STUDY ON CLIMATE ANOMALIES OF BANGLADESH USING STATISTICALLY DOWNSCALED CLIMATE PROJECTIONS FOR REPRESENTATIVE CONCENTRATION PATHWAYS (RCPs) OF IPCC FIFTH ASSESSMENT REPORT

M.Sc Engineering Thesis

By

Ahmmed Zulfiqar Rahaman

Department of Water Resources Engineering
Bangladesh University of Engineering and Technology (BUET)
Dhaka

March, 2019

STUDY ON CLIMATE ANOMALIES OF BANGLADESH USING STATISTICALLY DOWNSCALED CLIMATE PROJECTIONS FOR REPRESENTATIVE CONCENTRATION PATHWAYS (RCPs) OF IPCC FIFTH ASSESSMENT REPORT

M.Sc Engineering Thesis

By

Ahmmed Zulfiqar Rahaman

Roll No. 0413162025 (P)

Submitted to

Department of Water Resources Engineering,

Bangladesh University of Engineering and Technology, Dhaka

in partial fulfillment of the requirement for the degree of

Master of Science in Water Resources Engineering

Department of Water Resources Engineering

Bangladesh University of Engineering and Technology (BUET)

Dhaka

March, 2019

STUDY ON CLIMATE ANOMALIES OF BANGLADESH USING STATISTICALLY DOWNSCALED CLIMATE PROJECTIONS FOR REPRESENTATIVE CONCENTRATION PATHWAYS (RCPs) OF IPCC FIFTH ASSESSMENT REPORT

M.Sc Engineering Thesis

By

Ahmmed Zulfiqar Rahaman

Roll No. 0413162025 (P)

Submitted to
Department of Water Resources Engineering,
Bangladesh University of Engineering and Technology, Dhaka
in partial fulfillment of the requirement for the degree of
Master of Science in Water Resources Engineering

Department of Water Resources Engineering
Bangladesh University of Engineering and Technology (BUET)
Dhaka

March, 2019

Bangladesh University of Engineering and Technology, Dhaka
Department of Water Resources Engineering

Certificate of Thesis

The thesis titled "**Study on Climate Anomalies of Bangladesh using Statistically Downscaled Climate Projections for Representative Concentration Pathways (RCPs) of IPCC Fifth Assessment Report**", submitted by Ahmmed Zulfiqar Rahaman, Roll no. 0413162025 P, Session April 2013, to the Department of Water Resources Engineering, Bangladesh University of Engineering and Technology, has been accepted as satisfactory in partial fulfillment of the requirements for the degree of Master of Science in Water Resources Engineering and approved as to its style and content. Examination held on March 30, 2019.

____
Dr. Md. Mostafa Ali
Professor
Department of WRE, BUET, Dhaka
(Supervisor)

Chairman

____
Head
Department of WRE, BUET, Dhaka

Member
(Ex-Officio)

____
Dr. A.T.M. Hasan Zobeyer
Professor
Department of WRE, BUET, Dhaka

Member

____
Dr. Nasreen Jahan
Associate Professor
Department of WRE, BUET, Dhaka

Member

____
Malik Fida A Khan
Deputy Executive Director,
CEGIS, Gulshan, Dhaka

Member
(External)

CANDIDATE'S DECLARATION

It is hereby declared that this thesis or any part of it has not been submitted elsewhere for the award of any degree or diploma.

Supervisor	Candidate
____________________	________________________
Dr. Md. Mostafa Ali	Ahmmed Zulfiqar Rahaman
Professor Department of Water Resources Engineering, Bangladesh University of Engineering and Technology, Dhaka.	Roll No. 0413162025 P

ACKNOWLEDGEMENT

I would like to express my sincere gratitude to my supervisor Dr. Md. Mostafa Ali, Professor, Department of Water Resources Engineering, BUET for his excellent supervision, motivation and productive criticism throughout the research. This study would not be a successful one without his generous support and technical guidance.

I would like to express my thanks and gratitude to Dr. A.T.M. Hasan Zobeyer, Professor, Department of Water Resources Engineering, BUET, and Dr. Nasreen Jahan, Associate Professor, Department of Water Resources Engineering, BUET for their careful review and valuable suggestions. I am very much thankful to Mr. Malik Fida Abdullah Khan, Deputy Executive Director, Center for Environmental and Geographic Information Services (CEGIS) for his valuable comments, guidance and constructive criticism. His precious comments, constructive criticism and suggestions have made this study more enriched.

I am heartfelt thankful to Bhuiya Md. Tamim Al Hossain and Gazi Md. Riasat Amin of Center for Environmental and Geographic Information Services (CEGIS) for their valuable suggestions.

I would also like to convey my gratefulness to my parents (Late Sohel Ahemmed and Zinnatun Nahar), brother and my spouse (Toufika Toma) for their inspirations and assistance during my work.

Above all, I am grateful to Allah, the most Gracious, and most Merciful for giving me this excellent opportunity.

Ahmmed Zulfiqar Rahaman

March, 2019

ABSTRACT

Bangladesh being the most vulnerable country to climate change necessitates generation of climate anomalies for the whole country due to inadequate researches on CMIP5 RCP scenarios, which are new GHGs emission trajectories over IPCC SRES scenarios. Statistical Downscaling Model for the country has been developed thus using SDSM for maximum temperature, minimum temperature, rainfall and solar radiation data of BMD and CanESM2 GCM predictors. Climate projections have been performed followed by analysis of climate anomalies, shifting of season and long term drought severity for future periods 2030s (2016-2045), 2050s (2046-2065) and 2080s (2066-2095).

Both average maximum and minimum temperature has been found to be increased in future making southern part of Bangladesh hotter gradually. Indications of higher climate variability has been found from higher increase of average minimum temperature than average maximum temperature and fluctuations of seasonal rainfall variations. Changes in Indian monsoon circulation triggered by increased sea surface temperature and surface temperature is the prime cause of such inter-seasonal and inter-annual climate variability. Highest annual average maximum and minimum temperature increase are found to be 2.7ºC in Khulna and 3.3ºC in Satkhira respectively for 2080s under RCP8.5. Seasonal average maximum temperature increase is found higher in monsoon (4.5ºC) and post-monsoon season (4.0ºC) considering all scenarios. On the other hand, Bangladesh will face highest increment of average minimum temperature (5.2ºC) in post-monsoon season. Mean annual average rainfall increase has been found 8%, 9% and 19% for 2030s, 2050s and 2080s respectively under RCP8.5, whereas maximum increase is found 11% for 2080s under RCP4.5. Pre-monsoon and monsoon average rainfall increase are found to be 10%-22% and 10%-16% respectively, whereas rainfall is found to be decreased 7%-8% in winter and 15%-17% in post-monsoon, making dry season drier. Highest average rainfall increase would be occurred on northern part of Bangladesh up to 33% in Dinajpur and on an average 24% in north-west region in 2080s considering three RCPs. Mean annual average solar radiation is found to be decreased for all RCPs except 2030s in RCP4.5 and RCP8.5. Although, change of mean annual average radiation is very less in between -0.1% to -0.4%, it can hamper future agriculture production.

Season of rainfall has been found shifting towards pre-monsoon in the eastern portion of Bangladesh with relative to 1971-2000 decreasing monsoon rainfall occurrence except

north-west and south-west regions of Bangladesh. Highest increase in occurrence of pre-monsoon rainfall is found to be 5%-6% in in north-eastern region, which clearly depicts that haor area of Bangladesh will be more prone to early rainfall as well as early flash floods in future period.

Occurrence of severe and extreme meteorological long term drought will be increased almost all over Bangladesh in 2080s through decreasing occurrence of mild and moderate drought. Chance of increasing occurrence of severe drought is higher than extreme drought in both RCP4.5 and RCP8.5 scenarios. In most of the regions, occurrence of mild drought will be increased in 2050s and later decreased in 2080s for both RCPs. North-west region will remain drought prone in future. Occurrence of moderate, severe and extreme drought will be increased in far future up to 14%, up to 7% and up to 4% respectively considering RCP4.5 and RCP8.5. Duration of total drought occurrence will be decreased in 2050s, but will increase up to 8% throughout the country in 2080s considering both RCPs. Total duration of long term drought occurrence will be increased all over the western Bangladesh than other parts of the country with relative to 1981-2010. North-west region will face intensive severe drought spell than historical period. South west portion of Bangladesh will become prone to longer term drought with relative to 1981-2010. Total duration of drought occurrence will be decreased in eastern hill and north east regions. However, it is also clear that there is very insignificant correlation exist between overall rainfall pattern and long term drought over Bangladesh.

