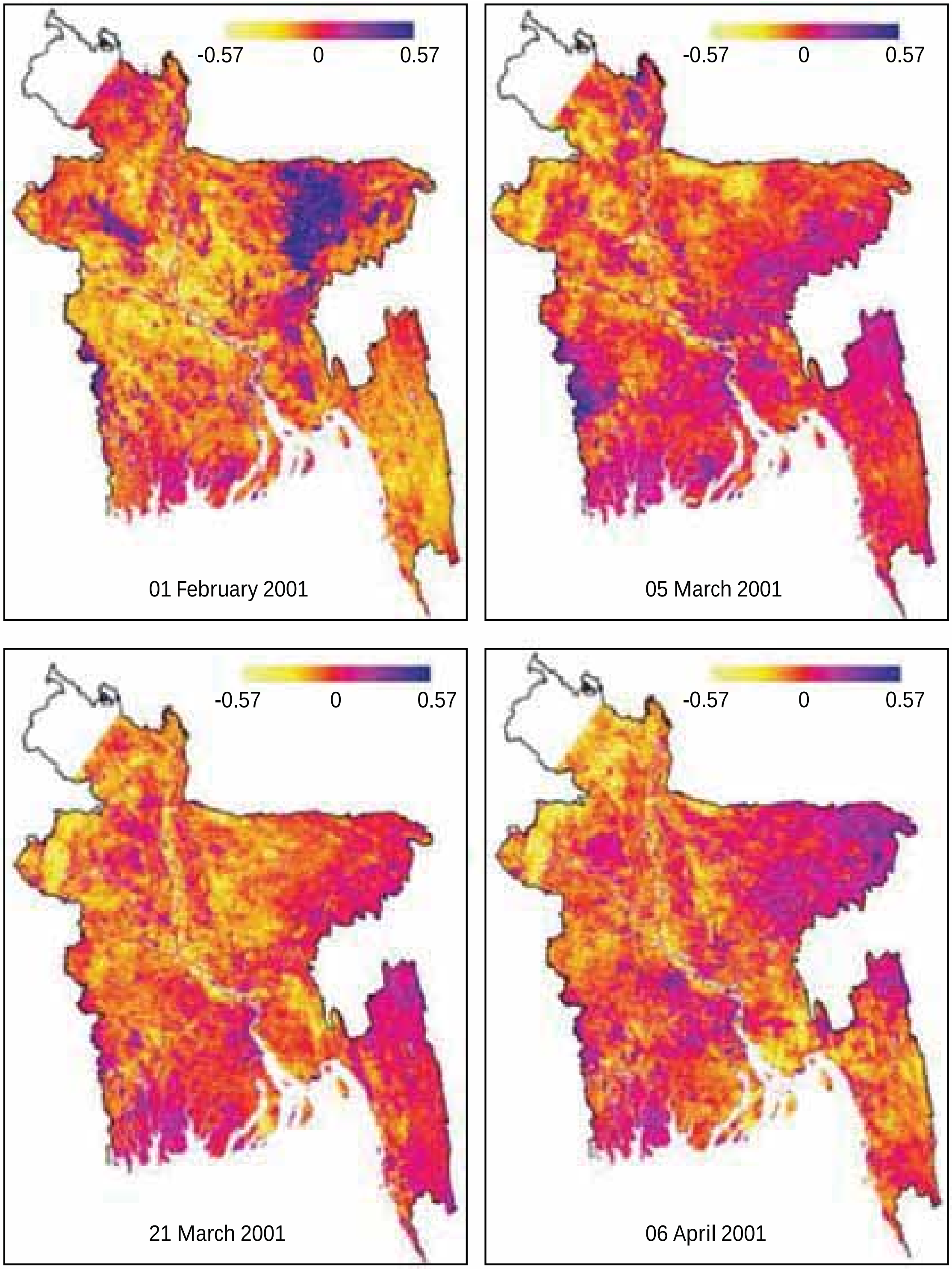


Figure 4.5: Difference between the NDVI of 16-day composite images and long-term mean NDVI

The drought onset, magnitude and duration can be monitored using the time series of 16 days composite MODIS NDVI data. The only and serious problem is cloud coverage during monsoon period. The cloud coverage deteriorates the actual NDVI values, which may be misleading in the drought monitoring and assessment. That is why it is difficult to monitor the drought condition throughout the year only by satellite image analysis. But the dry season onset of drought can be very effectively monitored by remote sensing. The specific findings of the RS image analysis are such that it validates the selection of drought vulnerable areas. It identifies more or less those areas as drought vulnerable (depending on NDVI and VCI values) which have been previously selected for drought vulnerability assessment from observed data on crop production losses by year.

4.3 Meteorological Index Analysis

There are a number of drought indices used to estimate the severity of drought in an area using algorithms that incorporate recent temperature, rainfall, and soil moisture. Palmer Drought Severity Index (PDSI) and the United States Drought Monitor (DM) - Drought Intensity Index are two widely used indices.

The PDSI is a soil moisture algorithm incorporating precipitation and temperature data, as well as the local available water content of the soil. The values vary between extremely moist (>4.0) and extreme drought (<4.0) with values between 2.0 and 2.0 near normal.

The DM is a synthesis of multiple indices and impacts, and represents a consensus of federal (U.S. Department of Agriculture [USDA] and NOAA) and academic scientists (National Drought Mitigation Center at University of Nebraska Lincoln). The DM produces a summary map of drought intensity for the nation and all states each week. Intensity values range from 0 (abnormally dry) to 4 (exceptional drought).

Another drought index is SPI or Standard Precipitation Index. Standardized precipitation is simply the difference of precipitation from the mean for a specified time period divided by the standard deviation. Here the mean and standard deviation are determined from past records. The resulting computation of standardized precipitation is linearly proportional to precipitation deficit and allows specification of probability, percent of average, and accumulated precipitation deficit.

The Standardized Precipitation Index (SPI) is calculated in the following sequence. A monthly precipitation data set is prepared for a period of m months, ideally a continuous period of at least 30 years. A set of averaging periods are selected to determine a set of time scales of period j months where j is 3, 6, 12, 24, or 48 months. These represent arbitrary but typical time scales for precipitation deficits to affect the five types of usable water sources. The data set is moving in the sense that each month a new value is determined from the previous i months. Each of the data sets is fitted to the Gamma function to define the relationship of probability to precipitation. Once the relationship of probability to precipitation is established from the historic records, the probability of any observed precipitation data point is calculated and used along with an estimate of the inverse normal to calculate the precipitation deviation for a normally distributed probability density with a mean of zero and standard deviation of unity. This value is the SPI for the particular precipitation data point.

Table 4.2: SPI values and drought categories

SPI values	Drought category	Number of drought occurrences in 100 years	Frequency of event
0 to -0.99	Mild	33	1 in 3 years
-1.00 to -1.49	Moderate	10	1 in 10 years
-1.50 to -1.99	Severe	5	1 in 20 years
< -2.00	Extreme	2.5	1 in 50 years

Source: McKee, et al., 1993

Using the SPI as the indicator, a functional and quantitative definition of drought can be established for each time scale. A drought event for time scale i is defined here as a period in which the SPI is continuously negative and the SPI reaches a value of -1.0 or less. The drought begins when the SPI first falls below zero and ends with the positive value of SPI following a value of -1.0 or less. Drought intensity is arbitrarily defined for values of the SPI with the following categories:

Table 4.3: SPI values and drought categories in the U.S.A

SPI values	Category
2.00 and above	Extremely wet
1.50 to 1.99	Very wet
1.00 to 1.49	Moderately wet
-0.99 to 0.99	Near normal
-1.00 to -1.49	Moderately dry
-1.50 to -1.99	Severely dry
-2.00 and less	Extremely dry

Source: National Climatic Data Center,U.S. Department of Commerce, 2012

The SPI calculation for any location is based on the long-term precipitation record for a desired period. This long-term record is fitted to a probability distribution, which is then transformed into a normal distribution so that the mean SPI for the location and desired period is zero (Edwards and McKee, 1997). Positive SPI values indicate greater than median precipitation, and negative values indicate less than median precipitation. SPI analysis can be done for consecutive 3 months, 6 months, 12 months, 24 months and 48 months. The analyses were done by using a tool named SPATSIM (SPatial and Time Series Information Modeling) software package which is developed by the Institute for Water Research (IWR) of Rhodes University, South Africa. Computing of the SPI involves fitting a gamma probability density function to a given frequency distribution of precipitation totals for a climate station. The gamma distribution is defined by its frequency or probability density function:

Where,

$$g(x) = \frac{1}{\beta^{\alpha}\Gamma(\alpha)} \chi^{\alpha-1} e^{-x/\beta}$$

$$\alpha = \frac{1}{4A}(1 + \sqrt{1 + \frac{4A}{3}})$$

$$\beta = \frac{\bar{x}}{\alpha}$$

$$A = \ln(\bar{x}) - \frac{\sum \ln(x)}{n}$$

n = number of precipitation observations

x= total precipitation for the period

The resulting parameters are then used to find the cumulative probability of an observed precipitation event for the given week and timescale for the station in question. The cumulative probability is given by:

$$G(x) = \int_0^x g(x)dx = \frac{1}{\beta^\alpha \Gamma(\alpha)} \int_0^x x^{a-1} e^{-x/\beta} dx$$

Letting t = x /b the equation becomes the incomplete gamma function:

$$G(x) = \frac{1}{\Gamma(\alpha)} \int^t t^{a-1} e^{-t} dt$$

Since the gamma function is undefined for x=0 and a precipitation distribution may contain zeros, the cumulative probability becomes:

$$H(x) = q + (1-q)G(x)$$

Where q is the probability of a zero. The cumulative probability H(x) is then transformed to the standard normal random variable Z with mean zero and variance of one, which is the value of the SPI.

Where:

$$Z = SPI = -(t - \frac{c_0 + c_1 t + c_2 t^2}{1 + d_1 t + d_2 t^2 + d_3 t^3}) \qquad \text{for} \quad 0 < H(x) \le 0.5$$

$$Z = SPI = +(t - \frac{c_0 + c_1 t + c_2 t^2}{1 + d_1 t + d_2 t^2 + d_3 t^3}) \qquad \text{for} \quad 0.5 < H(x) \le 1.0$$

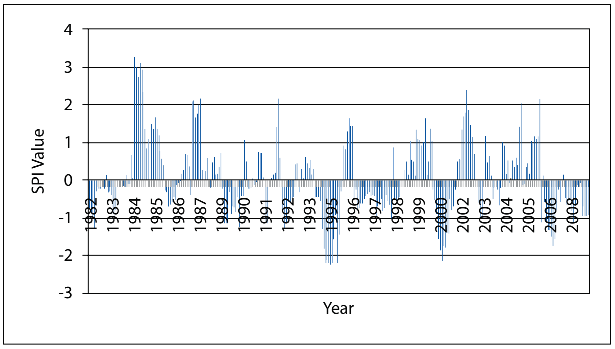
$$t = \sqrt{\ln(\frac{1}{(H(x))^2})} \qquad \text{for} \quad 0 < H(x) \le 0.5$$

$$t = \sqrt{\ln(\frac{1}{(1.0 - H(x))^2})} \qquad \text{for} \quad 0.5 < H(x) \le 1.0$$

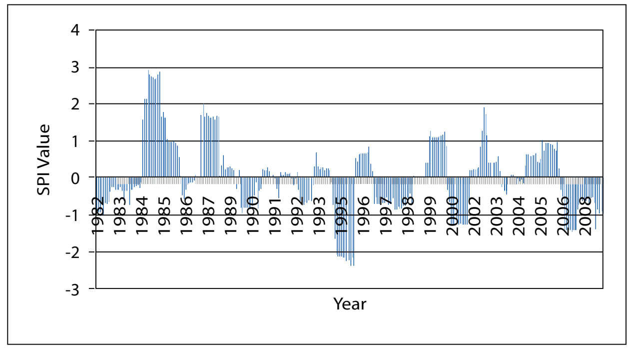
$$c_0 = 2.515517$$
$$c_1 = 0.802853$$
$$c_2 = 0.010328$$
$$d_1 = 1.432788$$
$$d_2 = 0.189269$$
$$d_3 = 0.001308$$

Hence, through SPI analysis, it can be understood whether meteorological drought condition prevails over a region or not. SPI analyses have been done for all the BMD station from year 1982 to 2008. From the analysis of the Rangpur station (10208) it is seen that more or less in all the analyses, year 1982, '83, '84, '95-'99, '00 to '01, '04 and '08 are drought years meteorologically (SPI value is negative). 1995 year has a SPI value near to -2.00 in all the analyses which makes this year a severe drought year according to the SPI analyses. As this analysis is solely depending upon rainfall hence, the drought that may be confirmed from this analysis is meteorological drought. Other analyses are given in Annexure-D.

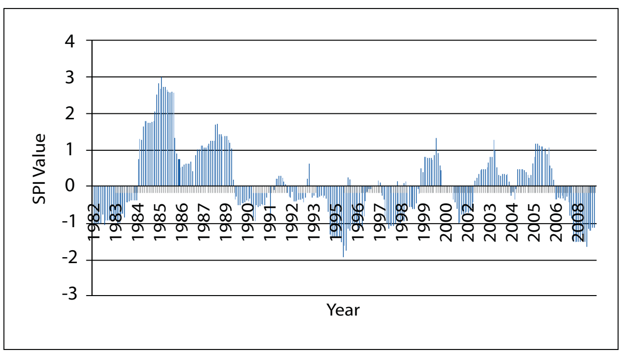
SPI analysis (6 months)



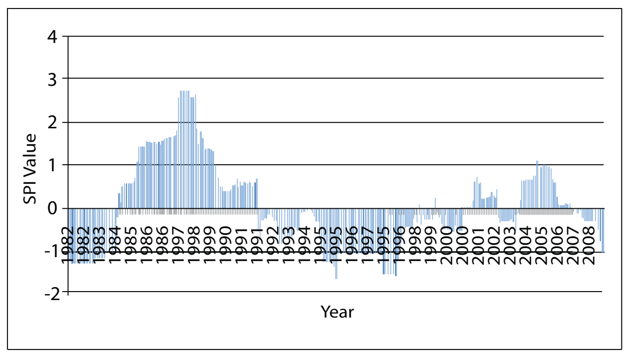
SPI analysis (12 months)



SPI analysis (24 months)



SPI analysis (48 months)



SPI analysis (3 months)

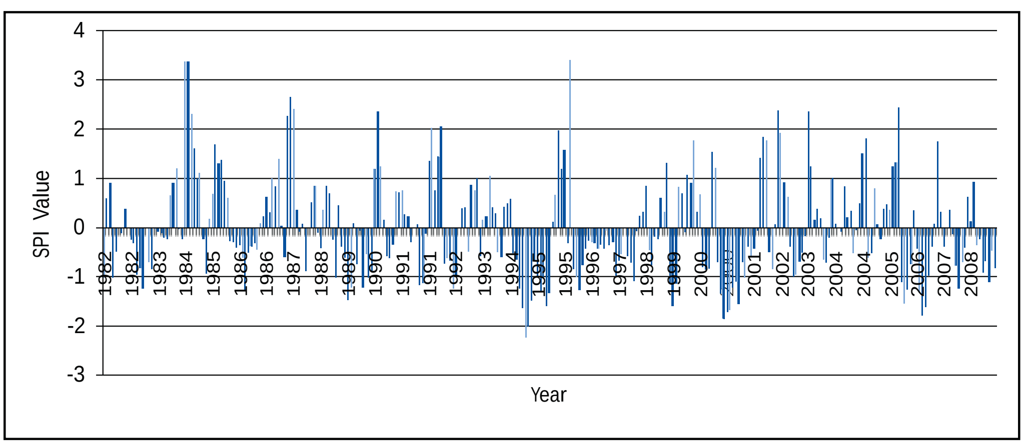


Figure 4.6: SPI analysis for Rangpur Station

Table 4.4: SPI analyses for selected stations

Sl No.	BMD station (Selected division-wise)	Years with SPI value within 0 to -2.00 (mild to severe drought)	Years with SPI value <=-2.00 (severe drought)
1	Rangpur (10208)	1982, 1983-84, 1995-99, 2000-01, 2004 and 2008	1995-96
2	Rajshahi (10320)	1982-84, 1986-87, 1992-93, 1997, 2002, 2004, 2006	1995-96
3	Sylhet (10705)	1986, 1992, 1995-97, 1999, 2002-2003, 2006	1986
4	Khulna (11604)	1983, 1986, 1990-91, 1992-93, 1994-95, 1996	1992, 1995
5	Barisal (11704)	1986-87, 1992-93, 1995-1998, 2000-2002, 2006-2008	1986, 1992, 1997-98
6	Chittagong (11921)	1982, 1985, 1989, 1992, 1995, 1999, 2005-07	1995-96
7	Dhaka (11111)	1982-83, 1990-91, 1992, 1995-96, 2002-04	Nil

4.4 Correlation between SPI and RS

In the remote sensing analysis, it was found that year 2001 had the year with NDVI lower than long term average NDVI. Hence specific SPI analysis was done in different regions of Bangladesh in the year 2001.

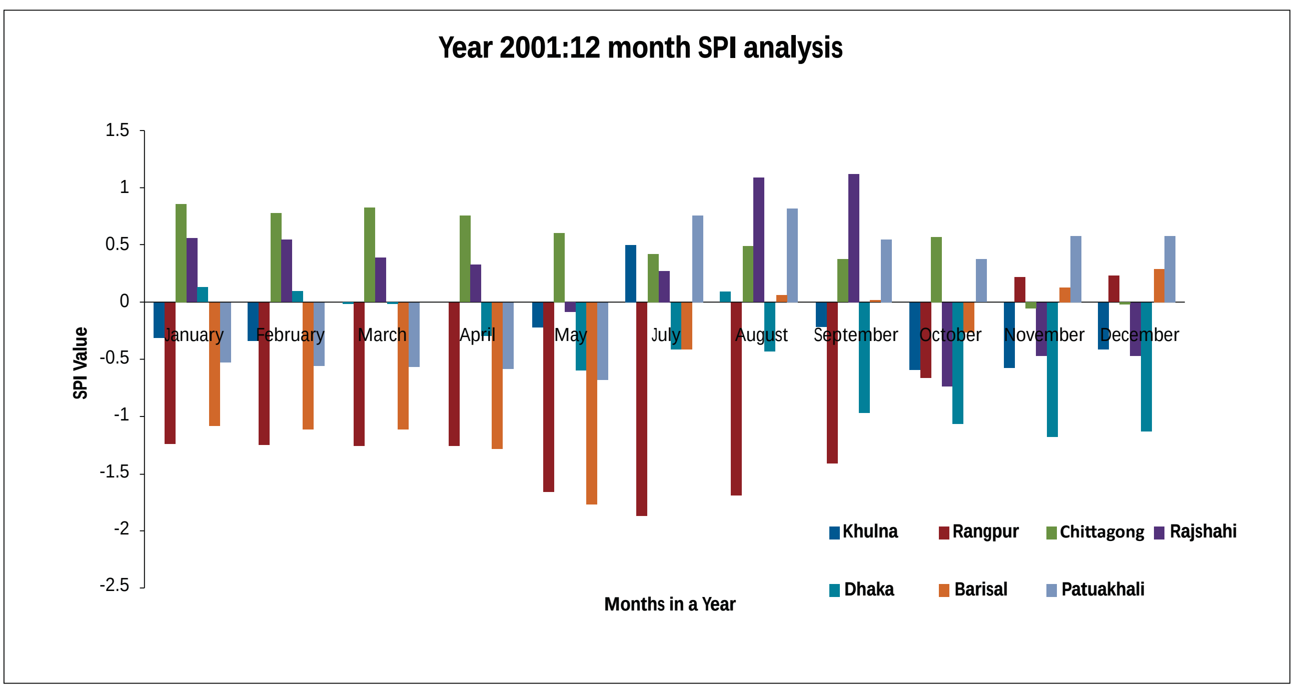


Figure 4.7: SPI analysis in different weather stations in year 2001

From the analysis it is seen that in Rangpur and Barisal station, most of the months have SPI values less than “zero”, and hencethese stations show mild to severe drought in the year 2001 according to SPI.

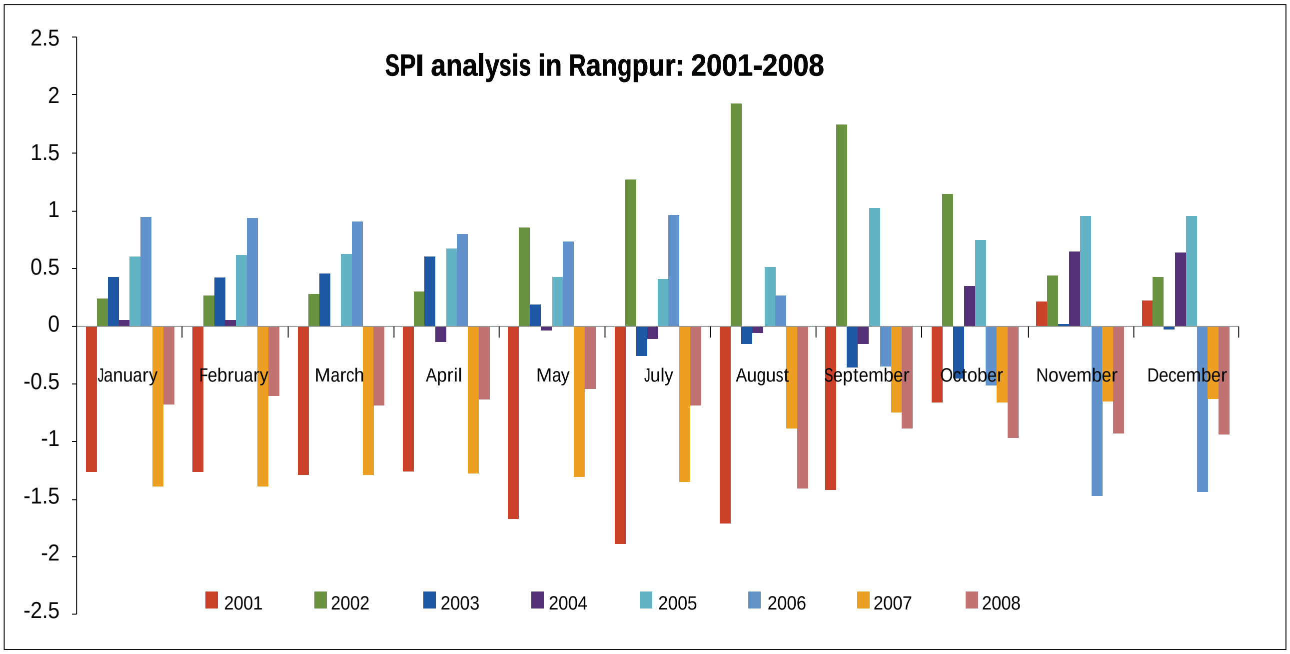


Figure 4.8: SPI analysis in Rangpur (year 2001-2008)

Further analysis for Rangpur is done as it shows minimum SPI value in year 2001 in comparison with other stations. This analysis reveals that in the span of year 2001 to 2008, Rangpur station has the minimum SPI value in year 2001. The year 2001 being a drought year (meteorologically) is hence supported by both SPI and remote sensing image analysis.

CHAPTER 5

Climate Change Induced Drought Assessment

5.1 Application of Cropping System Model

The Cropping System Model (CSM) that is used to identify climate change induced drought is DSSAT. It simulates growth and development of a crop over time, as well as the soil water, carbon and nitrogen processes and management practices. This design feature greatly simplifies the simulation of crop rotations since soil processes operate continuously, and different crops are planted, managed, and harvested according to cropping system information provided as inputs to the model. More accurately, DSSAT or Decision Support System for Agrotechnology Transfer is a crop modeling software which is based on a modular (incorporate models that can work independently but can be integrated for a simulation requirement) modeling approach and uses one set of code for simulating soil, water, nitrogen and carbon dynamics, while crop growth and development are simulated with some other modules.

More than 18 different crops can be simulated including maize, wheat, rice, barley, sorghum, millet, soybean, peanut, dry bean, chickpea, cowpea, faba bean, velvet bean, potato, tomato, bell pepper, cabbage, bahia and brachiaria and bare fallow. DSSAT v4.0 has been developed through collaboration between scientists at the University of Florida, the University of Georgia, University of Guelph, University of Hawaii, the International Center for Soil Fertility and Agricultural Development, Iowa State University and other scientists associated with the International Consortium for Agricultural Systems Applications (ICASA).

DSSAT includes-

- Primary modules that individually simulates various processes
- Land unit module which manages all simulation processes effecting a unit of land
- Main driver program that controls timing for each simulation

Collectively, these components simulate the changes over time in soil and plant that occur in a single land unit in response to weather and management practices.

The different modules of DSSAT are-

- Land module
- Management module
- Soil module
- Weather module
- Soil-plant-atmosphere module
- CROPGRO plant growth module
- CERES plant growth module
- SUBSTOR plant growth module

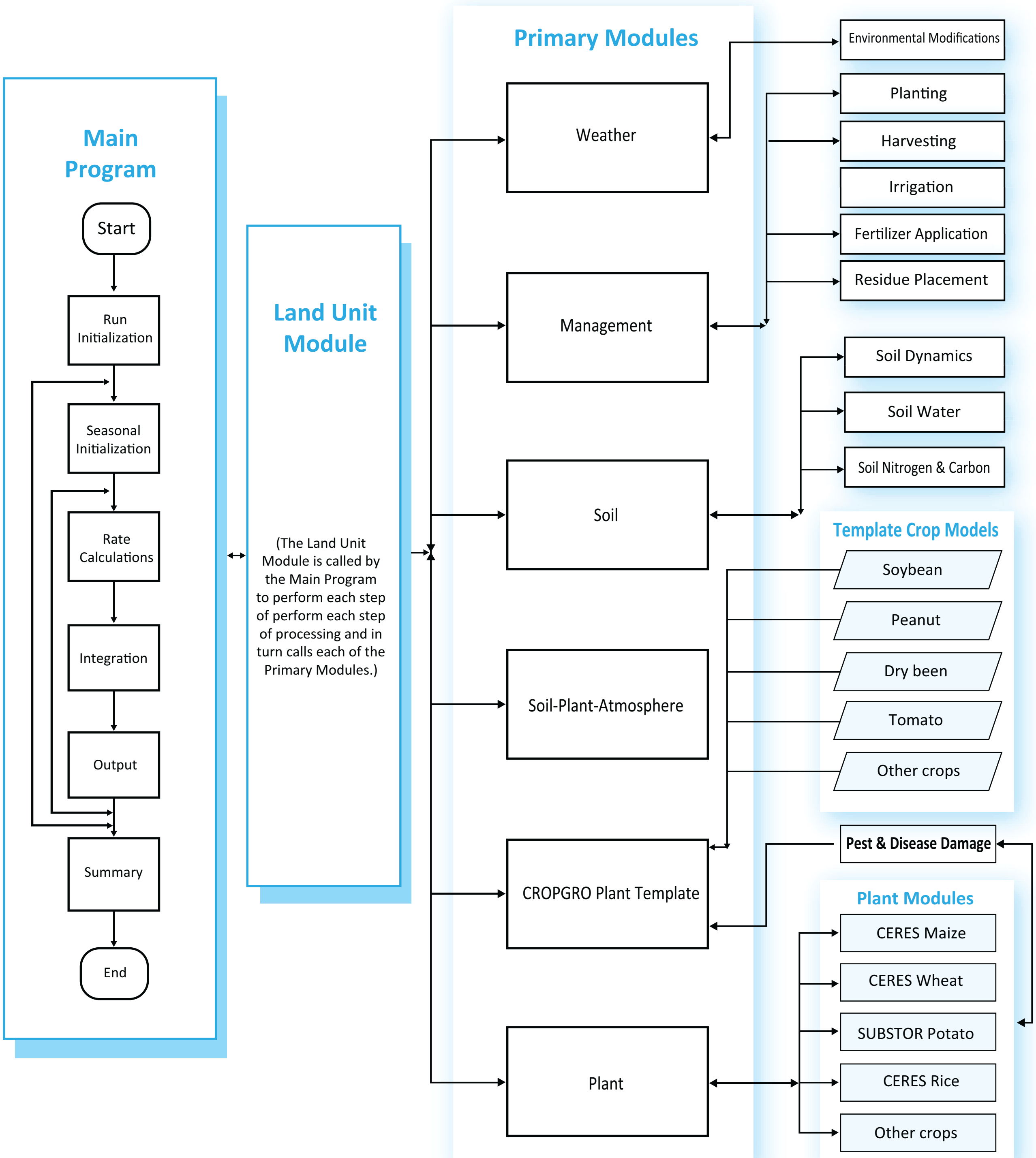


Figure 5.1: Overview of the components and modular structure of DSSAT-CSM

Among the various kinds of modeling systems in agriculture, DSSAT may fall under the category of "Simulation and optimizing model". It imitates the true scenario at daily time steps and the aspect of variability related to change in daily weather and soil condition are integrated. Hence it demands a large amount of input data to be available for the model to run (soil data, weather data, management data and crop growth parameters). As it estimates crop yield it also falls under the mechanistic and deterministic categories. It is mechanistic as it mimics relevant physical, biological and chemical processes and it is deterministic as it gives definite predictions for quantities without any associated probability distribution. It is also important to note that it is more of a data-driven model and largely depends on associated data authenticity.

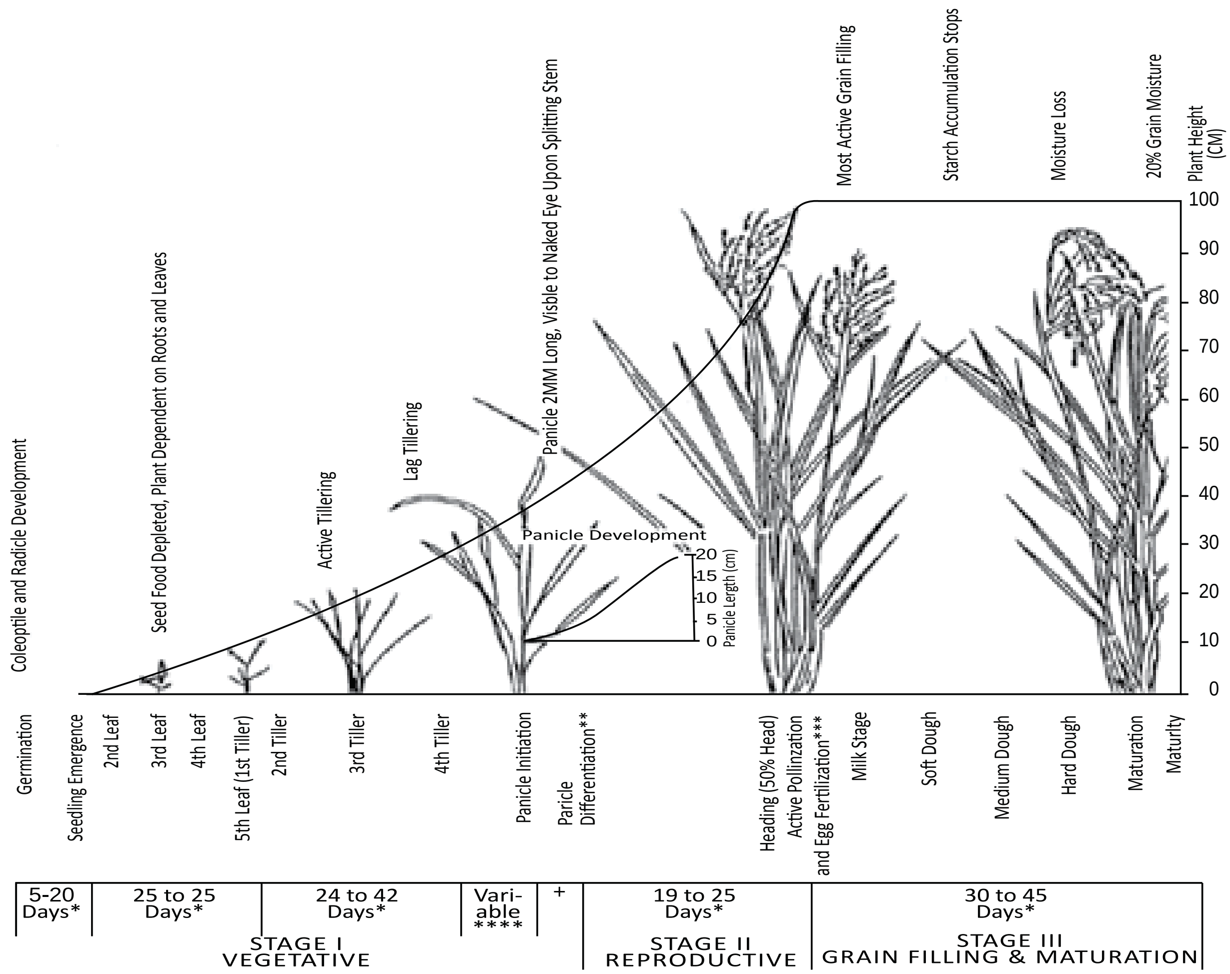
5.2 Model Calibration Parameters

The model needs detail dataset related to planting method, planting date, planting density, planting distribution, plant population at seedling, plant population at emergence, transplant age, row spacing, planting depth, irrigation dates, irrigation amount and efficiency, fertilizer application details, harvest details, organic amendments details, pesticide details, upper and lower horizon depth of soil, percentage of sand, silt, clay, bulk density, organic carbon, permeability of soil, ph in water, runoff potential, slope, drainage capacity, texture, fertility factor, color, rainfall, maximum temperature, minimum temperature, incoming solar radiation and cultivar genotypic details. The cultivar genotypic and phenotypic details that are required to run a specific cultivar type for crop growth simulation in DSSAT are given below.

- **P1:** Time period from seedling emergence till the basic vegetative phase (expressed in GDD in degree Celsius above a base temperature of 9 degree Celsius)
- **P20:** Critical photoperiod or the longest day length in hours at which the development occurs at the maximum rate
- **P5:** Time period, expressed in GDD, from beginning of grain filling to physiological maturity with a base temperature of 9 degree Celsius
- **P2R:** Extent to which phasic development leading to panicle initiation is delayed for each hour increase in P20 (expressed in GDD)
- **G1:** Potential spikelet number coefficient (estimated)-Typical value is 55
- **G2:** Single grain weight under ideal growing condition
- **G3:** Tailoring coefficient relative to IR64 cultivar under ideal condition
- **G4:** Temperature tolerance coefficient

GDD is growing degree days expressed in degree Celsius, where GDD = (((Tmax + T min)/2)- T base), for rice the base is 9 to 10 degree Celsius. For a specific time period (e.g. for maturity phase), the GDD can be calculated for each day, and then the daily values are summed up for the whole phase. The inventory of data used is given below:

- Daily Rainfall Data of year 1979-2008 (Secondary Data, Collected from BMD)
- Daily maximum Temperature of year 1979-2008 (Secondary Data, Collected from BMD)
- Daily minimum Temperature of year 1979-2008 (Secondary Data, Collected from BMD)
- Using GIS spatial analysis with thiessen polygon method, areal extent of influence of BMD weather stations over different upazila was found out
- Projected daily rainfall, maximum and minimum temperature of A2 and B1 scenario of year 2030 and 2050 at 0.25^{o} grid resolution with the help of MAGICC/SCENGE (Refer to Chapter 3)
- Daily Solar Radiation (Calculated by DSSAT weather module, from monthly means of Rainfall and Temperature)
- Upazila Specific Soil Data (Collected from SRDI upazila soil books)
- Irrigation, fertilizer, pesticide management practice (Considered From BRRI manuals)
- Cultivar typegenotypic and phenotypic coefficients of BR 11, BR 14, BRRI Dhan 29 (Collected from BARC)
- Growth stages of rice plant and their water requirement details (Calculated from CROPWAT)



+3 to 5 days
*Under warm conditions use the lower number of days and for coo conditions use the larger number of days.
**The reproductive stage begins with panicle initation.
*** Stage III begins when 50% of the florets are pollinated.
**** Variable time - 0 to 25 days (dependent upon variety).

Figure 5.2: Different growth stages of rice (Moldenhauer & Slaton, 2011)

Table 5.1: Planting details used for callibration

Cultivar	BR 11	BR 14 and BRRI Dhan 29
Lifespan	145 days	160 days
Tillering	5-6 times	5-6 times
Drain between beds	40 -50 cm	40 -50 cm
Seedbed Preparation	30 Ashar (Middle of June)	20 Kartik - 5 Oghran (Middle of November)
Transplanting date of seedling	Srabon (Middle of July)	Poush-Magh (Middle of December)
Average seedling age for transplanting	25 - 45 days	25 - 45 days
Row to row distance	25 cm	25 cm
Plant to plant distance	20 cm	20 cm

Cultivar	BR 11	BR 14 and BRRI Dhan 29
No of seedling in a hill	4-5 seedling	4-5 seedling
Depth of planting	2-3 cm	2-3 cm
Harvest date	10 kartik - 15 oghran	1-15 Baishakh
Insecticide	Diazinon, 16.8 kg/ha, Foliar Spray (Leda Poka, Holud Majra Poka, Pamri, Chatra Poka etc) at tillering stage and after flowering	Diazinon, 16.8 kg/ha, Foliar Spray (Leda Poka, Holud Majra Poka, Pamri, Chatra Poka etc) at tillering and after flowering
Fertilizer application timing	a. 1st Urea application after 20 -25 days of planting b. 2nd urea application after 55 days of planting c. TSP and MP at the initial phase of land preparation d. With 2^{nd} urea application, application of MP	a. 1st Urea application after 15-20 days of planting b. 2nd urea application after 30 days of planting c. 3rd urea application after 45 days of planting d. TSP and MP at the initial phase of land preparation e. With 2^{nd} urea application, application of MP
Fertilizer application depth	2-3 cm in water	2-3 cm in water
Irrigation application	Depending on weather station data and upazilla soil data, calculated for base year from CROPWAT (calculated with FAO dependable rainfall and fixed rice scheduling and puddling)	Depending on weather station data and upazilla soil data, calculated for base year from CROPWAT (calculated with FAO dependable rainfall and fixed rice scheduling and puddling)
Irrigation calculation requirement	Soil data (total available soil moisture, maximum rain infiltration rate, initial soil moisture depletion), daily rain data, daily ET data, crop data (rooting depth, yield response, critical depletion factor, Kc values in different stages of rice, time span of different stages etc.)	Soil data (total available soil moisture, maximum rain infiltration rate, initial soil moisture depletion), daily data, daily ET data, crop data rain (rooting depth, yield response, critical depletion factor, Kc values in different stages of rice, time span of different stages etc.)
Irrigation application efficiency	70%	70%
Fertility factor of soil	1	1

Table 5.2: Fertilizer application details (amount) used for calibration

T. Aman					HYV Boro				
Medium yield (2.5-3.2 ton/ha)					Medium yield (4.0-5.4 ton/ha)				
fertilizer (kg/ha)					fertilizer (kg/ha)				
Gondhok	Zinc	Nitrogen	Phosphet (MP)	Potash (TSP)	Nitrogen	Phosphet (MP)	Potash (TSP)	Gondhok	Zinc
–	–	30	20	–	80	60	40	10	2

5.3 Simulation Procedure

The input parameters need to be defined in the model before any simulation can take place. It follows a sequential data input. At first weather and soil data need to be incorporated in the model through weather module and soil module. Then in the crop management module one can specify the specific weather file that is extracted from weather moduleand soil data extracted from soil module. Then the cultivar of the specific crop chosen in the first place needs to be specified (BR 11 or BR 14 or BRRI Dhan 29 in case of rice is chosen as the plant). Then management data like planting method (seed or transplant), transplant age, ambient temperature while transplanting, and planting date needs to be specified. Then Irrigation scheduling (if needed), fertilizer application and pesticide application are specified. Again if CO_2 effect is under consideration it can be given under the environmental modification option. The simulation options that are simulation date and harvest date are also needed to be provided. All these data are incorporated in the management module. The integrated modules then can be simulated in the main driver program. The output is mainly yield which expressed in Kg/Ha.

The calibrated models were then used for the simulation of future yield. Four scenarios are selected which are-

- A2 Scenario-year 2030
- B1 Scenario-year 2030
- A2 Scenario-year 2050
- B1 Scenario-year 2050

For Boro (BR 14) and Aman (BR 11), change in temperature and rainfall have been considered according to the SRES future emission scenario A2 and B1 of year 2030 and 2050. CO_2 is considered as the base period CO_2 amount i.e. 375 ppm in this analysis. The base period considered for the future CO_2 emission and climatic parameter (rainfall and temperature) projection is 1979-2008. For BRRI Dhan 29 analysis was done considering temperature, rainfall and CO_2 sensitivity for selected locations. The increase of CO_2 in different scenarios of climate change is taken as per IPCC 4th Assessment technical report.

Table 5.3: IPCC estimates for CO_2 in different scenarios

Scenario	CO_2 (ppm)
Base	370
A2 2030	450
A2 2050	550
B1 2030	410
B1 2050	500

The results obtained for all these scenarios in the drought vulnerable upazilas are then analyzed. The results are given with yield reduction or increase in the area in tabular and visual format.

5.4 Result of the Model

The model simulations for A2 and B1 scenario in year 2030 and 2050 were done for 157 upazilas from the selected 213 drought vulnerable hotspots. Due to model mechanical limitation, others were removed from the simulation. The simulation has been done for selected cultivars BR 11 (T. Aman), BR 14 (Boro rice) and BRRI Dhan 29 (Boro rice). The details of input data (soil, weather, irrigation, fertilizer and planting methods etc.) are discussed earlier in this chapter. The simulation produces upazila based yield (Kg/Ha) according to the simulation criteria (i.e. simulation for 2030 or 2050 depending on input-projected weather data and other data). The yield results of the future projection period (2030 and 2050) are then calculated as % reduction or increment from base period yield data (1979-2008). The % reduction in yields are then converted to different stages of drought conditions by defining a range of reduction in % as a stage of drought according to BARC drought severity index, which is given in table 5.4.

Table 5.4: Drought severity classification from reduction of crop yield

Classes	Yield Reduction (%)
Very Slight	<10%
Slight	10-20%
Moderate	20-30%
Severe	30-40%
Very Severe	>40%

Source: BARC, 2001

The detailed result of yield reduction for BR 11 and BR 14 is given in Annexure-C. The simulation result of BRRI Dhan 29 and the drought severity maps of all these cultivars are given below.