Table of Contents

List of Tables

List of Figures

List of Abbreviations

AOGCM	Atmosphere-Ocean General Circulation Model
AR4	IPCC Fourth Assessment Report
AR5	IPCC Fifth Assessment Report
AWC	Available Water Content
BMD	Bangladesh Meteorological Department
CanESM2	The second generation Canadian Earth System Model
CCC	Climate Change Cell
CCCMA	Canadian Centre for Climate Modelling and Analysis
CCDS	Canadian Climate Data and Scenarios (CCDS
CDMP	Comprehensive Disaster Management Program
CEGIS	Center for Environmental and Geographic Information Services
CGCM4	Coupled Global Climate Model 4
CIAT	International Center for Tropical Agriculture
CMIP5	Coupled Model Inter-comparison Project (Phase 5)
CORDEX	Coordinated Regional Downscaling Experiment
EH	Eastern Hill
GCM	General Circulation Model
GED	general Economic Division
GHG	Green House Gas
IPCC	Intergovernmental Panel on Climate Change
JGCRI	Joint Global Change Research Institute
NAPA	National Adaptation Programme of Action
NC	North Central
NCEP	National Center for Environmental Prediction
NE	North East
NIES	National Institute for Environmental Studies
NW	North West
NWP	Numerical Weather Prediction
OECD	Organization for Economic Co-operation and Development
PCI	Precipitation Concentration Index

PDSI	Palmer Drought Severity Index
PRECIS	Providing Regional Climates for Impacts Studies
RCM	Regional Climate Model
RCP	Representative Concentration Pathways
RE	River and Estuary
SC	South Central
Sc-PDSI	Self-calibrated Palmer Drought Severity Index
SDSM	Statistical Downscaling Model
SE	South East
SPI	Standardized precipitation Index
SRES	Special Report on Emission Scenario
SW	South West
WB	World Bank
WCRP	World Climate Research Program
WMO	World Meteorological Organization

Chapter 1 Introduction

1.1 Background of the Study

Bangladesh is one of the most vulnerable countries to climate change around the world due to its geographical location. It suffers adverse impact from frequent extreme weather events due to anthropogenic climate change (MoEF, 2005; MoEF, 2009; Kreft et al., 2016; GED, 2018). This threat of climate change is the most powerful driver for undertaking preemptive measures in respect to long term development of Bangladesh delta, which instigates necessity to quantify the changing climate as well as the pattern of future climate (Rahaman et al., 2015). Intergovernmental Panel on Climate Change (IPCC) is dedicatedly working in assessing global climate pattern for future years analysing results of different General Circulation Model (GCMs) under Coupled Model Intercomparison Project, Phase 5 (CMIP5), basically which are coarse in resolution (Solomon et al., 2007; Stocker et al., 2013). The results of GCM are too dispersing to represent relatively small geographic coverage such as Bangladesh. There is always a demand for incorporating either statistically or dynamically downscaled output of GCMs in assessing local climatic variability for future scenarios (Chu et al. 2009; Mohammed, 2009; Debbarma et al., 2016). Dynamic downscaling method is robust, but it requires high computational facilities. Whereas, cheap, flexible and low computational facilities are required in statistical downscaling method, which uses different statistical methods to obtain higher resolution climate data (Wilby et al., 2007; Wilby et al., 2014). Moreover, IPCC adopted four Representative Concentration Pathways (RCPs) in IPCC fifth assessment report (AR5), which are greenhouse gas concentration trajectories replace Special Report on Emission Scenarios (SRES) projections published in IPCC fourth assessment report in 2000 (Moss et al., 2008). Extensive literature review (BCCRF, 2014; Pervez et al., 2014; Rahaman et al., 2015; Ali et al., 2016) reveals inadequacy of downscaled daily climate data in Bangladesh for RCPs.

Many researches and studies (Salvi et al., 2011; Mahmood et al., 2013; Pervez et al., 2014; Nury et al., 2014; Azad, 2015; Mondal et al., 2016, Ali et al., 2016) are available on downscaled climate data for both SRES scenarios and RCPs, but no studies have been found so far for RCPs covering whole Bangladesh where downscaled and projected climate data has been analysed to assess future climate anomalies.

In this context, statistical downscaling of GCM results has been performed in this study for different RCPs covering whole Bangladesh using Statistical Downscaling Model (SDSM). Future climate projections have been done and future climate anomalies are analyzed, which will facilitate to make adaptation and mitigation strategies for future development of Bangladesh.

1.2 Description of the Study Area

1.2.1 Geographical Setting

Bangladesh is located between 20^{o}34’ to and 26^{o}38’ North latitudes and 88^{o}01’ to and 92^{o}42’ East longitudes. Most part of the country has been formed by a delta plain of the Ganges, Brahmaputra, and Meghna Rivers and their tributaries. Geographically, Bangladesh is bordered by India to the west, north and east and by Myanmar to the southeast. To the south of the country lies the Bay of Bengal. Natural disasters, such as floods, cyclones and tidal surges, and cyclones often affect the country very badly.

1.2.2 Hydrologic Regions

Considering the geo-morphological and geo-hydrological position of different areas of the country, Bangladesh has been divided into the eight hydrological regions i.e. North Central (NC), North East (NE), North West (NW), South Central (SC), South East (SE), South West (SW), River and Estuary (RE) and Eastern Hill (EH) (Figure 1.1) which have different natural features (NWMP, 2001). The major part of the North West Region (61% area of the region) lies within the Brahmaputra Basin; the same happened to the North Central Region (94% area of the region) whereas North East is mainly in the Meghna Basin (74% area of the region).

Not only these regions differ in proportion in river basins, they also experience disparity in different climate condition. As for example, north-west region is the driest part of the country whereas north-east portion gets high amount of rainfall (more than 4000 mm) every year. The annual mean temperature is around 26°C across most of the country. January mean temperature ranges from 18°C at Rajshahi in the north-west to 20°C at in Chittagong in the south-east. April is the hottest month of Bangladesh and the maximum is found in Rajshahi (north-west) where the average daily maximum for April is 36°C. The maximum temperature in April is relatively low in the north-east and south-east part of the country (GED, 2018).