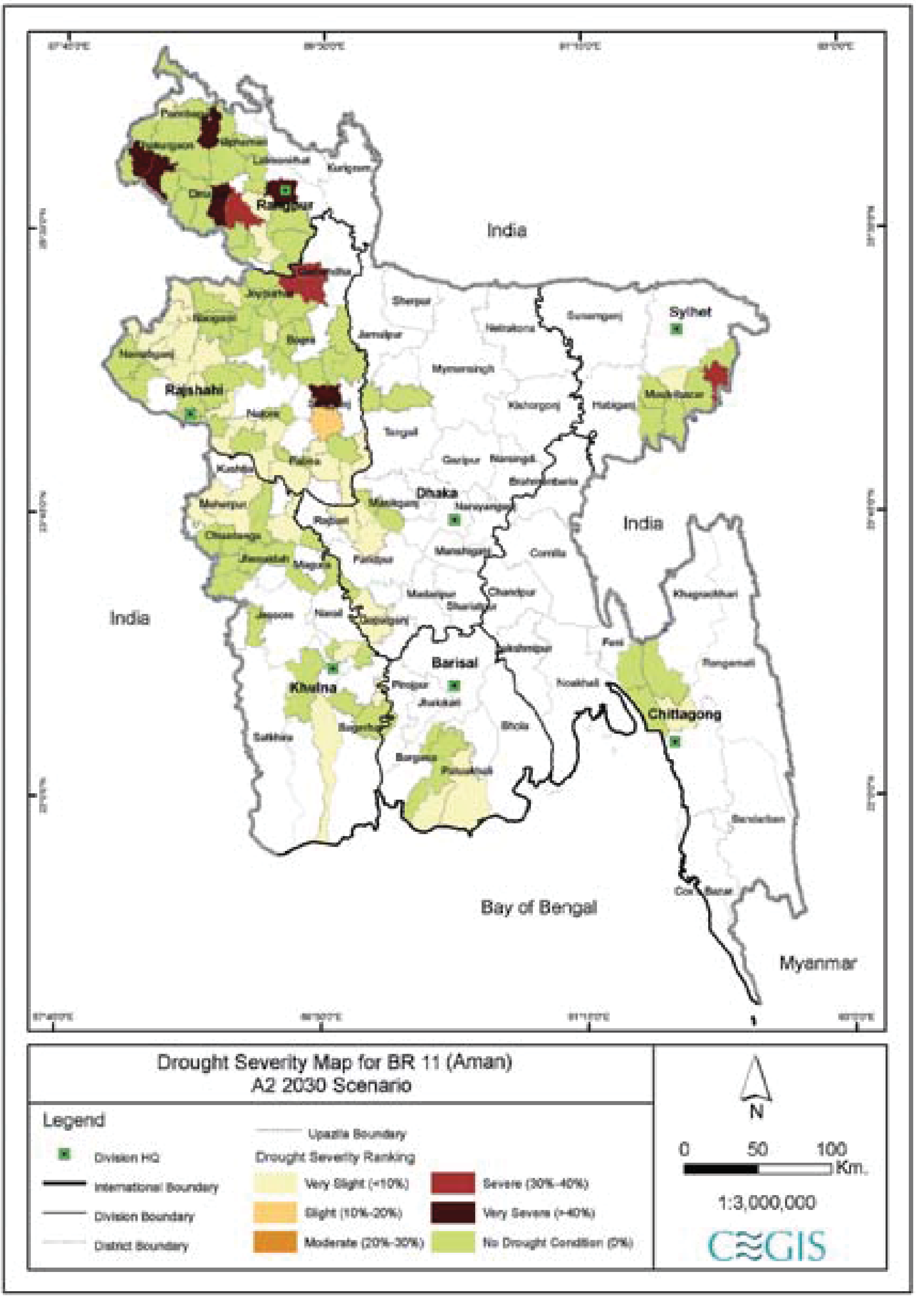


Figure 5.3: Drought severity map for BR 11 in A2 scenario (2030)

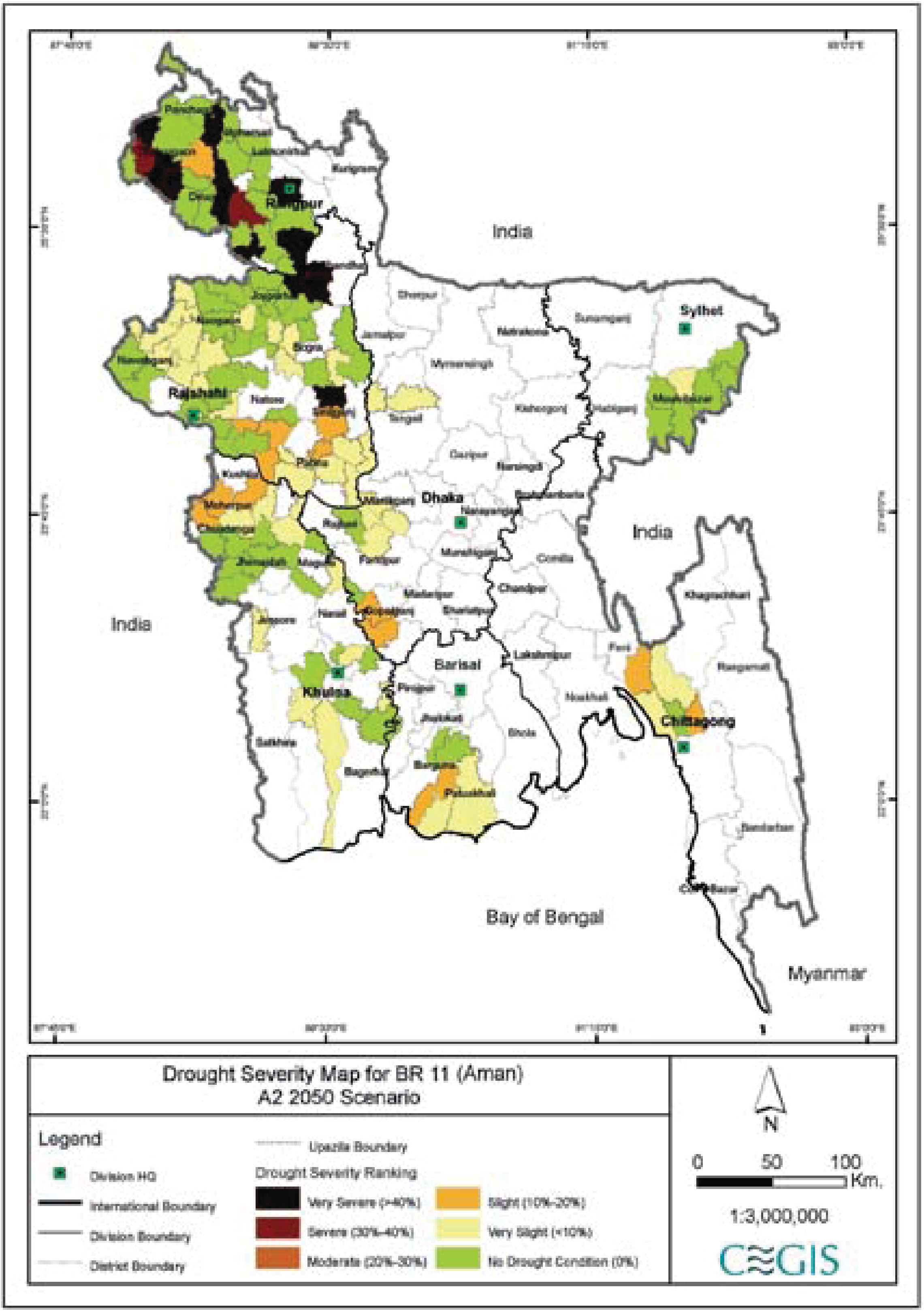


Figure 5.3: Drought severity map for BR 11 in A2 scenario (2050)

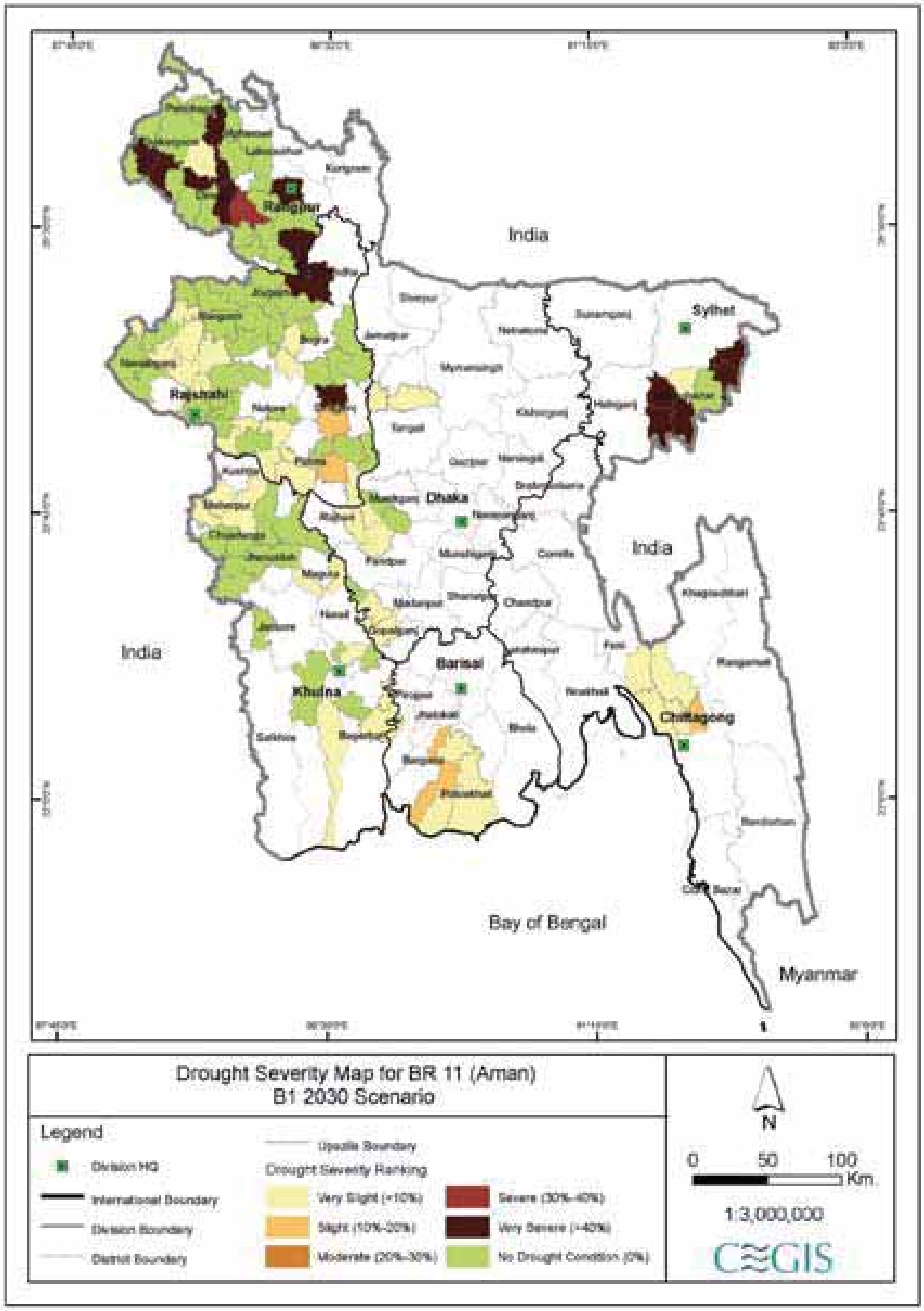


Figure 5.4: Drought severity map for BR 11 in B1 scenario (2030)

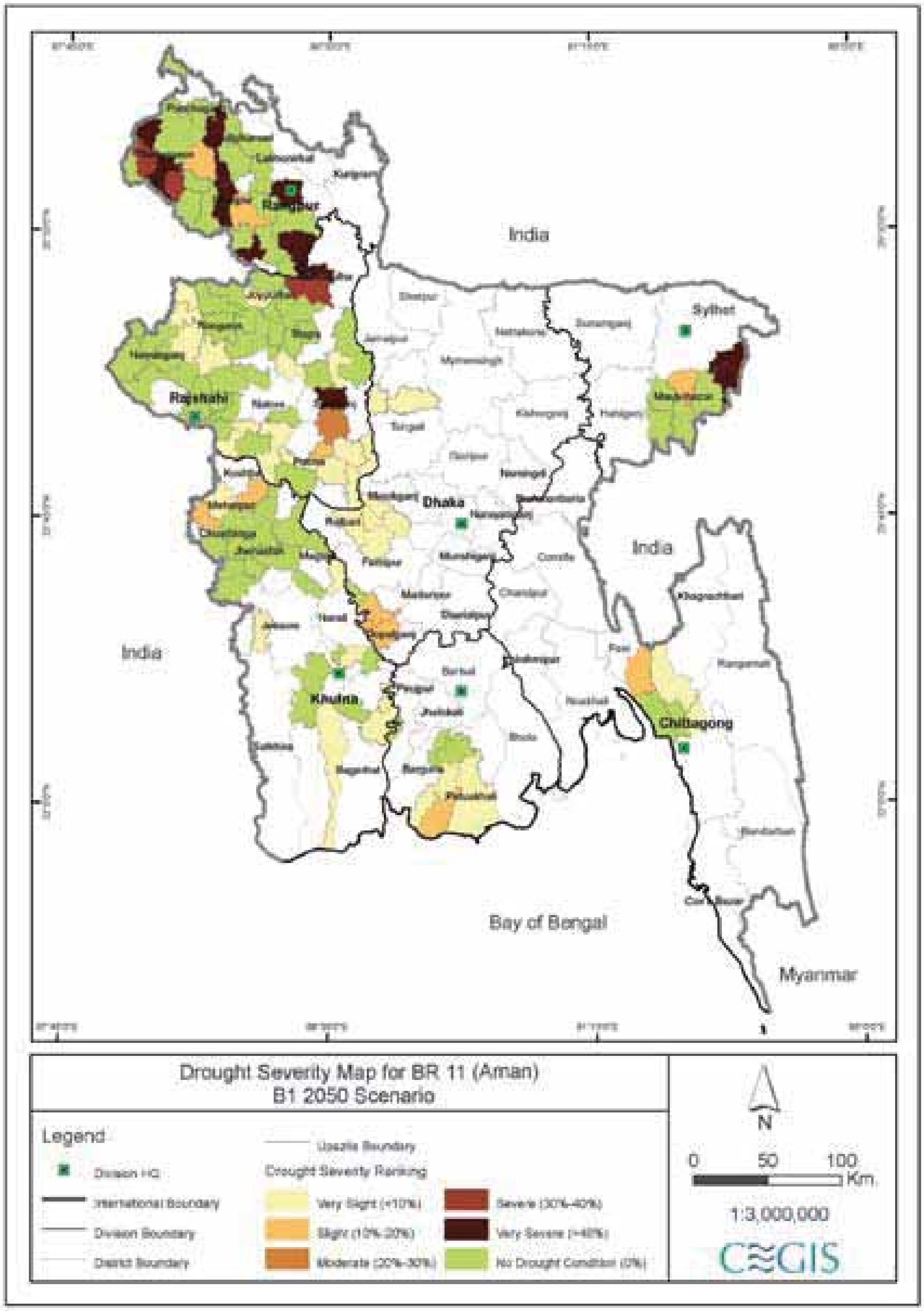


Figure 5.4: Drought severity map for BR 11 in B1 scenario (2050)

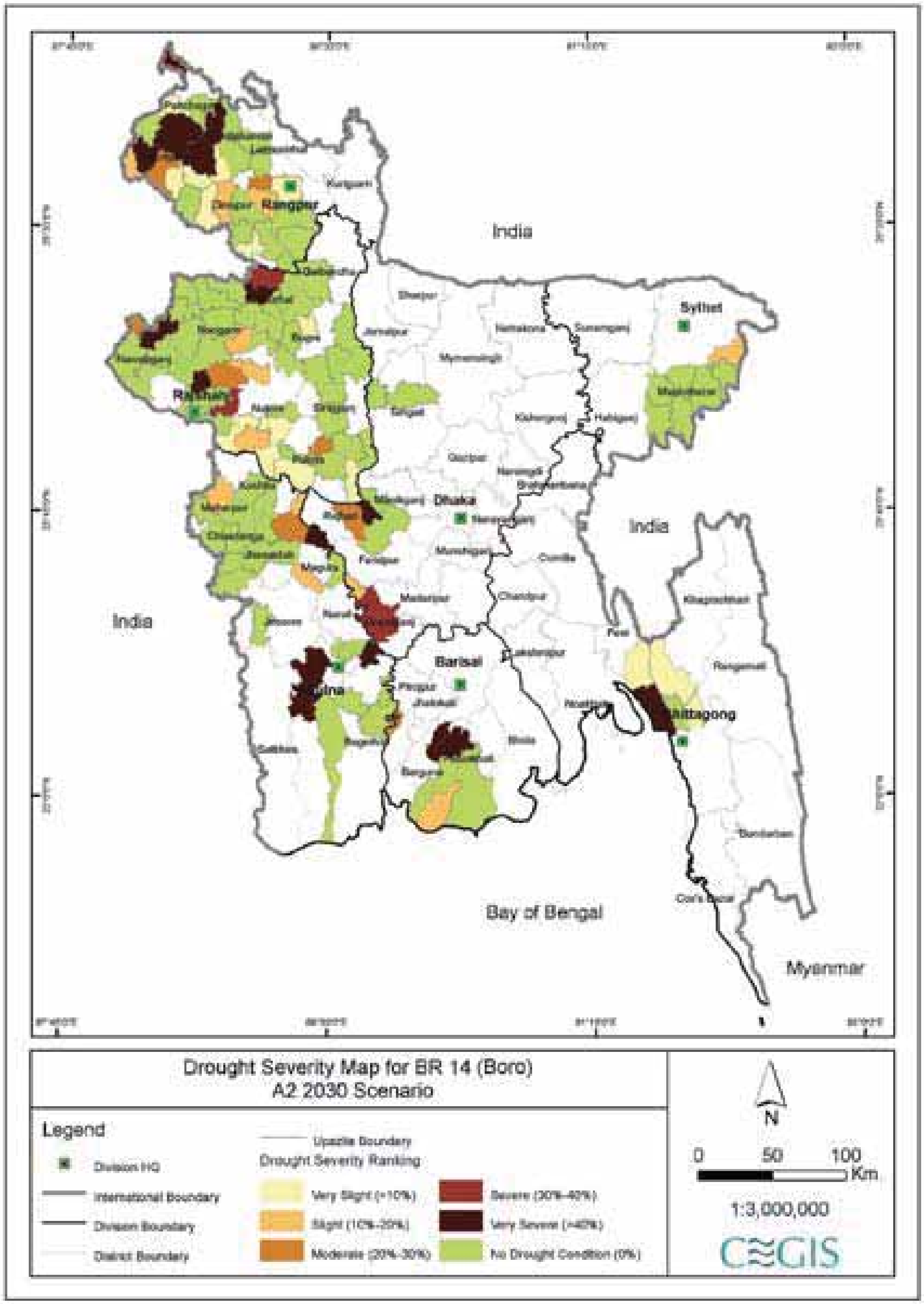


Figure 5.5: Drought severity map for BR 14 in A2 scenario (2030)

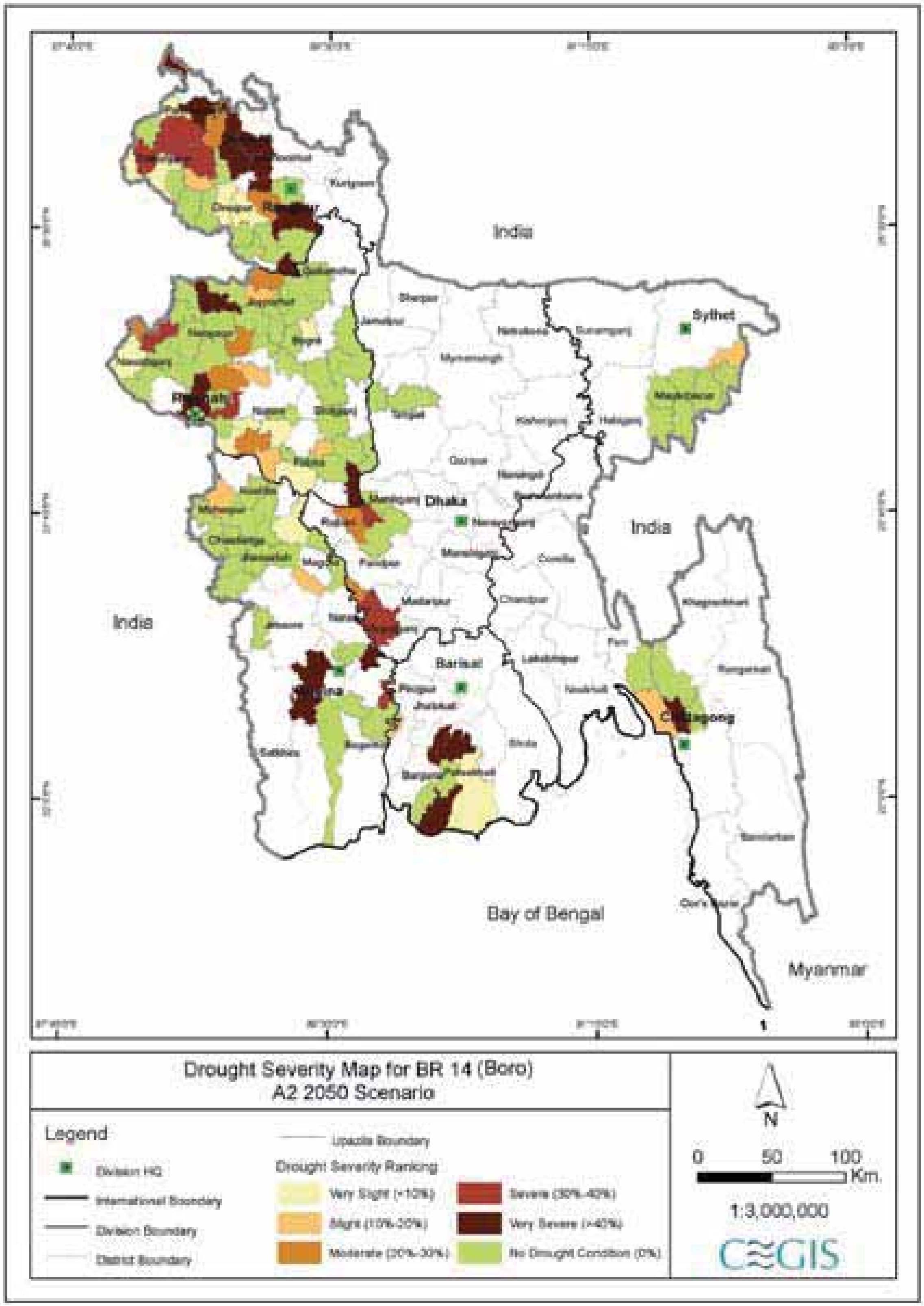


Figure 5.5: Drought severity map for BR 14 in A2 scenario (2050)

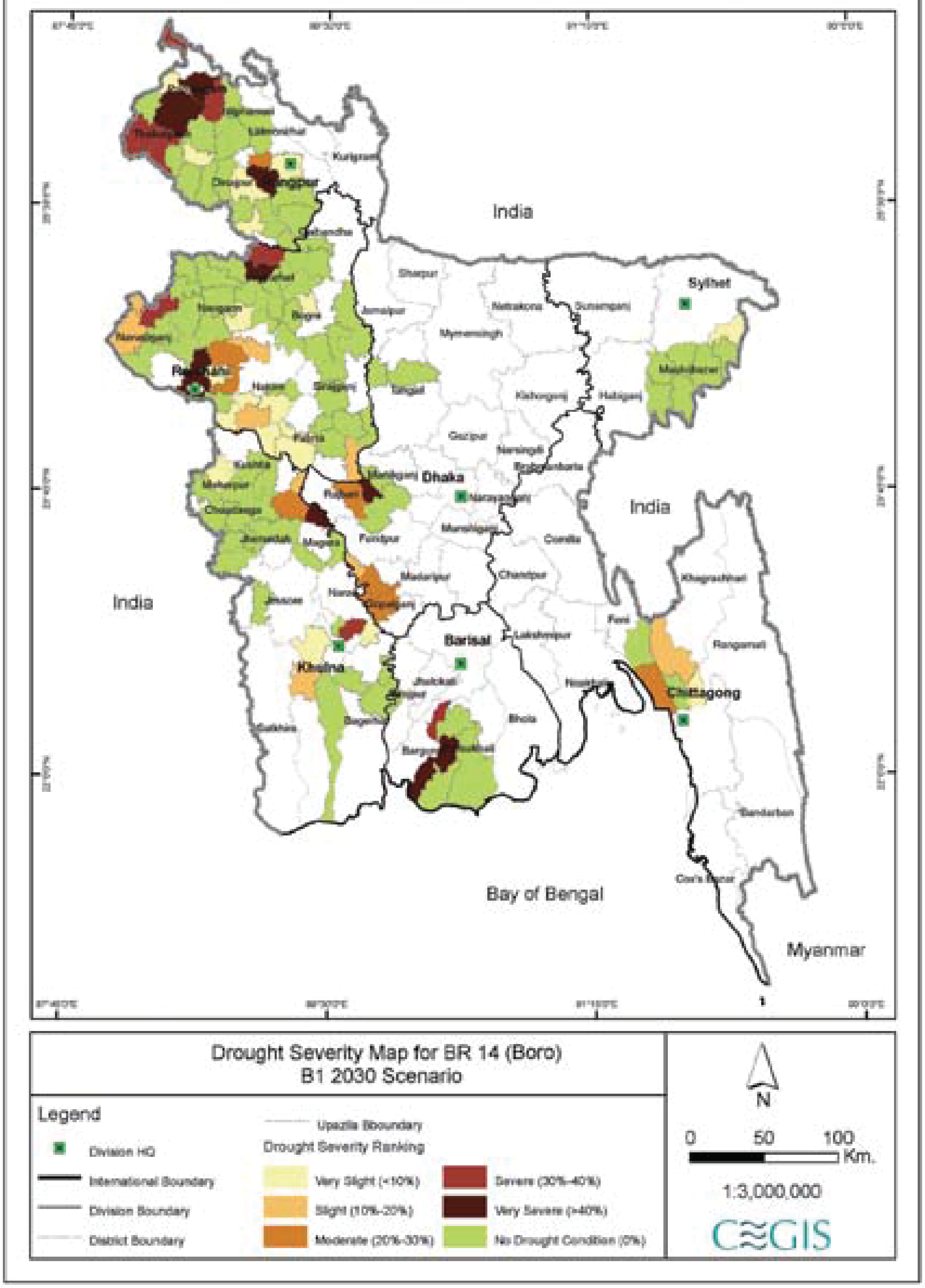


Figure 5.6: Drought severity map for BR 14 in B1 scenario (2030)

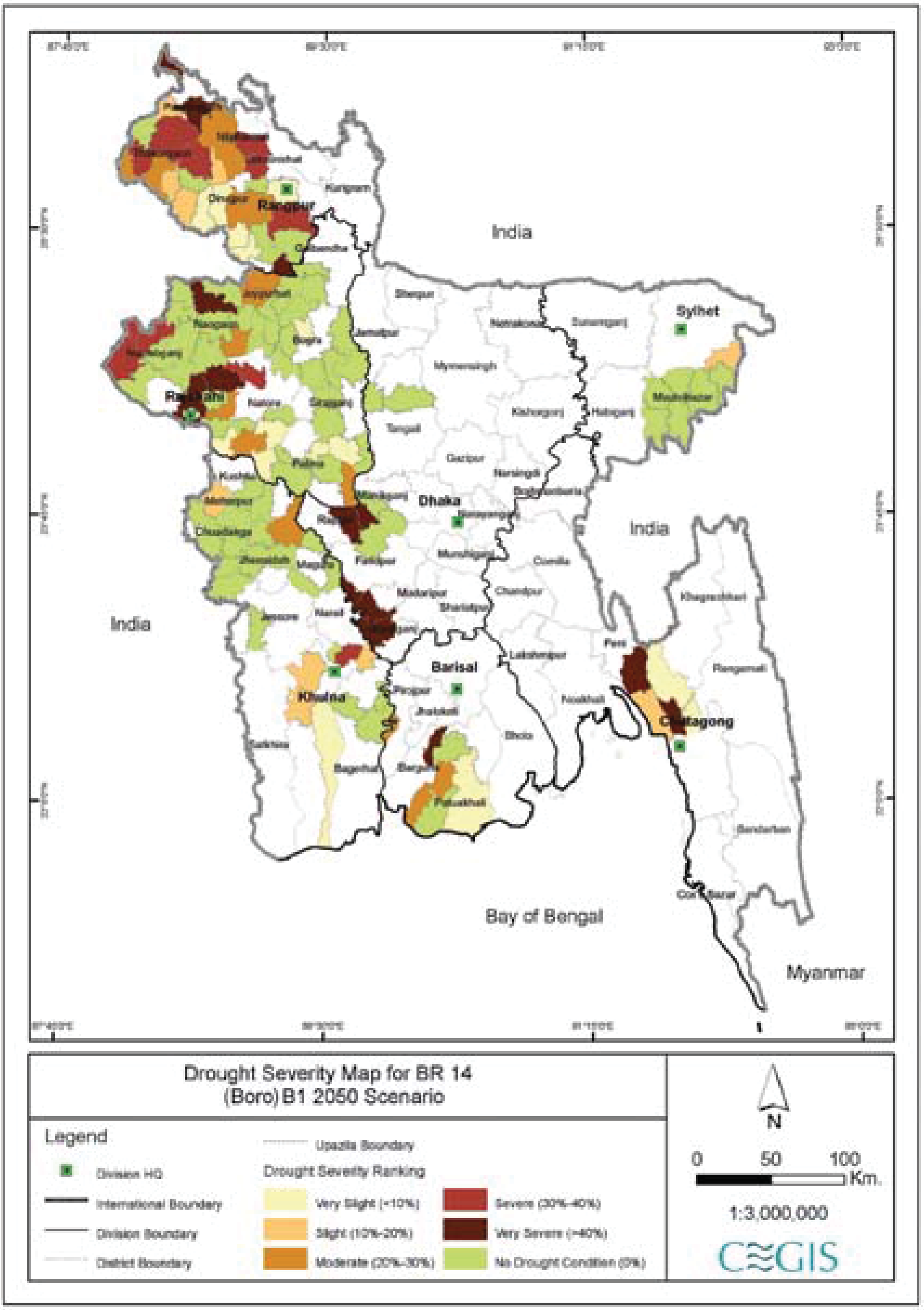


Figure 5.6: Drought severity map for BR 14 in B1 scenario (2050)

Table 5.5: Percentage increase and reduction in production of BRRI Dhan 29 considering temperature and rainfall change in different climatic scenarios from base year (Base year: 1979-2008)

District	A2 2030	A2 2050	B1 2030	B1 2050
Khulna	-4.63	-5.47	-3.93	-5.89
Chittagong	-15.74	-3.30	-5.71	-11.80
Rangpur	-16.49	-31.43	-16.10	-31.81
Rajshahi	-6.01	-11.53	-9.09	-9.58
Faridpur	-1.49	-2.10	-13.37	-14.23
Patuakhali	-4.63	-7.08	-1.50	-10.08
Sylhet	-4.89	-3.67	-16.70	-9.78
Bogra	-14.17	-16.06	-7.64	-27.24

Table 5.6: Percentage increase and reduction in production of BRRI Dhan 29 considering CO_2, temperature and rainfall change in different climatic scenarios from base year (Base year: 1979-2008)

District	A2 2030	A2 2050	B1 2030	B1 2050
Khulna	-7.45	-6.39	-6.83	-8.25
Chittagong	-8.64	-9.81	-6.21	-1.08
Rajshahi	-15.94	-14.62	-21.38	-17.78
Rangpur	-15.94	-14.62	-21.38	-18.37
Faridpur	-6.38	-4.64	-14.11	-13.48
Patuakhali	Increase	Increase	Increase	Increase
Sylhet	-6.94	Increase	-13.23	-4.68
Bogra	Increase	Increase	-4.62	-4.01

Note: (-) denotes decrease in yield

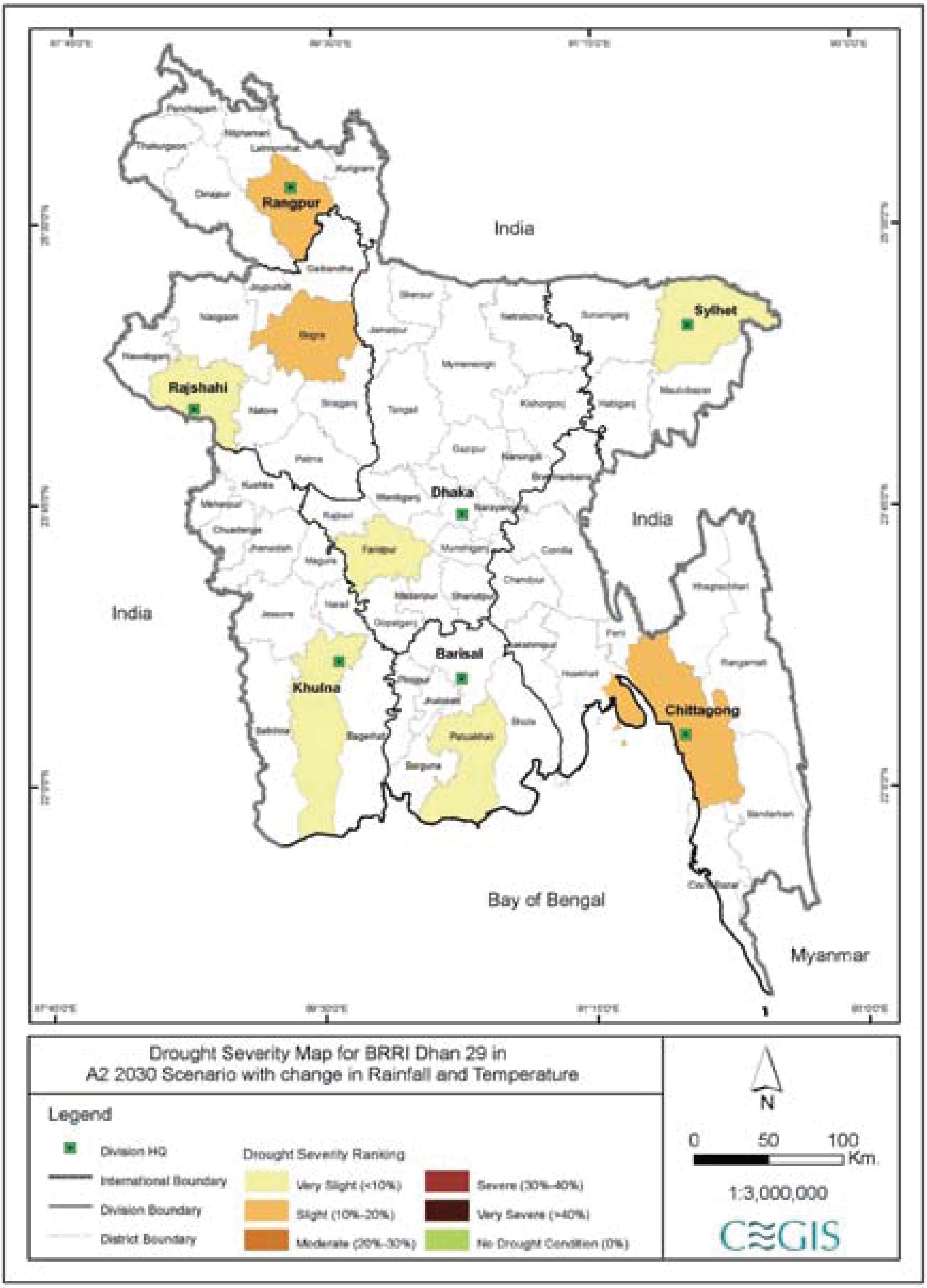


Figure 5.7: Drought severity map for BRRI Dhan 29 in A2 scenario
(in 2030 with rainfall and temperature change)

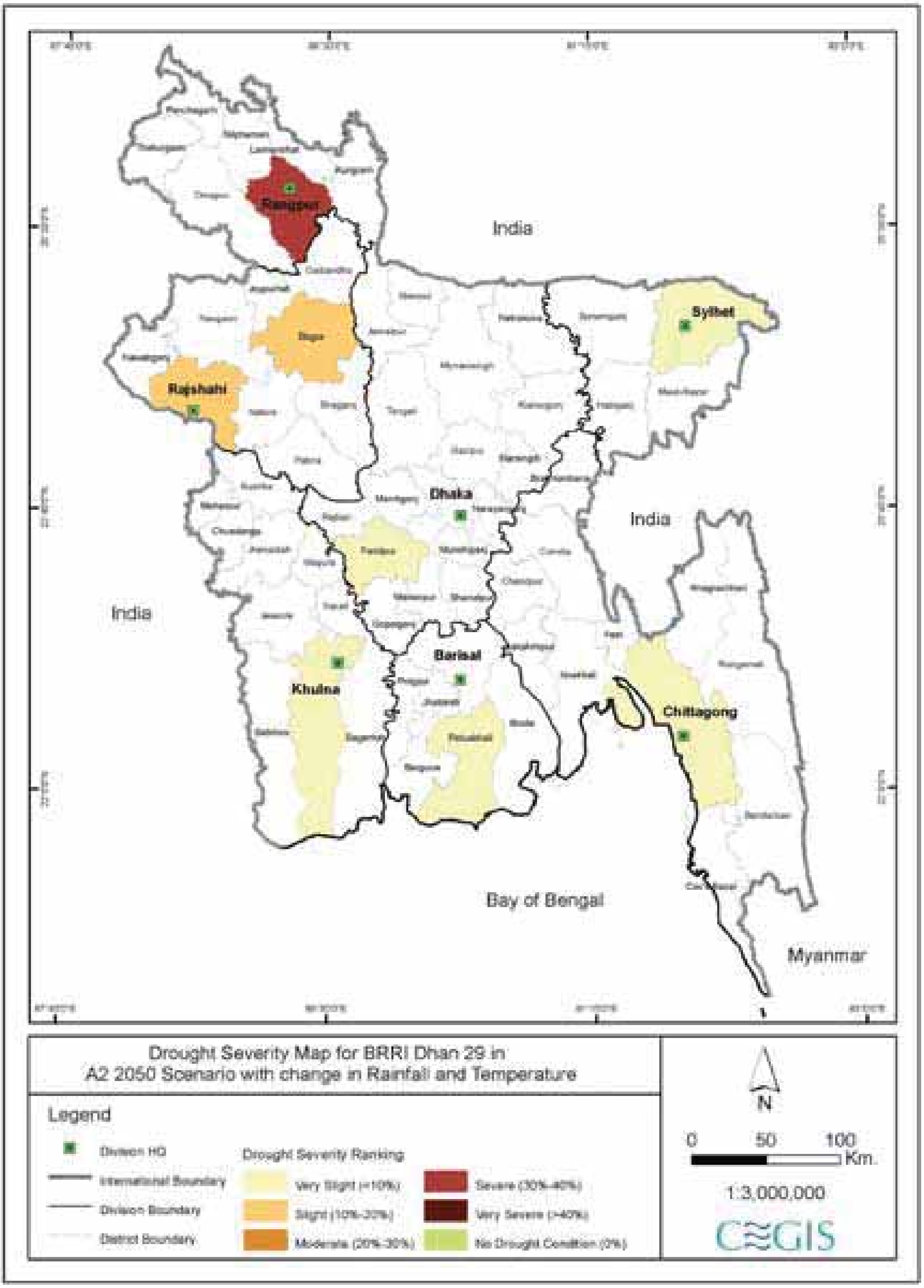


Figure 5.7: Drought severity map for BRRI Dhan 29 in A2 scenario
(in 2050 with rainfall and temperature change)

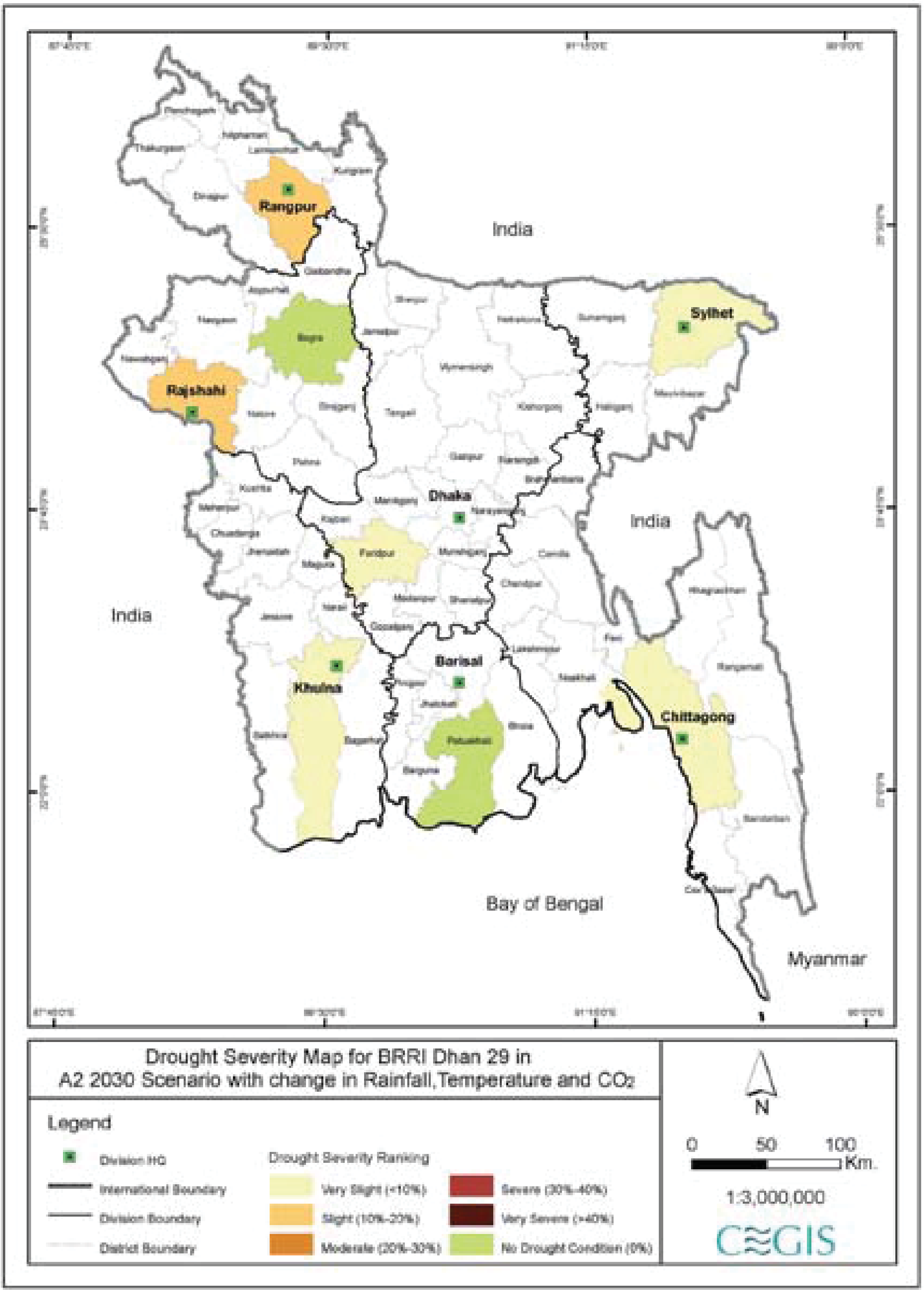


Figure 5.8: Drought severity map for BRRI Dhan 29 in A2 scenario (in 2030 with rainfall, temperature and CO_2 change)

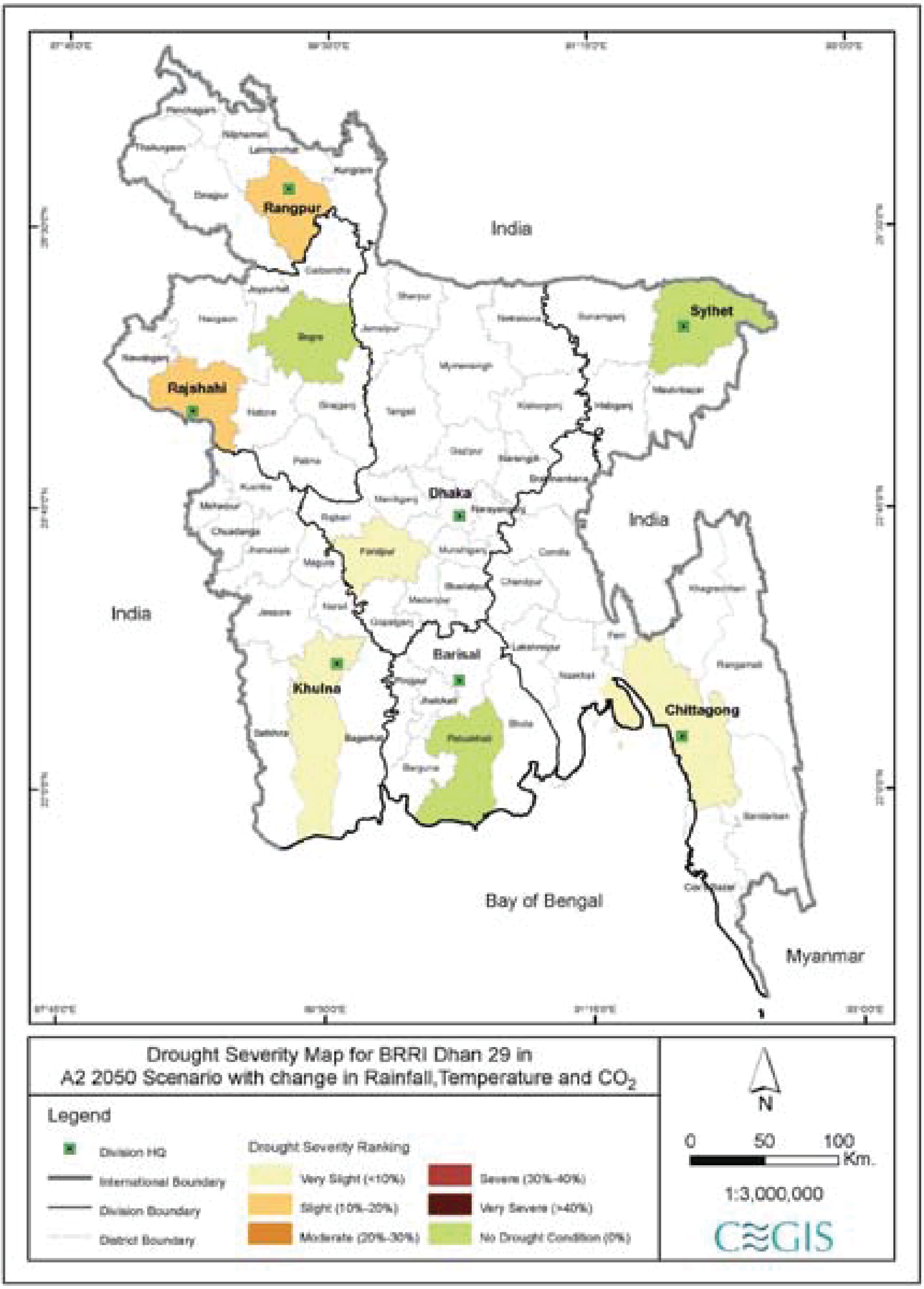


Figure 5.8: Drought severity map for BRRI Dhan 29 in A2 scenario (in 2050 with rainfall, temperature and CO_2 change)

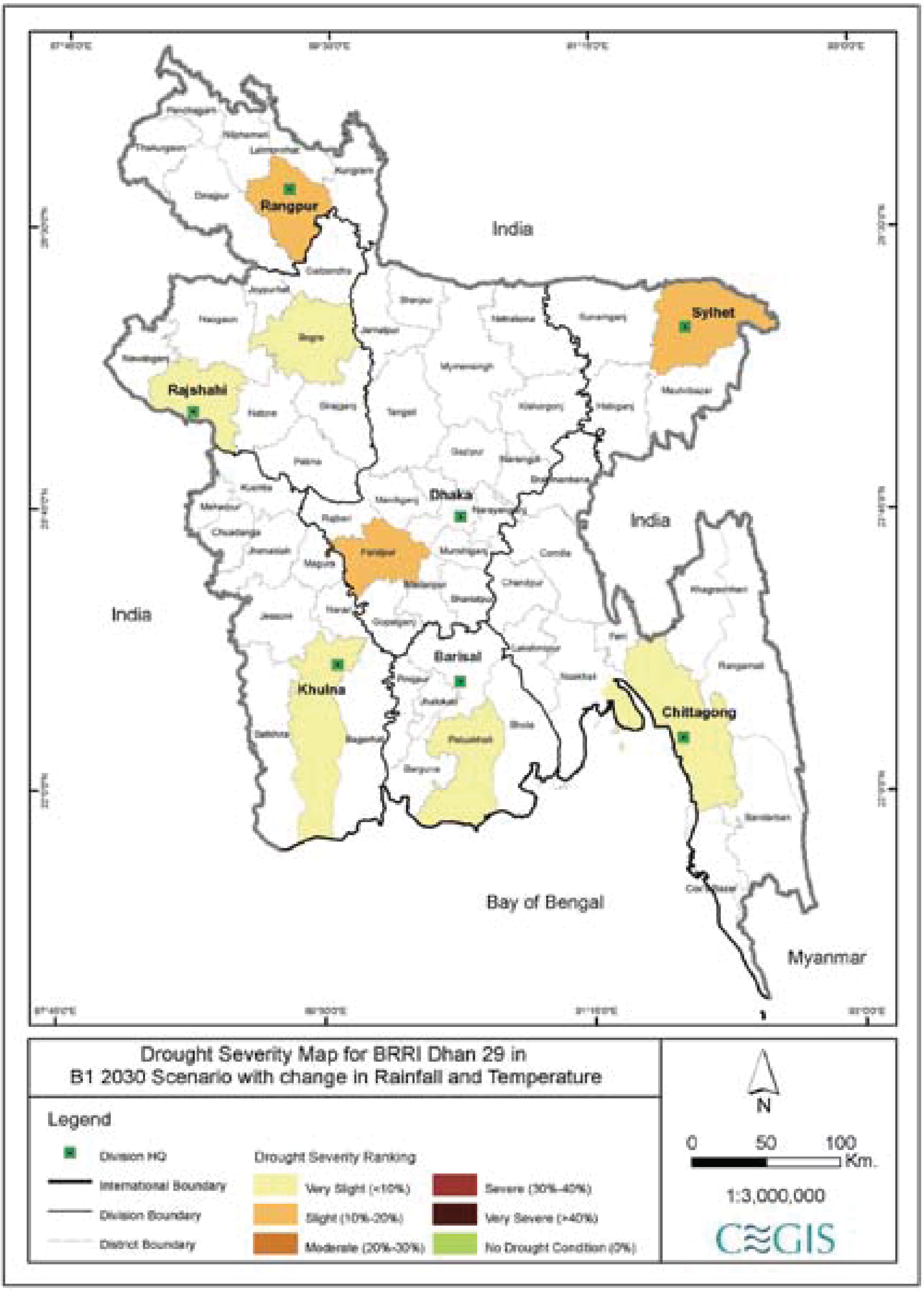


Figure 5.9: Drought severity map for BRRI Dhan 29 in B1 scenario (in 2030 with rainfall and temperature change)

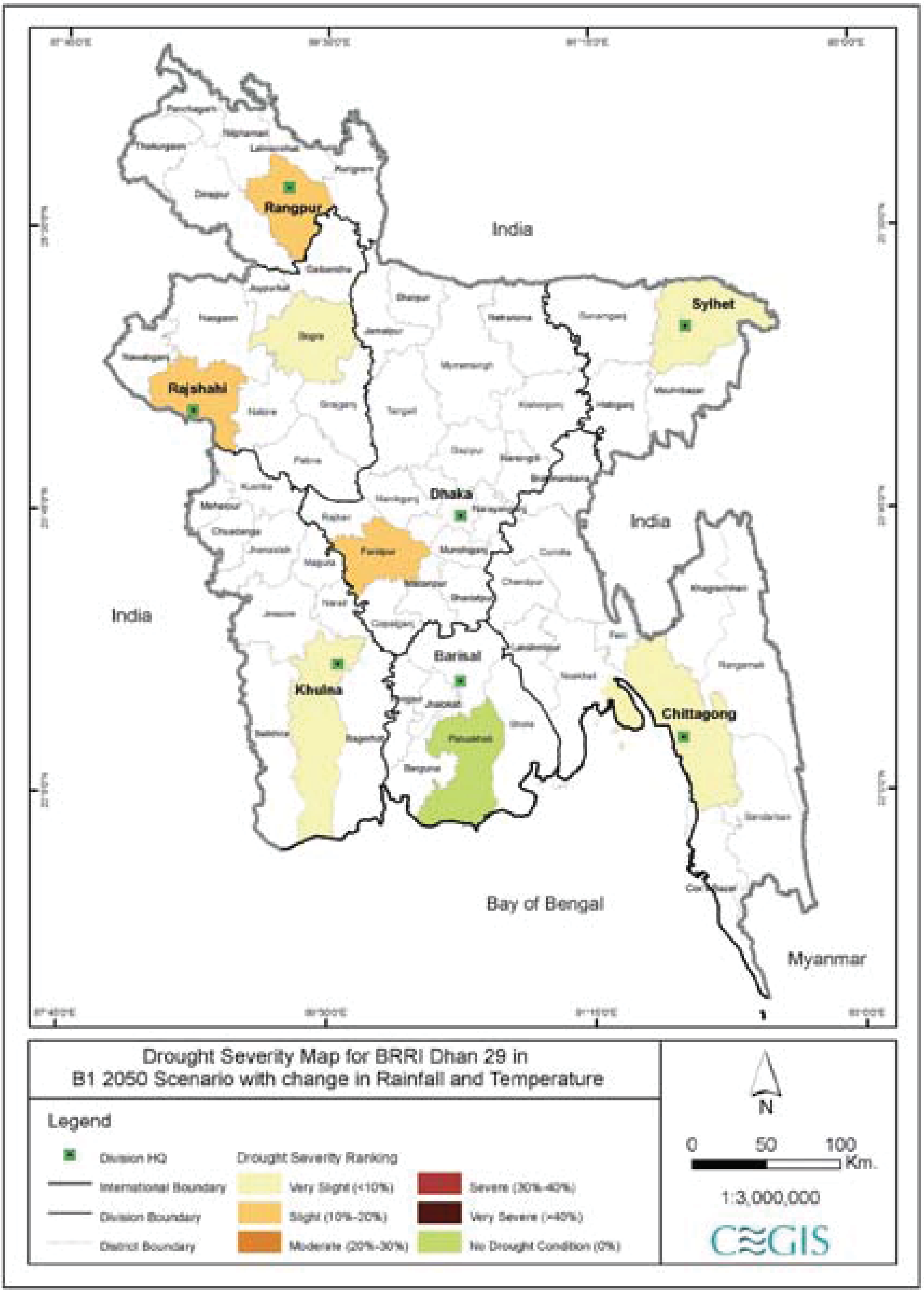


Figure 5.9: Drought severity map for BRRI Dhan 29 in B1 scenario
(in 2050 with rainfall and temperature change)

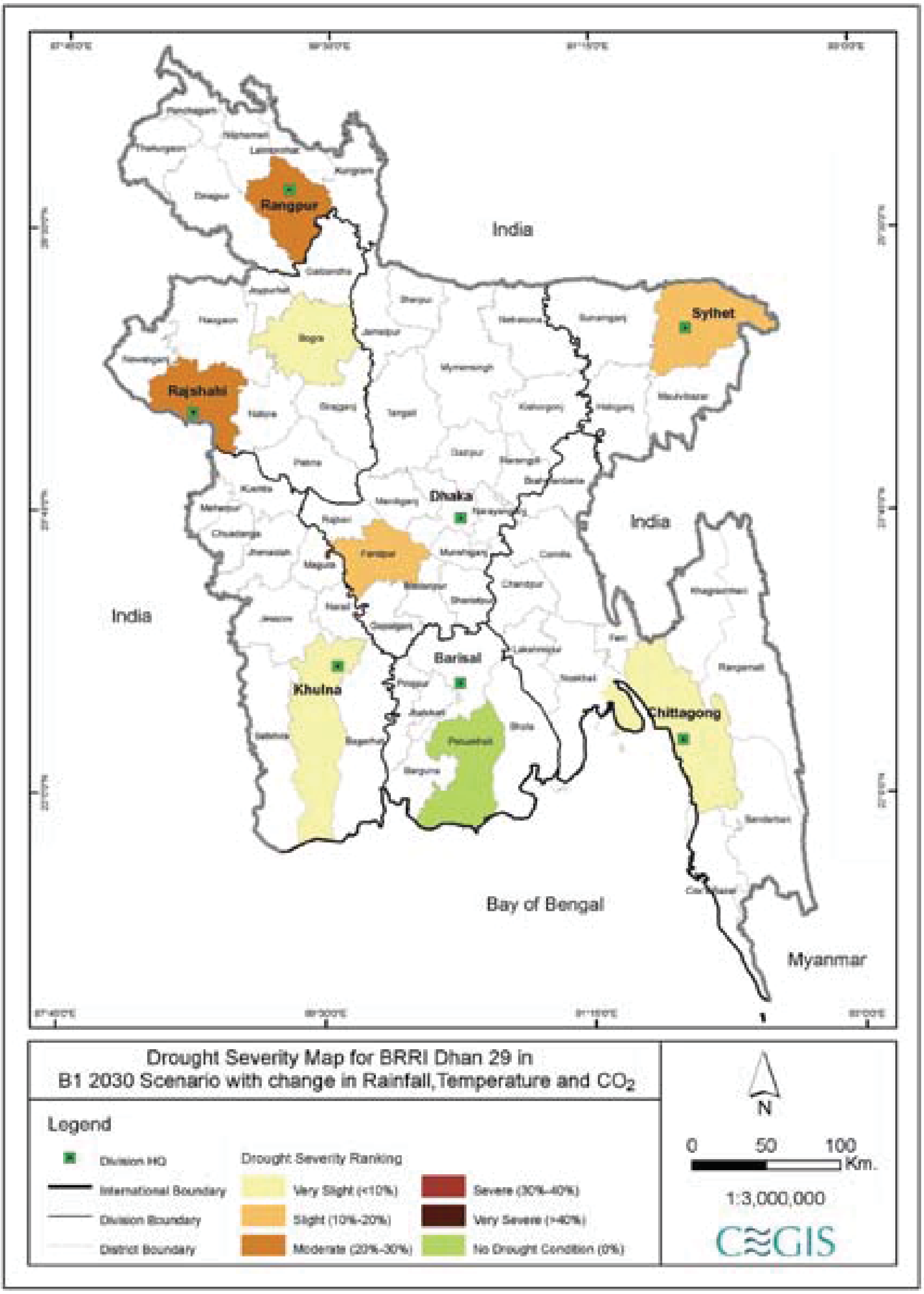


Figure 5.10: Drought severity map for BRRI Dhan 29 in B1 scenario (in 2030 with rainfall, temperature and CO_2 change)

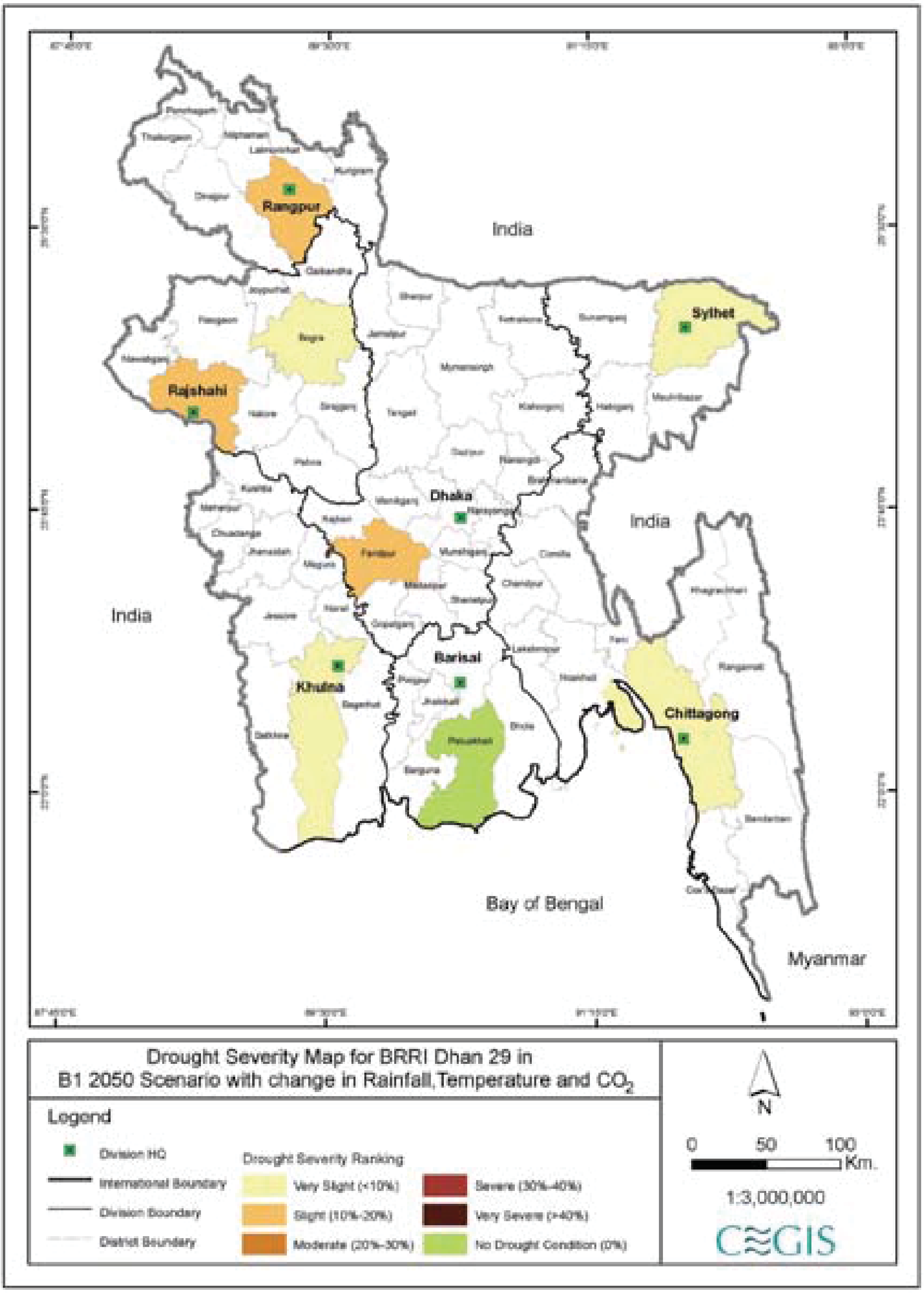


Figure 5.10: Drought severity map for BRRI Dhan 29 in B1 scenario
(in 2050 with rainfall, temperature and CO_2 change)

5.5 Interpretation of Result

The specific findings of the modeled output is that it gives an overall idea of how the yield production will be in near future (2030 and 2050) if climate change occurs according to the prediction of IPCC, both in A2 and B1 scenario, without the necessary management at that weather condition and with continuation of present irrigation and farm management practices of fertilizer application and pesticide application etc.

As a certain level of parameterization has been done for the base year (1979-2008), with management of irrigation and other applications in a more generalized way (as the extent of the study area is very large consisting of 213 upazila), this has been continued for future crop yield simulation to realize the effect of climate change on yield, if adaptation does not take place in crop and farm management practices.

The model result suggests an overall decrease in yield ranging from less than 10% to greater than 40% from present yield condition in vulnerable hotspots for both A2 and B1 scenario in year 2030 and 2050 for BR 11 and BR 14. In case of BR 29, the reduction in yield from base period in year 2030 and 2050 for both the scenarios ranges from less than 10% yield reduction to 30-40% yield reduction.

As B1 is more optimistic scenario than A2, higher yield loss is observed for A2 scenario. Among 2030 and 2050, 2030 simulation gives higher yield loss than 2050 in most cases for BR11 and BR14. Yield loss is higher for Aman in Rangpur division (north-west hydrological region), and Khulna. Yield loss for Boro is higher in Rajshahi division (north-west), south central (Barisal) and south-west region. Eastern hill and north-east have similar yield loss condition for both the crop types.

Table 5.7: Reduction in yield in different district level according to the model simulation in different climate change scenario

Climate scenario	Khulna	Chittagong	Rangpur	Rajshahi	Faridpur	Patuakhali	Sylhet	Bogra
A2 2030 (change in temperature and rainfall)	<10%	10-20%	10-20%	<10%	<10%	<10%	<10%	10-20%
A2 2050 (change in temperature and rainfall)	<10%	<10%	30-40%	10-20%	<10%	10%	<10%	10-20%
B1 2030 (change in temperature and rainfall)	<10%	<10%	10-20%	<10%	10-20%	<10%	10-20%	<10%
B1 2050 (change in temperature and rainfall)	<10%	10-20%	30-40%	<10%	10-20%	10-20%	<10%	20-30%
A2 2030 (with change in temperature, rainfall and CO_2)	<10%	<10%	10-20%	10-20%	<10%	No drought condition	<10%	No drought condition
A2 2050 (change in temperature, rainfall and CO_2)	<10%	<10%	10-20%	10-20%	<10%	No drought condition	No drought condition	No drought condition
B1 2030 (change in temperature, rainfall and CO_2)	<10%	<10%	20-30%	20-30%	10-20%	No drought condition	10-20%	<10%
B1 2050 (change in temperature, rainfall and CO_2)	<10%	<10%	10-20%	10-20%	10-20%	No drought condition	<10%	<10%

Note: Here, All % are reduction in yield, where <10% = Very Slight Drought; 10%-20% = Slight Drought; 20%-30% = Moderate Drought; 30%-40% = Severe Drought; >40% = Very Severe Drought

For BRRI Dhan 29, it is seen 2050 has higher yield loss than 2030 in TR (temperature and rainfall) changes combination in both A2 and B1 scenario. Khulna, Rajshahi and Faridpur have higher yield loss in TRC (temperature, rainfall and CO_2) changes combination than TR (temperature and rainfall) changes combination for BRRI Dhan 29 analysis.

In only a few cases yield has increased in future simulation. Further analysis with rainfall, temperature and CO_2 sensitivity might reveal the true reason behind it. As far drought is considered, much of the selected vulnerable hotspots would undergo through mild to severe drought according to the model simulation. The analysis was not done for 2100 as such analysis may not be appropriate in such distant time as it cannot be predicted whether present land-use or cropping system will exist at that time. Yet again, even climatic conditions predicted for 2100 lack certainty.

Climate change has varying impacts over the global and local weather, in a short (2030 span) and longer time span (higher than 2050). From IPCC report, it is evident that changes are occurring in temperature and rainfall spatially and temporally around the globe due to climate change. As crop yield is a factor of healthy growth of different stages of crop and getting proper temperature and water at its various stages, yield reduces where the crop faces water stress and nutrition stress. If, by any means, temperature and rainfall changes in such a way, that it becomes ideal for the crop to grow, yield will be increased. According to IPCC 2007, heavy precipitation events, i.e. frequency or proportion of total rainfall increases over most areas in late 20^{th} century.

What will be the specific effect of elevated CO_2 is still an ongoing research around the world. In particular, the DSSAT response ratio for increases from 350 to 550 ppm CO_2 is 1.15, or a 15% enhancement (Francesco et. al, 2006). Yield response ratio of a given crop is the ratio of the yield of that crop at elevated CO_2 concentration and the yield at a reference concentration. Hence it is scientifically proved that CO_2, has an enhancing effect on yield, at least till an optimum level, and also is a matter of further research.

Model quality is related to the quality of scientific data used in model development, calibration and validation. Even the best mechanistic model contains some empirism making parameter adjustments vital in new situations, which means that the model results are applicable only for that situation for which it has been calibrated like any other hydrodynamic model, e.g. the calibration of this model has been done for rice and for existing soil and weather condition of Bangladesh.

CHAPTER 6

Adaptation Options and Monitoring Protocol

6.1 Introduction

The Intergovernmental Panel on Climate Change (IPCC, 2007b) defines adaptation as the *"adjustment in natural or human systems in response to actual or expected climatic stimuli or their effects, which moderates harm or exploits beneficial opportunities".*

To select and develop the climate change adaptation option considering drought the following measures are necessary -

- dentify the key aspects related to climate change adaptation in agricultural sector of Bangladesh
- Review existing environmental and socio-economic frameworks related to climate change and drought
- Develop a framework for designing list of adaptation options which is relevant but not restricted to the existing national framework and policies

An extensive review of existing adaptation programs, frameworks and policies were performed to identify the key components of climate change adaptation relevant to agriculture. In this regard, adaptation options were selected on the basis of the following principles:

- All individual component of the adaptation option should be framed in a manner that these can be classified and executed in short, medium and long term. But overall, the proposed adaptation option framework should have a long term impact on the environment and socio-economic system.
- Sustainability should be given utmost importance and proposed options should produce no outcome that may impact sustainability, i.e., protecting the right of the future generation to resource exploitation.
- The options should be coherent with the existing national strategic priorities and policy agendas. For example, the adaptation and mitigation propositions should be in line with the NAPA (National Adaptation Programme of Action) and BCCSAP (Bangladesh Climate Change Strategy and Action Plan) so that these can be implemented by the public sector more readily than some new and technically sophisticated adaptation options.
- Adaptation responses need to be tailored to individual circumstances based on the kind of risk faced in order to be effective.

Adaptation options need to benefit the community and ensure community participation so that experiences of local-level adaptation strategies can be shared.

6.2 Adaptation Framework

The framework is based on five key components and will act as an effective tool for designing integrated adaptation options in national level. The components are:

- **Component-1:** Selecting adaptation options based on existing studies - options that are either fostered through indigenous knowledge introduced by the government or NGOs, and developed depending upon technical feasibility
- **Component-2:** Synthesizing potentially suitable adaptation options for location-specific conditions
- **Component-3:** Prioritizing and validating adaptation options by ground-truthing
- **Component-4:** Reviewing and collecting feedback from community people, relevant organizations and government bodies
- **Component-5:** Sharing knowledge and information for developing a National Drought Information System

The development of National Drought Information System will be a complete resource for adaptation related to drought, and every individual adaptation tool, research, studies in agricultural field related to drought will have its trace in it. It will also provide input and act as a catalyst for field-level demonstrations of viable adaptation options with potential to improve the capacity of rural livelihoods to adapt to climate change.

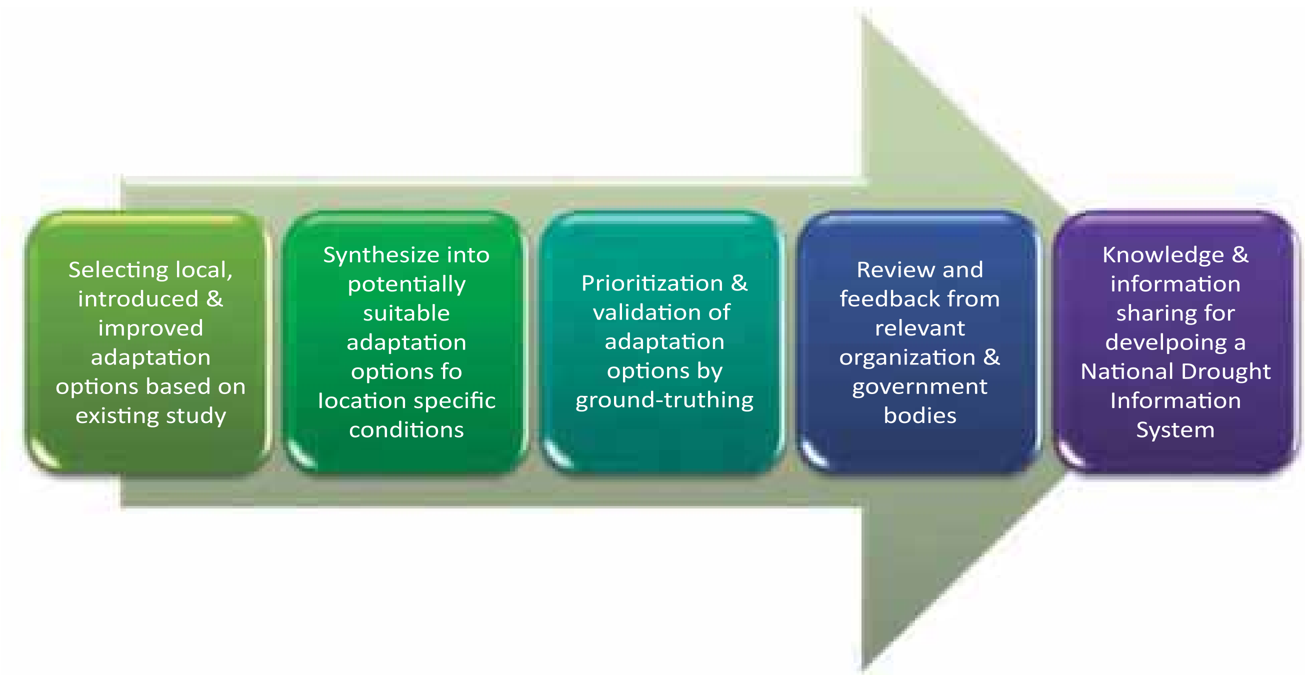


Figure 6.1: Proposed framework for drought adaptation

6.2.1 Strategic Measures of Adaptation

The overall adaptation strategy may focus on minimizing the production risk or loss. Adaptation needs can be correlated to climatic impacts and can be manifested by refinement in soil, water and crop management. Option for adaptation can be sub-divided into three levels -

- Farm Level Adaptation
- System Level Adaptation
- Planning Level Adaptation

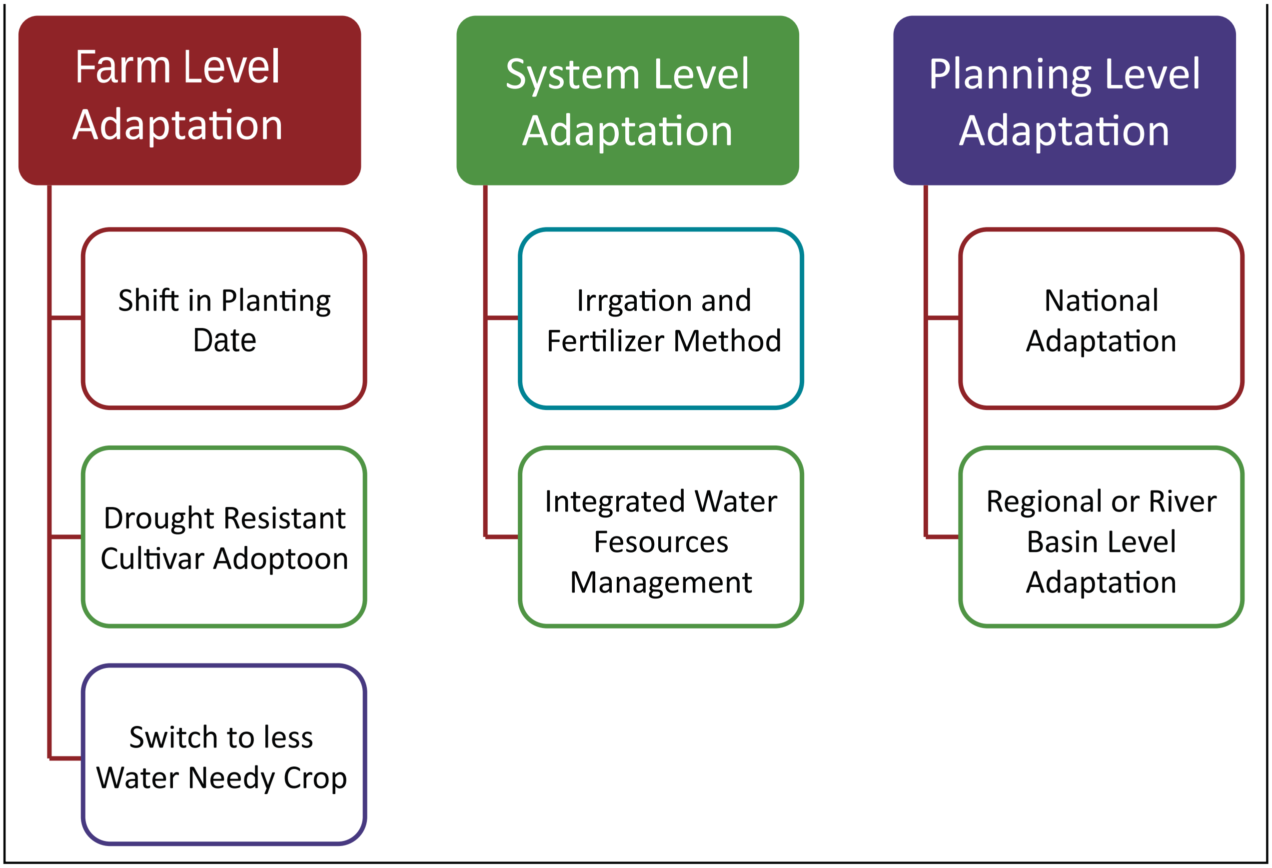


Figure 6.2: Strategic measures of drought adaptation

6.2.1.1 Farm Level Adaptation

Farm level adaptation options are such options which can be introduced at farm level by farmers and government officers who work directly with farmers. Such measures may include -

- Adoption of varieties and species of crops with increased resistance to heat stress, shock and drought
- Probable change from Boro to Wheat/Maize or other less water-needy crop cultivation to reduce the demand of water in cultivation phase
- In case of seasonal shift of monsoon, consequent shifting in planting date may be considered. For this, we may require at least 20 days forecast to know the onset of the monsoon, and subsequently inform the farmers for seedbed preparation and raising seedlings for Aman
- Modification of crop calendars, i.e., timing or location of cropping activities according to water stress (with due consideration to livelihood adaptation)
- Mulching
- Top soil tillage (to avoid land cracks of topsoil)
- Maintain database at farm level by collecting yield data for different cultivars at different region considering weather and soil sensitivity
- Developing climate resilient cropping patterns suited to different regions
- Field-level trials of the climate resilient cropping patterns and associated water management systems

It is evident from the drought prone pilot areas that small farmers are vulnerable in the months of March-April when boro cultivation suffers due to the lowering of groundwater level. The second period of crisis for small farmers seems to be July-August when drought affects seedlings and delays T-Aman transplantation. The third period of crisis is between September-October when the tillering and flowering of T-Aman become a critical factor due to prevailing drought conditions. Agricultural wage laborers are more vulnerable from May to June when employment opportunities decline.

Table 6.1: Drought tolerant and short growth duration rice variety for adaptation

Rice variety (drought tolerant or/ and short duration)	Speciality	Growth duration (days)	Average yield (ton/ha)	Season of cultivation
BRRI Dhan 42	Drought tolerant	100	3.5	Aus
BRRI Dhan 43	Drought tolerant	100	3.5	Aus
BRRI Dhan 55 (Aus)	Drought tolerant	105	5.2	Aus
BRRI Dhan 56	Drought tolerant	106	4.4	T. Aman
BRRI Dhan 57	Drought tolerant	100	4.0	T. Aman
BRRI Dhan 33	Aman rice with growth duration <130 days	118	4.5	Aman
BRR I Dhan 39	Same as before	122	4.5	Aman
BRRI Dhan 46	Same as before	124	4.7	Aman
BRRI Dhan 53	Same as before	128	4.5	Aman
BRRI hybrid dhan4	Same as before	118	6.5	Aman
BR 6	Boro rice with growth duration <150 days	140	4.5	Boro
BRRI Dhan 28	Same as before	140	6.0	Boro
BRRI Dhan 36	Same as before	140	5.0	Boro
BRRI Dhan 45	Same as before	145	6.5	Boro
BRRI Dhan 55 (Boro)	Same as before	145	7.3	Boro
BRRI Hybrid Dhan2	Same as before	145	8.0	Boro
BRRI Hybrid Dhan3	Same as before	145	9.0	Boro

In this table varieties which can be used in drought vulnerable hotspots are identified. Depending on water stress condition and season of requirement, varieties can be chosen. The yields for these varieties range from 3.5 ton/ha to 9.0 ton/ha (table 6.1). It is to be noted that while choosing drought resistant varieties, one must not give less importance to yield of that variety as very low-yielding variety, whether it is drought resistant or not will be of little help in the long run of securing food security in the context of climate change.

6.2.1.2 System Level Adaptation

System level adaptation options are such options which need to be introduced or modified in agricultural systems like irrigation or fertilizer application to adapt with climate change. Massive irrigation seems to be the most powerful measure when drought occurs, but if groundwater is already being exploited heavily during normal years, there is more risk in a dry year. The other source is surface water which is likely to fall short in dry years, as its availability is related to rainfall and upstream contribution. According to (FAO, 2008), the Ganges Brahmaputra Delta is a densely populated area where ground water is shallow, hence conjunctive use of surface and ground water is very important. Water management for agricultural production is a critical component that needs to adapt in the face of both climate and socio-economic pressures in the coming decades.

Changes in water use will be driven by the combined effects of

- Changes in water availability
- Changes in water demand for agriculture, as well as from competing sectors including urban development and industrialization
- Changes in water management

A small part of the T. Aman crop in Bangladesh is grown with supplementary irrigation. Wheat and other Rabi field crops first take advantage of the residual moisture after Kharif, followed by some irrigation. The Boro rice is almost fully irrigated, while the rate of irrigation varies for the Rabi crops. The potential to expand irrigation during the Kharif is high, but the expected average yield response to irrigation is rather low. Though during Rabi a high portion of the land is under irrigation, there is still scope for the further development of irrigation under the assumption that ground water and surface water can be exploited to a sustainable level only. Since the government has limited resources, it needs to know which measures in which parts of the country would be the most effective for drought mitigation. So specific adaptation option in this strategies measure might include -

- Modification of irrigation techniques, including amount, timing or technology (e.g. drip irrigation systems);
- Adoption of water-efficient technologies to ‘harvest’ water, conserve soil moisture (e.g. crop residue retention, zero-tillage);
- Improved water management to prevent water-logging;
- use of surface water, rain water and ground water;
- Integration of the crop, livestock, forestry and fishery sectors at farm and catchment levels (Integrated Water Resources Management);
- Supplementary irrigation system with rainfall in view of efficient use of irrigation water;
- Surface water retention for irrigation purposes (e.g. small pond);
- Water retention in crop fields using bundh (dyke management);
- Rainwater conservation;
- Application of local organic matters such as ash/leaf/compost/cowdung etc. (to enhance moisture holding capacity of the drought affected land);
- Improved watershed and resource management, integrating the different natural resources - water, soil, flora and fauna - through, for example, the promotion of Integrated Water Resources Management (IWRM) processes.

6.2.1.3 Planning Level Adaptation

Planning level adaptation is very important as this includes development of a planning framework that is workable in short and long term planning schemes. Such option may include -

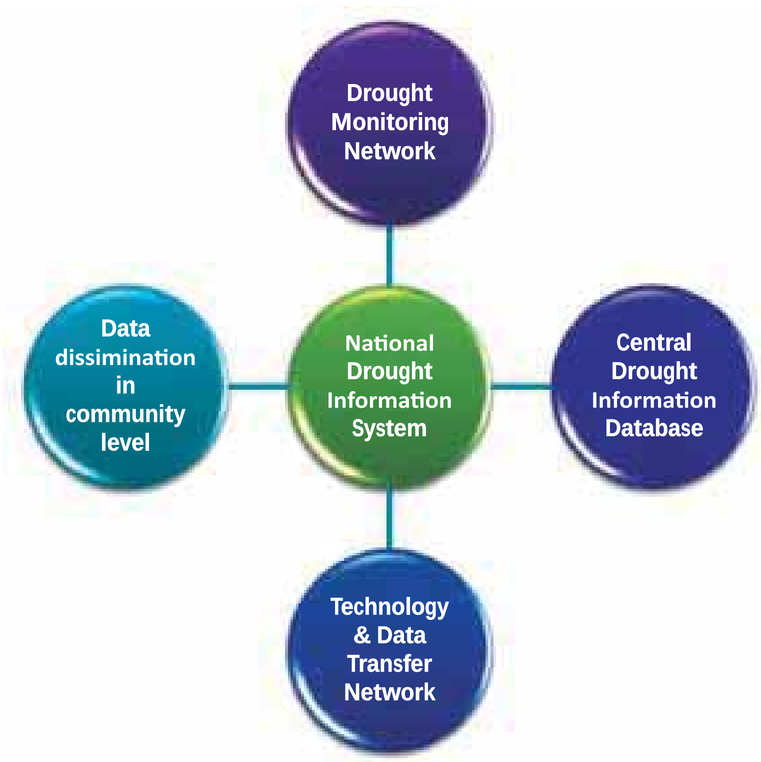
- Support provided to farmers from government in case of major crop failures by appropriate price subsidies, food for work program, credit and saving schemes at least until the harvest of the follow up crops
- Government may also give support to the farmers in case of exceptional drought years, may be in 1 out of 5 or 1 out of 10 years with drought relief or introducing crop insurance

- Building food reserves is also a planning level adaptation option which needs to be formulated and managed by the government so that in extreme drought years in drought vulnerable areas, people do not die out of hunger
- Implementation of seasonal climate forecasting by different government organizations so that timely warning is given to the farmers is also an important measure that might be taken by the government
- Additional adaptation strategies may involve land-use changes that take advantage of modified agro climatic conditions Landtype selection can be done from planning level by identifying agro-economic zones vulnerable to climate change
- Development of organized seed production and supply system and extension mechanism can also be considered
- Provision of appropriate law to protect specific users' rights in extreme cases is needed
- The government may empower local government or any local body it deems fit, to exercise its right to allocate water in scarcity zones during periods of severe drought, and to monitor the water regime and enforcement of the regulations through specifically designed mechanisms
- Finding how farming is vulnerable to drought at different weather condition so that appropriate response strategy can be formulated, is also a planning level measure to be taken
- Developing long-term water policies and related strategies, taking into account country-specific legal, institutional, economic, social, physical and environmental conditions (FAO, 2008)
- Mainstreaming policies and strategies to integrate the different sectors depending on water - rain fed and irrigated agriculture, livestock, fisheries, forestry, nature and biodiversity protection, manufacturing and industry, and municipal water use is also very important. Water policies need to address such issues as upstream-downstream competition over water resources and equitable allocation of water across regions and generations
- Enhancing water availability through better use of groundwater storage, enhancing groundwater recharge where feasible, and increasing surface water storage
- Managing demand by reducing water consumption and improving water use efficiency
- Institutional and governance reforms that balance demand and supply across sectors and that mainstream climate change adaptation
- Enhancing stakeholder participation and community involvement in water development and climate change adaptation
- Improving information and early warning systems to provide land and water users with timely and adequate information and knowledge about availability and suitability of resources to promote sustainable agriculture and prevent further environmental degradation. Information exchange and dialogue between the agriculture, water and climate communities is vital (FAO, 2008), not only at national level but also at trans-boundary river basin level
- Human resource, capacity and skills development of policy-makers and end-users to help them deal with new challenges
- Increasing investments in agriculture and rural development
- Monitoring the relative contribution of rain-fed and irrigated production to global food balances
- Determining the long-term sensitivity of food production systems to climate change
- Determining the operational room to manoeuvre across river basin systems on the basis of updated assessments of the partition between surface and ground water sources of supply, with the aim to improve the data for carrying out meaningful sensitivity analyses
- Building in as much operational flexibility as possible into local/irrigation-scheme-level water management strategies in anticipation of both increased demand and the need to adjust operational supply
- Preparation of investment plans and operational adjustments to address national and sub-regional and regional issues. These plans and adjustments will comprise:
- Watershed management, where a combination of irrigated agriculture, rain fed agriculture, pasture and forestry is practiced
- Seasonal storage systems in the monsoon regions, where the proportion of storage yield will decline but peak flood flows are likely to increase
- Supplemental irrigation areas, where the consequences of irregular rainfall are mitigated by short-term interventions to capture and store more soil moisture or runoff.