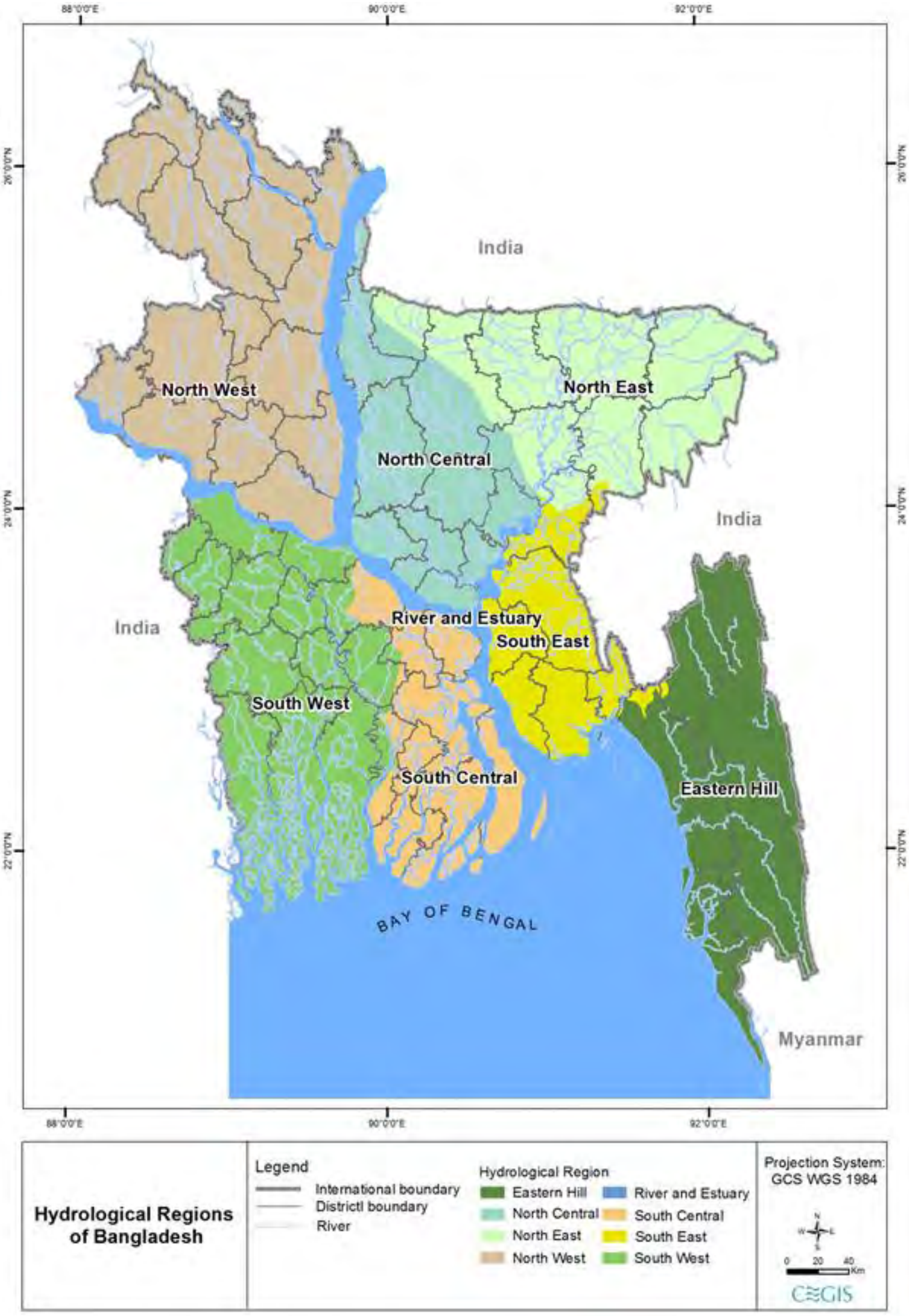


Figure 1.1: Bangladesh with its different hydrologic regions (Source: CEGIS)

1.2.3 Climatic Characteristics

Bangladesh has a sub-tropical monsoon climate characterized by heavy seasonal rainfall variations, moderate warm temperatures, and high humidity. Its climate is influenced primarily by monsoon and partly by pre-monsoon and post-monsoon circulations. The south-west monsoon originates over the Indian Ocean and carries warm, moist, and unstable air. Besides, the easterly trade winds are also active, providing warm and relatively drier circulation. Brammer (2014) showed strong inter-annual variability of annual precipitation and indicated that the variability is linked with El Nino and La Nina to some extent.

In Bangladesh there are four prominent seasons, namely, winter (December-February), pre-monsoon (March-May), monsoon (June-September) and post-monsoon (October-November). Climate characteristics for these four seasons are described below:

Winter (December-February):

Winter is relatively cooler and drier, with the average temperature ranging from a minimum of 7.2 to 12.8°C to a maximum of 23.9 to 31.1°C. The minimum temperature occasionally falls below 5°C in the northern region though frost is extremely rare. There is a south to north thermal gradient in winter mean temperature: generally the southern districts are 5°C warmer than the northern districts (Das, 2015). January is the coolest month, when the average temperature for most of the country is 16–20°C during the day and around 10°C at night. Mean annual rainfall is very low in this season around 40 mm ranges in between 25 mm to 60 mm.

Pre-monsoon (March-May):

Pre-monsoon is hot with an average maximum of 36.7°C, predominantly in the west for up to 10 days, very high rate of evaporation, and erratic but occasional heavy rainfall from March to June. In some places the temperature occasionally rises up to 40.6°C or more. The peak of the maximum temperatures are observed in April, the beginning of pre-monsoon season. In pre-monsoon season the mean temperature gradient is oriented in southwest to northeast direction with the warmer zone in the southwest and the cooler zone in the northeast (Das, 2015). Second highest rainfall occurs in this season is on an average 470 mm, which around 19% of the total annual rainfall.

Monsoon (June-September):

Monsoon is both hot and humid, brings heavy torrential rainfall throughout the season. About four-fifths of the mean annual rainfall occurs during monsoon. The mean monsoon temperatures are higher in the western districts compared to that for the eastern districts. Warm conditions generally prevail throughout the season, although cooler days are also observed during and following heavy downpours. Most of the rainfall occurs in the monsoon season (June-September) amounting to 1750 mm which is 71% of the total annual rainfall. Teknaf gets highest amount of monsoon rainfall around 3300 mm and Sylhet gets second highest 2800 mm.

Post-monsoon (October-November):

Post-monsoon is a short-living season characterized by withdrawal of rainfall and gradual lowering of night-time minimum temperature. Mean rainfall in this season is 210 mm. North-west region of Bangladesh in this season gets lowest rainfall.

On the basis of entire climatic condition Bangladesh can be divided into following seven distinct climatic zones (Figure 1.2). The familiar pattern of northwest to southeast isopleths is revealed in this classification. Characteristics of seven climate zones are described below which is adopted from Das (2015).

South-eastern zone (A): It comprises the Chittagong sub-region and a strip of land extending from southwest Sundarbans to the south of Comilla. The hills over 300m in height have north-eastern zone climate. The rest of the area has a small range of temperature, rarely goes over a mean of 32°C and below a mean of 13°C. Rainfall is heavy, usually over 2,540 mm. In winter dew fall is heavy.

North-eastern zone (B): This zone includes most of east and south Sylhet and a wedge shaped strip south of the Meghalaya Plateau. Here too, mean maximum temperature is rarely above 32°C but mean minimum is 10°C and below. Average humidity is even more than in south-eastern zone. In this zone winter rain is appreciable. Fog is very common in winter. This is the cloudiest part of Bangladesh. The higher hills and mountains of the Chittagong sub-region can also be classified under this zone.

Northern part of the northern region (C): This is an area of extremes. In summer the mean maximum temperature is well above 32°C whereas in winter the mean minimum is below 10°C. The summer is dry, with a scorching westerly wind, but the rainy season is very wet, with 2,000 to 3,000 mm of rainfall.

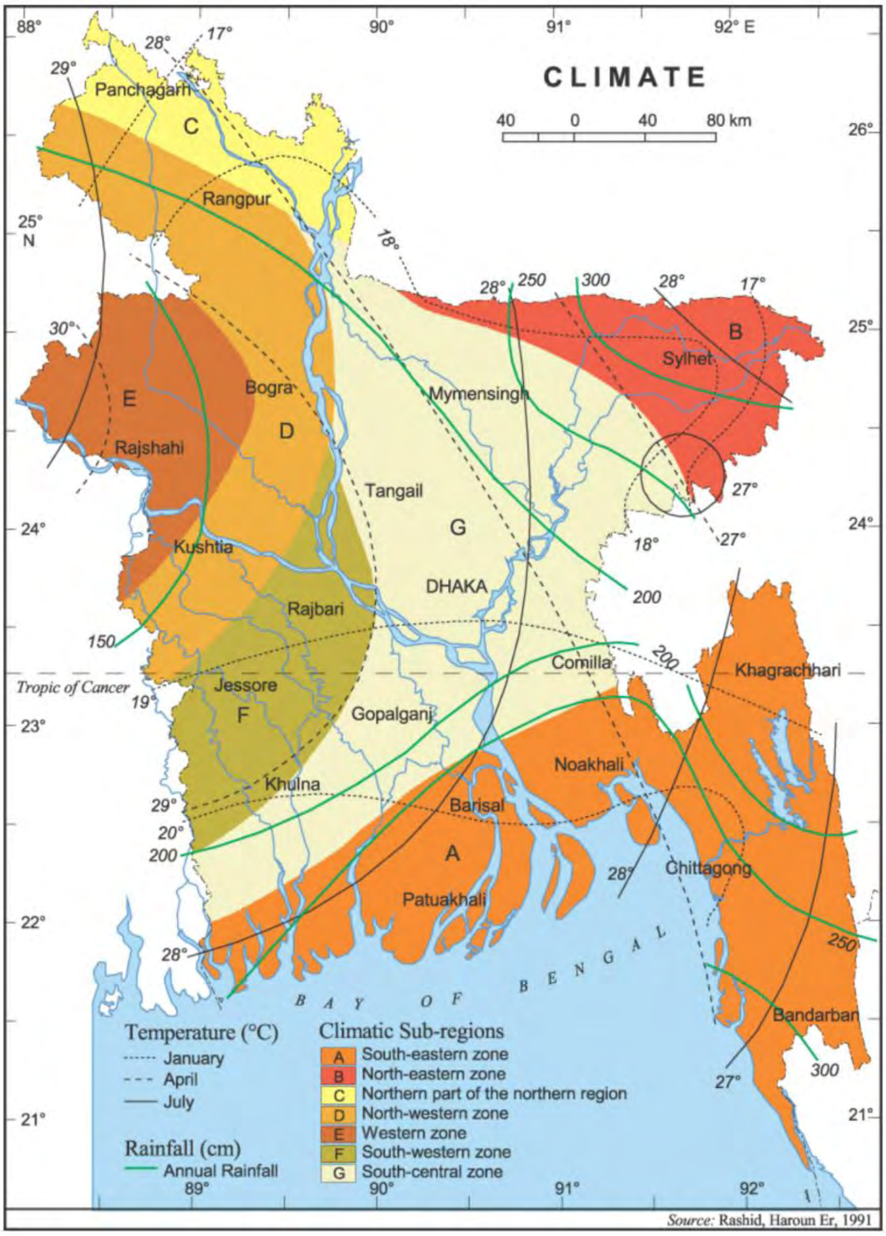


Figure 1.2: Climate zone of Bangladesh (Source: Rashid, 1991)

North-western (D): Except that the extremes are less and the rainfall is lower, this zone is similar to northern part of the northern region. The lower rainfall makes this area both atmospherically and pedologically drier.

Western zone (E): It comprises greater Rajshahi district and parts of adjacent districts. This is the driest area in Bangladesh with rainfall generally below 1,500 mm and summer humidity less than 50%. In summer, it is the hottest and driest of all climatic zones. Mean summer maximum temperature is over 35°C.

South-western zone (F): Here the extremes of the zones to the north are somewhat tempered. Rainfall is between 1,500 mm and 1,800 mm. The mean maximum temperature in summer is below 35°C. Dew-fall is heavier than in Western zone.

South-central zone (G): In this zone rainfall is abundant, being above 1,900 mm. The range of temperature is, as can be expected, much less than to the west, but somewhat more than in South-eastern zone. This is a transitory zone between the South-eastern,

North-western and South-western zones and most of the severe hail storms, and tornadoes are recorded in this area.

1.3 Research Objectives

The main objective of this study is to have a better understanding of characteristics of future local climate in Bangladesh under CMIP5 RCPs.

Specific objectives of this study are as following:

1. Development of statistical downscaling climate model for whole Bangladesh using SDSM.
2. Downscaling of different climate data i.e. maximum temperature, minimum temperature, rainfall and solar radiation using the developed statistical model.
3. Future projections of climate data (maximum temperature, minimum temperature, rainfall and solar radiation) for different RCPs under three different time slices 2030s (2016-2045), 2050s (2036-2065) and 2080s (2066-2095).
4. Assessment of future climate anomalies (seasonal change, season shifting and drought index) over Bangladesh for different RCPs.

As outcome of this study, a calibrated and validated statistical downscaling model for Bangladesh has been developed. Future climate data up to 2100 (maximum temperature, minimum temperature, precipitation and solar radiation) for different RCPs have been generated which will be useful for different impact studies for this country context. Local information on climate anomalies like seasonal change, season shifting and long term drought severity change etc. for future periods has also been generated over Bangladesh.

1.4 Organization of Chapters

Chapter 1 is the introductory chapter of this thesis which focuses on background of the study mentioning present state of the problems, description of the study area, research objectives with possible outcome and major limitations of the study.

Chapter 2 focuses on review of national and international published literatures on pros and cons of downscaling techniques, rationale of statistical downscaling, climate projections of different studies and condition of meteorological drought in Bangladesh.

Chapter 3 describes the overall approach of this study, followed by description of data collection and conceptual background of methodologies followed in this study with associated assumptions and possible limitations.

Chapter 4 discusses detailed steps of development of statistical downscaling model using SDSM followed by calibration and validation process of the model. Explanation has given how climate anomaly has been calculated from model generated output.

Chapter 5 discusses detailed steps of drought severity analysis using Self-calibrated Palmer Drought Severity Index (Sc-PDSI) program based on the SDSM generated data.

Chapter 6 is the illustration of the results generated in this study for different regions and all over the country and discussions of climate anomaly information in respect to maximum and minimum temperature, rainfall and solar radiation, shifting of season and changes of occurrence and severity of drought.

Chapter 7 finally gives a summary of the results obtained in this study and also includes recommendations for further study relevant to this topic.

Chapter 2 Literature Review

2.1 Introduction

Rigorous review of national and international published journal or conference papers, or reports have been performed to find out the rationale of this study, pros and cons of underlying theories and outcome of past relevant studies, which will facilitate to make this study more informative and authentic. In this Chapter, literature review has been discussed on different downscaling techniques with their strength and weakness, concept of Representative Concentration Pathways (RCPs), evidence of future climate change scenario generation through downscaling techniques, uses of Statistical Downscaling Model (SDSM) for statistical downscaling over the world including Bangladesh and future climate change scenarios assessed by different studies in Bangladesh. Finally, assessment of meteorological drought through different indices and status of future drought condition in Bangladesh are also included in the literature review. Apart from these, rationale, concept, assumptions and limitations of methodology followed specifically in this study has been extensively reviewed and cited in different sections of the next Chapter.

2.2 Downscaling Techniques

Downscaling means making the higher resolution climate data from coarser resolution data of General Circulation Models (GCMs), which is representative of local climate information instead of disperse information over a region. Mainly two types of downscaling techniques are available 1) dynamic downscaling and 2) statistical downscaling.

Dynamic Downscaling: Dynamic downscaling is the process through which finer resolution of climate information is extracted from GCM considering the dynamics of physical process. It involves nesting of high resolution Regional Climate Model (RCM) into coarser resolution GCM using its boundary. RCM uses GCM to define time–varying atmospheric boundary conditions (e.g. surface pressure, wind, temperature and vapor) around a finite domain, within which the physical dynamics of the atmosphere are modelled using horizontal grid spacing of 20–50 km (Wilby and Dawson, 2007; Wilby et al., 2009; Azad, 2015). Figure shows general approach of downscaling. The main drawbacks of dynamical downscaling are its needs for huge computational capability and time as GCM and sensitivity to choice of boundary conditions during initiation of experiments. (Christensen et al., 2007; Azad, 2015). The main advantage of dynamic downscaling apart from higher resolution are it can simulate smaller–scale atmospheric features such as orographic precipitation or low–level jets better than the host GCM, respond to the relative significance of different external forcings such as terrestrial–ecosystem or atmospheric chemistry changes.

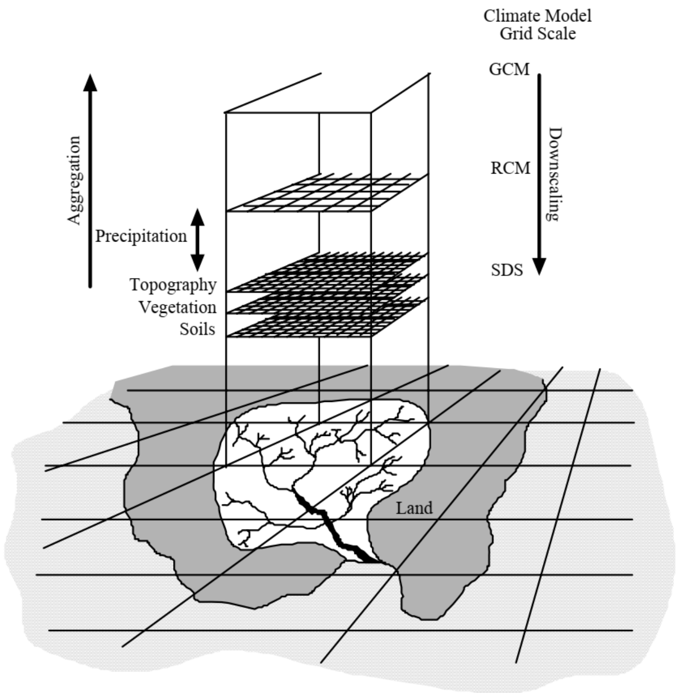


Figure 2.1: General approach of downscaling (from Wilby and Dawson, 2007)

Statistical Downscaling: Statistical downscaling is the process of generating station specific climate information from coarser GCM through establishing statistical relationship with local climate variable i.e. temperature, rainfall etc. and large-scale atmospheric variable of GCM like mean sea level pressure, geopotential height, vorticity, relative humidity etc. Statistical relationship can be developed through linear or non-linear multiple regression techniques, canonical correlation, artificial neural network, principal component analysis etc. Statistical downscaling methods have the advantage of being computationally inexpensive, able to access finer scales than dynamical methods and applicable to parameters that cannot be directly obtained from the RCM outputs (Christensen et al., 2007). On other hand, major weakness of this method is the inability to change the present day static established relationship of GCM predictors and local climate variables for future. Choice of predictor variables very crucial for this type of assessment. It also lacks coherency among multiple climate variables. Another reservation is that these empirically-based techniques cannot account for possible systematic changes in regional forcing conditions or feedback processes.