6.3 Drought Monitoring Protocol

Observational data and data access are prerequisites for adaptive management, yet many observational networks are shrinking day by day due to lack of fund and also due to the unavailability of skilled human resources. The IPCC has already identified that there are several gaps in knowledge in terms of observations and research needs related to climate change and water. There is a need to improve understanding and modeling of climate changes related to drought at scales relevant to decision making. Existing Information about the drought related impacts of climate change is inadequate - especially with respect to water scarcity- including their socio-economic dimensions. Finally, current tools to facilitate integrated appraisals of adaptation and mitigation options across multiple water-dependent sectors are inadequate. The proposed National Drought Information System (NDIS) which has been presented in component-5 of the framework will be an effective tool in this regard.

Figure 6.3: Conceptual mechanism of NDIS



An indicative methodology for the monitoring of drought under a monitoring protocol would involve the following steps:

- Identify, delineate, and map drought risk zones
- Test and categorize the economic viability of various long-term strategic management options within each homogeneous zone. (includes management options like stocking rate, type of small stock, type of production system, type of yield management system, drought-resistant fodder crops, and fodder banks)
- Test and categorize the economic viability of various short-term tactical management options within each homogeneous zone (short-term tactics should serve as release valves during progressing drought periods where the tactics include factors like marketing of stock and drought feeding)
- Monitoring for changes in meteorological parameters
- Local and regional collaboration
- Improving understanding and research capacity
- Developing a protocol for water use during a drought

- Maintenance of updated and precise database
- Monitoring of yield data
- Developing or using a GIS-based monitoring tool and assessment tool
- Developing a user friendly GIS-based drought assessment and management tool
- Developing a database of drought (NDIS)

A number of agriculture research institutes exists in Bangladesh, including the Bangladesh Agriculture Research Institute (BARI), Bangladesh Rice Research Institute (BRRI), Bangladesh Institute of Nuclear Agriculture (BINA), Bangladesh Agricultural Research Council (BARC) and the Bangladesh Agricultural University (BAU). Also, a number of research organizations like CEGIS and IWM are involved in environment and natural resource management. These organizations and other government and non-government organization will have active participation in the NDIS in order to utilize their existing knowledge, tools and data related to drought for successfully managing the drought phenomenon. SRDI, CEGIS, IWM, BAU, BARC, IRRI, FAO, WARPO, BWDB, BAU, BADC, BINA etc. organizations might be considered as the stakeholders of the proposed NDIS (National Drought Information System).

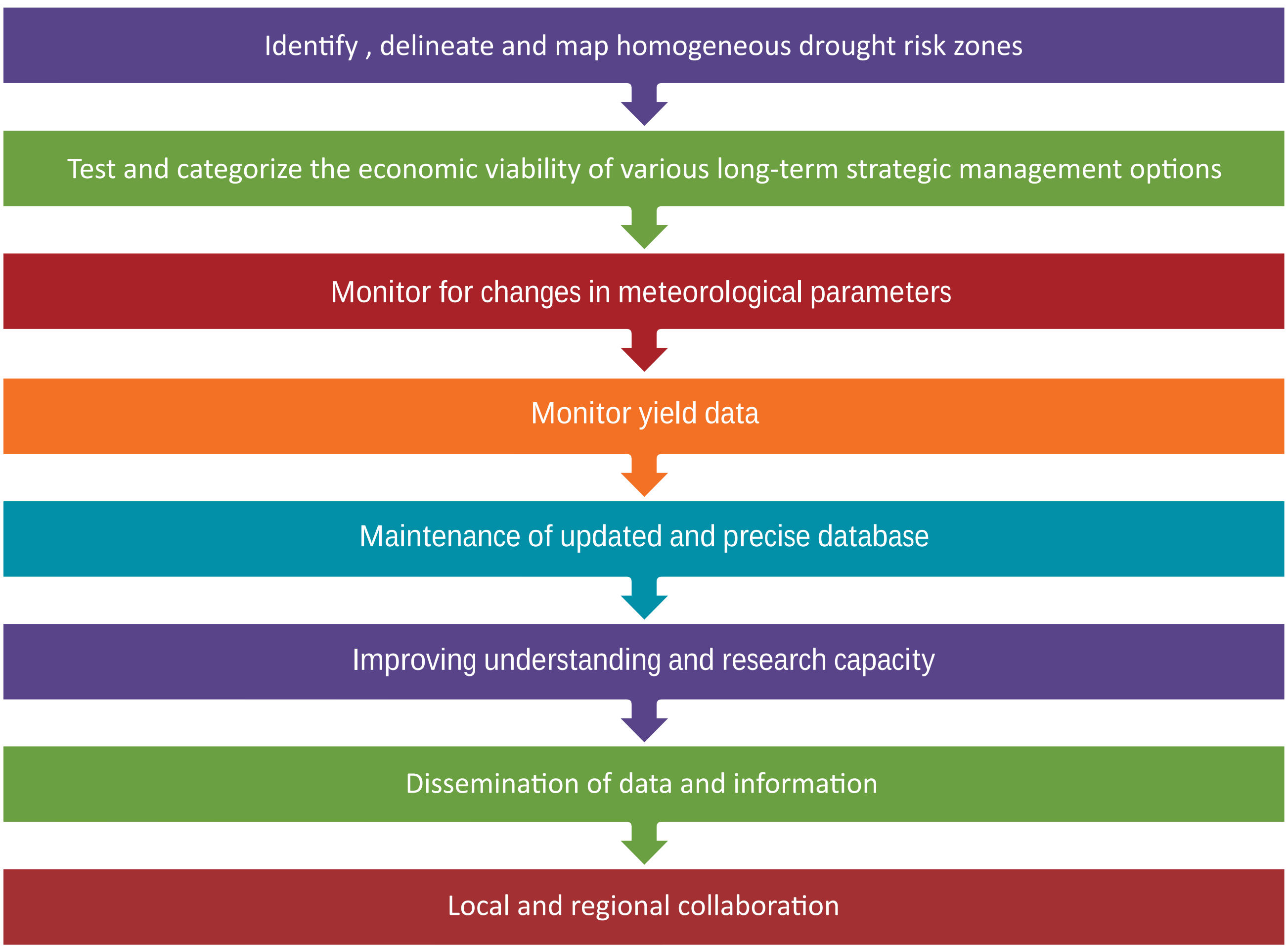


Figure 6.4: Proposed framework to monitor drought

6.3.1 Monitoring Tool

DRAS is a CEGIS developed Drought Assessment tool which assesses drought and represent the drought condition by GIS interface. This tool can be incorporated successfully in the proposed NDIS and in this study. DRAS is a base guideline for establishing and development of NDIS.

The GIS-based DRAS has been developed mainly for drought assessment and management. The model facilitates a quick assessment of yield reductions and net irrigation requirements of crops and water availability. As drought assessment requires different layers of information on soil and agricultural inputs along with hydrological parameters, the model is designed to process interactively, and compile and analyze the parameters spatially. The main processing of the model has been programmed in Visual Basic using the Access database interface to generate and analyze the different options. It is integrated with ArcView for the pre and post processing of the results. The ArcView software, along with Avenue programming, has been used to analyze and represent the results as shape files and tabular information. DRAS is divided into two components, the Availability model and Demand model.

Spatial and time series data are required from different sources for the assessment of water availability. Major spatial data layers are mainly rainfall station locations, water level and discharge stations and administrative units. Upazila administrative boundaries comprising union coverage are used for the selection of a particular area. Spatial queries have been designed to determine a selected area from the administrative layer and to generate a database for further processing. A wider setting is required for the selection of a river gauge to assess surface water availability, as gauges may not be located within the administrative units. Therefore, the user has specific options to select the discharge station which contributes to the area. Area-wise distribution of rainfall has been generated taking the weight factor for each rainfall station using the Thiessen polygon method. Surface water availability is assessed for the strips of land adjacent to the river with a particular width. Potential irrigated areas for different types of crops within the strips are extracted from the Thana Nirdeshika database by overlaying the surface water area with the soil associations. Surface water availability for the riverine area (land strips) is then shown spatially. Groundwater availability is assessed using the area-wise rainfall and recharge parameters, which generate a single value for the selected upazila.

DRAS, by using the model results, can generate two types of drought assessment maps. One contains a classified drought map for different crops under rainfed conditions, and the other presents a single average value for the upazila including the impact of existing irrigation and represents the upazila in the national-level drought assessment. The seasonal crop water demand for different crops and soil units can be shown spatially. Even a yield reduction map of a particular crop for different years can be presented through GIS so that differences in yield reduction can be observed, indicating the severity of the drought proneness of an area. In order to validate the model results, detailed information on the yields of the crops are needed to be collected (BARC, 2001).

6.3.2 Selection of Parameter

Drought monitoring can be successfully implemented through the proposed tools and framework if continuous monitoring is done. Selection of monitoring parameters, which may differ variety to variety, is very important to identify here for successful implementation of the protocol. Here is proposed a specific monitoring mechanism of Aman and Boro rice modified from a recent study done by IUCN (IUCN, 2011).

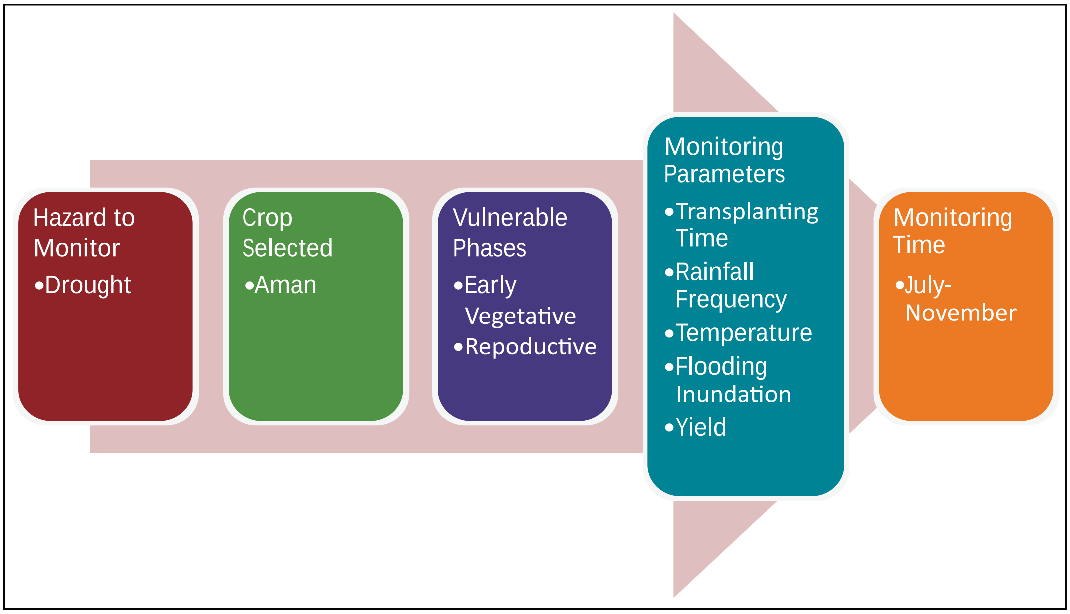


Figure 6.5: Steps for drought monitoring of Aman crop

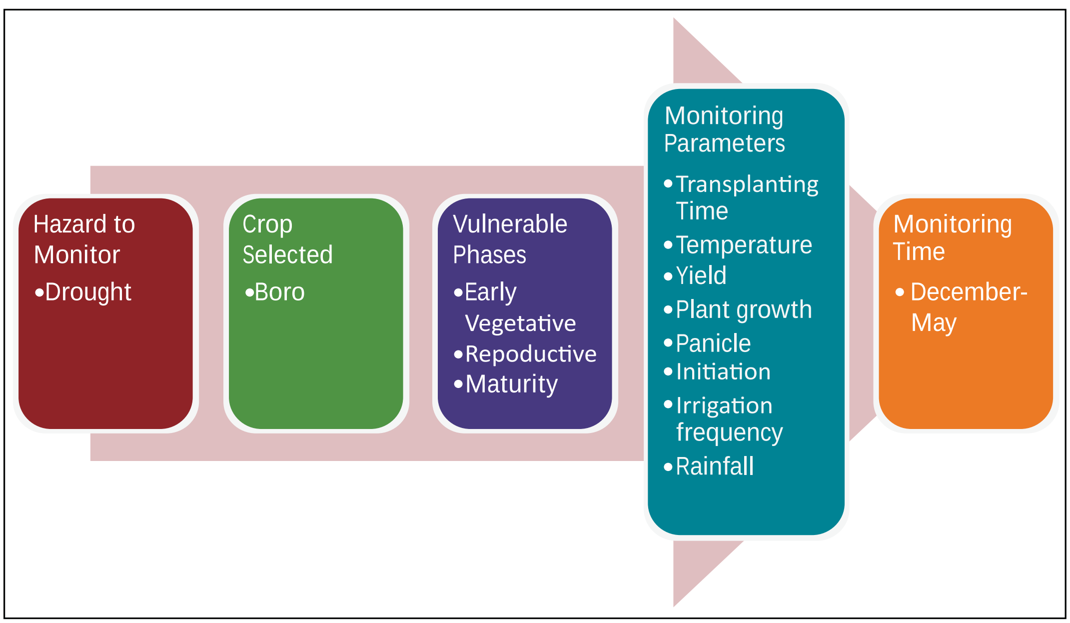


Figure 6.6: Steps for drought monitoring of Boro crop

6.3.3 Early Warning System

One of the main objectives of the Drought Monitoring Protocol is to establish a reliable early warning system. If a component of the early warning protocol is based on hydrological indicators, it will be easy to obtain and representative of the spatial and temporal situation of drought that allows drought on-set identification, control and assess their severity.

It is convenient that the indicators system is hydrological, so it can characterize hydrological droughts, because Drought Monitoring Protocol deals with the decision making process regarding the river basin water resources management under drought conditions. The indicators might be -

- Stored surface reservoir volumes
- Aquifer water levels
- River flows
- Reservoir outflows
- Precipitation

Indicators could be normalized in an appropriate threshold, e.g. from 0 to 1, to allow easy comparisons among different kind of indicators and the classification among severity drought categories.

This classification, and colour association, can be

- Normal status (green),
- Pre-alert status (yellow),
- Alert status (orange),
- Emergency or extreme status (red)

The data dissemination in community level can be effectively performed through use of existing latest and easily available technology like cellphone text message service. Based on the early warning component, data of drought prediction and risk will be processed in the central database of NDIS and zone specific information will be sent to community level via text message.

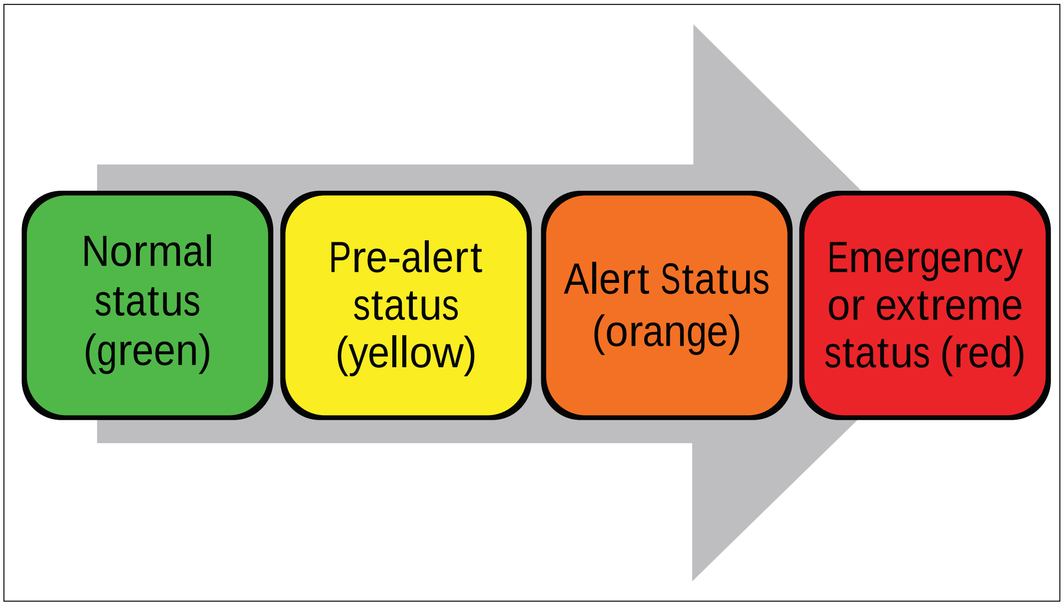


Figure 6.7: Proposed warning color codes of drought

Rationale for using a SMS (Short Message Service) based data dissemination service is based upon its -

- Availability: At present context, both cellphones and major cell operator's network coverage are easily available even in the remote rural areas
- Accessibility: People ranging from all stages of the society have access to cellphones
- Convenience: Cellphone SMS are cheap, easy to use and faster way of communicating in case of emergency drought response

The required technical components for establishing this data dissemination system can be -

- Dedicated SMS Gateway: A dedicated SMS gateway with legal and formal contract with a mobile operator
- Area Specific target Group Database: The target group in specific area (DAE officers, farmers) and their contact information database
- NDIS Database: The central drought information database of NDIS for data dissemination

CHAPTER 7

Conclusion

How drought can be linked with changing climate is a major finding of this study. A definition of drought is proposed also which touches the different facets of drought ranging from meteorological to hydrological to agricultural impact. Historical trend of drought in Bangladesh has also been studied to find a clear view of drought and its grasp over Bangladesh.

The changes in the climatic parameters predicted by IPCC have been reviewed and analyzed in the context of Bangladesh. MAGICC/SCENGEN has been used along with a simplified downscaling technique to produce outputs at 0.25° grid resolution of climatic parameters of year 2030 and 2050 in A2 and B1 SRES scenario.

In total 213 most vulnerable upazila have been identified in accordance to severity in different crop seasons to drought. Remote sensing analysis is done for further validation of the selected drought vulnerable areas by MODIS satellite image through VCI and NDVI analysis which helps in identifying the onset, magnitude and duration of drought for a specific year. The analysis finds 2001 as a drought year as it has a mean NDVI less than long term mean NDVI for dry season (January-May). SPI analysis is done to find the historical profile of drought. Through SPI analyses, it can be understood whether meteorological drought condition prevails over a region or not. The analyses have been done for all the BMD station from year 1979 to 2008. As this analysis is solely dependent upon rainfall hence the drought that may be confirmed from this analysis is meteorological drought. The analysis found that 1995-96 was the year when SPI value was below -2.00 (negative 2.00) in most of the BMD weather stations analyzed for rainfall which indicates severe meteorological drought. 1982, 1983, 1984, 1986, 1987, 1992, 1993, 1997, 1999, 2000, 2001, 2002, 2004, 2006 and 2008 have been found as drought years with SPI value ranging from 0 to -2.00 (i.e. mild to severe drought). A comparative assessment has been done in a smaller scale between SPI and remote sensing where it is found out that these two tools are complementary to each other in assessing drought.

DSSAT Cropping System Model is used to simulate future yield of year 2030 and 2050 for BR11, BR 14 and BRRI Dhan 29 in the hotspots. Weather data used are observed daily weather data (daily rainfall and daily maximum and minimum temperature) of the available years (1979-2008) of all the BMD weather stations within the perimeter of the specific upazila by delineating the effective zone in thissen polygon method. Soil data used are detailed soil data from SRDI (Soil Research Development Institute) upazila soil book. To get the future yield condition in changing climate, future weather data set were used without changing any other parameters like soil dataset, irrigation scheduling, and fertilizer application etc. The future climatic dataset is used from the MAGICC/SCENGEN projection of A2 and B1 scenario of year 2030 and 2050 at 0.25^0 grid resolution with base period from 1979-2008.

The model result suggests an overall decrease in yield ranging from less than 10% to greater than 40% from present yield condition in vulnerable hotspots for both A2 and B1 scenario in year 2030 and 2050 for BR 11 and BR 14. In case of BR 29, the reduction in yield from base period in year 2030 and 2050 for both the scenarios ranges from less than 10% yield reduction to 30-40% yield reduction.

In only a few cases yield has increased in future simulation. Further analysis with rainfall, temperature and CO_2 sensitivity might reveal the true reason behind it. As far drought is considered, much of the selected vulnerable hotspots would undergo through mild to severe drought according to the model simulation. The analysis was not done for 2100 as such analysis may not be appropriate in such distant time being as it cannot be predicted whether present land-use or cropping system will exist at that time. Yet again, even climatic conditions predicted for 2100 lack certainty.

A framework is proposed based on five key components which will act as an effective tool for designing integrated adaptation option menu in national level. The development of National Drought Information System (NDIS) will be a complete resource for adaptation related to drought, compiling trace of every individual adaptation tool, research, studies in agricultural field related to drought. It will also provide input and act as a catalyst for field-level demonstrations of viable adaptation options with potential to improve the capacity of rural livelihoods to adapt to climate change. The proposed NDIS will be an effective tool and the indicative methodology for the monitoring of drought under a monitoring protocol. One of the main objectives of the Drought Monitoring Protocol is establishing a reliable early warning system. The overall adaptation strategy focuses on minimizing the overall production risk or loss.

ANNEXURE A

Drought Vulnerable Hotspots

Table A-1: Selection of upazila according to drought vulnerability ranking

District	Upazilla	Rabi rank	Kharif -I rank	Kharif - II rank	Combined rank	Severity class	Severity rank
Bagerhat	Morrelganj		70		70	Very severe	37
Bagerhat	Bagerhat Sadar		94		94	Severe	66
Bagerhat	Kachua		102		102	Severe	78
Bagerhat	Rampal		112		112	Severe	93
Bagerhat	Mollahat			123	123	Severe	105
Barguna	Amtali	156			156	Moderate	128
Barguna	Betagi	114	107		221	Slight	181
Bogra	Kahaloo	20		55	75	Very severe	43
Bogra	Adamdighi	34	42	47	123	Severe	104
Bogra	Nandigram	17	118		135	Moderate	118
Bogra	Shajahanpur	118		44	162	Moderate	133
Bogra	Dhupchanchia	21	96	49	166	Moderate	139
Bogra	Sariakandi	166			166	Moderate	141
Bogra	Bogra Sadar	120		48	168	Moderate	146
Bogra	Sherpur	109		66	175	Moderate	154
Bogra	Dhunat	175			175	Moderate	155
Bogra	Shibganj	83	104	42	229	Slight	186
Chittagong	Chandanaish	67			67	Very severe	35
Chittagong	Boalkhali	80			80	Very severe	48
Chittagong	Patiya	84			84	Severe	54
Chittagong	Banshkhali	86			86	Severe	57
Chittagong	Mirsharai	99			99	Severe	72
Chittagong	Hathazari	119			119	Severe	100
Chittagong	Rangunia	123			123	Moderate	107
Chittagong	Fatikchhari	125			125	Moderate	109
Chittagong	Satkania	126			126	Moderate	111
Chittagong	Lohagara	129			129	Moderate	114
Chittagong	Chandgaon	147			147	Moderate	123
Chittagong	Chittagong Port	161			161	Moderate	132
Chittagong	Bakalia	164			164	Moderate	135
Chittagong	Sitakunda	66		99	165	Moderate	136
Chittagong	Raozan	167			167	Moderate	144
Chittagong	Patenga	140		71	211	Slight	174
Chuadanga	Jiban Nagar	117	6		123	Severe	106
Chuadanga	Damurhuda	75	56		131	Moderate	116
Chuadanga	Chuadanga Sadar	105	69		174	Moderate	152
Chuadanga	Alamdanga	101	76		177	Moderate	156
Cox's Bazar	Ramu	56			56	Very severe	22
Cox's Bazar	Chakaria	128			128	Moderate	112
Cox's Bazar	Pekua	174			174	Moderate	153
Cox's Bazar	Teknaf	52		128	180	Moderate	158
Cox's Bazar	Ukhia	64		118	182	Moderate	159
Cox's Bazar	Cox's Bazar Sadar	76		115	191	Slight	163
Cox's Bazar	Maheshkhali	93		101	194	Slight	165
Cox's Bazar	Kutubdia	133		89	222	Slight	182
Dinajpur	Hakimpur	18		12	30	Very severe	7

District	Upazilla	Rabi rank	Kharif-I rank	Kharif-II rank	Combined rank	Severity class	Severity rank
Dinajpur	Nawabganj	49		35	84	Very severe	52
Dinajpur	Ghoraghat	55		29	84	Severe	53
Dinajpur	Dinajpur Sadar	47	49	27	123	Severe	103
Dinajpur	Parbatipur	113		21	134	Moderate	117
Dinajpur	Biral	72	61	40	173	Moderate	151
Dinajpur	Chirirbandar	97	86	24	207	Slight	172
Dinajpur	Khansama	158		58	216	Slight	178
Dinajpur	Kaharole	98	99	45	242	Slight	194
Dinajpur	Bochaganj	131	89	63	283	Slight	201
Dinajpur	Birganj	142	111	46	299	Slight	205
Faridpur	Faridpur Sadar			104	104	Severe	84
Faridpur	Alfadanga		87	60	147	Moderate	122
Gaibandha	Sadullapur			68	68	Very severe	36
Gaibandha	Palashbari			120	120	Severe	101
Gaibandha	Gobindaganj	89		69	158	Moderate	130
Gopalganj	Gopalganj Sadar		108	76	184	Slight	161
Gopalganj	Kashiani		106	100	206	Slight	171
Jamalpur	Bakshiganj			105	105	Severe	85
Jamalpur	Jamalpur Sadar			116	116	Severe	98
Jamalpur	Sarishabari	173		129	302	Slight	207
Jessore	Sharsha	65	15		80	Very severe	47
Jessore	Abhaynagar		97		97	Severe	70
Jessore	Chaugachha	137	20		157	Moderate	129
Jessore	Jhikargachha	144	21		165	Moderate	137
Jessore	Kotwali	149	19		168	Moderate	147
Jessore	Bagher Para	162	51		213	Slight	176
Jessore	Keshabpur		105	112	217	Slight	179
Jessore	Manirampur	169	55		224	Slight	183
Jhenaidah	Shailkupa		77		77	Very severe	45
Jhenaidah	Maheshpur	91	10		101	Severe	75
Jhenaidah	Kotchandpur	95	17		112	Severe	94
Jhenaidah	Kaliganj	122	46		168	Moderate	148
Jhenaidah	Jhenaidah Sadar	150	44		194	Slight	166
Jhenaidah	Harinakunda	148	57		205	Slight	170
Joypurhat	Panchbibi	36		2	38	Very severe	10
Joypurhat	Khetlal	14	23	20	57	Very severe	25
Joypurhat	Kalai	3	52	7	62	Very severe	29
Joypurhat	Akkelpur	40	36	18	94	Severe	65
Joypurhat	Joypurhat Sadar	69	74	9	152	Moderate	125
Khulna	Dacope		85		85	Severe	55
Khulna	Terokhada		90		90	Severe	61
Khulna	Dighalia		101		101	Severe	76
Khulna	Batiaghata		113		113	Severe	96
Khulna	Koyra	155	78		233	Slight	189
Khulna	Dumuria	171	92		263	Slight	199
Khulna	Paikgachha	151	38	130	319	Slight	210
Kushtia	Daulatpur	57	30	80	167	Moderate	143
Kushtia	Bheramara	110	39	84	233	Slight	188
Kushtia	Mirpur	73	54	122	249	Slight	195
Kushtia	Kushtia Sadar	88	62	109	259	Slight	197

District	Upazilla	Rabi rank	Kharif -I rank	Kharif-II rank	Combined rank	Severity class	Severity rank
Kushtia	Kumarkhali	154	95	85	334	Slight	211
Magura	Magura Sadar		66		66	Very severe	32
Magura	Sreepur		83		83	Very severe	49
Magura	Shalikha	112	43		155	Moderate	127
Magura	Mohammadpur		91	97	188	Slight	162
Manikganj	Harirampur			111	111	Severe	92
Manikganj	Shibalaya			126	126	Moderate	110
Maulvibazar	Kamalganj	70			70	Very severe	38
Maulvibazar	Kulaura	79			79	Very severe	46
Maulvibazar	Juri	94			94	Severe	67
Maulvibazar	Sreemangal	100			100	Severe	74
Maulvibazar	Barlekha	103			103	Severe	81
Maulvibazar	Rajnagar	145			145	Moderate	121
Maulvibazar	Maulvibazar Sadar	152			152	Moderate	126
Meherpur	Meherpur Sadar	24	47		71	Very severe	39
Meherpur	Mujib Nagar	19	53		72	Very severe	41
Meherpur	Gangni	62	25		87	Severe	59
Mymensingh	Dhobaura	168			168	Moderate	149
Mymensingh	Haluaghat	170			170	Moderate	150
Naogaon	Niamatpur	7	5	3	15	Very severe	1
Naogaon	Porsha	4	3	16	23	Very severe	4
Naogaon	Sapahar	5	4	17	26	Very severe	5
Naogaon	Patnitala	12	18	1	31	Very severe	8
Naogaon	Mahadebpur	8	31	6	45	Very severe	13
Naogaon	Raninagar	1	12	41	54	Very severe	21
Naogaon	Manda	2	28	33	63	Very severe	30
Naogaon	Dhamoirhat	29	33	5	67	Very severe	34
Naogaon	Atrai	15	1	88	104	Severe	83
Naogaon	Naogaon Sadar	30	63	36	129	Moderate	113
Naogaon	Badalgachhi	87	68	13	168	Moderate	145
Narail	Narail Sadar		59		59	Very severe	27
Narail	Kalia		58	90	148	Moderate	124
Narail	Lohagara		73	93	166	Moderate	140
Natore	Baraigram	43	40		83	Very severe	51
Natore	Gurudaspur	45	45		90	Severe	62
Natore	Singra	23	71	119	213	Slight	175
Natore	Lalpur	107	60	75	242	Slight	193
Natore	Natore Sadar	81	64	110	255	Slight	196
Natore	Bagatipara	116	82	92	290	Slight	204
Nawabganj	Nachole	9	7	4	20	Very severe	3
Nawabganj	Shibganj	11	8	14	33	Very severe	9
Nawabganj	Gomastapur	16	9	22	47	Very severe	14
Nawabganj	Chapai Nababganj Sadar	22	16	19	57	Very severe	24
Nawabganj	Bholahat	10	26	28	64	Very severe	31
Netrakona	Kalmakanda			87	87	Severe	58
Netrakona	Durgapur	165			165	Moderate	138
Nilphamari	Kishoreganj			62	62	Very severe	28
Nilphamari	Nilphamari Sadar			67	67	Very severe	33

District	Upazilla	Rabi rank	Kharif-I rank	Kharif-II rank	Combined rank	Severity class	Severity rank
Nilphamari	Jaldhaka			106	106	Severe	87
Pabna	Sujanagar			74	74	Very severe	42
Pabna	Bera			91	91	Severe	63
Pabna	Santhia			102	102	Severe	77
Pabna	Faridpur		103		103	Severe	80
Pabna	Chatmohar	71	37		108	Severe	90
Pabna	Atgharia	132	50		182	Slight	160
Pabna	Bhangura	141	84		225	Slight	184
Pabna	Ishwardi	121	48	72	241	Slight	192
Pabna	Pabna Sadar	124	81	81	286	Slight	203
Panchagarh	Tentulia			53	53	Very severe	18
Panchagarh	Debiganj			57	57	Very severe	23
Panchagarh	Boda			95	95	Severe	68
Panchagarh	Panchagarh Sadar			103	103	Severe	79
Panchagarh	Atwari			107	107	Severe	88
Patuakhali	Patuakhali Sadar	163			163	Moderate	134
Patuakhali	Mirzaganj	115	116		231	Slight	187
Patuakhali	Kala Para	138	98	79	315	Slight	209
Patuakhali	Galachipa	130	117	127	374	Slight	213
Pirojpur	Zianagar		110		110	Severe	91
Rajbari	Goalanda			50	50	Very severe	16
Rajbari	Rajbari Sadar			86	86	Severe	56
Rajbari	Pangsha	172	88	78	338	Slight	212
Rajshahi	Tanore	6	2	11	19	Very severe	2
Rajshahi	Godagari	13	11	15	39	Very severe	12
Rajshahi	Shah Makhdum	25	13	10	48	Very severe	15
Rajshahi	Durgapur		29	25	54	Very severe	20
Rajshahi	Paba	42	24	23	89	Severe	60
Rajshahi	Mohanpur	26	14	64	104	Severe	82
Rajshahi	Puthia		72	34	106	Severe	86
Rajshahi	Bagha	92	35	32	159	Moderate	131
Rajshahi	Baghmara	63	22	82	167	Moderate	142
Rajshahi	Charghat	160	27	8	195	Slight	167
Rajshahi	Rajpara	106	79	56	241	Slight	191
Rajshahi	Matihar	134	75	52	261	Slight	198
Rajshahi	Boalia	136	93	73	302	Slight	206
Rangpur	Badarganj			39	39	Very severe	11
Rangpur	Mitha Pukur			51	51	Very severe	17
Rangpur	Rangpur Sadar			113	113	Severe	95
Rangpur	Taraganj			124	124	Moderate	108
Rangpur	Pirganj	143		37	180	Moderate	157
Satkhira	Assasuni	51	32		83	Very severe	50
Satkhira	Debhata	59	41		100	Severe	73
Satkhira	Kaliganj	77	65		142	Moderate	120
Satkhira	Shyamnagar	111	80		191	Slight	164
Satkhira	Tala	82	67	59	208	Slight	173
Satkhira	Kalaroa	135	100		235	Slight	190
Satkhira	Satkhira Sadar	108	34	132	274	Slight	200
Sherpur	Sreebardi			77	77	Very severe	44

District	Upazilla	Rabi rank	Kharif -I rank	Kharif-II rank	Combined rank	Severity class	Severity rank
Sirajganj	Chauhali			117	117	Severe	99
Sirajganj	Ullah Para	139			139	Moderate	119
Sirajganj	Royganj	127		70	197	Slight	169
Sirajganj	Tarash	39	115	65	219	Slight	180
Sirajganj	Kazipur	146		83	229	Slight	185
Tangail	Ghatail			98	98	Severe	71
Tangail	Madhupur			121	121	Severe	102
Tangail	Bhuapur			131	131	Moderate	115
Thakurgaon	Baliadangi			30	30	Very severe	6
Thakurgaon	Thakurgaon Sadar			54	54	Very severe	19
Thakurgaon	Ranisankail	159		38	197	Slight	168
Thakurgaon	Haripur	153		61	214	Slight	177
Thakurgaon	Pirganj	157	114	43	314	Slight	208