Other than these two, weather generator and weather typing are another two low skilled methods which use empirical relation to downscale climate data.

Weather Generator: Weather generator or stochastic weather generator can exactly replicate many observed climate statistics like mean, variance through modifying the parameters of conventional weather generator like LARS-WG, WGEN, EARWIG (Wilby et al., 2007; Alam, 2015). The weather generator develops empirical relationship between GCM variables and long term local climate variables for a given location to stochastically generate future weather data. Main disadvantage of this method is its low capability to produce inter-annual or decadal climate variability.

Weather Typing: It involves construction of climate change scenario through generating synthetic weather patterns from prevailing patterns of atmospheric circulation and resampling from observed data distribution. Weather pattern downscaling is founded on sensible linkages between climate on the large scale and weather at the local scale (Wilby et al., 2007). The technique is also valid for a wide variety of environmental variables as well as multi–site applications. However, it is a poor basis for downscaling rare events, and dependency on stationary circulation–to–surface climate relationships is another drawback.

2.3 Representative Concentration Pathways (RCPs)

Representative Concentration Pathways (RCPs) defines a specific emissions trajectory and subsequent radiative forcing (a radiative forcing is a measure of the influence a factor has in altering the balance of incoming and outgoing energy in the Earth-atmosphere system, measured in watts per square metre). RCPs was introduced by IPCC in 2007 responding the calls for improvements to SRES (Special Report on Emission Scenarios). The RCPs are the latest iteration of the scenario process, and are using in IPCC Fifth Assessment Report (AR5) in preference to SRES.

There are four pathways: RCP8.5, RCP6, RCP4.5 and RCP2.6. According to van Vuuren (2011a)-

"*Two important characteristics of RCPs are reflected in their names. The word "representative" signifies that each of the RCPs represents a larger set of scenarios in the literature. In fact, as a set, the RCPs should be compatible with the full range of* *emissions scenarios available in the current scientific literature, with and without climate policy. The words "concentration pathway" are meant to emphasize that these RCPs are not the final new, fully integrated scenarios (i.e. they are not a complete package of socio-economic, emission and climate projections), but instead are internally consistent sets of projections of the components of radiative forcing that are used in subsequent phases. The use of the word "concentration" instead of "emissions" also emphasizes that concentrations are used as the primary product of the RCPs, designed as input to climate models. Coupled carbon-cycle climate models can then as well calculate associated emission levels (which can be compared to the original emissions of the IAMs) (see Hibbard et.al., 2007). In total, a set of four pathways were produced that lead to radiative forcing levels of 8.5, 6, 4.5 and 2.6 W/m2,by the end of the century. Each of the RCPs covers the 1850–2100 period, and extensions have been formulated for the period thereafter (up to 2300)."*

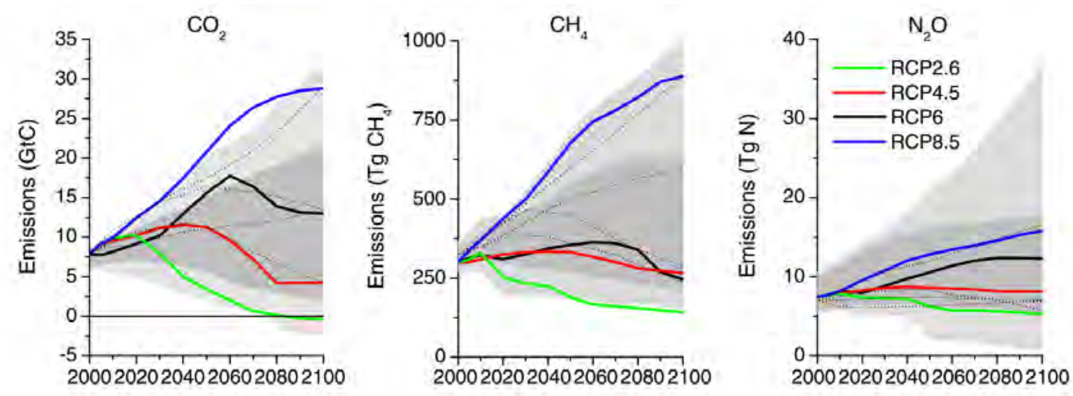


Figure 2.2: Emission of major GHGs across the RCPs. Grey area indicates the 98th and 90th percentiles (light/dark grey) of the literature. The dotted lines indicate four of the SRES marker scenarios. Note that the literature values are not harmonized (van Vuuren et.al., 2011a).

Perhaps the most innovative aspect of the RCPs is that instead of starting with socio-economic 'storylines' from which emission trajectories and climate impacts are projected (the SRES methodology), RCPs each describe an emission trajectory and concentration by the year 2100, and consequent forcing. Following are the characteristics of different RCPs quoted from van Vuuren et.al. 2011:

RCP 8.5 was developed using the MESSAGE model and the IIASA Integrated Assessment Framework by the International Institute for Applied Systems Analysis (IIASA), Austria. This RCP is characterized by increasing greenhouse gas emissions over time, representative of scenarios in the literature that lead to high greenhouse gas concentration levels (Riahi et al. 2007).

RCP6 was developed by the AIM modeling team at the National Institute for Environmental Studies (NIES) in Japan. It is a stabilization scenario in which total radiative forcing is stabilized shortly after 2100, without overshoot, by the application of a range of technologies and strategies for reducing greenhouse gas emissions (Fujino et al. 2006; Hijioka et al. 2008).

RCP 4.5 was developed by the GCAM modeling team at the Pacific Northwest National Laboratory's Joint Global Change Research Institute (JGCRI) in the United States. It is a stabilization scenario in which total radiative forcing is stabilized shortly after 2100, without overshooting the long-run radiative forcing target level.

RCP2.6 was developed by the IMAGE modeling team of the PBL Netherlands Environmental Assessment Agency. The emission pathway is representative of scenarios in the literature that lead to very low greenhouse gas concentration levels. It is a "peak-and-decline" scenario; its radiative forcing level first reaches a value of around 3.1 W/m2 by mid-century, and returns to 2.6 W/m2 by 2100. In order to reach such radiative forcing levels, greenhouse gas emissions (and indirectly emissions of air pollutants) are reduced substantially, over time.

Table 2.1: Median Temperature Anomaly over Pre-industrial Levels and SRES Comparisons Based on Nearest Temperature Anomaly (Moss et.al., 2010)

Name	Radiative Forcing	CO2 equiv (PPM)	Temp Anomaly (^{0}C)	Pathway	SRES Temp Anomaly Equivalent
RCP8.5	8.5 W/m^2 in 2100	1370	4.9	Rising	SRES A1F1
RCP6.0	6 W/m^2 post 2100	850	3.0	Stabilization without overshoot	SRES B2
RCP4.5	4.5 W/m^2 post 2100	650	2.4	Stabilization without overshoot	SRES B1
RCP2.6 (RCP3PD)	3 W/m^2 before 2100, declining to 2.6 Wm^2 by 2100	490	1.5	Peak and decline	None

2.4 Climate Projections through Downscaling

Atmosphere-Ocean General Circulation Models (AOGCMs) constitute the primary tool for capturing the global climate system behavior (Christensen et al., 2007) giving climate information over a vast region, with coarser resolution which varies from 125 km to 400 km. It does not allow the system to capture local climate information like for a country, which necessitated statistical downscaling or regional climate projections through dynamic downscaling. This type regional to local information is necessary in order to assess the impacts of climate change on human and natural systems and to develop suitable adaptation and mitigation strategies at the national level (Giorgi et al., 2009). According to (Bengtsson, 1996; May and Roeckner, 2001; Déqué and Gibelin, 2002) model grids of 100 km and finer have become feasible and 50 km will likely be usual practice in the near future. The process of regional climate projections have already been started worldwide. Both dynamic and statistical downscaling have been increasingly used to address a variety of climate-change issues and have by now become an important method in climate-change research (Huntingford and Gash, 2005).

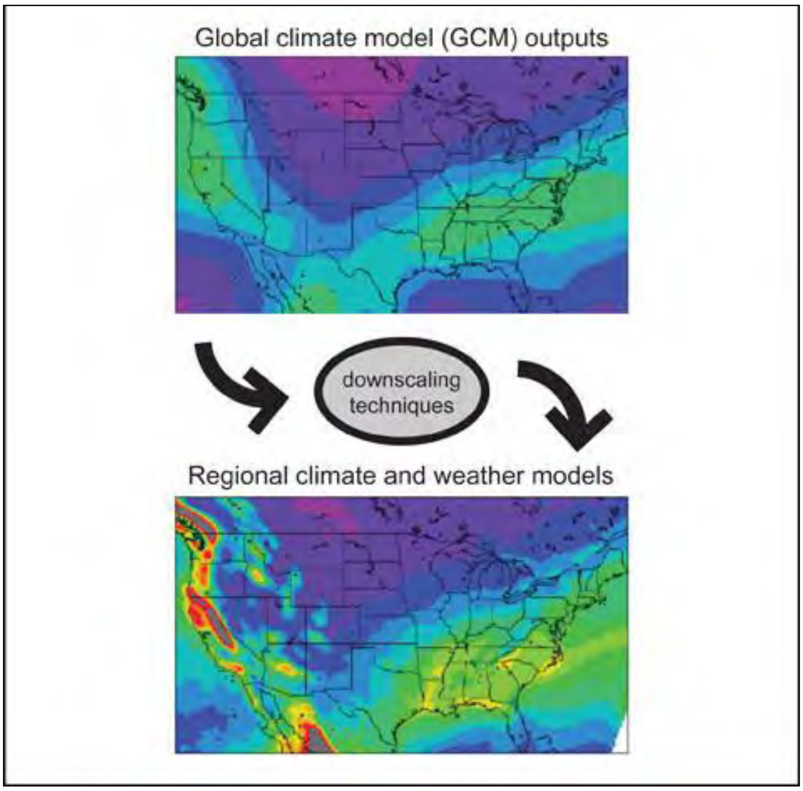


Figure 2.2: RCM result vs. GCM result after downscaling the GCM output by RCM (Source: PKSF, 2014)

The Coordinated Regional Downscaling Experiment (CORDEX) has been initiated to under program by World Climate Research Program (WCRP) to develop an improved framework for generating regional-scale climate projections for impact assessment and adaptation studies worldwide within the IPCC AR5 timeline and beyond. Providing Regional Climates for Impacts Studies (PRECIS) is a RCM developed by the Hadley Center of the United Kingdom, also applied in Bangladesh (Islam et.al, 2008, Rajib et al., 2012; Haque, 2014) to assess local level climate information for many impact assessment studies. Moreover, usage of statistical downscaling is also increased significantly in last two decades which has been reflected in numerous published papers (Salvi et al., 2011; Belay, 2011; Hassan et al., 2012; Wilby et al., 2013; Mahmood et al., 2013; Pervez et al., 2014; Nury et al., 2014; Azad, 2015; Mondal et al., 2016, Dorji et al., 2017). The applications of downscaling techniques vary widely with respect to regions, spatial and temporal scales, type of predictors and predictands, and climate statistics. In addition, empirical downscaling methods often offer a framework for testing the ability of physical models to simulate the empirically found links between large-scale and small-scale climate (Busuioc et al., 1999; von Storch et al., 1993).

2.5 Climate Projections in Bangladesh

Bangladesh is one of the countries most likely to suffer adverse impacts from anthropogenic climate change (Ali, 1999; IPCC, 2007; Haq, 2017; Bhuyan et al., 2018). Quantification of climate change is thus essential and since 1990, numerous studies have been conducted in this regard for Bangladesh.

Researchers have used either very traditional tools like trend analysis or directly using GCM output with or without bias correction or downscaling techniques using RCMs/ statistical tool to assess the future climate. In case of modeling experiment, very little information has been found using CMIP5 RCP scenarios, rather series of quantification available for SRES scenarios (Hasan et al., 2013; Islam and Hasan, 2012; Nowreen et al., 2014; Rajib et al., 2011). Hasan et al., (2014) mentioned that climate predictions using the RCP scenarios for the historical periods have less bias than the earlier scenarios used in the Fourth Assessment Report (e.g., A1B, A2, B1 and B2).

2.5.1 Temperature

There are various estimates of temperature rise in Bangladesh. One estimate (e.g. Ahmed and Alam, 1999) is that the average increase in temperature would be 1.3ºC by the year 2030 and 2.6ºC by the year 2075 with respect to the base year 1990. National Adaptation Program of Action (NAPA) recommended 1.0º, 1.4º and 2.4ºC temperature rises by the years 2030, 2050 and 2100, respectively (MoEF, 2005). Met office (2011) found temperature increases over Bangladesh are in the region of 3 to 3.5°C by 2100 for SRES scenarios with high confidence interval. On the other hand, Rajib et al. (2012) showed using PRECIS RCM that warming in Bangladesh prevails invariably every month, which might eventually result in an average annual increase of 4°C by the year 2100. Another study of the OECD compared the results of 17 GCMs for SRES B2 scenarios to assess the future climate. All climate models predicted a steady increase in temperature for Bangladesh, with little inter-model variances (Agrawala et al., 2003). On the Other hand, Hasan et al. (2015) using CMIP5 models projected that annual mean temperature will increase by 1.4–4.1°C by 2050s and 2.3–6.4°C by 2080s under different RCP scenarios.

Recently, Fahad et al. (2017) using multi-model ensemble of CMIP5 models showed that, at the end of the century, the mean temperature will increase over Bangladesh varying from 5.77 to 3.24ºC under RCP8.5. Spatial analysis of the 11 RCMs exhibited that the southwest and the south central parts of Bangladesh will experience a greater temperature rise in the future.

Moreover, Biswas et al. (2017) gave indication of increase of maximum and minimum temperature increase in different regions of Bangladesh, monthly maximum temperature increase would be 0.60-0.99ºC in 2050 and 0.83-2.93ºC in 2100 compared to 2010 under different RCPs. Increase in monthly minimum temperature is likely to be 0.98-1.31ºC in 2050 and 0.75-2.93ºC in 2100 compared to 2010. He found higher increase in minimum temperature than maximum temperature.

However, the seasonal variation of temperature will be more (Ahmed and Alam, 1999) in winter than in summer: 1.3ºC in winter and 0.7ºC in summer for 2030 and 2.1ºC for winter and 1.7ºC for summer for 2075. Rajib et al. (2012) found similar result showing higher temperature increase during December or January (around 5 °C in 2071–2100) compared to the monsoon season months like July (around 3 °C in 2071–2100).

In case of regional variation, Rouf et al. (2011) showed the past, present and future climatic pattern (temperature and rainfall) of northwestern and southwestern part of Bangladesh based on AOGCM and BMD (1979-2006) data. The mean temperature for Bangladesh was found to rise in near future and future (increase up to 4.34°C/100 years), the rate is projected to be 5.39°C/100 years in northwest and 4.37°C/100 years in southwest region. Bhuyan et al. (2018) took both BMD data (1981-2008) and MPI-ESM-LR (CMIP5) model data in the north-western region and found increasing rate of 5.3˚C per century for average maximum temperature and future normal temperature will be increased at a rate of 1.62˚C during the period 2040-2100, whereas, the average annual temperature of Bangladesh is expected to increase by 1.4 ± 0.6 °C by 2050 (Ramamasy et al., 2007) relative to 1953–2004.

2.5.2 Rainfall

Met Office, (2011) predicted that precipitation will be increased in Bangladesh under the SRES A1B emission scenario. Increases of up to 20% could occur in the north of the country with increases of 5-10% more typical through the rest of the country. Hasan et al. (2014 and 2015) using ECAHM5 model data of CORDEX domain found significant increase of rainfall in the pre-monsoon season than that of any other seasons of the year. The likely range of increase in the annual precipitation is projected to be 5%– 50% during pre-monsoon and 10% for both monsoon and post-monsoon seasons under the RCP8.5 scenario in the 2080s era. However, up to 45% reduction of precipitation will be observed during winter in 2050s under the RCP 8.5 scenario. In 2017, CIAT (2017) summarized from CMIP5 downscaling that rainfall is expected to increase in Bangladesh by 9-12% by 2050 based on the studies of (Collins et al., 2013 and Ramírez-Villegas et al., 2015).