ANNEXURE B

Selected Screenshots of DSSAT

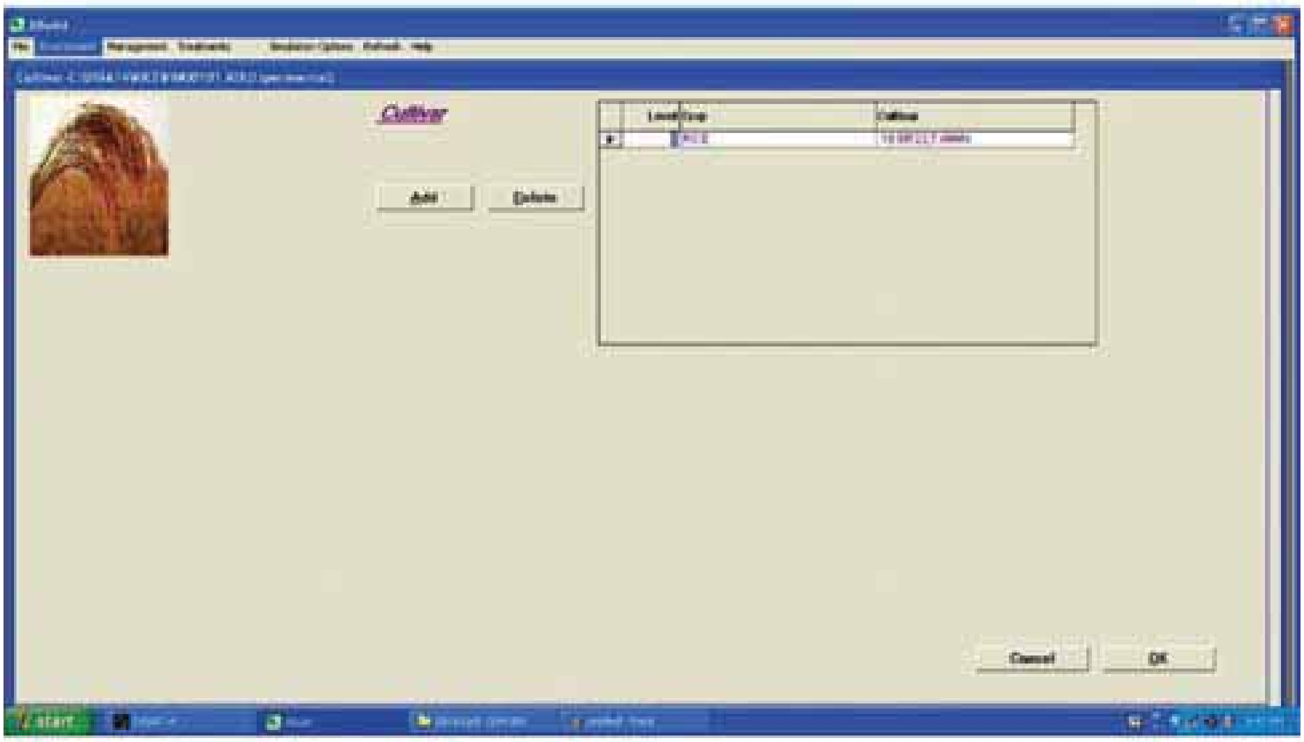


Figure 1: Cultivar selection window

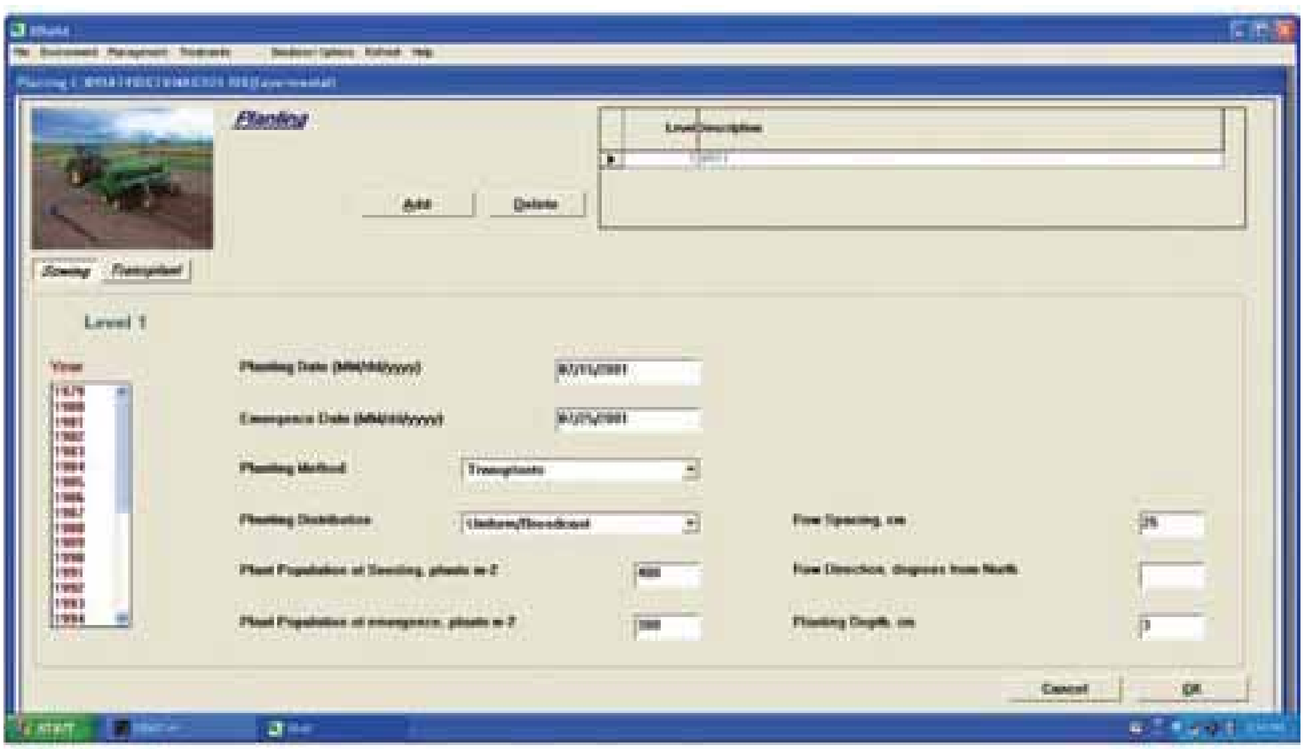


Figure 2: Planting method window

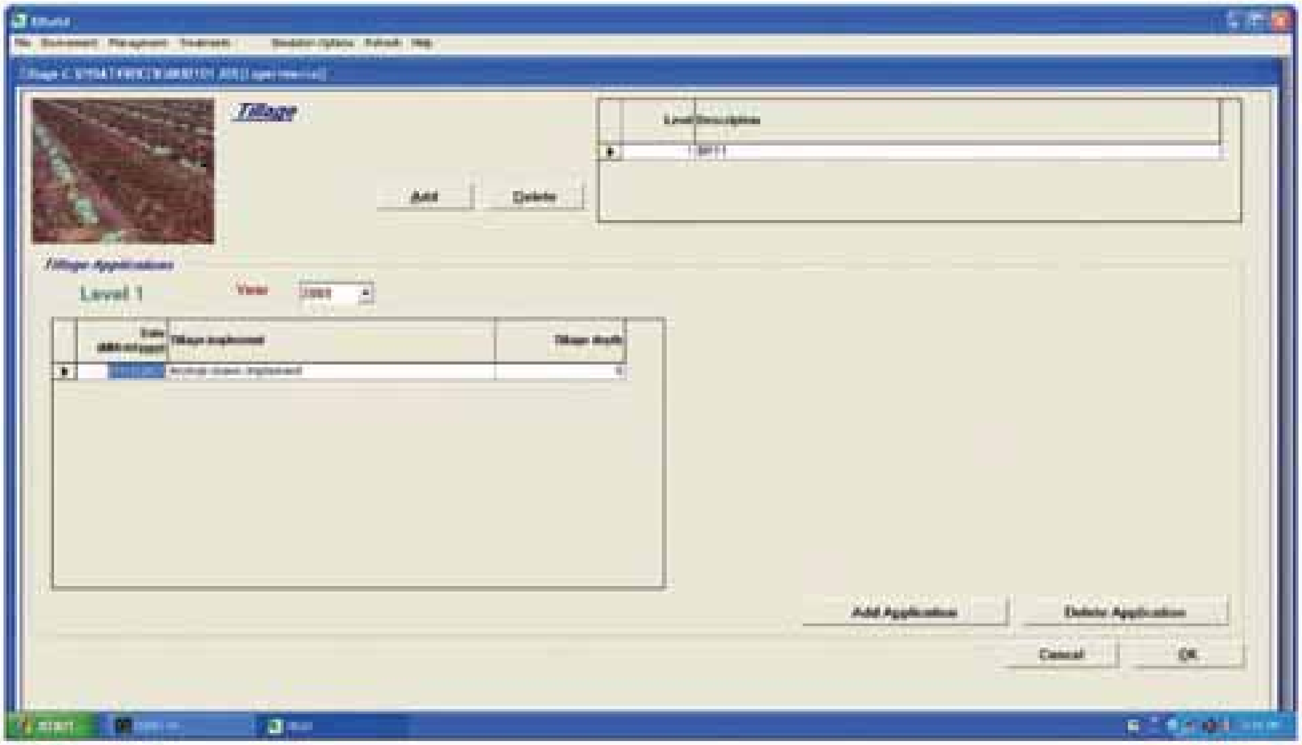


Figure 3: Tillage method window

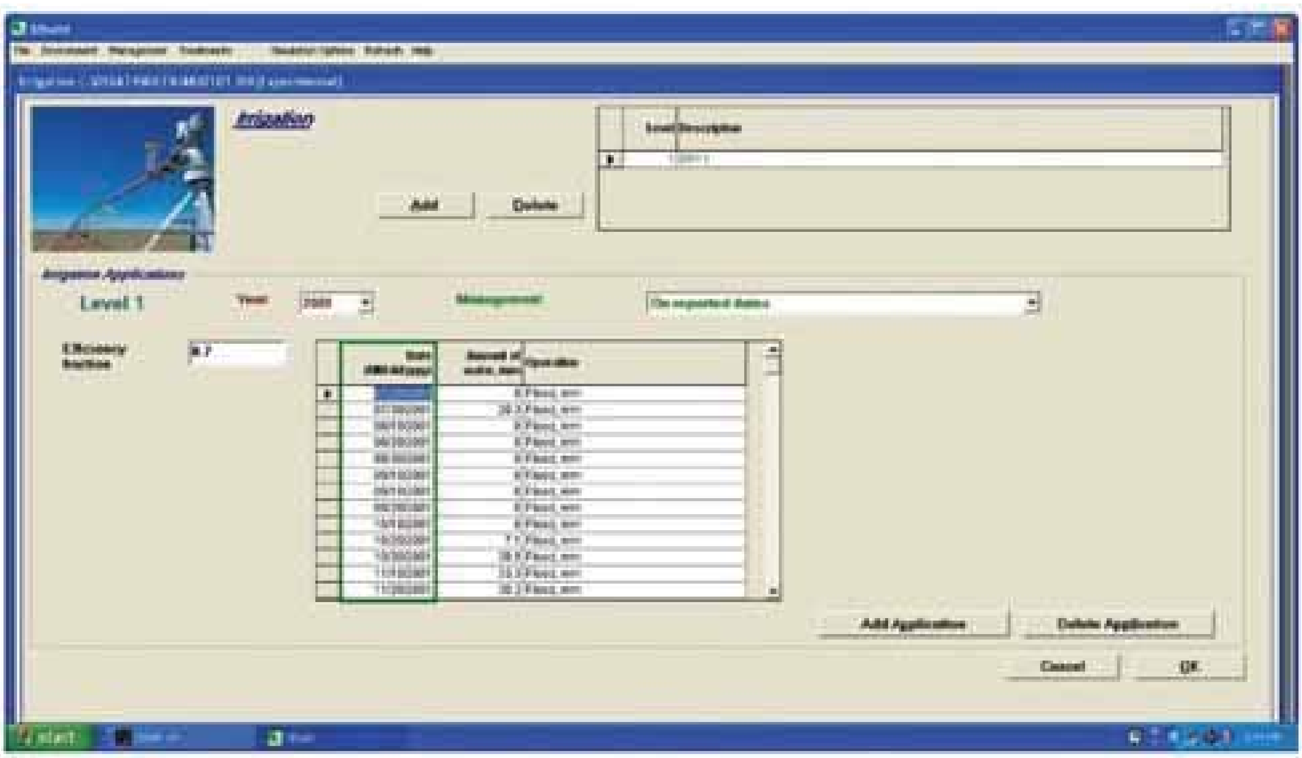


Figure 4: Irrigation method window

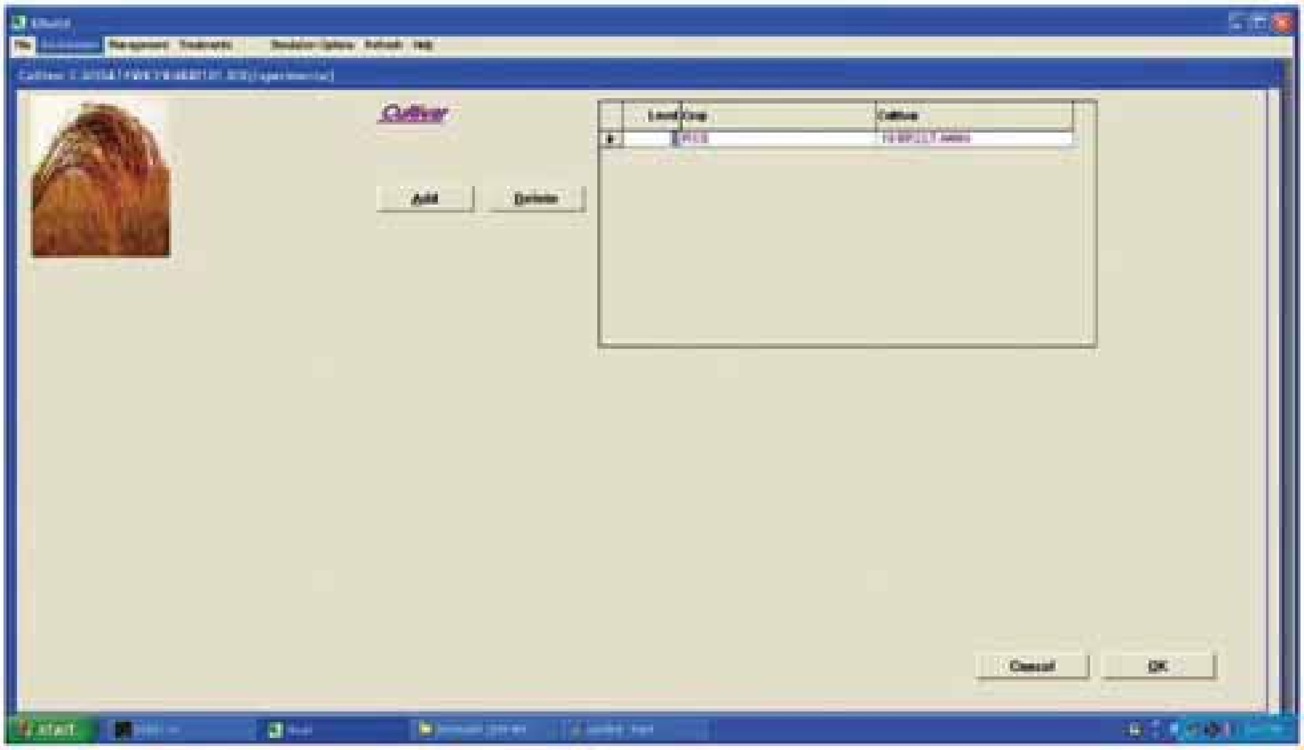


Figure 5: Fertilizer method window

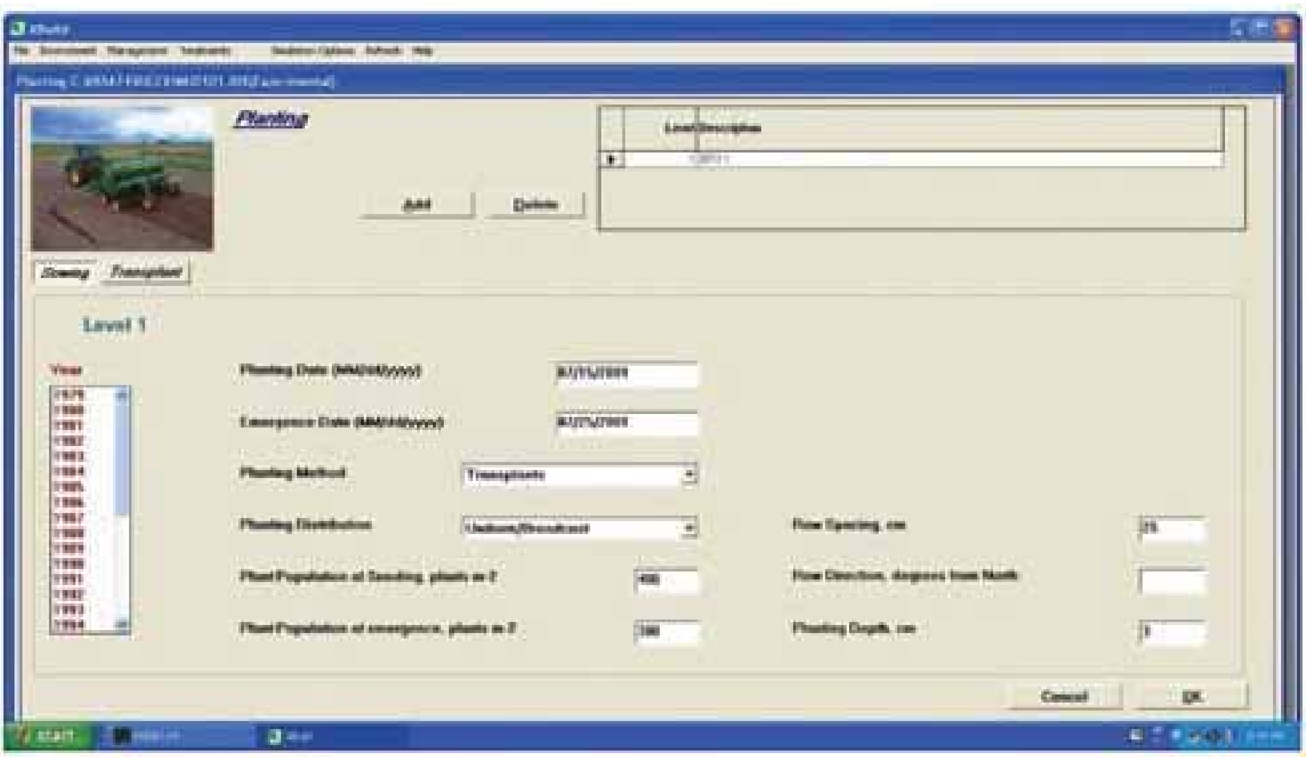


Figure 6: Pesticide method window

ANNEXURE C

Model Simulated Drought Vulnerability for BR 11 and BR 14 in 2030 and 2050 for A2 and B1 Scenario

Table C1: % Change in yield and drought severity for selected hotspots in A2 and B1 scenario for year 2030 and 2050 for BR 11 and BR 14

District	Upazilla	Scenario	Rice Variety	Yield Decrease	Drought Severity of Aman	Rice Variety	Yield Decrease	Drought Severity of Boro
Bagerhat	Kachua	A2(Year 2030)	Aman	<10%	Very Slight	Boro	0.00	No Drought Condition
Bagerhat	Kachua	A2(Year2050)	Aman	<10%	Very Slight	Boro	30-40%	Severe
Bagerhat	Kachua	B1(Year 2030)	Aman	<10%	Very Slight	Boro	0.00	No Drought Condition
Bagerhat	Kachua	B1(Year 2050)	Aman	<10%	Very Slight	Boro	0.00	No Drought Condition
Bagerhat	Mollahat	A2(Year 2030)	Aman	0.00	No Drought Condition	Boro	>40%	Very Severe
Bagerhat	Mollahat	A2(Year 2050)	Aman	0.00	No Drought Condition	Boro	>40%	Very Severe
Bagerhat	Mollahat	B1(Year 2030)	Aman	0.00	No Drought Condition	Boro	<10%	Very Slight
Bagerhat	Mollahat	B1(Year 2050)	Aman	0.00	No Drought Condition	Boro	10-20%	Slight
Bagerhat	Morrelganj	A2(Year 2030)	Aman	0.00	No Drought Condition	Boro	0.00	No Drought Condition
Bagerhat	Morrelganj	A2(Year 2050)	Aman	0.00	No Drought Condition	Boro	0.00	No Drought Condition
Bagerhat	Morrelganj	B1(Year 2030)	Aman	<10%	Very Slight	Boro	0.00	No Drought Condition
Bagerhat	Morrelganj	B1(Year 2050)	Aman	<10%	Very Slight	Boro	0.00	No Drought Condition
Bagerhat	Rampal	A2(Year 2030)	Aman	0.00	No Drought Condition	Boro	0.00	No Drought Condition
Bagerhat	Rampal	A2(Year 2050)	Aman	0.00	No Drought Condition	Boro	0.00	No Drought Condition
Bagerhat	Rampal	B1(Year 2030)	Aman	0.00	No Drought Condition	Boro	0.00	No Drought Condition
Bagerhat	Rampal	B1(Year 2050)	Aman	0.00	No Drought Condition	Boro	0.00	No Drought Condition
Barguna	Amtali	A2(Year 2030)	Aman	0.00	No Drought Condition	Boro	0.00	No Drought Condition
Barguna	Amtali	A2(Year 2050)	Aman	10-20%	Slight	Boro	0.00	No Drought Condition
Barguna	Amtali	B1(Year 2030)	Aman	10-20%	Slight	Boro	>40%	Very Severe
Barguna	Amtali	B1(Year 2050)	Aman	<10%	Very Slight	Boro	20-30%	Moderate
Bogra	Adamdighi	A2(Year 2030)	Aman	0.00	No Drought Condition	Boro	0.00	No Drought Condition
Bogra	Adamdighi	A2(Year 2050)	Aman	0.00	No Drought Condition	Boro	0.00	No Drought Condition
Bogra	Adamdighi	B1(Year 2030)	Aman	0.00	No Drought Condition	Boro	0.00	No Drought Condition
Bogra	Adamdighi	B1(Year 2050)	Aman	0.00	No Drought Condition	Boro	0.00	No Drought Condition

District	Upazilla	Scenario	Rice Variety	Yield Decrease	Drought Severity of Aman	Rice Variety	Yield Decrease	Drought Severity of Boro
Kushtia	Mirpur	B1(Year 2030)	Aman	<10%	Very Slight	Boro	0.00	No Drought Condition
Kushtia	Mirpur	B1(Year 2050)	Aman	10-20%	Slight	Boro	0.00	No Drought Condition
Magura	Mohammadpur	A2(Year 2030)	Aman	0.00	No Drought Condition	Boro	0.00	No Drought Condition
Magura	Mohammadpur	A2(Year 2050)	Aman	<10%	Very Slight	Boro	0.00	No Drought Condition
Magura	Mohammadpur	B1(Year 2030)	Aman	<10%	Very Slight	Boro	0.00	No Drought Condition
Magura	Mohammadpur	B1(Year 2050)	Aman	<10%	Very Slight	Boro	0.00	No Drought Condition
Magura	Shalikha	A2(Year 2030)	Aman	0.00	No Drought Condition	Boro	10-20%	Slight
Magura	Shalikha	A2(Year 2050)	Aman	0.00	No Drought Condition	Boro	10-20%	Slight
Magura	Shalikha	B1(Year 2030)	Aman	<10%	Very Slight	Boro	0.00	No Drought Condition
Magura	Shalikha	B1(Year 2050)	Aman	0.00	No Drought Condition	Boro	0.00	No Drought Condition
Magura	Sreepur	A2(Year 2030)	Aman	0.00	No Drought Condition	Boro	>40%	Very Severe
Magura	Sreepur	A2(Year 2050)	Aman	0.00	No Drought Condition	Boro	0.00	No Drought Condition
Magura	Sreepur	B1(Year 2030)	Aman	0.00	No Drought Condition	Boro	>40%	Very Severe
Magura	Sreepur	B1(Year 2050)	Aman	0.00	No Drought Condition	Boro	0.00	No Drought Condition
Manikganj	Harirampur	A2(Year 2030)	Aman	0.00	No Drought Condition	Boro	0.00	No Drought Condition
Manikganj	Harirampur	A2(Year 2050)	Aman	<10%	Very Slight	Boro	0.00	No Drought Condition
Manikganj	Harirampur	B1(Year 2030)	Aman	0.00	No Drought Condition	Boro	0.00	No Drought Condition
Manikganj	Harirampur	B1(Year 2050)	Aman	<10%	Very Slight	Boro	0.00	No Drought Condition
Manikganj	Shiblaya	A2(Year 2030)	Aman	0.00	No Drought Condition	Boro	0.00	No Drought Condition
Manikganj	Shiblaya	A2(Year 2050)	Aman	<10%	Very Slight	Boro	0.00	No Drought Condition
Manikganj	Shiblaya	B1(Year 2030)	Aman	0.00	No Drought Condition	Boro	0.00	No Drought Condition
Manikganj	Shiblaya	B1(Year 2050)	Aman	<10%	Very Slight	Boro	0.00	No Drought Condition
Maulvibazar	Baralekha	A2(Year 2030)	Aman	0.00	No Drought Condition	Boro	10-20%	Slight
Maulvibazar	Baralekha	A2(Year 2050)	Aman	0.00	No Drought Condition	Boro	10-20%	Slight
Maulvibazar	Baralekha	B1(Year 2030)	Aman	>40%	Very Severe	Boro	<10%	Very Slight
Maulvibazar	Baralekha	B1(Year 2050)	Aman	>40%	Very Severe	Boro	10-20%	Slight
Maulvibazar	Juri	A2(Year 2030)	Aman	30-40%	Severe	Boro	0.00	No Drought Condition

District	Upazilla	Scenario	Rice Variety	Yield Decrease	Drought Severity of Aman	Rice Variety	Yield Decrease	Drought Severity of Boro
Maulvibazar	Juri	A2(Year2050)	Aman	0.00	No Drought Condition	Boro	0.00	No Drought Condition
Maulvibazar	Juri	B1(Year 2030)	Aman	>40%	Very Severe	Boro	0.00	No Drought Condition
Maulvibazar	Juri	B1(Year 2050)	Aman	>40%	Very Severe	Boro	0.00	No Drought Condition
Maulvibazar	Kamalganj	A2(Year 2030)	Aman	0.00	No Drought Condition	Boro	0.00	No Drought Condition
Maulvibazar	Kamalganj	A2(Year 2050)	Aman	0.00	No Drought Condition	Boro	0.00	No Drought Condition
Maulvibazar	Kamalganj	B1(Year 2030)	Aman	>40%	Very Severe	Boro	0.00	No Drought Condition
Maulvibazar	Kamalganj	B1(Year 2050)	Aman	0.00	No Drought Condition	Boro	0.00	No Drought Condition
Maulvibazar	Kulaura	A2(Year 2030)	Aman	0.00	No Drought Condition	Boro	0.00	No Drought Condition
Maulvibazar	Kulaura	A2(Year 2050)	Aman	0.00	No Drought Condition	Boro	0.00	No Drought Condition
Maulvibazar	Kulaura	B1(Year 2030)	Aman	0.00	No Drought Condition	Boro	0.00	No Drought Condition
Maulvibazar	Kulaura	B1(Year 2050)	Aman	0.00	No Drought Condition	Boro	0.00	No Drought Condition
Maulvibazar	Maulovibazar Sadar	A2(Year 2030)	Aman	0.00	No Drought Condition	Boro	0.00	No Drought Condition
Maulvibazar	Maulovibazar Sadar	A2(Year 2050)	Aman	0.00	No Drought Condition	Boro	0.00	No Drought Condition
Maulvibazar	Maulovibazar Sadar	B1(Year2030)	Aman	>40%	Very Severe	Boro	0.00	No Drought Condition
Maulvibazar	Maulovibazar Sadar	B1(Year 2050)	Aman	0.00	No Drought Condition	Boro	0.00	No Drought Condition
Maulvibazar	Rajnagar	A2(Year 2030)	Aman	<10%	Very Slight	Boro	0.00	No Drought Condition
Maulvibazar	Rajnagar	A2(Year 2050)	Aman	<10%	Very Slight	Boro	0.00	No Drought Condition
Maulvibazar	Rajnagar	B1(Year 2030)	Aman	<10%	Very Slight	Boro	0.00	No Drought Condition
Maulvibazar	Rajnagar	B1(Year 2050)	Aman	10-20%	Slight	Boro	0.00	No Drought Condition
Maulvibazar	Sreemangal	A2(Year 2030)	Aman	0.00	No Drought Condition	Boro	0.00	No Drought Condition
Maulvibazar	Sreemangal	A2(Year 2050)	Aman	0.00	No Drought Condition	Boro	0.00	No Drought Condition
Maulvibazar	Sreemangal	B1(Year 2030)	Aman	>40%	Very Severe	Boro	0.00	No Drought Condition
Maulvibazar	Sreemangal	B1(Year 2050)	Aman	0.00	No Drought Condition	Boro	0.00	No Drought Condition
Meherpur	Gangni	A2(Year 2030)	Aman	<10%	Very Slight	Boro	10-20%	Slight

District	Upazilla	Scenario	Rice Variety	Yield Decrease	Drought Severity of Aman	Rice Variety	Yield Decrease	Drought Severity of Boro
Meherpur	Gangni	A2(Year 2050)	Aman	10-20%	Slight	Boro	10-20%	Slight
Meherpur	Gangni	B1(Year 2030)	Aman	<10%	Very Slight	Boro	<10%	Very Slight
Meherpur	Gangni	B1(Year 2050)	Aman	<10%	Very Slight	Boro	10-20%	Slight
Meherpur	Meherpur Sadar	A2(Year 2030)	Aman	<10%	Very Slight	Boro	0.00	No Drought Condition
Meherpur	Meherpur Sadar	A2(Year 2050)	Aman	10-20%	Slight	Boro	0.00	No Drought Condition
Meherpur	Meherpur Sadar	B1(Year 2030)	Aman	<10%	Very Slight	Boro	0.00	No Drought Condition
Meherpur	Meherpur Sadar	B1(Year 2050)	Aman	10-20%	Slight	Boro	0.00	No Drought Condition
Naogaon	Atrai	A2(Year 2030)	Aman	0.00	No Drought Condition	Boro	10-20%	Slight
Naogaon	Atrai	A2(Year 2050)	Aman	0.00	No Drought Condition	Boro	10-20%	Slight
Naogaon	Atrai	B1(Year 2030)	Aman	0.00	No Drought Condition	Boro	10-20%	Slight
Naogaon	Atrai	B1(Year 2050)	Aman	0.00	No Drought Condition	Boro	30-40%	Severe
Naogaon	Badlagachi	A2(Year 2030)	Aman	0.00	No Drought Condition	Boro	0.00	No Drought Condition
Naogaon	Badlagachi	A2(Year 2050)	Aman	<10%	Very Slight	Boro	0.00	No Drought Condition
Naogaon	Badlagachi	B1(Year 2030)	Aman	0.00	No Drought Condition	Boro	0.00	No Drought Condition
Naogaon	Badlagachi	B1(Year 2050)	Aman	0.00	No Drought Condition	Boro	0.00	No Drought Condition
Naogaon	Dhamoirhat	A2(Year 2030)	Aman	<10%	Very Slight	Boro	0.00	No Drought Condition
Naogaon	Dhamoirhat	A2(Year 2050)	Aman	0.00	No Drought Condition	Boro	0.00	No Drought Condition
Naogaon	Dhamoirhat	B1(Year 2030)	Aman	0.00	No Drought Condition	Boro	0.00	No Drought Condition
Naogaon	Dhamoirhat	B1(Year 2050)	Aman	0.00	No Drought Condition	Boro	0.00	No Drought Condition
Naogaon	Mahadebpur	A2(Year 2030)	Aman	0.00	No Drought Condition	Boro	0.00	No Drought Condition
Naogaon	Mahadebpur	A2(Year 2050)	Aman	0.00	No Drought Condition	Boro	0.00	No Drought Condition
Naogaon	Mahadebpur	B1(Year 2030)	Aman	0.00	No Drought Condition	Boro	0.00	No Drought Condition
Naogaon	Mahadebpur	B1(Year 2050)	Aman	0.00	No Drought Condition	Boro	0.00	No Drought Condition
Naogaon	Manda	A2(Year 2030)	Aman	<10%	Very Slight	Boro	0.00	No Drought Condition
Naogaon	Manda	A2(Year 2050)	Aman	<10%	Very Slight	Boro	0.00	No Drought Condition
Naogaon	Manda	B1(Year 2030)	Aman	<10%	Very Slight	Boro	0.00	No Drought Condition
Naogaon	Manda	B1(Year 2050)	Aman	<10%	Very Slight	Boro	0.00	No Drought Condition

District	Upazilla	Scenario	Rice Variety	Yield Decrease	Drought Severity of Aman	Rice Variety	Yield Decrease	Drought Severity of Boro
Naogaon	Naogaon Sadar	A2(Year 2030)	Aman	0.00	No Drought Condition	Boro	10-20%	Slight
Naogaon	Naogaon Sadar	A2(Year 2050)	Aman	0.00	No Drought Condition	Boro	20-30%	Moderate
Naogaon	Naogaon Sadar	B1(Year 2030)	Aman	0.00	No Drought Condition	Boro	<10%	Very Slight
Naogaon	Naogaon Sadar	B1(Year 2050)	Aman	0.00	No Drought Condition	Boro	20-30%	Moderate
Naogaon	Niamatpur	A2(Year 2030)	Aman	<10%	Very Slight	Boro	0.00	No Drought Condition
Naogaon	Niamatpur	A2(Year 2050)	Aman	<10%	Very Slight	Boro	0.00	No Drought Condition
Naogaon	Niamatpur	B1(Year 2030)	Aman	<10%	Very Slight	Boro	0.00	No Drought Condition
Naogaon	Niamatpur	B1(Year 2050)	Aman	<10%	Very Slight	Boro	0.00	No Drought Condition
Naogaon	Patnitola	A2(Year 2030)	Aman	0.00	No Drought Condition	Boro	0.00	No Drought Condition
Naogaon	Patnitola	A2(Year 2050)	Aman	0.00	No Drought Condition	Boro	>40%	Very Severe
Naogaon	Patnitola	B1(Year 2030)	Aman	0.00	No Drought Condition	Boro	0.00	No Drought Condition
Naogaon	Patnitola	B1(Year 2050)	Aman	0.00	No Drought Condition	Boro	>40%	Very Severe
Naogaon	Porsha	A2(Year 2030)	Aman	<10%	Very Slight	Boro	0.00	No Drought Condition
Naogaon	Porsha	A2(Year 2050)	Aman	<10%	Very Slight	Boro	0.00	No Drought Condition
Naogaon	Porsha	B1(Year 2030)	Aman	<10%	Very Slight	Boro	0.00	No Drought Condition
Naogaon	Porsha	B1(Year 2050)	Aman	<10%	Very Slight	Boro	0.00	No Drought Condition
Naogaon	Sapahar	A2(Year 2030)	Aman	<10%	Very Slight	Boro	0.00	No Drought Condition
Naogaon	Sapahar	A2(Year 2050)	Aman	<10%	Very Slight	Boro	0.00	No Drought Condition
Naogaon	Sapahar	B1(Year 2030)	Aman	0.00	No Drought Condition	Boro	0.00	No Drought Condition
Naogaon	Sapahar	B1(Year 2050)	Aman	<10%	Very Slight	Boro	0.00	No Drought Condition
Natore	Bagatipara	A2(Year 2030)	Aman	<10%	Very Slight	Boro	<10%	Very Slight
Natore	Bagatipara	A2(Year 2050)	Aman	10-20%	Slight	Boro	<10%	Very Slight
Natore	Bagatipara	B1(Year 2030)	Aman	<10%	Very Slight	Boro	<10%	Very Slight
Natore	Bagatipara	B1(Year2050)	Aman	<10%	Very Slight	Boro	0.00	No Drought Condition
Natore	Baraigram	A2(Year 2030)	Aman	<10%	Very Slight	Boro	<10%	Very Slight
Natore	Baraigram	A2(Year 2050)	Aman	10-20%	Slight	Boro	<10%	Very Slight
Natore	Baraigram	B1(Year 2030)	Aman	<10%	Very Slight	Boro	<10%	Very Slight

District	Upazilla	Scenario	Rice Variety	Yield Decrease	Drought Severity of Aman	Rice Variety	Yield Decrease	Drought Severity of Boro
Natore	Baraigram	B1(Year 2050)	Aman	<10%	Very Slight	Boro	<10%	Very Slight
Natore	Gurudaspur	A2(Year 2030)	Aman	0.00	No Drought Condition	Boro	0.00	No Drought Condition
Natore	Gurudaspur	A2(Year 2050)	Aman	0.00	No Drought Condition	Boro	0.00	No Drought Condition
Natore	Gurudaspur	B1(Year 2030)	Aman	0.00	No Drought Condition	Boro	0.00	No Drought Condition
Natore	Gurudaspur	B1(Year 2050)	Aman	0.00	No Drought Condition	Boro	0.00	No Drought Condition
Natore	Lalpur	A2(Year2030)	Aman	0.00	No Drought Condition	Boro	10-20%	Slight
Natore	Lalpur	A2(Year 2050)	Aman	0.00	No Drought Condition	Boro	20-30%	Moderate
Natore	Lalpur	B1(Year 2030)	Aman	0.00	No Drought Condition	Boro	10-20%	Slight
Natore	Lalpur	B1(Year 2050)	Aman	0.00	No Drought Condition	Boro	20-30%	Moderate
Nawabganj	Bholahat	A2(Year 2030)	Aman	<10%	Very Slight	Boro	20-30%	Moderate
Nawabganj	Bholahat	A2(Year 2050)	Aman	<10%	Very Slight	Boro	20-30%	Moderate
Nawabganj	Bholahat	B1(Year 2030)	Aman	<10%	Very Slight	Boro	10-20%	Slight
Nawabganj	Chapainababganj Sadar	A2(Year 2030)	Aman	0.00	No Drought Condition	Boro	0.00	No Drought Condition
Nawabganj	Chapainababganj Sadar	A2(Year 2050)	Aman	0.00	No Drought Condition	Boro	0.00	No Drought Condition
Nawabganj	Chapainababganj Sadar	B1(Year 2030)	Aman	0.00	No Drought Condition	Boro	0.00	No Drought Condition
Nawabganj	Chapainababganj Sadar	B1(Year 2050)	Aman	0.00	No Drought Condition	Boro	0.00	No Drought Condition
Nawabganj	Gomostapur	A2(Year 2030)	Aman	<10%	Very Slight	Boro	>40%	Very Severe
Nawabganj	Gomostapur	A2(Year 2050)	Aman	<10%	Very Slight	Boro	30-40%	Severe
Nawabganj	Gomostapur	B1(Year 2030)	Aman	0.00	No Drought Condition	Boro	30-40%	Severe
Nawabganj	Gomostapur	B1(Year 2050)	Aman	0.00	No Drought Condition	Boro	30-40%	Severe
Nawabganj	Nachole	A2(Year 2030)	Aman	<10%	Very Slight	Boro	0.00	No Drought Condition
Nawabganj	Nachole	A2(Year 2050)	Aman	<10%	Very Slight	Boro	0.00	No Drought Condition

District	Upazilla	Scenario	Rice Variety	Yield Decrease	Drought Severity of Aman	Rice Variety	Yield Decrease	Drought Severity of Boro
Nawabganj	Nachole	B1(Year 2030)	Aman	<10%	Very Slight	Boro	0.00	No Drought Condition
Nawabganj	Nachole	B1(Year 2050)	Aman	0.00	No Drought Condition	Boro	0.00	No Drought Condition
Nawabganj	Shibganj	A2(Year 2030)	Aman	0.00	No Drought Condition	Boro	0.00	No Drought Condition
Nawabganj	Shibganj	A2(Year 2050)	Aman	0.00	No Drought Condition	Boro	<10%	Very Slight
Nawabganj	Shibganj	B1(Year 2030)	Aman	0.00	No Drought Condition	Boro	10-20%	Slight
Nawabganj	Shibganj	B1(Year 2050)	Aman	0.00	No Drought Condition	Boro	30-40%	Severe
Netrakona	Durgapur	A2(Year 2030)	Aman	0.00	No Drought Condition	Boro	0.00	No Drought Condition
Netrakona	Durgapur	A2(Year 2050)	Aman	0.00	No Drought Condition	Boro	0.00	No Drought Condition
Netrakona	Durgapur	B1(Year 2030)	Aman	0.00	No Drought Condition	Boro	<10%	Very Slight
Netrakona	Durgapur	B1(Year 2050)	Aman	0.00	No Drought Condition	Boro	0.00	No Drought Condition
Nilphamari	Domar	A2(Year 2030)	Aman	0.00	No Drought Condition	Boro	0.00	No Drought Condition
Nilphamari	Domar	A2(Year 2050)	Aman	0.00	No Drought Condition	Boro	>40%	Very Severe
Nilphamari	Domar	B1(Year 2030)	Aman	0.00	No Drought Condition	Boro	0.00	No Drought Condition
Nilphamari	Domar	B1(Year 2050)	Aman	0.00	No Drought Condition	Boro	20-30%	Moderate
Nilphamari	Jaldhaka	A2(Year 2030)	Aman	0.00	No Drought Condition	Boro	0.00	No Drought Condition
Nilphamari	Jaldhaka	A2(Year 2050)	Aman	0.00	No Drought Condition	Boro	>40%	Very Severe
Nilphamari	Jaldhaka	B1(Year 2030)	Aman	0.00	No Drought Condition	Boro	0.00	No Drought Condition
Nilphamari	Jaldhaka	B1(Year 2050)	Aman	0.00	No Drought Condition	Boro	30-40%	Severe
Nilphamari	Kishoreganj	A2(Year 2030)	Aman	0.00	No Drought Condition	Boro	0.00	No Drought Condition
Nilphamari	Kishoreganj	A2(Year 2050)	Aman	0.00	No Drought Condition	Boro	>40%	Very Severe
Nilphamari	Kishoreganj	B1(Year 2030)	Aman	0.00	No Drought Condition	Boro	0.00	No Drought Condition
Nilphamari	Kishoreganj	B1(Year 2050)	Aman	0.00	No Drought Condition	Boro	30-40%	Severe
Nilphamari	Nilphamary Sadar	A2(Year 2030)	Aman	0.00	No Drought Condition	Boro	0.00	No Drought Condition
Nilphamari	Nilphamary Sadar	A2(Year 2050)	Aman	0.00	No Drought Condition	Boro	>40%	Very Severe
Nilphamari	Nilphamary Sadar	B1(Year 2030)	Aman	0.00	No Drought Condition	Boro	0.00	No Drought Condition

District	Upazilla	Scenario	Rice Variety	Yield Decrease	Drought Severity of Aman	Rice Variety	Yield Decrease	Drought Severity of Boro
Nilphamari	Nilphamari Sadar	B1(Year 2050)	Aman	0.00	No Drought Condition	Boro	20-30%	Moderate
Pabna	Atgharia	A2(Year 2030)	Aman	0.00	No Drought Condition	Boro	0.00	No Drought Condition
Pabna	Atgharia	A2(Year 2050)	Aman	<10%	Very Slight	Boro	0.00	No Drought Condition
Pabna	Atgharia	B1(Year 2030)	Aman	<10%	Very Slight	Boro	<10%	Very Slight
Pabna	Atgharia	B1(Year 2050)	Aman	<10%	Very Slight	Boro	0.00	No Drought Condition
Pabna	Bera	A2(Year 2030)	Aman	<10%	Very Slight	Boro	<10%	Very Slight
Pabna	Bera	A2(Year 2050)	Aman	<10%	Very Slight	Boro	>40%	Very Severe
Pabna	Bera	B1(Year 2030)	Aman	<10%	Very Slight	Boro	10-20%	Slight
Pabna	Bera	B1(Year 2050)	Aman	<10%	Very Slight	Boro	20-30%	Moderate
Pabna	Faridpur	A2(Year 2030)	Aman	<10%	Very Slight	Boro	20-30%	Moderate
Pabna	Faridpur	A2(Year 2050)	Aman	10-20%	Slight	Boro	10-20%	Slight
Pabna	Faridpur	B1(Year 2030)	Aman	0.00	No Drought Condition	Boro	0.00	No Drought Condition
Pabna	Faridpur	B1(Year 2050)	Aman	10-20%	Slight	Boro	<10%	Very Slight
Pabna	Ishwardi	A2(Year 2030)	Aman	<10%	Very Slight	Boro	<10%	Very Slight
Pabna	Ishwardi	A2(Year 2050)	Aman	10-20%	Slight	Boro	10-20%	Slight
Pabna	Ishwardi	B1(Year 2030)	Aman	<10%	Very Slight	Boro	<10%	Very Slight
Pabna	Ishwardi	B1(Year 2050)	Aman	<10%	Very Slight	Boro	<10%	Very Slight
Pabna	Pabna Sadar	A2(Year 2030)	Aman	<10%	Very Slight	Boro	<10%	Very Slight
Pabna	Pabna Sadar	A2(Year 2050)	Aman	<10%	Very Slight	Boro	<10%	Very Slight
Pabna	Pabna Sadar	B1(Year2030)	Aman	<10%	Very Slight	Boro	<10%	Very Slight
Pabna	Pabna Sadar	B1(Year 2050)	Aman	0.00	No Drought Condition	Boro	0.00	No Drought Condition
Pabna	Sathia	A2(Year 2030)	Aman	<10%	Very Slight	Boro	0.00	No Drought Condition
Pabna	Sathia	A2(Year 2050)	Aman	<10%	Very Slight	Boro	0.00	No Drought Condition
Pabna	Sathia	B1(Year 2030)	Aman	10-20%	Slight	Boro	0.00	No Drought Condition
Pabna	Sathia	B1(Year 2050)	Aman	<10%	Very Slight	Boro	0.00	No Drought Condition
Panchagarh	Atwari	A2(Year 2030)	Aman	<10%	Very Slight	Boro	<10%	Very Slight

District	Upazilla	Scenario	Rice Variety	Yield Decrease	Drought Severity of Aman	Rice Variety	Yield Decrease	Drought Severity of Boro
Panchagarh	Atwari	A2(Year 2050)	Aman	0.00	No Drought Condition	Boro	<10%	Very Slight
Panchagarh	Atwari	B1(Year 2030)	Aman	0.00	No Drought Condition	Boro	<10%	Very Slight
Panchagarh	Atwari	B1(Year 2050)	Aman	0.00	No Drought Condition	Boro	10-20%	Slight
Panchagarh	Boda	A2(Year 2030)	Aman	0.00	No Drought Condition	Boro	0.00	No Drought Condition
Panchagarh	Boda	A2(Year 2050)	Aman	0.00	No Drought Condition	Boro	>40%	Very Severe
Panchagarh	Boda	B1(Year 2030)	Aman	0.00	No Drought Condition	Boro	>40%	Very Severe
Panchagarh	Boda	B1(Year 2050)	Aman	0.00	No Drought Condition	Boro	>40%	Very Severe
Panchagarh	Debiganj	A2(Year 2030)	Aman	>40%	Very Severe	Boro	>40%	Very Severe
Panchagarh	Debiganj	A2(Year 2050)	Aman	>40%	Very Severe	Boro	20-30%	Moderate
Panchagarh	Debiganj	B1(Year 2030)	Aman	>40%	Very Severe	Boro	30-40%	Severe
Panchagarh	Debiganj	B1(Year 2050)	Aman	>40%	Very Severe	Boro	20-30%	Moderate
Panchagarh	Tetulia	A2(Year 2030)	Aman	0.00	No Drought Condition	Boro	>40%	Very Severe
Panchagarh	Tetulia	A2(Year 2050)	Aman	0.00	No Drought Condition	Boro	>40%	Very Severe
Panchagarh	Tetulia	B1(Year 2030)	Aman	0.00	No Drought Condition	Boro	30-40%	Severe
Panchagarh	Tetulia	B1(Year 2050)	Aman	0.00	No Drought Condition	Boro	>40%	Very Severe
Patuakhali	Galachipa	A2(Year 2030)	Aman	<10%	Very Slight	Boro	0.00	No Drought Condition
Patuakhali	Galachipa	A2(Year 2050)	Aman	<10%	Very Slight	Boro	<10%	Very Slight
Patuakhali	Galachipa	B1(Year 2030)	Aman	<10%	Very Slight	Boro	0.00	No Drought Condition
Patuakhali	Galachipa	B1(Year 2050)	Aman	<10%	Very Slight	Boro	<10%	Very Slight
Patuakhali	Kalapara	A2(Year 2030)	Aman	<10%	Very Slight	Boro	10-20%	Slight
Patuakhali	Kalapara	A2(Year 2050)	Aman	<10%	Very Slight	Boro	>40%	Very Severe
Patuakhali	Kalapara	B1(Year 2030)	Aman	<10%	Very Slight	Boro	0.00	No Drought Condition
Patuakhali	Kalapara	B1(Year 2050)	Aman	10-20%	Slight	Boro	0.00	No Drought Condition
Patuakhali	Mirzagonj	A2(Year 2030)	Aman	0.00	No Drought Condition	Boro	>40%	Very Severe
Patuakhali	Mirzagonj	A2(Year 2050)	Aman	0.00	No Drought Condition	Boro	>40%	Very Severe
Patuakhali	Mirzagonj	B1(Year 2030)	Aman	10-20%	Slight	Boro	30-40%	Severe
Patuakhali	Mirzagonj	B1(Year 2050)	Aman	0.00	No Drought Condition	Boro	>40%	Very Severe