In the same year, Fahad et al. (2017) found a significant increase of rainfall in the pre- and post-monsoon period. A significant increase of mean rainfall up to 12%, over northeast and southeast regions of Bangladesh will be occurred. The highest increase of rainfall, up to 20.39%, was projected to occur over the eastern hilly region of Bangladesh. Greater increase of precipitation is expected over Bangladesh for 2080s than for the 2020s and 2050s. The results indicate a decrease in rainfall by up to 8.22% over the SW of Bangladesh.

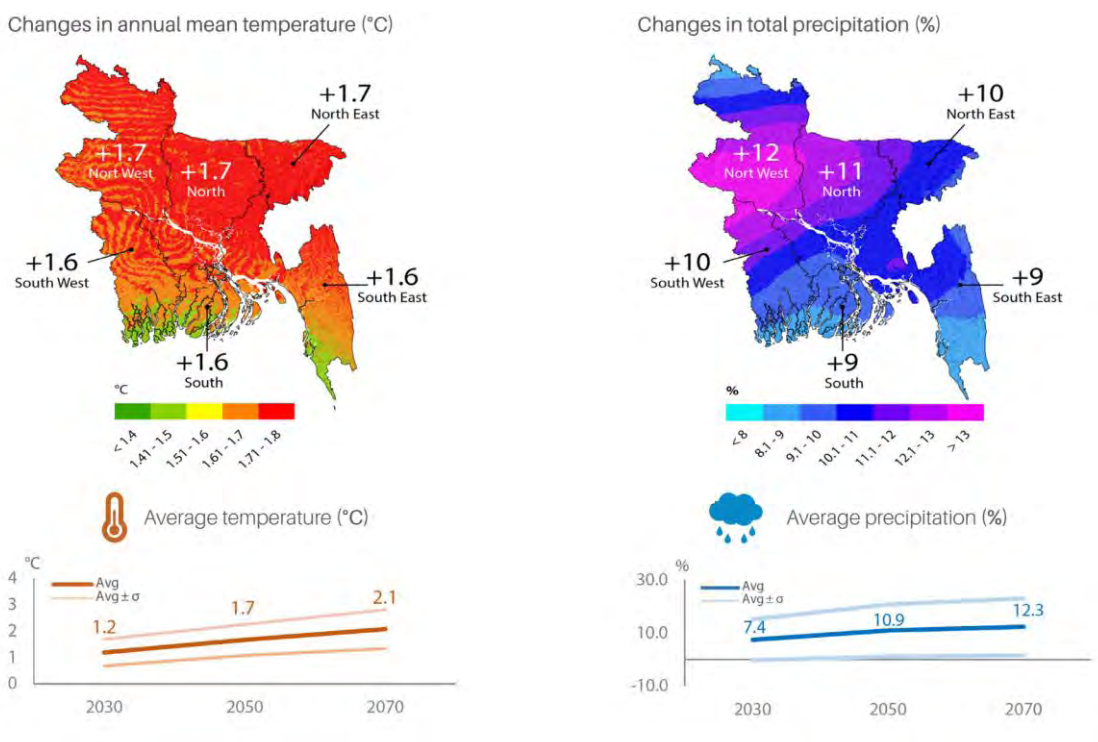


Figure 2.3: Temperature and rainfall projections over Bangladesh (Source: CIAT, 2017)

In case of trend, Ahasan et al. (2010) found that the country's average monsoon rainfall is decreasing at a rate of 0.53 mm/year. Following same pattern, Rouf et al. (2011) found decreasing trend of future average rainfall over Bangladesh (decreases up to 1.96 mm/100 years). The mean average rainfall of northwest region will decrease slowly in northwest (up to 0.66mm/100 years and but quite rapid in southwest region (up to to 3.62 mm/100 years). Rahman et al. (2016) also investigated temporal variability of rainfall in the North-West part of Bangladesh over the period of 1975-2014 using BMD data and found annual and monsoon rainfall in decreasing trends in recent times at a rate of 0.102 mm/year and 0.080 mm per year respectively, which implies that study region are intended towards drought.

Hasan et al. (2014) studied the rainfall trend for the southeast part of coastal Bangladesh and found increasing pre-monsoon rainfall trend. Bari et al. (2016) also illustrated investigating 50 years (1964-2013) of seasonal and annual rainfall trends over northern Bangladesh that pre-monsoon and post-monsoon rainfall is increasing in most of the rainfall stations. Monsoon rainfall showed a decreasing trend in the majority of the area studied. The maximum decrement in monsoon rainfall was found for Sylhet station (8.10 mm/year) and minimum in Mymensingh (1.53 mm/year). Although, an upward monsoon rainfall trend was found for Rangpur (2.02 mm/year). Results of study by Choudhury et al. (2012) and Mondol et al. (2018) had shown similar findings that the rainfall in Bangladesh is moderately seasonal, with an intensity increasing from the pre-monsoon to the monsoon season, driven by weak tropical depressions from the Bay of Bengal. Stephenson et al. (2001) found a weakening of the monsoon circulation using results from the recent atmospheric general circulation experiments for Asian summer monsoon. However, Biswas et al. (2017) found north-east region of Bangladesh will remain the highest rainfall zone in future. Rainfall in south-west region is likely to increase in 2050 and 2100 compared to historical average. There would be higher precipitation in north-west and south-west regions of the country during 2100. The CDMP (2012) also reported increased annual rainfalls in north-west and southwest regions.

In a nutshell, many researches have been performed to find out climate projections especially for temperature and rainfall. Most of the studies have found more or less similar findings. Ranges of climate anomaly have been varied in most of the cases, but it is due to the difference in selection of base period, GCMs, scenarios and analysis techniques.

2.5.3 Solar Radiation

Researches on solar radiation projections have been not found too much CDMP (2012) found decreasing solar radiation trend in all over Bangladesh. They reported that winter, pre-monsoon, monsoon and post-monsoon sunshine hours are declining at a rate of 4.6%, 4.1%, 3.4% and 5.3%, respectively in every 10 years in Bangladesh. The analysis of sunshine duration by (PKSF, 2014) revealed that the average sunshine hours are declining for all the selected stations of BMD. The maximum decreasing rate for Dhaka is 0.52 hours a day every 10 years and minimum rate is 0.17 hours a day in a decade. Analysis of data for all the stations reveals that the declining rate is higher in west than in east and in north than in south regions. This study also indicates decreasing pattern of solar radiation. However, Biswas et al. (2017) has found increased solar radiation during December to April in most of the regions of Bangladesh.

2.6 Meteorological Drought in Bangladesh

The drought prone areas in Bangladesh are mostly concentrated in the north-west region. The mean annual rainfall in drought prone zone is 1250-1750 mm, falling mainly in 4 to 5 wet months. The drought situation of the area becomes severe during April-May due to the cumulative effect of presence of soils with low moisture holding capacity (<200 mm available moisture), increasing number of dry days (Precipitation <0.5 PET) and occurrence of extreme summer temperature of more than 40°C. In these areas, period of dry days ranges between 32-48 days, starting from end of March to mid of May and during this period the temperature also rises more than 40°C for 5 to 15 days. In addition, some soils have low moisture holding capacities, which show different degrees of droughtiness. Rabi and pre-Kharif drought (January/May) occurs due to the cumulative effect of dry days, higher temperatures during pre-Kharif (>40°C in March/May) and low soil moisture availability.

Kharif drought occurs from 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). The Madhupur tract in the central parts of the country is also drought prone. The geographical distribution of drought prone areas for different seasons (shown in Figure 2.4 and 2.5) illustrates that the western parts as well as Barind area of the country are at greater risk from droughts during both the Kharif and pre-Kharif seasons.

Meteorological drought is a short-lived, recurring natural disaster, which originates from the deficit of precipitation and can bring significant economic losses. Due to the critical influence of large variability of precipitation, detection of drought becomes very important for policy making efforts too. Several studies have been performed thus to assess meteorological drought pattern of Bangladesh. Although, researches regarding future drought characteristics are found very less than past drought analysis.

Israt et al. (2012) and CDMP (2013) expressed that Bangladesh is vulnerable to recurrent droughts. After 1971 Bangladesh has experienced droughts of major magnitude in 1972, 1973, 1975, 1979, 1980, 1983, 1985, 1992, 1994 and 1995. Drought analysis of Israt et al., (2012) in the eastern part of Bangladesh using climate indices shows that generally the month of January, February, March, November and December are drought affected. The month of April faces drought almost every year. May and October face drought occasionally.