District	Upazilla	Scenario	Rice Variety	Yield Decrease	Drought Severity of Aman	Rice Variety	Yield Decrease	Drought Severity of Boro
Patuakhali	Patuakhali Sadar	A2(Year 2030)	Aman	0.00	No Drought Condition	Boro	>40%	Very Severe
Patuakhali	Patuakhali Sadar	A2(Year 2050)	Aman	0.00	No Drought Condition	Boro	>40%	Very Severe
Patuakhali	Patuakhali Sadar	B1(Year 2030)	Aman	<10%	Very Slight	Boro	0.00	No Drought Condition
Patuakhali	Patuakhali Sadar	B1(Year 2050)	Aman	0.00	No Drought Condition	Boro	0.00	No Drought Condition
Pirozpur	Zianagar	A2(Year 2030)	Aman	0.00	No Drought Condition	Boro	20-30%	Moderate
Pirozpur	Zianagar	A2(Year2050)	Aman	0.00	No Drought Condition	Boro	10-20%	Slight
Pirozpur	Zianagar	B1(Year 2030)	Aman	<10%	Very Slight	Boro	0.00	No Drought Condition
Pirozpur	Zianagar	B1(Year 2050)	Aman	0.00	No Drought Condition	Boro	20-30%	Moderate
Rajbari	Goalanda	A2(Year2030)	Aman	<10%	Very Slight	Boro	>40%	Very Severe
Rajbari	Goalanda	A2(Year 2050)	Aman	<10%	Very Slight	Boro	30-40%	Severe
Rajbari	Goalanda	B1(Year 2030)	Aman	<10%	Very Slight	Boro	>40%	Very Severe
Rajbari	Goalanda	B1(Year 2050)	Aman	<10%	Very Slight	Boro	>40%	Very Severe
Rajbari	Rajbari Sadar	A2(Year 2030)	Aman	<10%	Very Slight	Boro	20-30%	Moderate
Rajbari	Rajbari Sadar	A2(Year 2050)	Aman	0.00	No Drought Condition	Boro	20-30%	Moderate
Rajbari	Rajbari Sadar	B1(Year 2030)	Aman	<10%	Very Slight	Boro	20-30%	Moderate
Rajbari	Rajbari Sadar	B1(Year 2050)	Aman	<10%	Very Slight	Boro	>40%	Very Severe
Rajshahi	Bagha	A2(Year 2030)	Aman	<10%	Very Slight	Boro	<10%	Very Slight
Rajshahi	Bagha	A2(Year 2050)	Aman	0.00	No Drought Condition	Boro	<10%	Very Slight
Rajshahi	Bagha	B1(Year 2030)	Aman	<10%	Very Slight	Boro	<10%	Very Slight
Rajshahi	Bagha	B1(Year 2050)	Aman	<10%	Very Slight	Boro	<10%	Very Slight
Rajshahi	Baghmara	A2(Year 2030)	Aman	0.00	No Drought Condition	Boro	20-30%	Moderate
Rajshahi	Baghmara	A2(Year 2050)	Aman	0.00	No Drought Condition	Boro	20-30%	Moderate
Rajshahi	Baghmara	B1(Year 2030)	Aman	0.00	No Drought Condition	Boro	20-30%	Moderate
Rajshahi	Baghmara	B1(Year 2050)	Aman	0.00	No Drought Condition	Boro	>40%	Very Severe
Rajshahi	Charghat	A2(Year 2030)	Aman	0.00	No Drought Condition	Boro	0.00	No Drought Condition
Rajshahi	Charghat	A2(Year 2050)	Aman	0.00	No Drought Condition	Boro	0.00	No Drought Condition
Rajshahi	Charghat	B1(Year 2030)	Aman	0.00	No Drought Condition	Boro	0.00	No Drought Condition

District	Upazilla	Scenario	Rice Variety	Yield Decrease	Drought Severity of Aman	Rice Variety	Yield Decrease	Drought Severity of Boro
Rajshahi	Charghat	B1(Year 2050)	Aman	0.00	No Drought Condition	Boro	0.00	No Drought Condition
Rajshahi	Mohanpur	A2(Year 2030)	Aman	<10%	Very Slight	Boro	>40%	Very Severe
Rajshahi	Mohanpur	A2(Year 2050)	Aman	<10%	Very Slight	Boro	>40%	Very Severe
Rajshahi	Mohanpur	B1(Year 2030)	Aman	<10%	Very Slight	Boro	>40%	Very Severe
Rajshahi	Mohanpur	B1(Year 2050)	Aman	0.00	No Drought Condition	Boro	>40%	Very Severe
Rajshahi	Paba	A2(Year 2030)	Aman	0.00	No Drought Condition	Boro	0.00	No Drought Condition
Rajshahi	Paba	A2(Year 2050)	Aman	0.00	No Drought Condition	Boro	>40%	Very Severe
Rajshahi	Paba	B1(Year 2030)	Aman	0.00	No Drought Condition	Boro	>40%	Very Severe
Rajshahi	Paba	B1(Year 2050)	Aman	0.00	No Drought Condition	Boro	>40%	Very Severe
Rajshahi	Puthia	A2(Year 2030)	Aman	<10%	Very Slight	Boro	30-40%	Severe
Rajshahi	Puthia	A2(Year 2050)	Aman	<10%	Very Slight	Boro	30-40%	Severe
Rajshahi	Puthia	B1(Year 2030)	Aman	0.00	No Drought Condition	Boro	20-30%	Moderate
Rajshahi	Puthia	B1(Year 2050)	Aman	0.00	No Drought Condition	Boro	20-30%	Moderate
Rajshahi	Tanore	A2(Year 2030)	Aman	<10%	Very Slight	Boro	0.00	No Drought Condition
Rajshahi	Tanore	A2(Year 2050)	Aman	<10%	Very Slight	Boro	0.00	No Drought Condition
Rajshahi	Tanore	B1(Year 2030)	Aman	<10%	Very Slight	Boro	0.00	No Drought Condition
Rajshahi	Tanore	B1(Year 2050)	Aman	0.00	No Drought Condition	Boro	0.00	No Drought Condition
Rangpur	Badarganj	A2(Year 2030)	Aman	<10%	Very Slight	Boro	10-20%	Slight
Rangpur	Badarganj	A2(Year 2050)	Aman	0.00	No Drought Condition	Boro	20-30%	Moderate
Rangpur	Badarganj	B1(Year 2030)	Aman	0.00	No Drought Condition	Boro	>40%	Very Severe
Rangpur	Badarganj	B1(Year 2050)	Aman	0.00	No Drought Condition	Boro	20-30%	Moderate
Rangpur	Mithapukur	A2(Year 2030)	Aman	0.00	No Drought Condition	Boro	0.00	No Drought Condition
Rangpur	Mithapukur	A2(Year 2050)	Aman	0.00	No Drought Condition	Boro	>40%	Very Severe
Rangpur	Mithapukur	B1(Year 2030)	Aman	0.00	No Drought Condition	Boro	0.00	No Drought Condition
Rangpur	Mithapukur	B1(Year 2050)	Aman	0.00	No Drought Condition	Boro	30-40%	Severe
Rangpur	Pirganj	A2(Year 2030)	Aman	0.00	No Drought Condition	Boro	0.00	No Drought Condition
Rangpur	Pirganj	A2(Year 2050)	Aman	>40%	Very Severe	Boro	0.00	No Drought Condition

District	Upazilla	Scenario	Rice Variety	Yield Decrease	Drought Severity of Aman	Rice Variety	Yield Decrease	Drought Severity of Boro
Bogra	Bogra Sadar	A2(Year 2030)	Aman	0.00	No Drought Condition	Boro	<10%	Very Slight
Bogra	Bogra Sadar	A2(Year 2050)	Aman	0.00	No Drought Condition	Boro	<10%	Very Slight
Bogra	Bogra Sadar	B1(Year 2030)	Aman	0.00	No Drought Condition	Boro	<10%	Very Slight
Bogra	Bogra Sadar	B1(Year 2050)	Aman	0.00	No Drought Condition	Boro	<10%	Very Slight
Bogra	Dhunat	A2(Year 2030)	Aman	0.00	No Drought Condition	Boro	0.00	No Drought Condition
Bogra	Dhunat	A2(Year 2050)	Aman	<10%	Very Slight	Boro	0.00	No Drought Condition
Bogra	Dhunat	B1(Year 2030)	Aman	0.00	No Drought Condition	Boro	0.00	No Drought Condition
Bogra	Dhunat	B1(Year 2050)	Aman	<10%	Very Slight	Boro	0.00	No Drought Condition
Bogra	Dhupchachia	A2(Year 2030)	Aman	<10%	Very Slight	Boro	0.00	No Drought Condition
Bogra	Dhupchachia	A2(Yea2050)	Aman	<10%	Very Slight	Boro	0.00	No Drought Condition
Bogra	Dhupchachia	B1(Year 2030)	Aman	0.00	No Drought Condition	Boro	0.00	No Drought Condition
Bogra	Dhupchachia	B1(Year 2050)	Aman	0.00	No Drought Condition	Boro	0.00	No Drought Condition
Bogra	Kahaloo	A2(Year 2030)	Aman	0.00	No Drought Condition	Boro	0.00	No Drought Condition
Bogra	Kahaloo	A2(Year 2050)	Aman	<10%	Very Slight	Boro	0.00	No Drought Condition
Bogra	Kahaloo	B1(Year 2030)	Aman	<10%	Very Slight	Boro	0.00	No Drought Condition
Bogra	Kahaloo	B1(Year 2050)	Aman	0.00	No Drought Condition	Boro	0.00	No Drought Condition
Bogra	Nandigram	A2(Year 2030)	Aman	0.00	No Drought Condition	Boro	0.00	No Drought Condition
Bogra	Nandigram	A2(Year 2050)	Aman	<10%	Very Slight	Boro	0.00	No Drought Condition
Bogra	Nandigram	B1(Year 2030)	Aman	<10%	Very Slight	Boro	0.00	No Drought Condition
Bogra	Nandigram	B1(Year 2050)	Aman	<10%	Very Slight	Boro	0.00	No Drought Condition
Bogra	Sariakandi	A2(Year 2030)	Aman	0.00	No Drought Condition	Boro	0.00	No Drought Condition
Bogra	Sariakandi	A2(Year 2050)	Aman	0.00	No Drought Condition	Boro	0.00	No Drought Condition
Bogra	Sariakandi	B1(Year 2030)	Aman	0.00	No Drought Condition	Boro	0.00	No Drought Condition
Bogra	Sariakandi	B1(Year 2050)	Aman	0.00	NoDrought Condition	Boro	0.00	No Drought Condition
Bogra	Sherpur	A2(Year 2030)	Aman	0.00	No Drought Condition	Boro	0.00	No Drought Condition
Bogra	Sherpur	A2(Year 2050)	Aman	0.00	No Drought Condition	Boro	0.00	No Drought Condition
Bogra	Sherpur	B1(Year 2030)	Aman	0.00	No Drought Condition	Boro	0.00	No Drought Condition

District	Upazilla	Scenario	Rice Variety	Yield Decrease	Drought Severity of Aman	Rice Variety	Yield Decrease	Drought Severity of Boro
Rangpur	Pirganj	B1(Year 2030)	Aman	>40%	Very Severe	Boro	0.00	No Drought Condition
Rangpur	Pirganj	B1(Year 2050)	Aman	>40%	Very Severe	Boro	0.00	No Drought Condition
Rangpur	Rangpur Sadar	A2(Year 2030)	Aman	>40%	Very Severe	Boro	<10%	Very Slight
Rangpur	Rangpur Sadar	A2(Year 2050)	Aman	>40%	Very Severe	Boro	0.00	No Drought Condition
Rangpur	Rangpur Sadar	B1(Year 2030)	Aman	>40%	Very Severe	Boro	<10%	Very Slight
Rangpur	Rangpur Sadar	B1(Year 2050)	Aman	>40%	Very Severe	Boro	<10%	Very Slight
Rangpur	Taraganj	A2(Year 2030)	Aman	0.00	No Drought Condition	Boro	20-30%	Moderate
Rangpur	Taraganj	A2(Year 2050)	Aman	0.00	No Drought Condition	Boro	>40%	Very Severe
Rangpur	Taraganj	B1(Year 2030)	Aman	0.00	No Drought Condition	Boro	20-30%	Moderate
Rangpur	Taraganj	B1(Year 2050)	Aman	0.00	No Drought Condition	Boro	0.00	No Drought Condition
Sirajganj	Chawhali	A2(Year 2030)	Aman	<10%	Very Slight	Boro	0.00	No Drought Condition
Sirajganj	Chawhali	A2(Year 2050)	Aman	<10%	Very Slight	Boro	0.00	No Drought Condition
Sirajganj	Chawhali	B1(Year 2030)	Aman	0.00	No Drought Condition	Boro	0.00	No Drought Condition
Sirajganj	Chawhali	B1(Year 2050)	Aman	<10%	Very Slight	Boro	0.00	No Drought Condition
Sirajganj	Royganj	A2(Year 2030)	Aman	>40%	Very Severe	Boro	0.00	No Drought Condition
Sirajganj	Royganj	A2(Year 2050)	Aman	>40%	Very Severe	Boro	0.00	No Drought Condition
Sirajganj	Royganj	B1(Year 2030)	Aman	>40%	Very Severe	Boro	0.00	No Drought Condition
Sirajganj	Royganj	B1(Year 2050)	Aman	>40%	Very Severe	Boro	0.00	No Drought Condition
Sirajganj	Shahjadpur	A2(Year 2030)	Aman	0.00	No Drought Condition	Boro	0.00	No Drought Condition
Sirajganj	Shahjadpur	A2(Year 2050)	Aman	<10%	Very Slight	Boro	0.00	No Drought Condition
Sirajganj	Shahjadpur	B1(Year 2030)	Aman	0.00	No Drought Condition	Boro	0.00	No Drought Condition
Sirajganj	Shahjadpur	B1(Year 2050)	Aman	<10%	Very Slight	Boro	<10%	Very Slight
Sirajganj	Ullahpara	A2(Year 2030)	Aman	10-20%	Slight	Boro	0.00	No Drought Condition
Sirajganj	Ullahpara	A2(Year 2050)	Aman	10-20%	Slight	Boro	0.00	No Drought Condition
Sirajganj	Ullahpara	B1(Year 2030)	Aman	10-20%	Slight	Boro	0.00	No Drought Condition
Sirajganj	Ullahpara	B1(Year 2050)	Aman	20-30%	Moderate	Boro	0.00	No Drought Condition
Sirajganj	Kazipur	A2(Year 2030)	Aman	0.00	No Drought Condition	Boro	0.00	No Drought Condition

District	Upazilla	Scenario	Rice Variety	Yield Decrease	Drought Severity of Aman	Rice Variety	Yield Decrease	Drought Severity of Boro
Sirajganj	Kazipur	A2(Year 2050)	Aman	0.00	No Drought Condition	Boro	0.00	No Drought Condition
Sirajganj	Kazipur	B1(Year 2030)	Aman	0.00	No Drought Condition	Boro	0.00	No Drought Condition
Sirajganj	Kazipur	B1(Year 2050)	Aman	0.00	No Drought Condition	Boro	0.00	No Drought Condition
Tangail	Bhuapur	A2(Year 2030)	Aman	0.00	No Drought Condition	Boro	0.00	No Drought Condition
Tangail	Bhuapur	A2(Year 2050)	Aman	<10%	Very Slight	Boro	0.00	No Drought Condition
Tangail	Bhuapur	B1(Year 2030)	Aman	<10%	Very Slight	Boro	0.00	No Drought Condition
Tangail	Bhuapur	B1(Year 2050)	Aman	<10%	Very Slight	Boro	0.00	No Drought Condition
Tangail	Ghatail	A2(Year 2030)	Aman	0.00	No Drought Condition	Boro	0.00	No Drought Condition
Tangail	Ghatail	A2(Year 2050)	Aman	<10%	Very Slight	Boro	0.00	No Drought Condition
Tangail	Ghatail	B1(Year 2030)	Aman	<10%	Very Slight	Boro	0.00	No Drought Condition
Tangail	Ghatail	B1(Year 2050)	Aman	<10%	Very Slight	Boro	0.00	No Drought Condition
Thakurgaon	Baliadangi	A2(Year 2030)	Aman	0.00	No Drought Condition	Boro	0.00	No Drought Condition
Thakurgaon	Baliadangi	A2(Year 2050)	Aman	>40%	Very Severe	Boro	0.00	No Drought Condition
Thakurgaon	Baliadangi	B1(Year 2030)	Aman	0.00	No Drought Condition	Boro	0.00	No Drought Condition
Thakurgaon	Baliadangi	B1(Year 2050)	Aman	>40%	Very Severe	Boro	0.00	No Drought Condition
Thakurgaon	Haripur	A2(Year 2030)	Aman	0.00	No Drought Condition	Boro	10-20%	Slight
Thakurgaon	Haripur	A2(Year 2050)	Aman	0.00	No Drought Condition	Boro	<10%	Very Slight
Thakurgaon	Haripur	B1(Year 2030)	Aman	0.00	No Drought Condition	Boro	30-40%	Severe
Thakurgaon	Haripur	B1(Year 2050)	Aman	0.00	No Drought Condition	Boro	20-30%	Moderate
Thakurgaon	Pirganj	A2(Year 2030)	Aman	>40%	Very Severe	Boro	20-30%	Moderate
Thakurgaon	Pirganj	A2(Year 2050)	Aman	>40%	Very Severe	Boro	<10%	Very Slight
Thakurgaon	Pirganj	B1(Year 2030)	Aman	>40%	Very Severe	Boro	30-40%	Severe
Thakurgaon	Pirganj	B1(Year 2050)	Aman	>40%	Very Severe	Boro	20-30%	Moderate
Thakurgaon	Ranisankail	A2(Year 2030)	Aman	>40%	Very Severe	Boro	>40%	Very Severe
Thakurgaon	Ranisankail	A2(Year 2050)	Aman	30-40%	Severe	Boro	30-40%	Severe
Thakurgaon	Ranisankail	B1(Year2030)	Aman	>40%	Very Severe	Boro	30-40%	Severe
Thakurgaon	Ranisankail	B1(Year 2050)	Aman	30-40%	Severe	Boro	30-40%	Severe
Thakurgaon	Thakurgaon Sadar	A2(Year 2030)	Aman	0.00	No Drought Condition	Boro	>40%	Very Severe
Thakurgaon	Thakurgaon Sadar	A2(Year 2050)	Aman	0.00	No Drought Condition	Boro	30-40%	Severe
Thakurgaon	Thakurgaon Sadar	B1(Year 2030)	Aman	0.00	No Drought Condition	Boro	>40%	Very Severe
Thakurgaon	Thakurgaon Sadar	B1(Year 2050)	Aman	0.00	No Drought Condition	Boro	30-40%	Severe

District	Upazilla	Scenario	Rice Variety	Yield Decrease	Drought Severity of Aman	Rice Variety	Yield Decrease	Drought Severity of Boro
Bogra	Sherpur	B1(Year 2050)	Aman	0.00	No Drought Condition	Boro	0.00	No Drought Condition
Bogra	Shibganj	A2(Year 2030)	Aman	0.00	No Drought Condition	Boro	0.00	No Drought Condition
Bogra	Shibganj	A2(Year 2050)	Aman	0.00	No Drought Condition	Boro	0.00	No Drought Condition
Bogra	Shibganj	B1(Year 2030)	Aman	0.00	No Drought Condition	Boro	0.00	No Drought Condition
Bogra	Shibganj	B1(Year 2050)	Aman	0.00	No Drought Condition	Boro	0.00	No Drought Condition
Chittagong	Fatikchari	A2(Year 2030)	Aman	0.00	No Drought Condition	Boro	<10%	Very Slight
Chittagong	Fatikchari	A2(Year 2050)	Aman	<10%	Very Slight	Boro	0.00	No Drought Condition
Chittagong	Fatikchari	B1(Year 2030)	Aman	<10%	Very Slight	Boro	10-20%	Slight
Chittagong	Fatikchari	B1(Year 2050)	Aman	<10%	Very Slight	Boro	<10%	Very Slight
Chittagong	Hathazari	A2(Year 2030)	Aman	<10%	Very Slight	Boro	0.00	No Drought Condition
Chittagong	Hathazari	A2(Year 2050)	Aman	0.00	No Drought Condition	Boro	>40%	Very Severe
Chittagong	Hathazari	B1(Year 2030)	Aman	<10%	Very Slight	Boro	0.00	No Drought Condition
Chittagong	Hathazari	B1(Year 2050)	Aman	0.00	No Drought Condition	Boro	>40%	Very Severe
Chittagong	Mirshharai	A2(Year 2030)	Aman	0.00	No Drought Condition	Boro	<10%	Very Slight
Chittagong	Mirshharai	A2(Year 2050)	Aman	10-20%	Slight	Boro	0.00	No Drought Condition
Chittagong	Mirshharai	B1(Year 2030)	Aman	<10%	Very Slight	Boro	0.00	No Drought Condition
Chittagong	Mirshharai	B1(Year 2050)	Aman	10-20%	Slight	Boro	>40%	Very Severe
Chittagong	Rauzan	A2(Year 2030)	Aman	<10%	Very Slight	Boro	<10%	Very Slight
Chittagong	Rauzan	A2(Year 2050)	Aman	10-20%	Slight	Boro	0.00	No Drought Condition
Chittagong	Rauzan	B1(Year 2030)	Aman	10-20%	Slight	Boro	<10%	Very Slight
Chittagong	Rauzan	B1(Year 2050)	Aman	<10%	Very Slight	Boro	<10%	Very Slight
Chittagong	Sitakunda	A2(Year 2030)	Aman	0.00	No Drought Condition	Boro	>40%	Very Severe
Chittagong	Sitakunda	A2(Year 2050)	Aman	<10%	Very Slight	Boro	10-20%	Slight
Chittagong	Sitakunda	B1(Year 2030)	Aman	<10%	Very Slight	Boro	20-30%	Moderate
Chittagong	Sitakunda	B1(Year 2050)	Aman	0.00	No Drought Condition	Boro	10-20%	Slight
Chuadanga	Alamdanga	A2(Year 2030)	Aman	<10%	Very Slight	Boro	0.00	No Drought Condition
Chuadanga	Alamdanga	A2(Year 2050)	Aman	<10%	Very Slight	Boro	0.00	No Drought Condition

District	Upazilla	Scenario	Rice Variety	Yield Decrease	Drought Severity of Aman	Rice Variety	Yield Decrease	Drought Severity of Boro
Chuadanga	Alamdanga	B1(Year 2030)	Aman	<10%	Very Slight	Boro	0.00	No Drought Condition
Chuadanga	Alamdanga	B1(Year 2050)	Aman	0.00	No Drought Condition	Boro	0.00	No Drought Condition
Chuadanga	Chudanga Sadar	A2(Year 2030)	Aman	0.00	No Drought Condition	Boro	0.00	No Drought Condition
Chuadanga	Chudanga Sadar	A2(Year 2050)	Aman	0.00	No Drought Condition	Boro	0.00	No Drought Condition
Chuadanga	Chudanga Sadar	B1(Year 2030)	Aman	0.00	No Drought Condition	Boro	0.00	No Drought Condition
Chuadanga	Chudanga Sadar	B1(Year 2050)	Aman	0.00	No Drought Condition	Boro	0.00	No Drought Condition
Chuadanga	Damurhuda	A2(Year 2030)	Aman	0.00	No Drought Condition	Boro	0.00	No Drought Condition
Chuadanga	Damurhuda	A2(Year 2050)	Aman	0.00	No Drought Condition	Boro	0.00	No Drought Condition
Chuadanga	Damurhuda	B1(Year 2030)	Aman	0.00	No Drought Condition	Boro	0.00	No Drought Condition
Chuadanga	Damurhuda	B1(Year 2050)	Aman	0.00	No Drought Condition	Boro	0.00	No Drought Condition
Chuadanga	Jibonnagar	A2(Year 2030)	Aman	0.00	No Drought Condition	Boro	0.00	No Drought Condition
Chuadanga	Jibonnagar	A2(Year 2050)	Aman	0.00	No Drought Condition	Boro	0.00	No Drought Condition
Chuadanga	Jibonnagar	B1(Year 2030)	Aman	0.00	No Drought Condition	Boro	0.00	No Drought Condition
Chuadanga	Jibonnagar	B1(Year 2050)	Aman	0.00	No Drought Condition	Boro	0.00	No Drought Condition
Dinajpur	Biral	A2(Year 2030)	Aman	0.00	No Drought Condition	Boro	0.00	No Drought Condition
Dinajpur	Biral	A2(Year 2050)	Aman	0.00	No Drought Condition	Boro	0.00	No Drought Condition
Dinajpur	Biral	B1(Year 2030)	Aman	0.00	No Drought Condition	Boro	0.00	No Drought Condition
Dinajpur	Biral	B1(Year 2050)	Aman	0.00	No Drought Condition	Boro	10-20%	Slight
Dinajpur	Birampur	A2(Year 2030)	Aman	0.00	No Drought Condition	Boro	<10%	Very Slight
Dinajpur	Birampur	A2(Year 2050)	Aman	>40%	Very Severe	Boro	0.00	No Drought Condition
Dinajpur	Birampur	B1(Year 2030)	Aman	0.00	No Drought Condition	Boro	<10%	Very Slight
Dinajpur	Birampur	B1(Year 2050)	Aman	>40%	Very Severe	Boro	<10%	Very Slight
Dinajpur	Birganj	A2(Year 2030)	Aman	0.00	No Drought Condition	Boro	>40%	Very Severe
Dinajpur	Birganj	A2(Year2050)	Aman	10-20%	Slight	Boro	30-40%	Severe
Dinajpur	Birganj	B1(Year 2030)	Aman	<10%	Very Slight	Boro	0.00	No Drought Condition
Dinajpur	Birganj	B1(Year 2050)	Aman	10-20%	Slight	Boro	30-40%	Severe
Dinajpur	Bochaganj	A2(Year 2030)	Aman	0.00	No Drought Condition	Boro	<10%	Very Slight

District	Upazilla	Scenario	Rice Variety	Yield Decrease	Drought Severity of Aman	Rice Variety	Yield Decrease	Drought Severity of Boro
Dinajpur	Bochaganj	A2(Year 2050)	Aman	>40%	Very Severe	Boro	0.00	No Drought Condition
Dinajpur	Bochaganj	B1(Year 2030)	Aman	0.00	No Drought Condition	Boro	0.00	No Drought Condition
Dinajpur	Bochaganj	B1(Year 2050)	Aman	30-40%	Severe	Boro	10-20%	Slight
Dinajpur	Chirirbandar	A2(Year 2030)	Aman	>40%	Very Severe	Boro	10-20%	Slight
Dinajpur	Chirirbandar	A2(Year 2050)	Aman	>40%	Very Severe	Boro	<10%	Very Slight
Dinajpur	Chirirbandar	B1(Year 2030)	Aman	>40%	Very Severe	Boro	0.00	No Drought Condition
Dinajpur	Chirirbandar	B1(Year 2050)	Aman	>40%	Very Severe	Boro	<10%	Very Slight
Dinajpur	Dinajpur Sadar	A2(Year 2030)	Aman	0.00	No Drought Condition	Boro	<10%	Very Slight
Dinajpur	Dinajpur Sadar	A2(Year 2050)	Aman	0.00	No Drought Condition	Boro	0.00	No Drought Condition
Dinajpur	Dinajpur Sadar	B1(Year 2030)	Aman	0.00	No Drought Condition	Boro	0.00	No Drought Condition
Dinajpur	Dinajpur Sadar	B1(Year 2050)	Aman	0.00	No Drought Condition	Boro	<10%	Very Slight
Dinajpur	Fulbari	A2(Year 2030)	Aman	0.00	No Drought Condition	Boro	0.00	No Drought Condition
Dinajpur	Fulbari	A2(Year 2050)	Aman	0.00	No Drought Condition	Boro	0.00	No Drought Condition
Dinajpur	Fulbari	B1(Year 2030)	Aman	0.00	No Drought Condition	Boro	0.00	No Drought Condition
Dinajpur	Fulbari	B1(Year 2050)	Aman	0.00	No Drought Condition	Boro	<10%	Very Slight
Dinajpur	Ghoraghat	A2(Year 2030)	Aman	0.00	No Drought Condition	Boro	0.00	No Drought Condition
Dinajpur	Ghoraghat	A2(Year 2050)	Aman	0.00	No Drought Condition	Boro	>40%	Very Severe
Dinajpur	Ghoraghat	B1(Year 2030)	Aman	0.00	No Drought Condition	Boro	0.00	No Drought Condition
Dinajpur	Ghoraghat	B1(Year 2050)	Aman	0.00	No Drought Condition	Boro	>40%	Very Severe
Dinajpur	Kaharole	A2(Year 2030)	Aman	0.00	No Drought Condition	Boro	<10%	Very Slight
Dinajpur	Kaharole	A2(Year 2050)	Aman	0.00	No Drought Condition	Boro	10-20%	Slight
Dinajpur	Kaharole	B1(Year 2030)	Aman	>40%	Very Severe	Boro	<10%	Very Slight
Dinajpur	Kaharole	B1(Year 2050)	Aman	0.00	No Drought Condition	Boro	0.00	No Drought Condition
Dinajpur	Khansama	A2(Year 2030)	Aman	0.00	No Drought Condition	Boro	<10%	Very Slight
Dinajpur	Khansama	A2(Year 2050)	Aman	>40%	Very Severe	Boro	0.00	No Drought Condition
Dinajpur	Khansama	B1(Year 2030)	Aman	>40%	Very Severe	Boro	0.00	No Drought Condition
Dinajpur	Khansama	B1(Year 2050)	Aman	>40%	Very Severe	Boro	10-20%	Slight

District	Upazilla	Scenario	Rice Variety	Yield Decrease	Drought Severity of Aman	Rice Variety	Yield Decrease	Drought Severity of Boro
Dinajpur	Nawabganj	A2(Year 2030)	Aman	<10%	Very Slight	Boro	0.00	No Drought Condition
Dinajpur	Nawabganj	A2(Year 2050)	Aman	0.00	No Drought Condition	Boro	0.00	No Drought Condition
Dinajpur	Nawabganj	B1(Year 2030)	Aman	0.00	No Drought Condition	Boro	0.00	No Drought Condition
Dinajpur	Nawabganj	B1(Year 2050)	Aman	0.00	No Drought Condition	Boro	0.00	No Drought Condition
Dinajpur	Parbatipur	A2(Year 2030)	Aman	30-40%	Severe	Boro	0.00	No Drought Condition
Dinajpur	Parbatipur	A2(Year 2050)	Aman	30-40%	Severe	Boro	<10%	Very Slight
Dinajpur	Parbatipur	B1(Year 2030)	Aman	30-40%	Severe	Boro	<10%	Very Slight
Dinajpur	Parbatipur	B1(Year 2050)	Aman	10-20%	Slight	Boro	20-30%	Moderate
Faridpur	Alfadanga	A2(Year 2030)	Aman	0.00	No Drought Condition	Boro	10-20%	Slight
Faridpur	Alfadanga	A2(Year 2050)	Aman	0.00	No Drought Condition	Boro	20-30%	Moderate
Faridpur	Alfadanga	B1(Year2030)	Aman	0.00	No Drought Condition	Boro	10-20%	Slight
Faridpur	Alfadanga	B1(Year 2050)	Aman	0.00	No Drought Condition	Boro	>40%	Very Severe
Faridpur	Faridpur Sadar	A2(Year 2030)	Aman	<10%	Very Slight	Boro	0.00	No Drought Condition
Faridpur	Faridpur Sadar	A2(Year 2050)	Aman	<10%	Very Slight	Boro	0.00	No Drought Condition
Faridpur	Faridpur Sadar	B1(Year 2030)	Aman	<10%	Very Slight	Boro	0.00	No Drought Condition
Faridpur	Faridpur Sadar	B1(Year 2050)	Aman	<10%	Very Slight	Boro	0.00	No Drought Condition
Gaibandha	Gobindaganj	A2(Year 2030)	Aman	30-40%	Severe	Boro	0.00	No Drought Condition
Gaibandha	Gobindaganj	A2(Year 2050)	Aman	>40%	Very Severe	Boro	0.00	No Drought Condition
Gaibandha	Gobindaganj	B1(Year 2030)	Aman	>40%	Very Severe	Boro	0.00	No Drought Condition
Gaibandha	Gobindaganj	B1(Year 2050)	Aman	30-40%	Severe	Boro	0.00	No Drought Condition
Gaibandha	Polashbari	A2(Year 2030)	Aman	30-40%	Severe	Boro	0.00	No Drought Condition
Gaibandha	Polashbari	A2(Year 2050)	Aman	>40%	Very Severe	Boro	0.00	No Drought Condition
Gaibandha	Polashbari	B1(Year 2030)	Aman	>40%	Very Severe	Boro	0.00	No Drought Condition
Gaibandha	Polashbari	B1(Year 2050)	Aman	>40%	Very Severe	Boro	0.00	No Drought Condition
Gopalganj	Gopalganj Sadar	A2(Year 2030)	Aman	<10%	Very Slight	Boro	30-40%	Severe
Gopalganj	Gopalganj Sadar	A2(Year 2050)	Aman	10-20%	Slight	Boro	30-40%	Severe
Gopalganj	Gopalganj Sadar	B1(Year 2030)	Aman	<10%	Very Slight	Boro	20-30%	Moderate

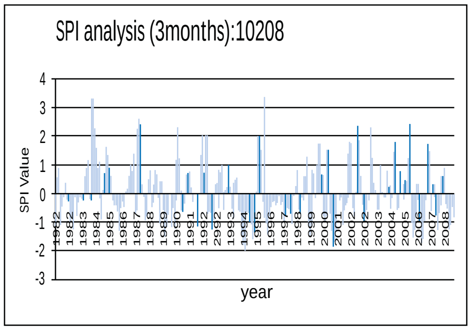
District	Upazilla	Scenario	Rice Variety	Yield Decrease	Drought Severity of Aman	Rice Variety	Yield Decrease	Drought Severity of Boro
Gopalganj	Gopalganj Sadar	B1(Year 2050)	Aman	10-20%	Slight	Boro	>40%	Very Severe
Gopalganj	Kashiani	A2(Year 2030)	Aman	<10%	Very Slight	Boro	30-40%	Severe
Gopalganj	Kashiani	A2(Year 2050)	Aman	10-20%	Slight	Boro	30-40%	Severe
Gopalganj	Kashiani	B1(Year 2030)	Aman	<10%	Very Slight	Boro	20-30%	Moderate
Gopalganj	Kashiani	B1(Year 2050)	Aman	10-20%	Slight	Boro	>40%	Very Severe
Jessore	Jhikargacha	A2(Year 2030)	Aman	0.00	No Drought Condition	Boro	0.00	No Drought Condition
Jessore	Jhikargacha	A2(Year 2050)	Aman	<10%	Very Slight	Boro	0.00	No Drought Condition
Jessore	Jhikargacha	B1(Year 2030)	Aman	0.00	No Drought Condition	Boro	0.00	No Drought Condition
Jessore	Jhikargacha	B1(Year 2050)	Aman	<10%	Very Slight	Boro	0.00	No Drought Condition
Jhenaidah	Harinakunda	A2(Year 2030)	Aman	0.00	No Drought Condition	Boro	0.00	No Drought Condition
Jhenaidah	Harinakunda	A2(Year 2050)	Aman	0.00	No Drought Condition	Boro	0.00	No Drought Condition
Jhenaidah	Harinakunda	B1(Year 2030)	Aman	0.00	No Drought Condition	Boro	0.00	No Drought Condition
Jhenaidah	Harinakunda	B1(Year 2050)	Aman	0.00	No Drought Condition	Boro	0.00	No Drought Condition
Jhenaidah	Shailkupa	A2(Year 2030)	Aman	<10%	Very Slight	Boro	20-30%	Moderate
Jhenaidah	Shailkupa	A2(Year 2050)	Aman	<10%	Very Slight	Boro	<10%	Very Slight
Jhenaidah	Shailkupa	B1(Year 2030)	Aman	0.00	No Drought Condition	Boro	20-30%	Moderate
Jhenaidah	Shailkupa	B1(Year 2050)	Aman	0.00	No Drought Condition	Boro	20-30%	Moderate
Jhenaidah	Jhenaidah Sadar	A2(Year 2030)	Aman	0.00	No Drought Condition	Boro	0.00	No Drought Condition
Jhenaidah	Jhenaidah Sadar	A2(Year 2050)	Aman	0.00	No Drought Condition	Boro	0.00	No Drought Condition
Jhenaidah	Jhenaidah Sadar	B1(Year 2030)	Aman	0.00	No Drought Condition	Boro	0.00	No Drought Condition
Jhenaidah	Jhenaidah Sadar	B1(Year2050)	Aman	0.00	No Drought Condition	Boro	0.00	No Drought Condition
Jhenaidah	Kotchadpur	A2(Year 2030)	Aman	0.00	No Drought Condition	Boro	0.00	No Drought Condition
Jhenaidah	Kotchadpur	A2(Year 2050)	Aman	0.00	No Drought Condition	Boro	0.00	No Drought Condition
Jhenaidah	Kotchadpur	B1(Year 2030)	Aman	0.00	No Drought Condition	Boro	0.00	No Drought Condition
Jhenaidah	Kotchadpur	B1(Year 2050)	Aman	0.00	No Drought Condition	Boro	0.00	No Drought Condition
Jhenaidah	Maheshpur	A2(Year 2030)	Aman	0.00	No Drought Condition	Boro	0.00	No Drought Condition
Jhenaidah	Maheshpur	A2(Year 2050)	Aman	0.00	No Drought Condition	Boro	0.00	No Drought Condition

District	Upazilla	Scenario	Rice Variety	Yield Decrease	Drought Severity of Aman	Rice Variety	Yield Decrease	Drought Severity of Boro
Jhenaidah	Maheshpur	B1(Year 2030)	Aman	0.00	No Drought Condition	Boro	0.00	No Drought Condition
Jhenaidah	Maheshpur	B1(Year 2050)	Aman	0.00	No Drought Condition	Boro	0.00	No Drought Condition
Joypurhat	Akkelpur	A2(Year 2030)	Aman	0.00	No Drought Condition	Boro	0.00	No Drought Condition
Joypurhat	Akkelpur	A2(Year 2050)	Aman	0.00	No Drought Condition	Boro	0.00	No Drought Condition
Joypurhat	Akkelpur	B1(Year 2030)	Aman	0.00	No Drought Condition	Boro	0.00	No Drought Condition
Joypurhat	Akkelpur	B1(Year 2050)	Aman	0.00	No Drought Condition	Boro	0.00	No Drought Condition
Joypurhat	Joypurhat Sadar	A2(Year 2030)	Aman	0.00	No Drought Condition	Boro	>40%	Very Severe
Joypurhat	Joypurhat Sadar	A2(Year 2050)	Aman	0.00	No Drought Condition	Boro	10-20%	Slight
Joypurhat	Joypurhat Sadar	B1(Year 2030)	Aman	0.00	No Drought Condition	Boro	>40%	Very Severe
Joypurhat	Joypurhat Sadar	B1(Year 2050)	Aman	<10%	Very Slight	Boro	20-30%	Moderate
Joypurhat	Kalai	A2(Year 2030)	Aman	0.00	No Drought Condition	Boro	0.00	No Drought Condition
Joypurhat	Kalai	A2(Year 2050)	Aman	0.00	No Drought Condition	Boro	0.00	No Drought Condition
Joypurhat	Kalai	B1(Year 2030)	Aman	0.00	No Drought Condition	Boro	0.00	No Drought Condition
Joypurhat	Kalai	B1(Year 2050)	Aman	0.00	No Drought Condition	Boro	0.00	No Drought Condition
Joypurhat	Khetlal	A2(Year 2030)	Aman	0.00	No Drought Condition	Boro	0.00	No Drought Condition
Joypurhat	Khetlal	A2(Year 2050)	Aman	0.00	No Drought Condition	Boro	0.00	No Drought Condition
Joypurhat	Khetlal	B1(Year 2030)	Aman	0.00	No Drought Condition	Boro	0.00	No Drought Condition
Joypurhat	Khetlal	B1(Year 2050)	Aman	0.00	No Drought Condition	Boro	0.00	No Drought Condition
Joypurhat	Panchbibi	A2(Year 2030)	Aman	0.00	No Drought Condition	Boro	30-40%	Severe
Joypurhat	Panchbibi	A2(Year 2050)	Aman	0.00	No Drought Condition	Boro	20-30%	Moderate
Joypurhat	Panchbibi	B1(Year 2030)	Aman	0.00	No Drought Condition	Boro	30-40%	Severe
Joypurhat	Panchbibi	B1(Year 2050)	Aman	0.00	No Drought Condition	Boro	20-30%	Moderate
Khulna	Dacope	A2(Year 2030)	Aman	<10%	Very Slight	Boro	0.00	No Drought Condition
Khulna	Dacope	A2(Year 2050)	Aman	<10%	Very Slight	Boro	0.00	No Drought Condition
Khulna	Dacope	B1(Year 2030)	Aman	<10%	Very Slight	Boro	0.00	No Drought Condition

District	Upazilla	Scenario	Rice Variety	Yield Decrease	Drought Severity of Aman	Rice Variety	Yield Decrease	Drought Severity of Boro
Khulna	Dacope	B1(Year 2050)	Aman	<10%	Very Slight	Boro	<10%	Very Slight
Khulna	Dighalia	A2(Year 2030)	Aman	0.00	No Drought Condition	Boro	0.00	No Drought Condition
Khulna	Dighalia	A2(Year 2050)	Aman	0.00	No Drought Condition	Boro	0.00	No Drought Condition
Khulna	Dighalia	B1(Year 2030)	Aman	0.00	No Drought Condition	Boro	0.00	No Drought Condition
Khulna	Dighalia	B1(Year 2050)	Aman	0.00	No Drought Condition	Boro	0.00	No Drought Condition
Khulna	Dumuria	A2(Year 2030)	Aman	0.00	No Drought Condition	Boro	>40%	Very Severe
Khulna	Dumuria	A2(Year 2050)	Aman	0.00	No Drought Condition	Boro	>40%	Very Severe
Khulna	Dumuria	B1(Year 2030)	Aman	0.00	No Drought Condition	Boro	<10%	Very Slight
Khulna	Dumuria	B1(Year 2050)	Aman	0.00	No Drought Condition	Boro	10-20%	Slight
Khulna	Paikgacha	A2(Year 2030)	Aman	0.00	No Drought Condition	Boro	>40%	Very Severe
Khulna	Paikgacha	A2(Year 2050)	Aman	<10%	Very Slight	Boro	>40%	Very Severe
Khulna	Paikgacha	B1(Year 2030)	Aman	0.00	No Drought Condition	Boro	10-20%	Slight
Khulna	Paikgacha	B1(Year 2050)	Aman	0.00	No Drought Condition	Boro	10-20%	Slight
Khulna	Terokhada	A2(Year 2030)	Aman	<10%	Very Slight	Boro	0.00	No Drought Condition
Khulna	Terokhada	A2(Year 2050)	Aman	<10%	Very Slight	Boro	0.00	No Drought Condition
Khulna	Terokhada	B1(Year 2030)	Aman	<10%	Very Slight	Boro	30-40%	Severe
Khulna	Terokhada	B1(Year 2050)	Aman	<10%	Very Slight	Boro	30-40%	Severe
Kushtia	Khoksha	A2(Year 2030)	Aman	<10%	Very Slight	Boro	10-20%	Slight
Kushtia	Khoksha	A2(Year 2050)	Aman	<10%	Very Slight	Boro	<10%	Very Slight
Kushtia	Khoksha	B1(Year 2030)	Aman	0.00	No Drought Condition	Boro	10-20%	Slight
Kushtia	Khoksha	B1(Year 2050)	Aman	0.00	No Drought Condition	Boro	20-30%	Moderate
Kushtia	Khushtia Sadar	A2(Year 2030)	Aman	0.00	No Drought Condition	Boro	0.00	No Drought Condition
Kushtia	Khushtia Sadar	A2(Year 2050)	Aman	<10%	Very Slight	Boro	0.00	No Drought Condition
Kushtia	Khushtia Sadar	B1(Year 2030)	Aman	0.00	No Drought Condition	Boro	0.00	No Drought Condition
Kushtia	Khushtia Sadar	B1(Year 2050)	Aman	0.00	No Drought Condition	Boro	0.00	No Drought Condition
Kushtia	Mirpur	A2(Year 2030)	Aman	<10%	Very Slight	Boro	0.00	No Drought Condition
Kushtia	Mirpur	A2(Year 2050)	Aman	10-20%	Slight	Boro	0.00	No Drought Condition

ANNEXURE D

SPI Analysis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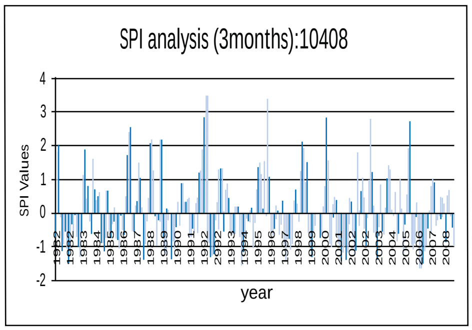
SPI Value
year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SPI Values
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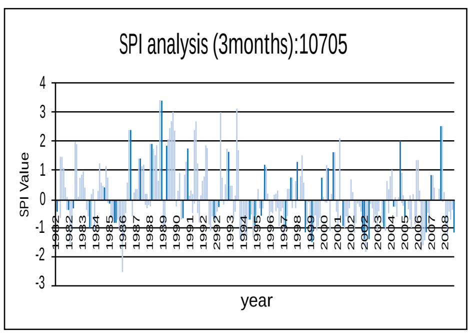
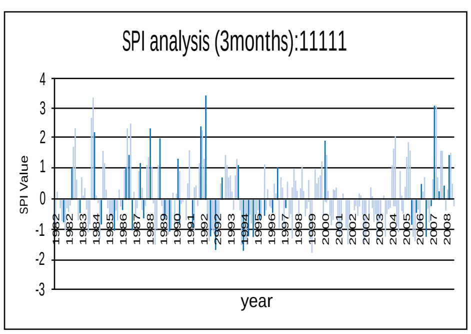

SPI analysis (3months):10705
SPI Value
year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SPI Value
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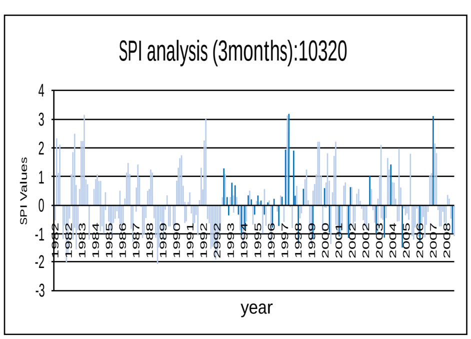
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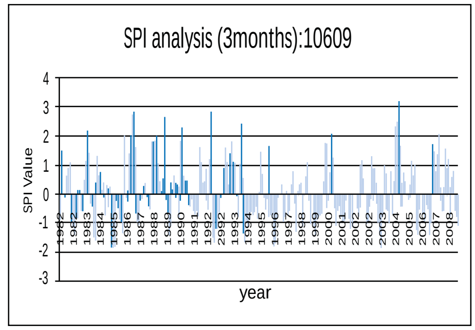
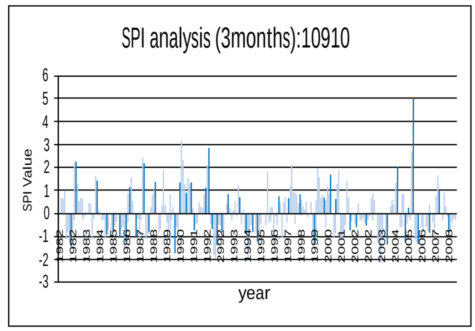
SPI Values
year


SPI analysis (3months):10609
SPI Value
year


SPI analysis (3months):10910
SPI Value
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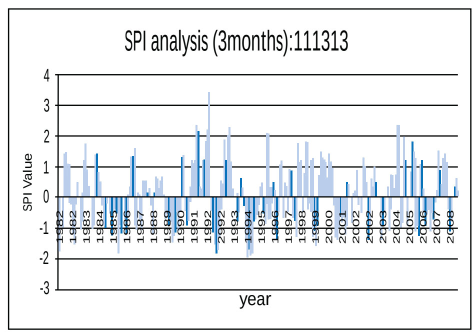
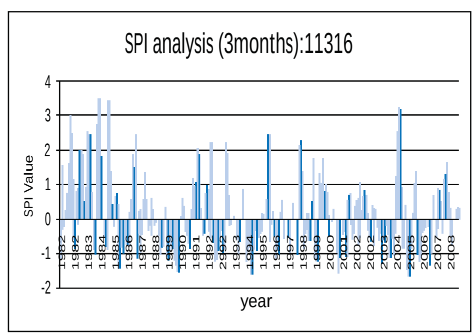
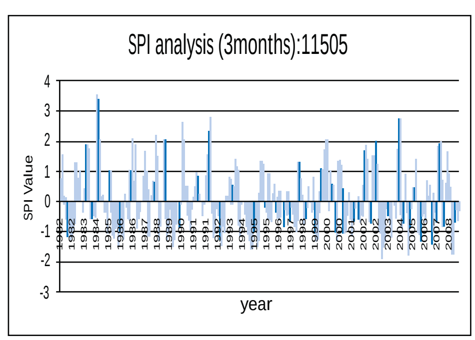
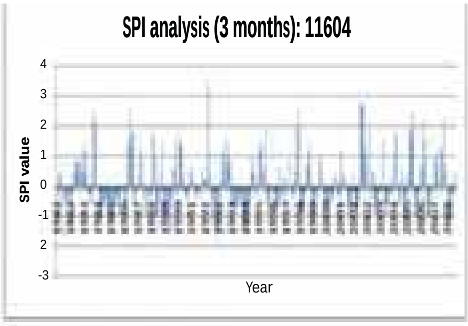
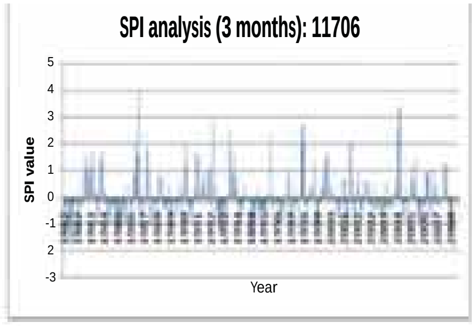
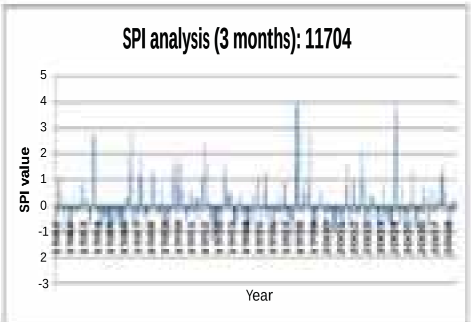

SPI analysis (3months):111313
SPI Value
year

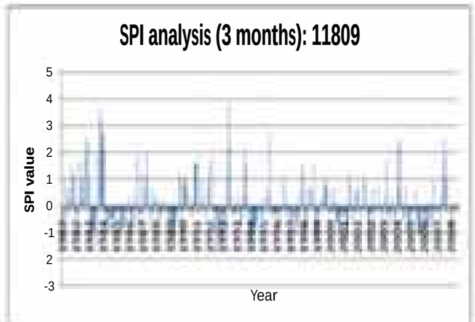

SPI analysis (3months):11316
SPI Value
year


SPI analysis (3months):11505
SPI Value
year


SPI analysis (3 months): 11604
SPI value
Year


SPI analysis (3 months): 11706
SPI value
Year


SPI analysis (3 months): 11704
SPI value
Year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SPI value
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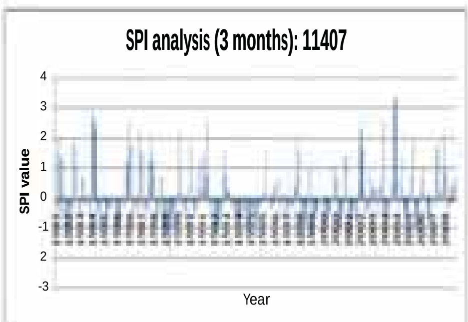
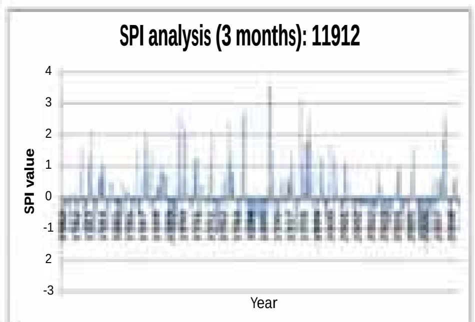

SPI analysis (3 months): 11407
SPI value
Year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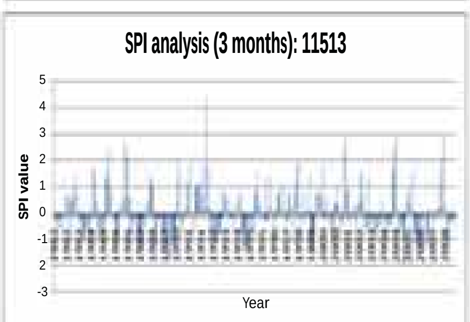
SPI value
Year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SPI value
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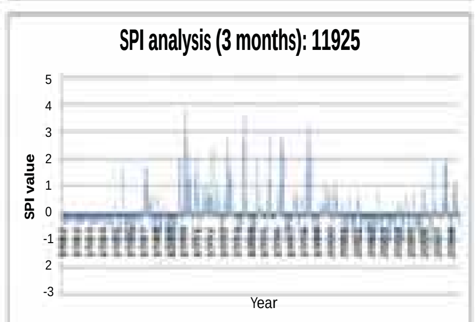
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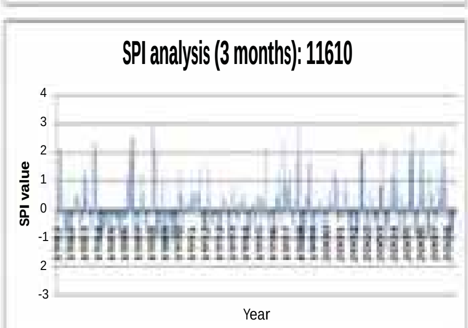
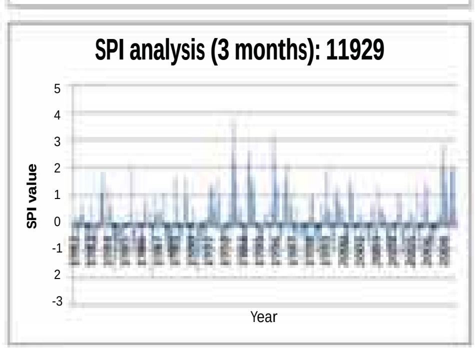
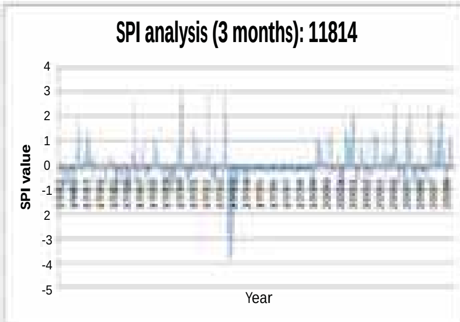
SPI value
Year


SPI analysis (3 months): 11610
SPI value
Year


SPI analysis (3 months): 11929
SPI value
Year


SPI analysis (3 months): 11814
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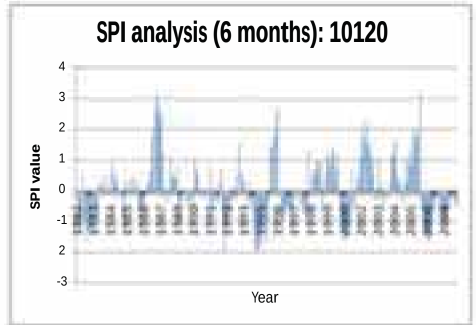
3
2
1
0
-1
2
-3
-4
-5
SPI value
Year


SPI analysis (6 months): 10120
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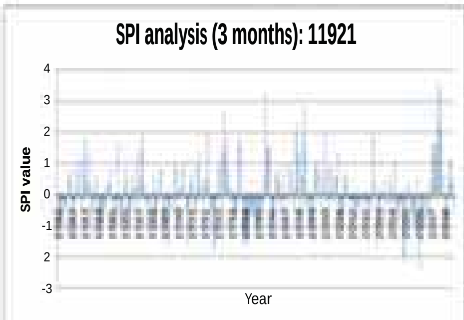
1
0
-1
2
-3
SPI value
Year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2
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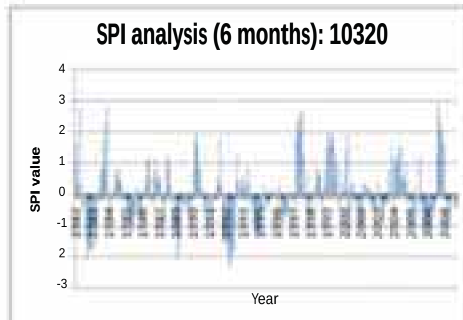
SPI value
Year


SPI analysis (6 months): 10320
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2
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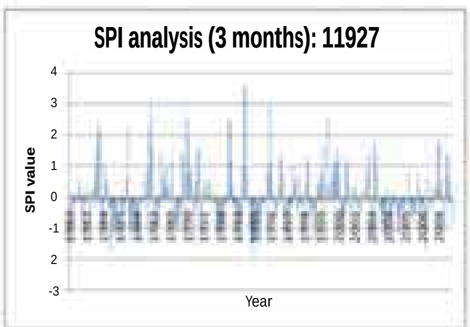
SPI value
Year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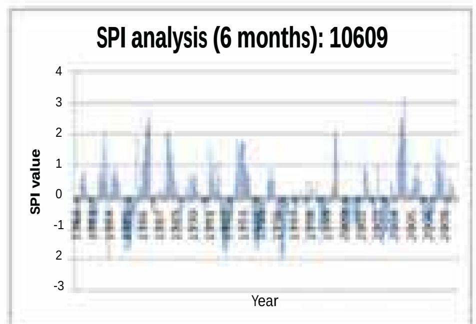
SPI value
Year


SPI analysis (6 months): 10609
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1
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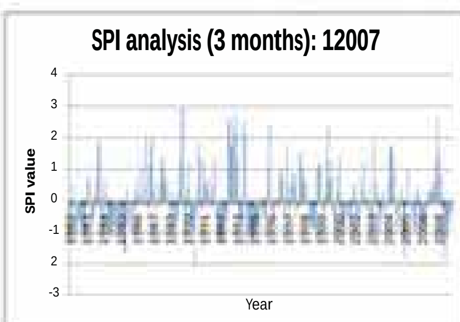
-1
2
-3
SPI value
Year


SPI analysis (3 months): 12007
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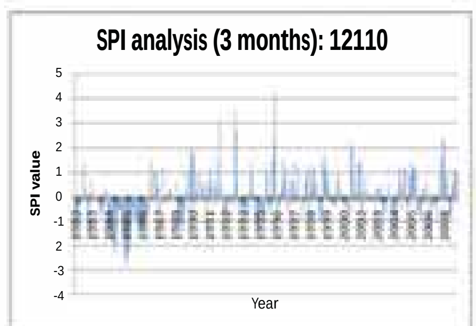
2
-3
SPI value
Year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SPI value
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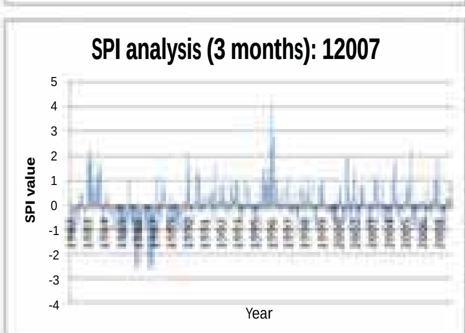
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SPI value
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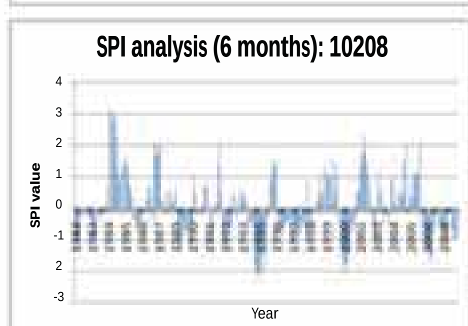
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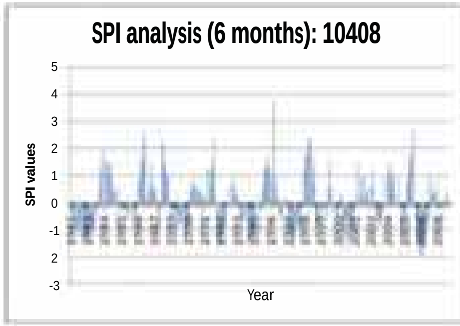
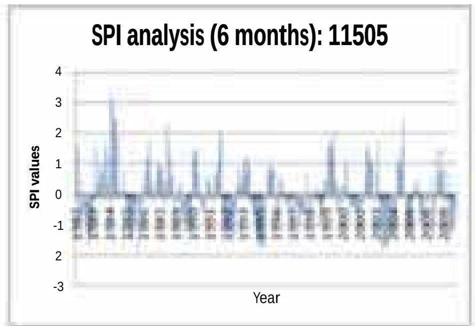
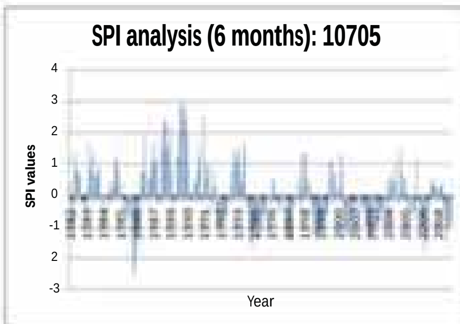
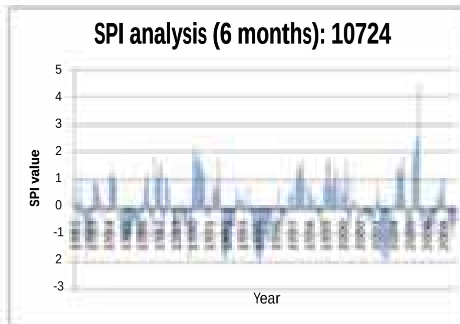
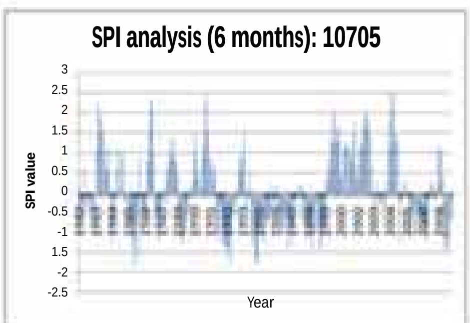
SPI value
Year

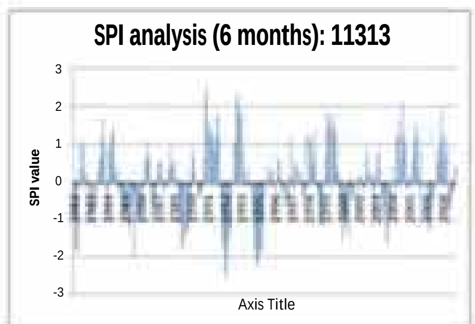

SPI analysis (6 months): 10408
SPI values
Year

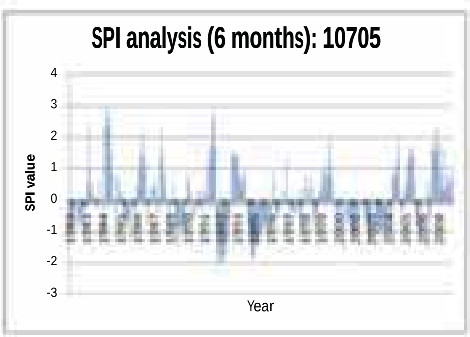

SPI analysis (6 months): 11505
SPI values
Year

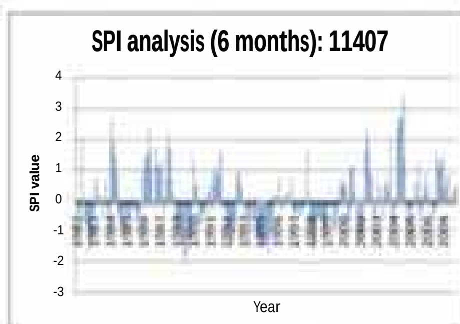

SPI analysis (6 months): 10705
SPI values
Year

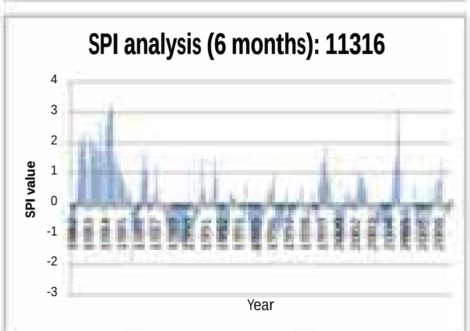

SPI analysis (6 months): 10724
SPI value
Year

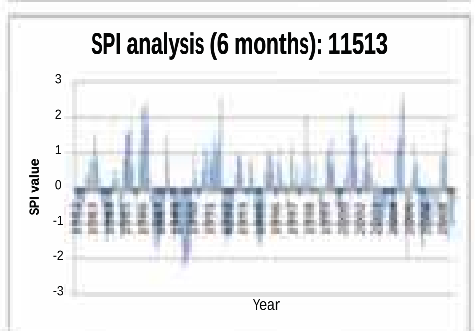

SPI analysis (6 months): 10705
SPI value
Year

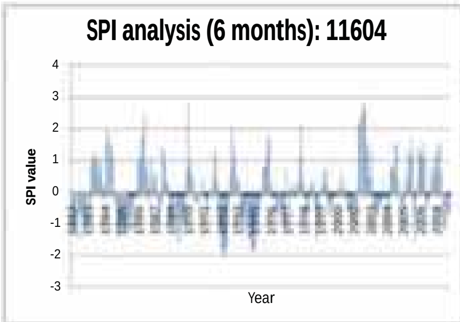

SPI analysis (6 months): 11313
SPI value
Axis Title

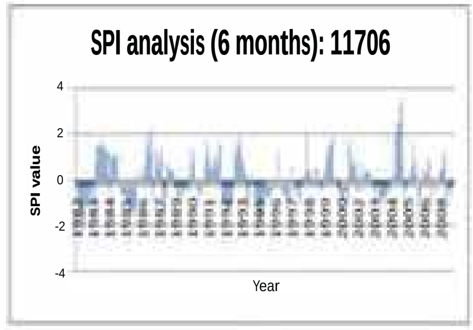

SPI analysis (6 months): 10705
SPI value
Year

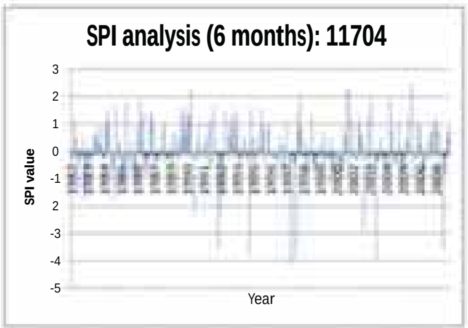

SPI analysis (6 months): 11407
SPI value
Year

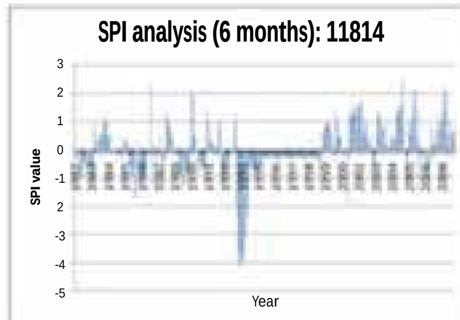

SPI analysis (6 months): 11316
SPI value
Year

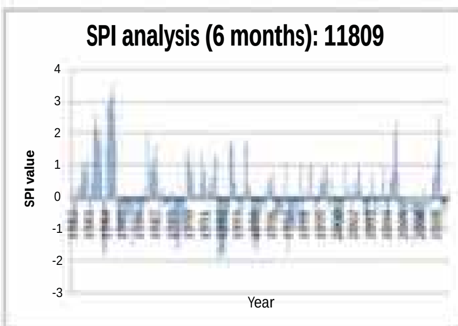

SPI analysis (6 months): 11513
SPI value
Year

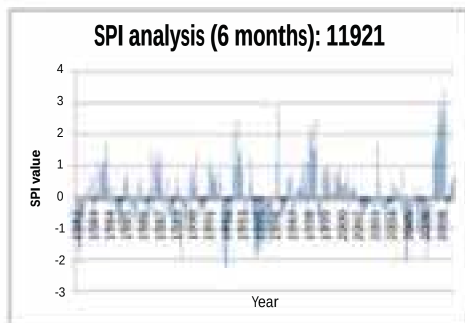

SPI analysis (6 months): 11604
SPI value
4
3
2
1
0
-1
-2
-3
Year

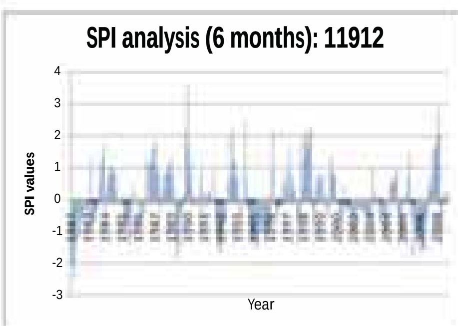

SPI analysis (6 months): 11706
SPI value
4
2
0
-2
-4
Year

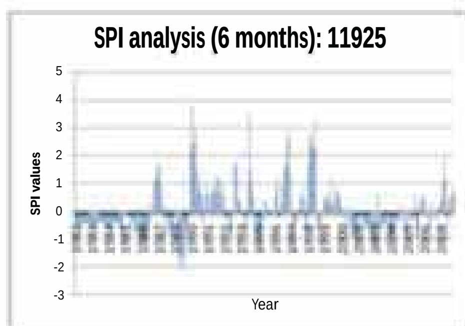

SPI analysis (6 months): 11704
SPI value
3
2
1
0
-1
2
-3
-4
-5
Year

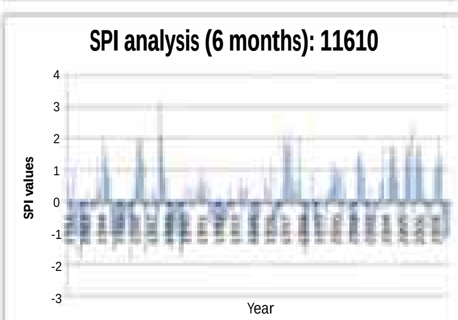

SPI analysis (6 months): 11814
SPI value
3
2
1
0
-1
2
-3
-4
-5
Year

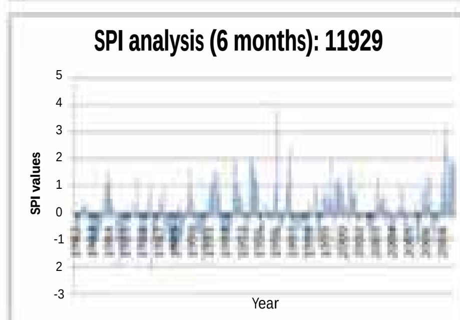

SPI analysis (6 months): 11809
SPI value
4
3
2
1
0
-1
-2
-3
Year

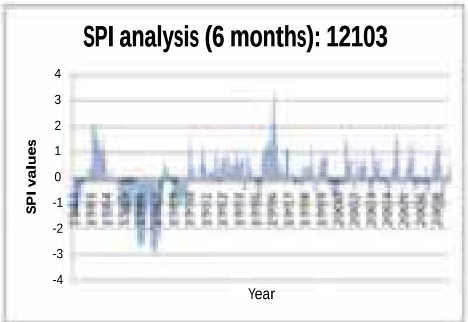

SPI analysis (6 months): 11921
SPI value
4
3
2
1
0
-1
-2
-3
Year

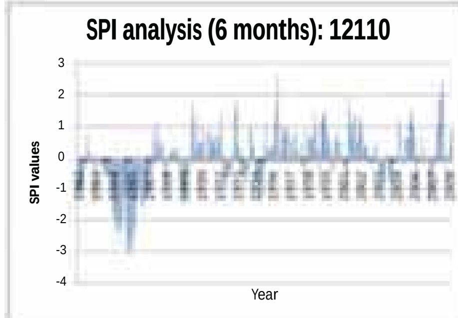

SPI analysis (6 months): 11912
SPI values
4
3
2
1
0
-1
-2
-3
Year

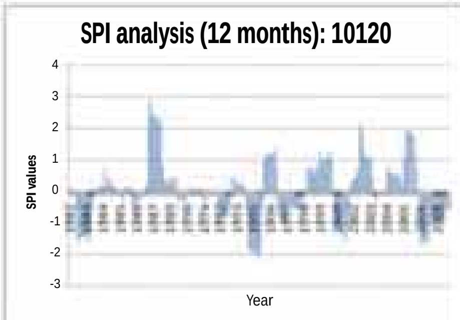

SPI analysis (6 months): 11925
SPI values
5
4
3
2
1
0
-1
-2
-3
Year

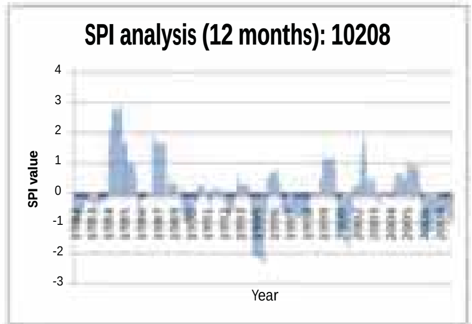

SPI analysis (6 months): 11610
SPI values
4
3
2
1
0
-1
-2
-3
Year

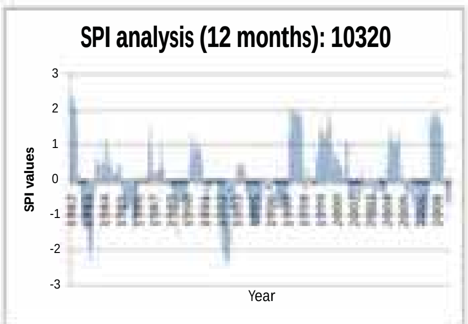

SPI analysis (6 months): 11929
SPI values
5
4
3
2
1
0
-1
2
-3
Year

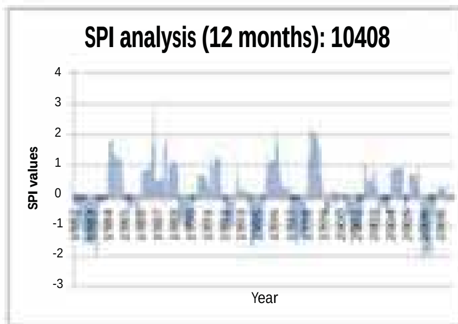

SPI analysis (6 months): 12103
SPI values
4 3 2 1 0 -1 -2 -3 -4
Year

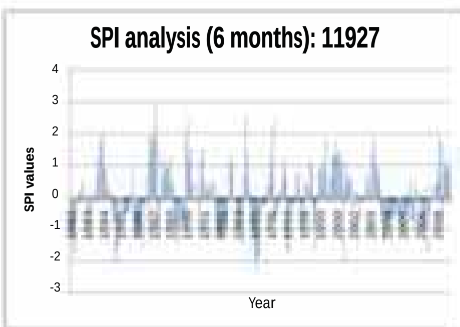

SPI analysis (6 months): 12110
SPI values
3 2 1 0 -1 -2 -3 -4
Year

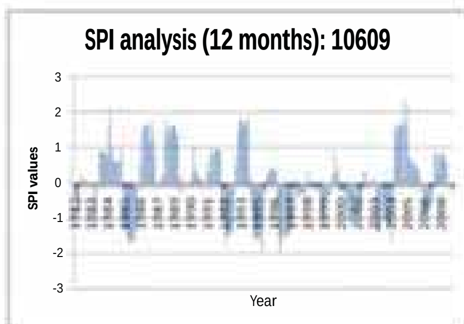

SPI analysis (12 months): 10120
SPI values
4 3 2 1 0 -1 -2 -3
Year

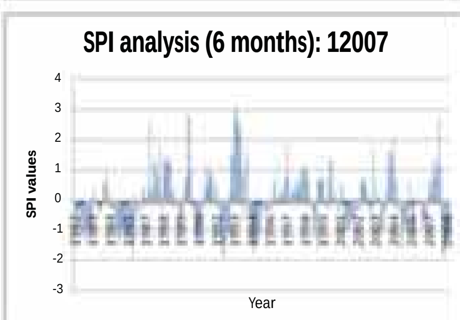

SPI analysis (12 months): 10208
SPI value
4 3 2 1 0 -1 -2 -3
Year

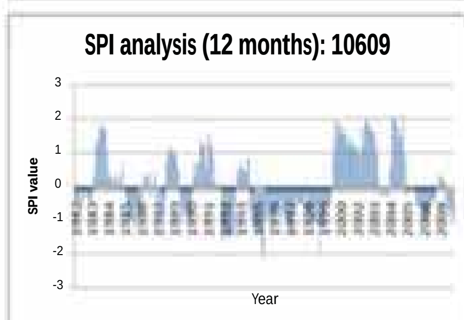

SPI analysis (12 months): 10320
SPI values
3 2 1 0 -1 -2 -3
Year

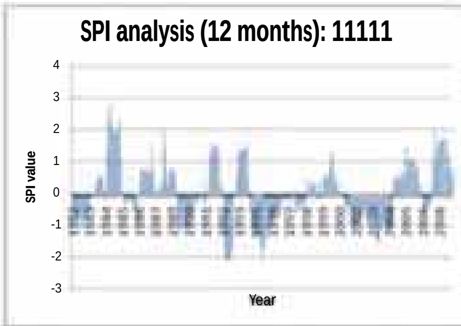

SPI analysis (12 months): 10408
SPI values
4 3 2 1 0 -1 -2 -3
Year

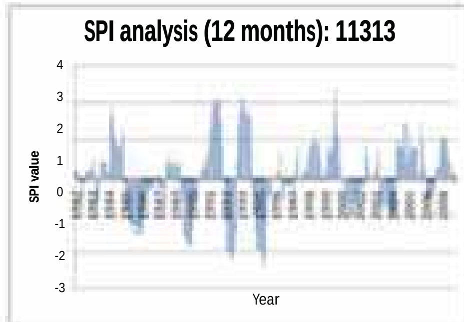

SPI analysis (6 months): 11927
SPI values
4 3 2 1 0 -1 -2 -3
Year

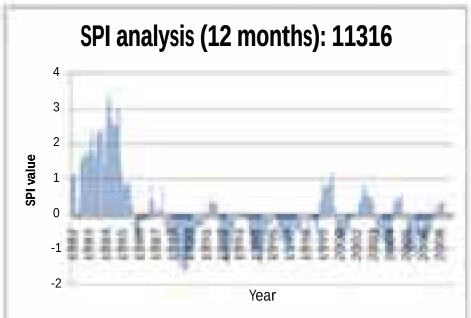

SPI analysis (12 months): 10609
SPI values
3 2 1 0 -1 -2 -3
Year

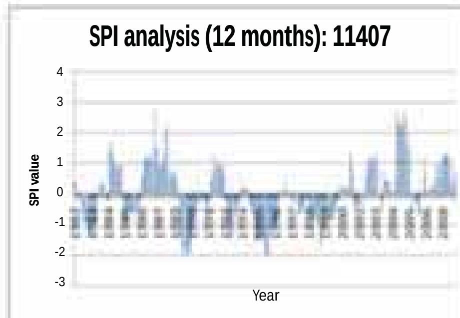

SPI analysis (6 months): 12007
SPI values
4 3 2 1 0 -1 -2 -3
Year

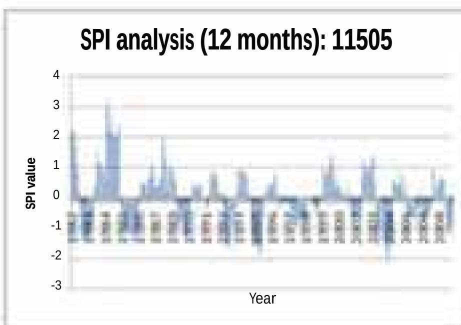

SPI analysis (12 months): 10609
SPI value
3 2 1 0 -1 -2 -3
Year

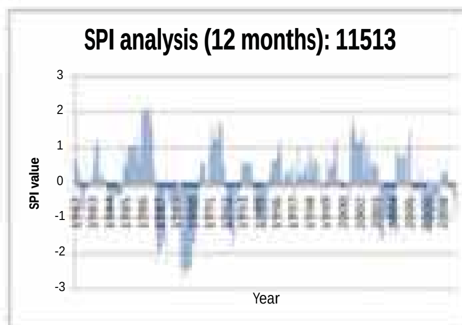

SPI analysis (12 months): 11111
4 3 2 1 0 -1 -2 -3
SPI value
Year

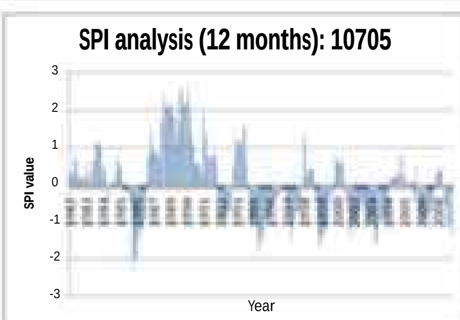

SPI analysis (12 months): 11313
4 3 2 1 0 -1 -2 -3
SPI value
Year

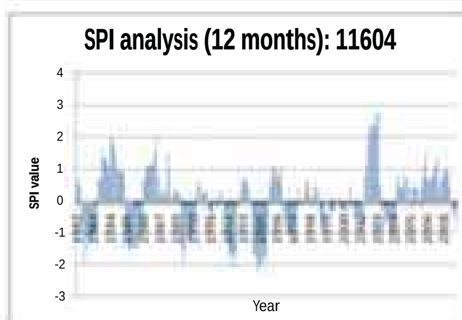

SPI analysis (12 months): 11316
4 3 2 1 0 -1 -2
SPI value
Year

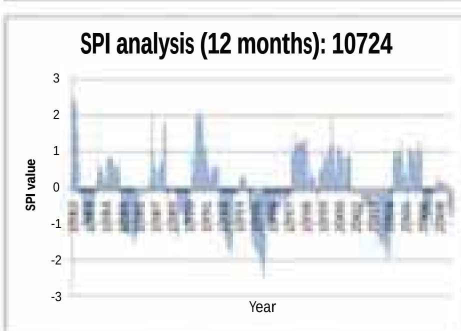

SPI analysis (12 months): 11407
4 3 2 1 0 -1 -2 -3
SPI value
Year

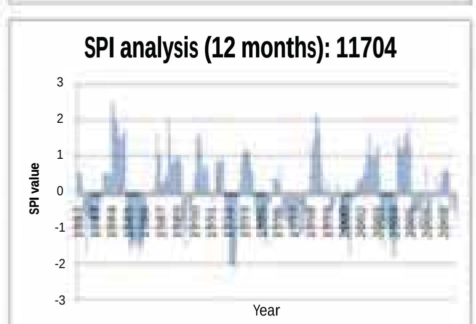

SPI analysis (12 months): 11505
4 3 2 1 0 -1 -2 -3
SPI value
Year

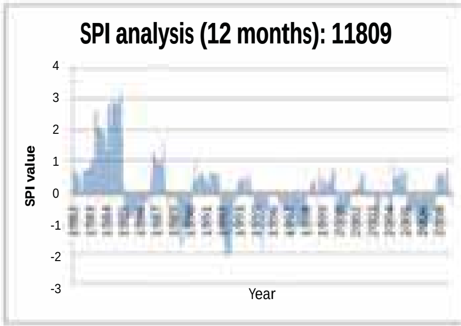

SPI analysis (12 months): 11513
3 2 1 0 -1 -2 -3
SPI value
Year

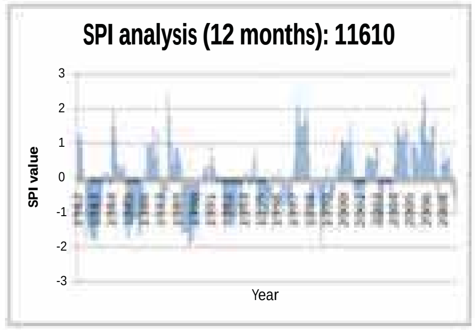

SPI analysis (12 months): 10705
3 2 1 0 -1 -2 -3
SPI value
Year

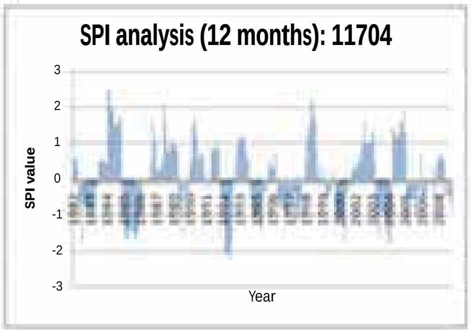

SPI analysis (12 months): 11604
4 3 2 1 0 -1 -2 -3
SPI value
Year

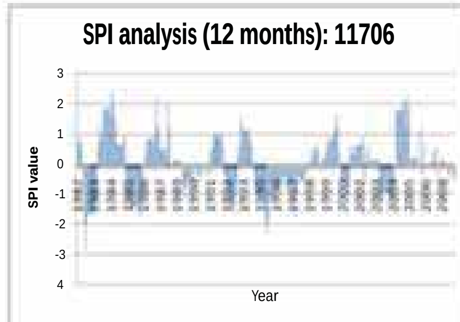

SPI analysis (12 months): 10724
3 2 1 0 -1 -2 -3
SPI value
Year

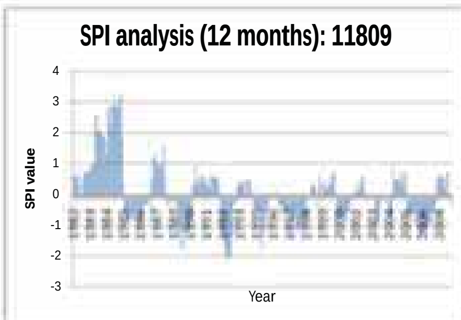

SPI analysis (12 months): 11704
3 2 1 0 -1 -2 -3
SPI value
Year

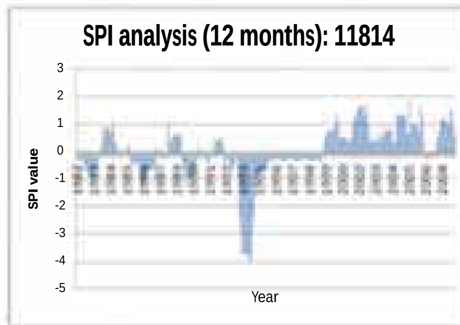

SPI analysis (12 months): 11809
SPI value
Year

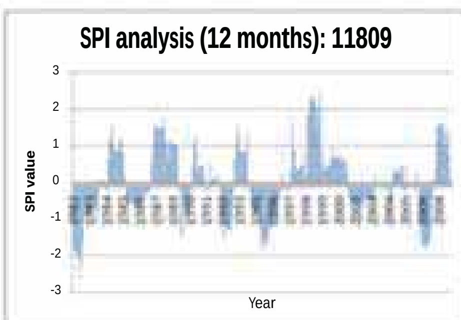

SPI analysis (12 months): 11610
SPI value
Year

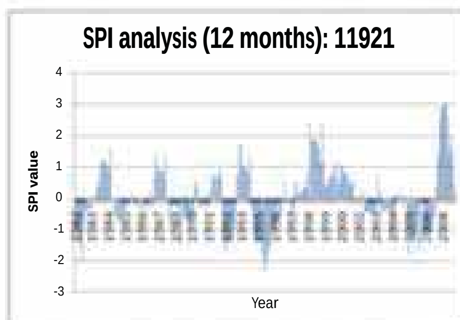

SPI analysis (12 months): 11704
SPI value
Year

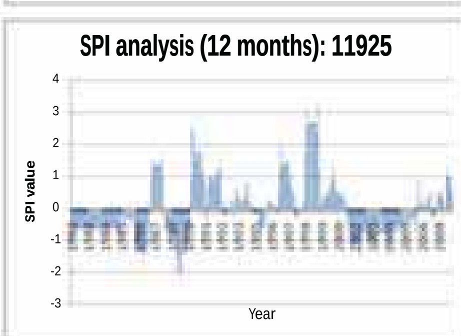

SPI analysis (12 months): 11706
SPI value
Year

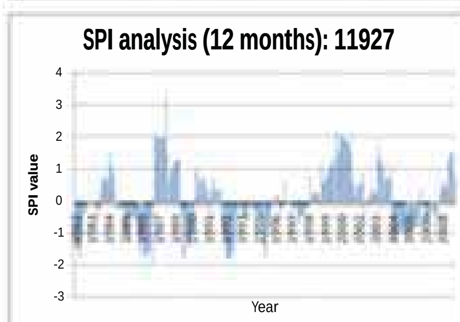

SPI analysis (12 months): 11809
SPI value
Year

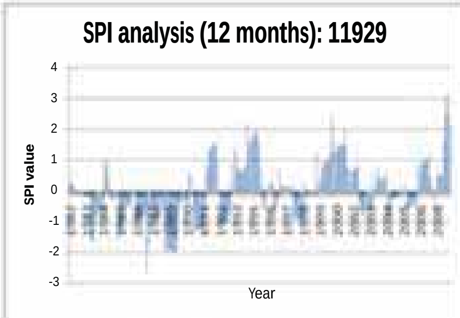

SPI analysis (12 months): 11814
SPI value
Year

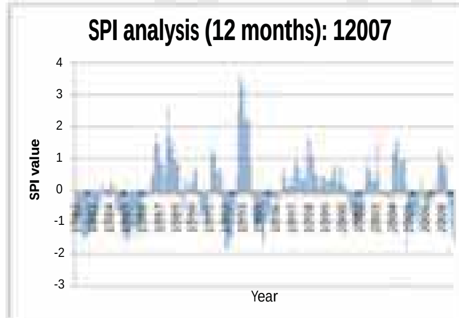

SPI analysis (12 months): 11809
SPI value
Year

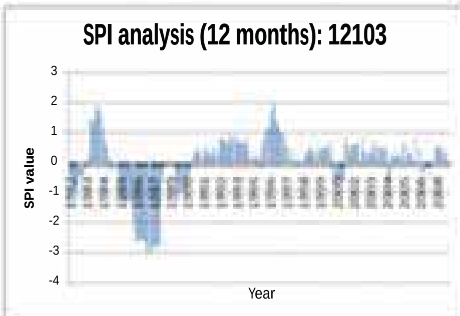

SPI analysis (12 months): 11921
SPI value
Year

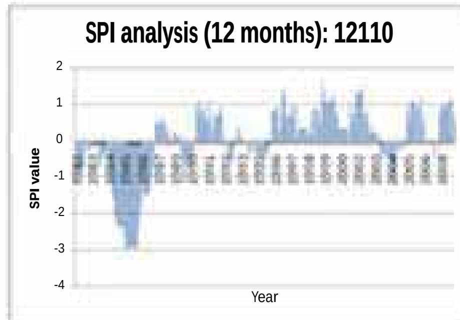

SPI analysis (12 months): 11925
SPI value
Year

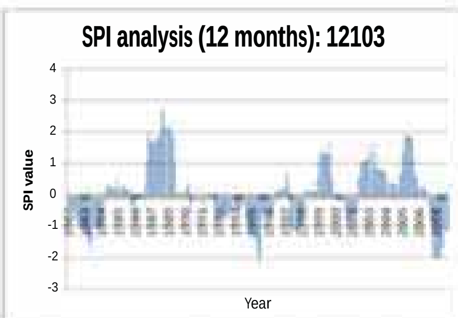

SPI analysis (12 months): 11927
SPI value
Year

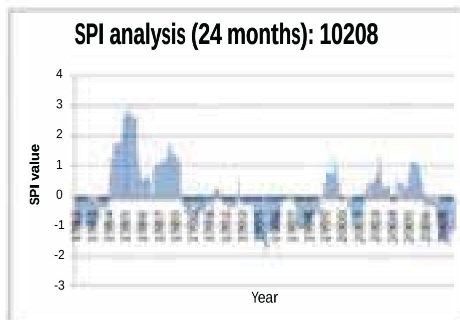

SPI analysis (12 months): 11929
SPI value
Year

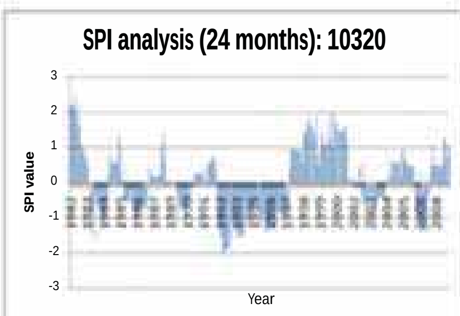

SPI analysis (12 months): 12007
SPI value
Year

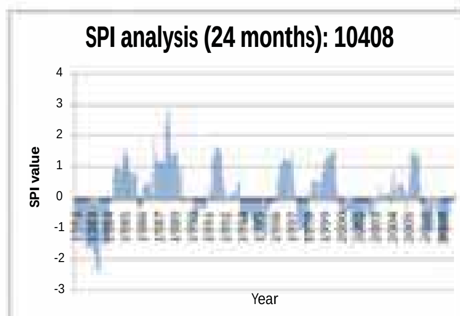

SPI analysis (12 months): 12103
SPI value
Year

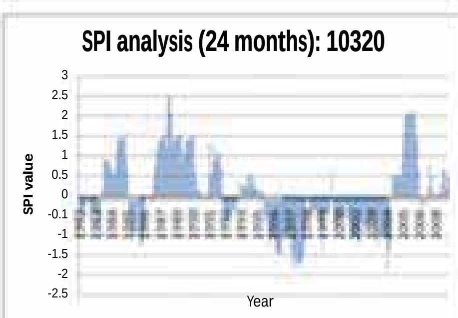

SPI analysis (12 months): 12110
SPI value
Year

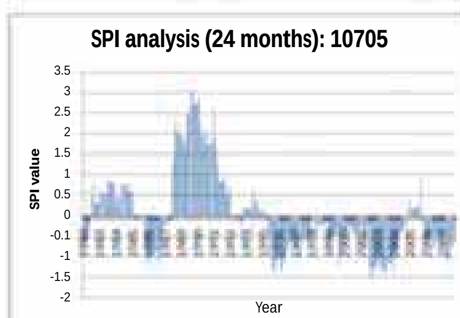

SPI analysis (12 months): 12103
SPI value
Year

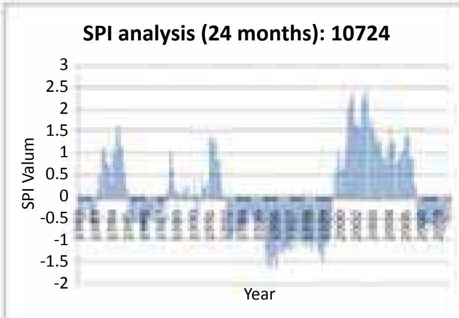

SPI analysis (24 months): 10208
SPI value
Year

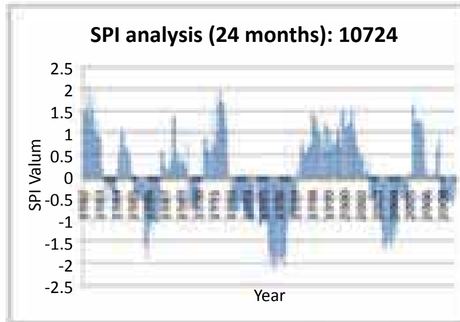

SPI analysis (24 months): 10320
SPI value
Year

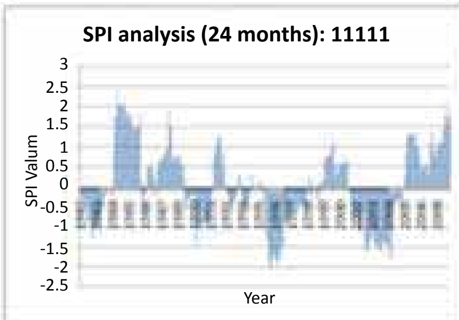

SPI analysis (24 months): 10408
SPI value
Year

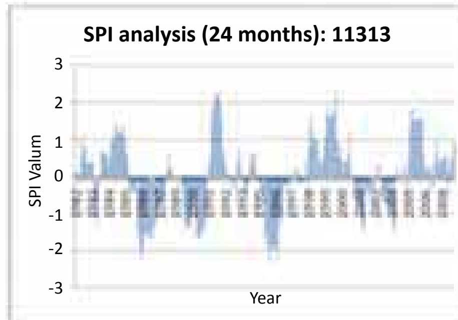

SPI analysis (24 months): 10320
SPI value
Year

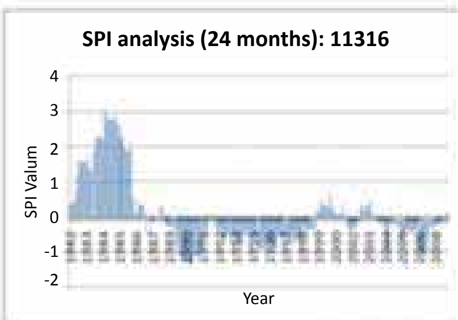

SPI analysis (24 months): 10705
SPI value
Year

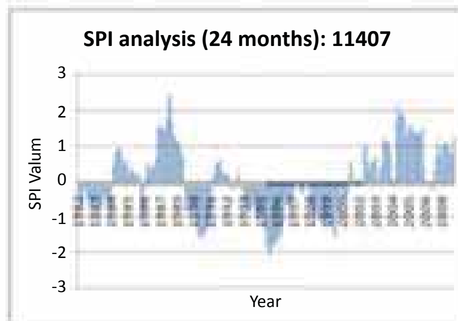

SPI analysis (24 months): 10724
3
2.5
2
1.5
1
0.5
0
-0.5
-1
-1.5
-2
SPI Valum
Year

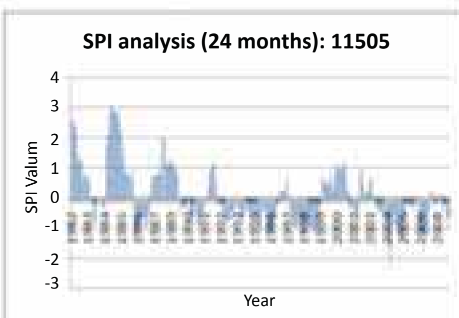

SPI analysis (24 months): 10724
2.5
2
1.5
1
0.5
0
-0.5
-1
-1.5
-2
-2.5
SPI Valum
Year

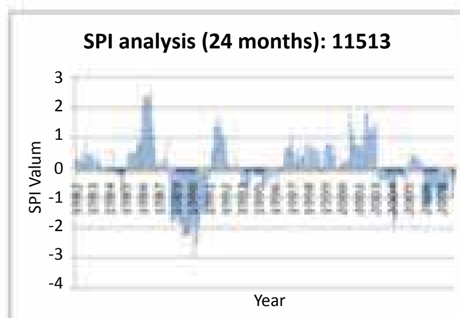

SPI analysis (24 months): 11111
3
2.5
2
1.5
1
0.5
0
-0.5
-1
-1.5
-2
-2.5
SPI Valum
Year

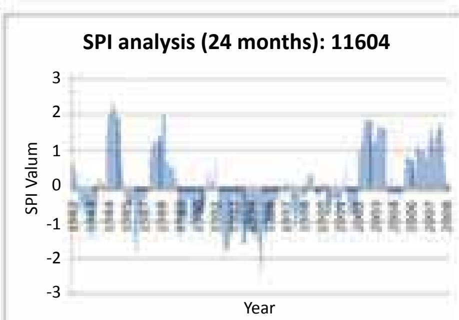

SPI analysis (24 months): 11313
3
2
1
0
-1
-2
-3
SPI Valum
Year

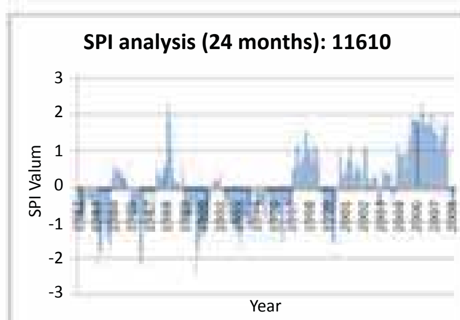

SPI analysis (24 months): 11316
4
3
2
1
0
-1
-2
SPI Valum
Year

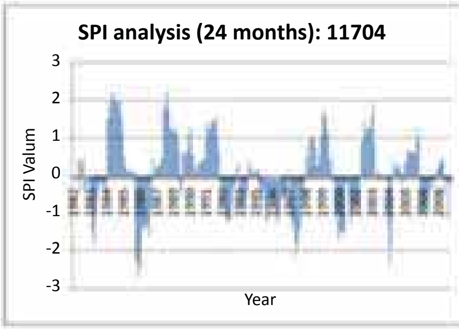

SPI analysis (24 months): 11407
3
2
1
0
-1
-2
-3
SPI Valum
Year


SPI analysis (24 months): 11505
4
3
2
1
0
-1
-2
-3
SPI Valum
Year

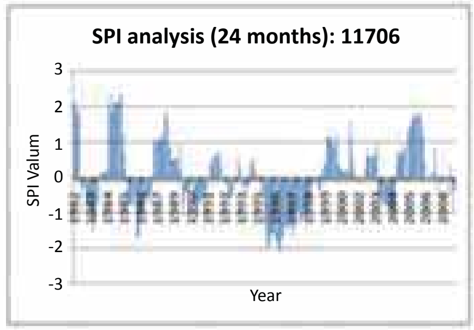

SPI analysis (24 months): 11513
3
2
1
0
-1
-2
-3
-4
SPI Valum
Year


SPI analysis (24 months): 11604
3
2
1
0
-1
-2
-3
SPI Valum
Year

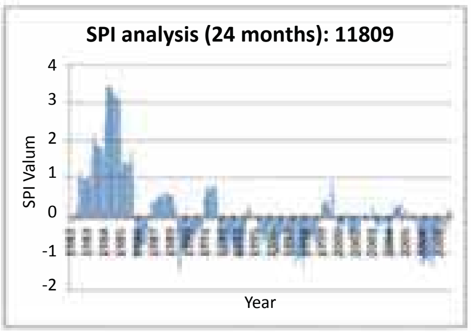

SPI analysis (24 months): 11610
3
2
1
0
-1
-2
-3
SPI Valum
Year



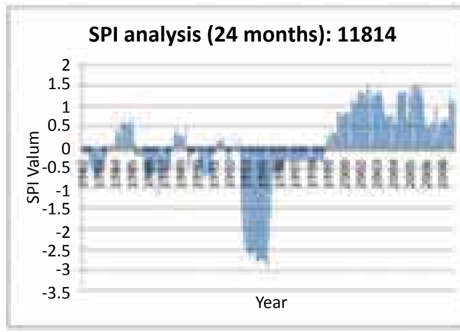
SPI analysis (24 months): 11704



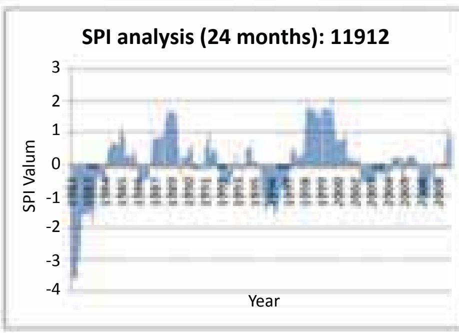
SPI analysis (24 months): 11706



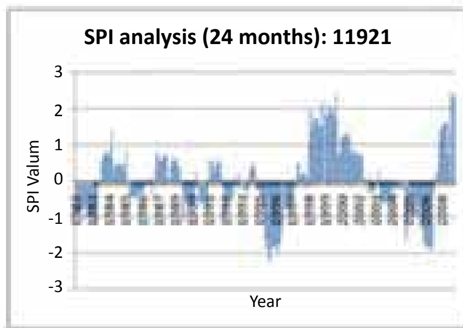
SPI analysis (24 months): 11809



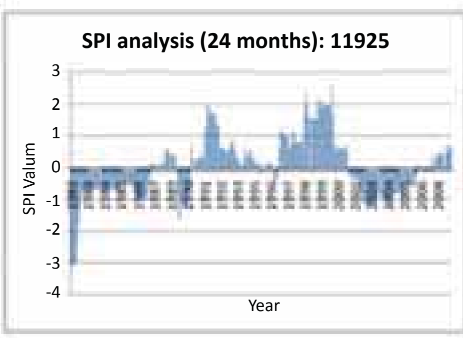
SPI analysis (24 months): 11814



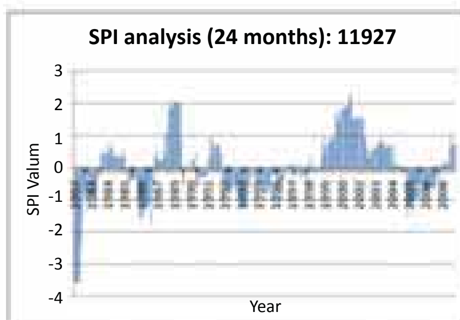
SPI analysis (24 months): 11912



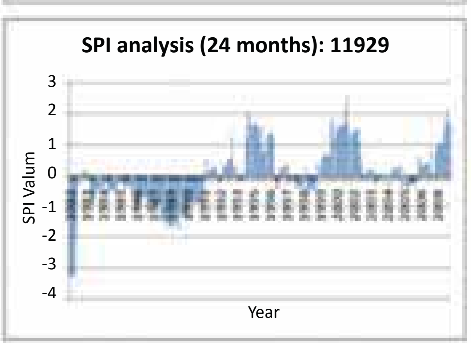
SPI analysis (24 months): 11921



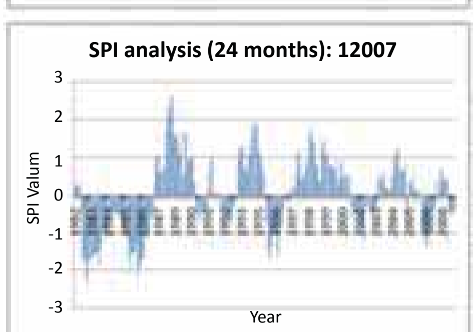
SPI analysis (24 months): 11925



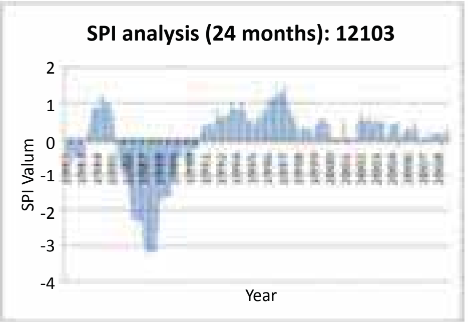
SPI analysis (24 months): 11927

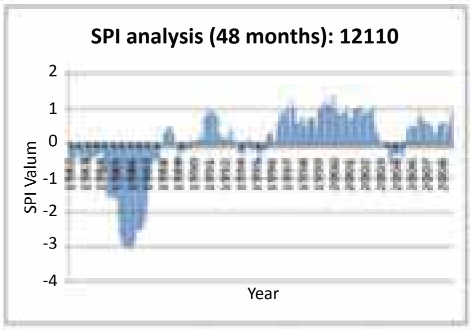


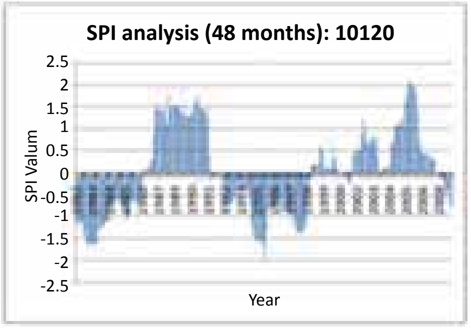
SPI analysis (24 months): 11929

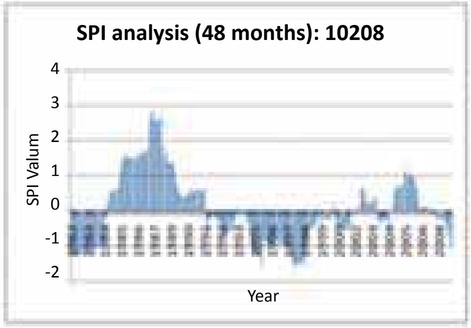


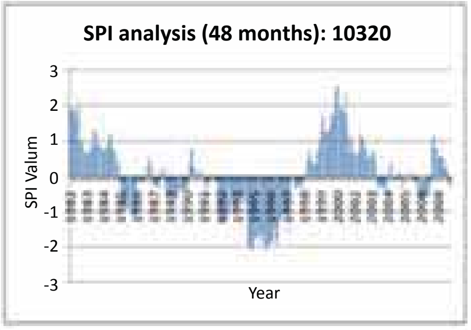
SPI analysis (24 months): 12007

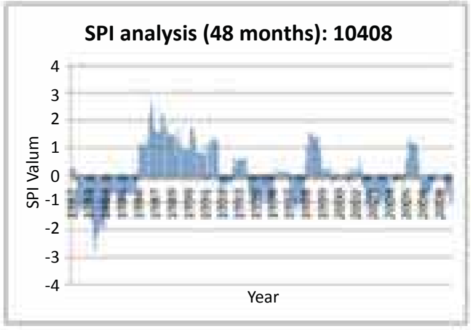

SPI analysis (24 months): 12103
2
1
0
-1
-2
-3
-4
SPI Valum
Year

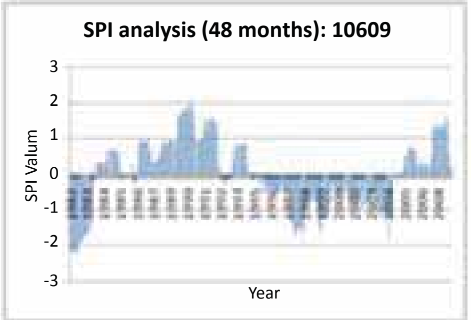

SPI analysis (48 months): 12110
2
1
0
-1
-2
-3
-4
SPI Valum
Year

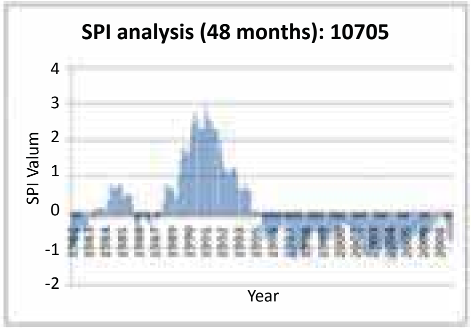

SPI analysis (48 months): 10120
2.5
2
1.5
1
0.5
0
-0.5
-1
-1.5
-2
-2.5
SPI Valum
Year

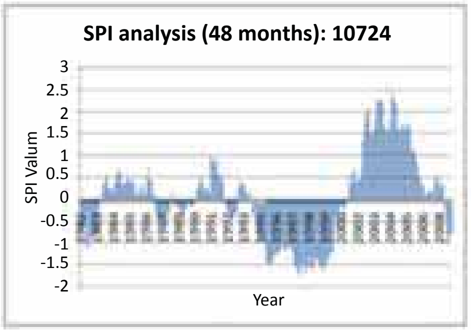

SPI analysis (48 months): 10208
4
3
2
1
0
-1
-2
SPI Valum
Year

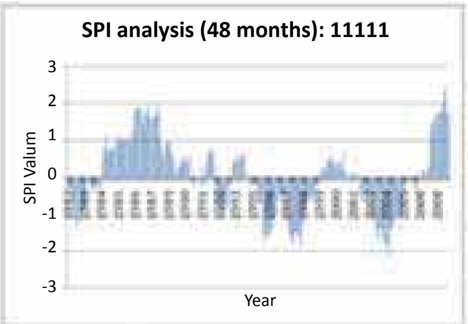

SPI analysis (48 months): 10320
3
2
1
0
-1
-2
-3
SPI Valum
Year

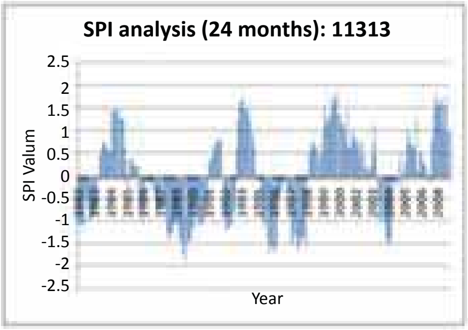

SPI analysis (48 months): 10408
4
3
2
1
0
-1
-2
-3
-4
SPI Valum
Year

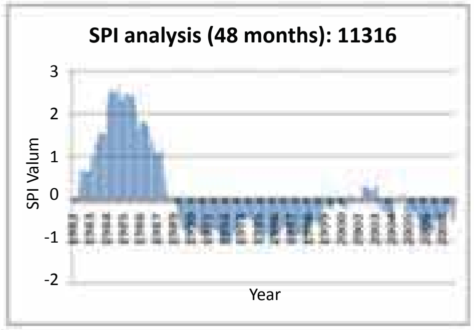

SPI analysis (48 months): 10609
3
2
1
0
-1
-2
-3
SPI Valum
Year

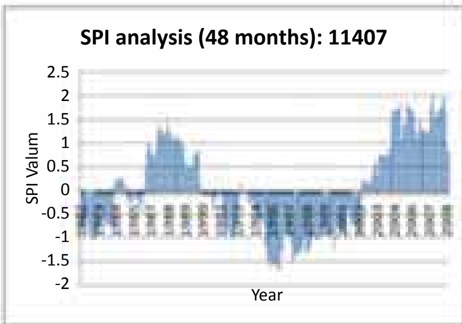

SPI analysis (48 months): 10705
4
3
2
1
0
-1
-2
SPI Valum
Year

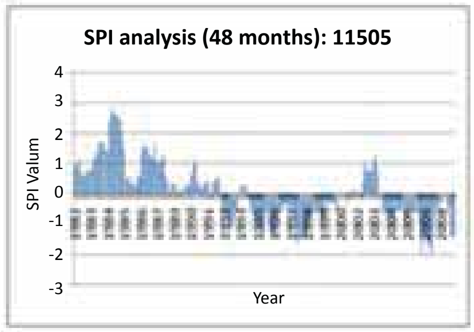

SPI analysis (48 months): 10724
3
2.5
2
1.5
1
0.5
0
-0.5
-1
-1.5
-2
SPI Valum
Year

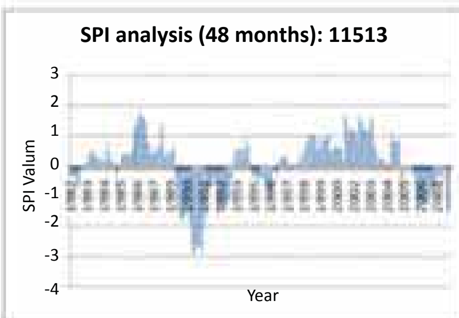

SPI analysis (48 months): 11111
3
2
1
0
-1
-2
-3
SPI Valum
Year

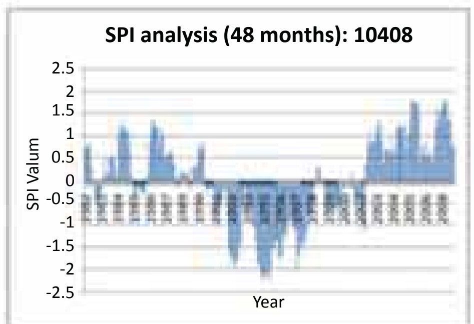

SPI analysis (24 months): 11313
2.5
2
1.5
1
0.5
0
-0.5
-1
-1.5
-2
-2.5
SPI Valum
Year

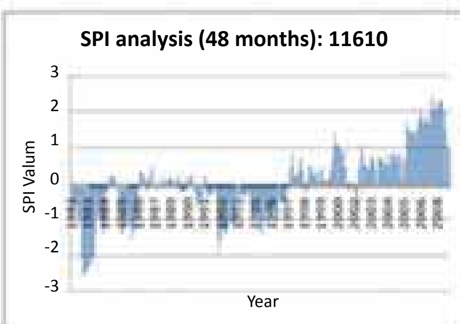

SPI analysis (48 months): 11316
3
2
1
0
-1
-2
SPI Valum
Year

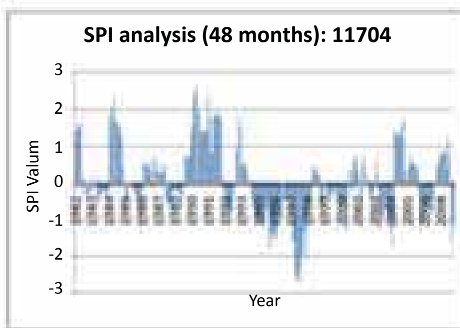

SPI analysis (48 months): 11407
2.5
2
1.5
1
0.5
0
-0.5
-1
-1.5
-2
SPI Valum
Year

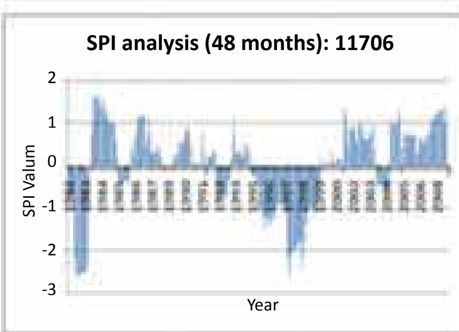

SPI analysis (48 months): 11505
4
3
2
1
0
-1
-2
-3
SPI Valum
Year

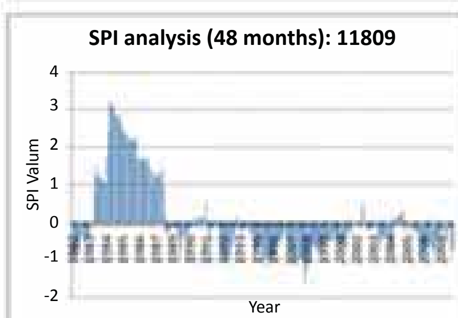

SPI analysis (48 months): 11513
3
2
1
0
-1
-2
-3
-4
SPI Valum
Year

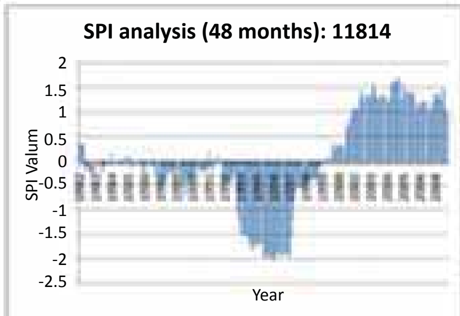

SPI analysis (48 months): 10408
2.5
2
1.5
1
0.5
0
-0.5
-1
-1.5
-2
-2.5
SPI Valum
Year

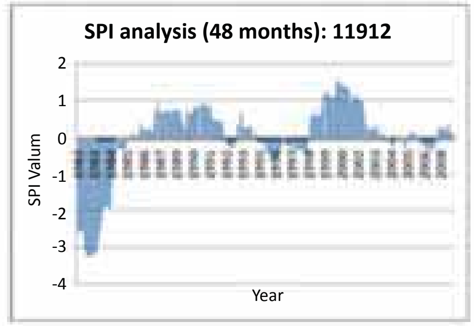

SPI analysis (48 months): 11610
3
2
1
0
-1
-2
-3
SPI Valum
Year

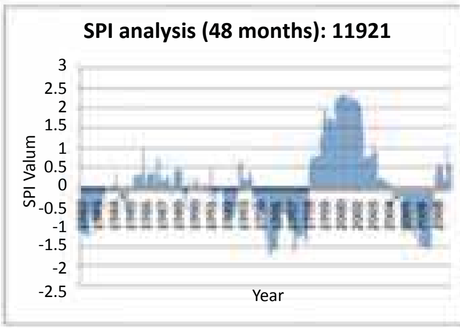

SPI analysis (48 months): 11704
3
2
1
0
-1
-2
-3
SPI Valum
Year

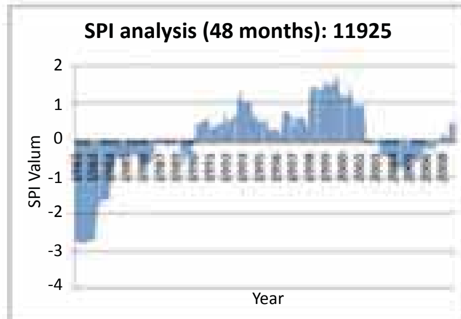

SPI analysis (48 months): 11706
2
1
0
-1
-2
-3
SPI Valum
Year

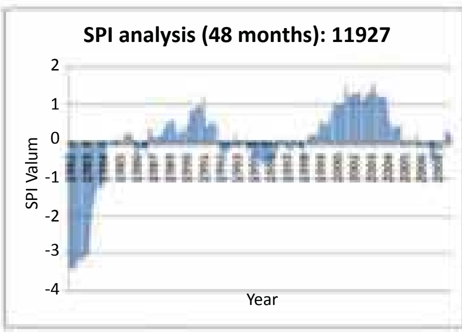

SPI analysis (48 months): 11809
4
3
2
1
0
-1
-2
SPI Valum
Year

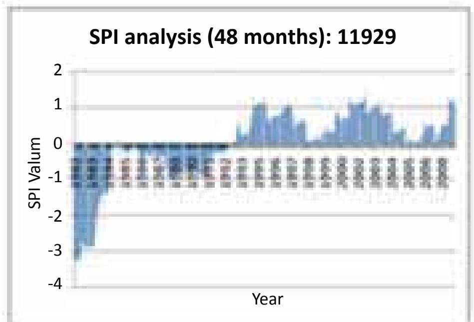

SPI analysis (48 months): 11814
2
1.5
1
0.5
0
-0.5
-1
-1.5
-2
-2.5
SPI Valum
Year

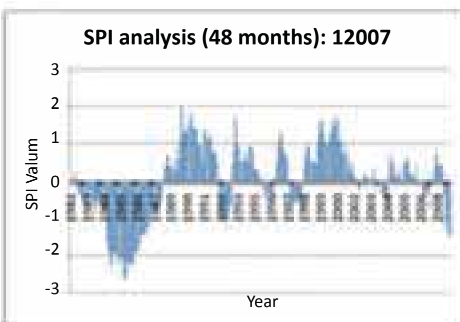

SPI analysis (48 months): 11912
2
1
0
-1
-2
-3
-4
SPI Valum
Year

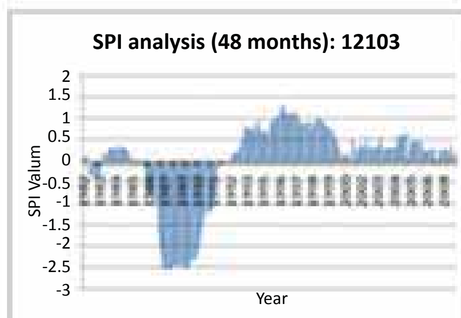

SPI analysis (48 months): 11921
3
2.5
2
1.5
1
0.5
0
-0.5
-1
-1.5
-2
-2.5
SPI Valum
Year

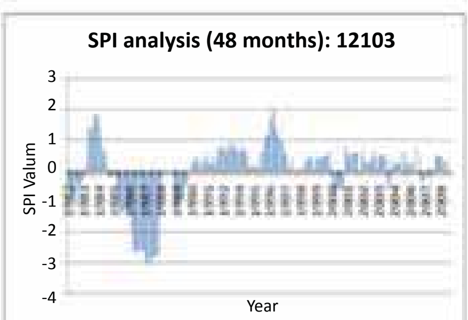

SPI analysis (48 months): 11925
2
1
0
-1
-2
-3
-4
SPI Valum
Year

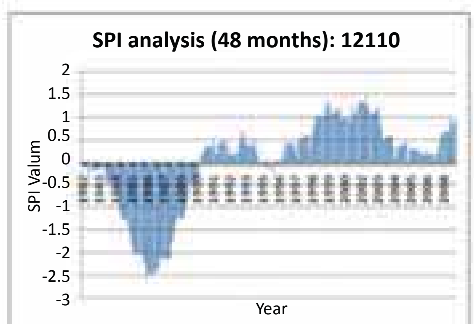

SPI analysis (48 months): 11927
2
1
0
-1
-2
-3
-4
SPI Valum
Year


SPI analysis (48 months): 11929
2
1
0
-1
-2
-3
-4
SPI Valum
Year


SPI analysis (48 months): 12007
3
2
1
0
-1
-2
-3
SPI Valum
Year


SPI analysis (48 months): 12103
2
1.5
1
0.5
0
-0.5
-1
-1.5
-2
-2.5
-3
SPI Valum
Year


SPI analysis (48 months): 12103
3
2
1
0
-1
-2
-3
-4
SPI Valum
Year


SPI analysis (48 months): 12110
2
1.5
1
0.5
0
-0.5
-1
-1.5
-2
-2.5
-3
SPI Valum
Year

ANNEXURE E

Details of BMD Weather Stations used for Weather Data Analysis in Model Simulation and SPI Analysis

Sl No.	ID of Station	Name of Station	Ground Elevation	Height of Installation	Latitude	Longitude	Date of Installation
1	10208	RANGPUR	33.04000	11.30000	25.73000	89.23000	22 -MAY -83
2	10320	RAJSHAHI	17.24000	12.10000	24.36000	88.60000	20 -JUN -63
3	10408	BOGRA	18.44000	14.60000	24.85000	89.36000	04 -JAN -43
4	10609	MYMENSINGH	18.44000	11.00000	24.74000	90.42000	01 -JAN -77
5	10705	SYLHET	33.94000	6.40000	24.89000	91.88000	01 -MAY -52
6	10724	SREEMANGAL	22.54000	12.20000	24.30000	91.73000	08 -MAR -05
7	10910	ISHWARDI	13.34000	6.40000	24.14000	89.06000	12 -APR -63
8	11111	DHAKA	9.14000	10.00000	23.76000	90.38000	01 -JAN -58
9	11313	COMILLA	6.54000	8.50000	23.46000	91.18000	12 -MAR -72
10	11316	CHANDPUR	6.04000	11.90000	23.22000	90.66000	13 -MAR -64
11	11407	JESSORE	6.54000	11.00000	23.17000	89.21000	20 -JUN -57
12	11505	FARIDPUR	8.54000	11.40000	23.60000	89.83000	07 -MAY -83
13	11513	MADARIPUR	7.44000	10.00000	23.16000	90.20000	18 -SEP -76
14	11604	KHULNA	2.54000	11.70000	22.80000	89.55000	09 -MAY -21
15	11610	SATKHIRA	4.44000	12.00000	22.72000	89.07000	20 -MAY -21
16	11704	BARISAL	2.54000	12.80000	22.70000	90.37000	01 -APR -63
17	11706	BHOLA	4.74000	8.50000	22.68000	90.65000	13 -JUL -70
18	11805	FENI	6.74000	12.00000	23.01000	91.40000	12 -NOV -73
19	11809	MAIJDEE COURT	5.34000	11.20000	22.84000	91.10000	03 -AUG -83
20	11814	HATIYA	2.84000	12.30000	22.38000	91.11000	01 -JUL -65
21	11912	SITAKUNDA	7.74000	11.80000	22.61000	91.66000	13 -MAY -77
22	11916	SANDWIP	2.54000	11.80000	22.51000	91.43000	01 -MAY -66
23	11921	CHITTAGONG	6.24000	12.50000	22.26000	91.81000	23 -NOV -46
24	11925	KUTUBDIA	3.14000	11.60000	21.82000	91.86000	20 -JUN -77
25	11927	COXS BAZAR	2.54000	12.50000	21.44000	91.97000	04 -JUN -51
26	11929	TEKNAF	5.44000	8.20000	20.86000	92.30000	16 -DEC -76
27	12007	RANGAMATI	69.34000	11.90000	22.65000	92.18000	12 -JAN -57
28	12103	PATUAKHALI	1.94000	11.30000	22.34000	90.31000	06 -JUN -73
29	12110	KHEPUPARA	2.24000	14.90000	21.99000	90.24000	30 -JUL -73
30	41909	TANGAIL	10.64000	11.40000	24.25000	89.91000	27 -MAY -83
31	41917	JOYDEBPUR	8.40000		23.98000	90.45000	01 -JUN -88
32	41967	KAPTAI	25.90000	31.50000	22.48000	92.23000	13 -MAR -63

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