Das et al. (2012) assessed meteorological drought events occurrence in Bangladesh using monthly rainfall and mean air temperature from the surface observations and Regional Climate Model (RegCM) by calculating Standardized Precipitation Index (SPI) and Palmer Drought Severity Index (PDSI) for the period 1961–1990. The PDSI results for model and observed data are nearly same to SPI calculations. Frequency of moderate drought is found higher all over the Bangladesh. Wet regions are affected by more extreme droughts than the dry region in 1- and 6-month scale. But dry region experienced more severe drought than the wet region. It is evident that SPI and PDSI calculation over a region provides better consistency of drought situation instead of single station information.

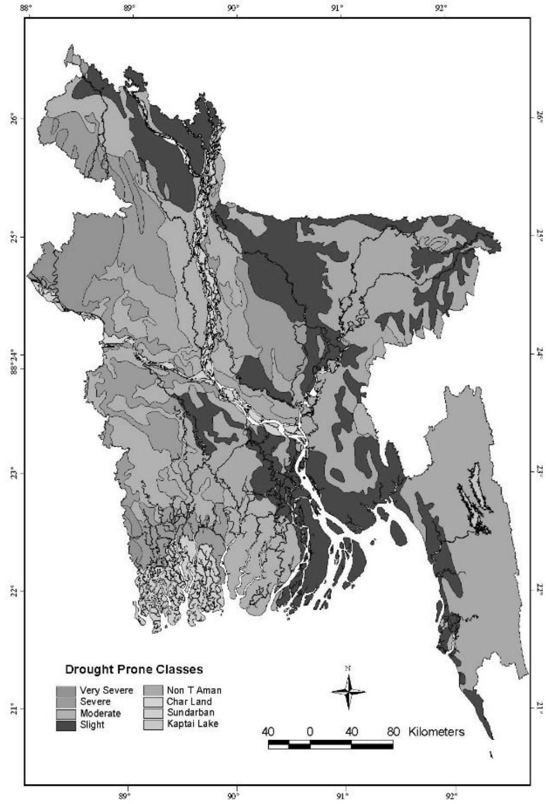


Figure 2.4: Drought prone (Kharif) areas of Bangladesh

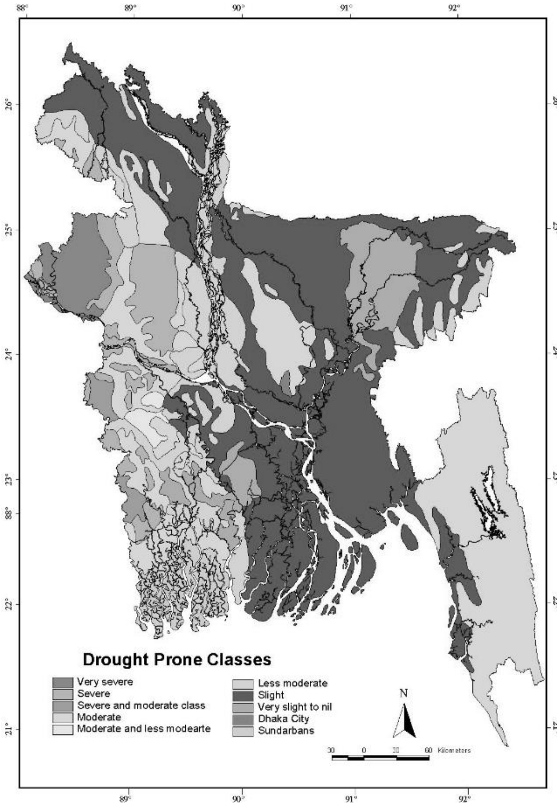


Figure 2.5: Drought prone (Rabi and Pre Kharif) areas of Bangladesh

Data Source: Soil Resources Development Institute

Shahid (2008) studied severity of droughts from the rainfall data recorded in 12 rainfall gauge stations for the period of 1961–1999 over western region of Bangladesh using Standardized Precipitation Index (SPI) and found the north and north-western parts of Bangladesh are most vulnerable to droughts and moderate drought occurrences are higher in the southern part of the country compared to other parts. More crucial finding of this study was no relation was found in between the rainfall distribution and drought potential zones.

Mondol et al. (2017) demonstrated that drought occurred in Bangladesh on an average of 2.5 years. Drought was more prominent in the northern, south-western, and eastern regions in Bangladesh compared to the rest of the areas of the country. The southwest areas of the country, Jessore and Satkhira, and the coastal areas, including Bhola and Patuakhali, were more prone to meteorological drought. The eastern part of the country was comparatively free of meteorological drought. In contrast, in the south eastern part, the Chittagong hill tract areas experienced much drought.

Rahman et al. (2016) investigated drought occurrences using SPI method and showed that comparatively moderate drought occurred more frequently than severe and extreme. The northern, north-western, western, south-western and central parts were the most drought-prone areas of the country in terms of occurrence and severity. Low annual and seasonal rainfall, high variability in rainfall and climate change impacts, and particularly increased maximum temperatures greatly influence droughts in Bangladesh.

Two researches (Hasan et al., 2013 and Hossain et al., 2017) are found most recently done on future drought characteristics. Hasan et al. (2013) assessed future drought conditions using 25km high resolution downscaled and projected climate data of SRES A1B scenario and found all three types of droughts will be decreased in future years where there will be a comparative higher frequency of drought at mid-21st Century considering seasonal (using 3 months SPI) drought events. Few drought prone areas, especially in the north western parts of the country will experience increasing number of drought events.

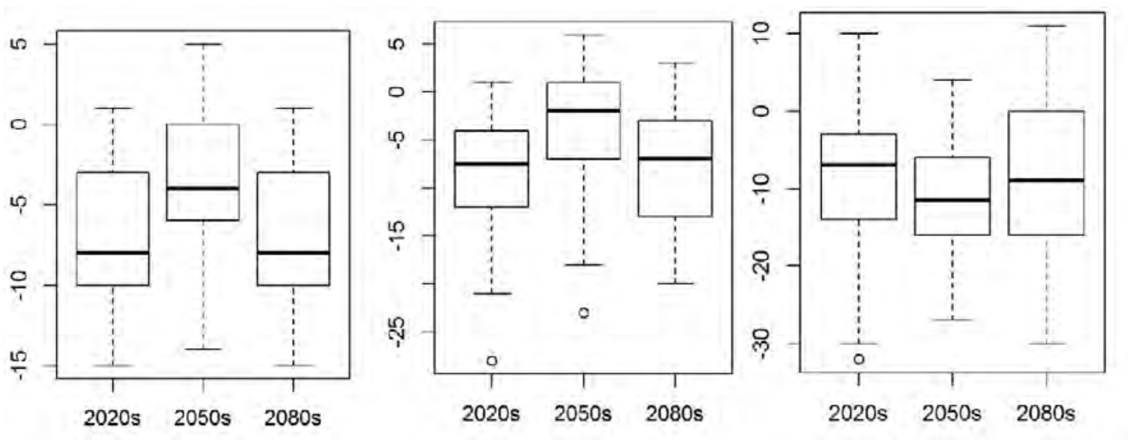


Figure 2.6: Changes of the frequency of extreme, severe and moderate drought events (from left to right) during 2020s, 2050s and 2080s time slices from the baseline (1971 to 2010) period (Source: Hasan et al., 2013)

Hossain et al. (2017) worked with Sc-PDSI program to calculate PDSI values over Bangladesh for future periods using multi model ensemble mean of five GCMs (CCSM4, GFDL-ESM2M, HadGEM2-ES, MIROC5, and MPI-ESM-MR) for RCP 4.5. Study found prevalence of mild and moderate drought situations in most BMD stations and drought situation is found more prevalent in the north-west and south-west regions. Study concluded that, Sc-PDSI successfully illustrates the spatial variability of the drought patterns in Bangladesh. The climate change scenario results identifies the changing drought pattern in the country due to the increasing temperature and spatial variability of rainfall distribution. Drought situation is expected to increase further in the country for the both near future and end of century periods on average changing its severity. Study by CDMP (2013) also concluded similar findings about drought severity.

Chapter 3 Methodology

3.1 Introduction

This chapter illustrates the overall approach of this study with underlying concept, assumptions and limitations of the methodology. Rationale of the methodology followed is also described. Data collection for this study is also described in next section.

Figure 3.1 shows the overall approach of this study.

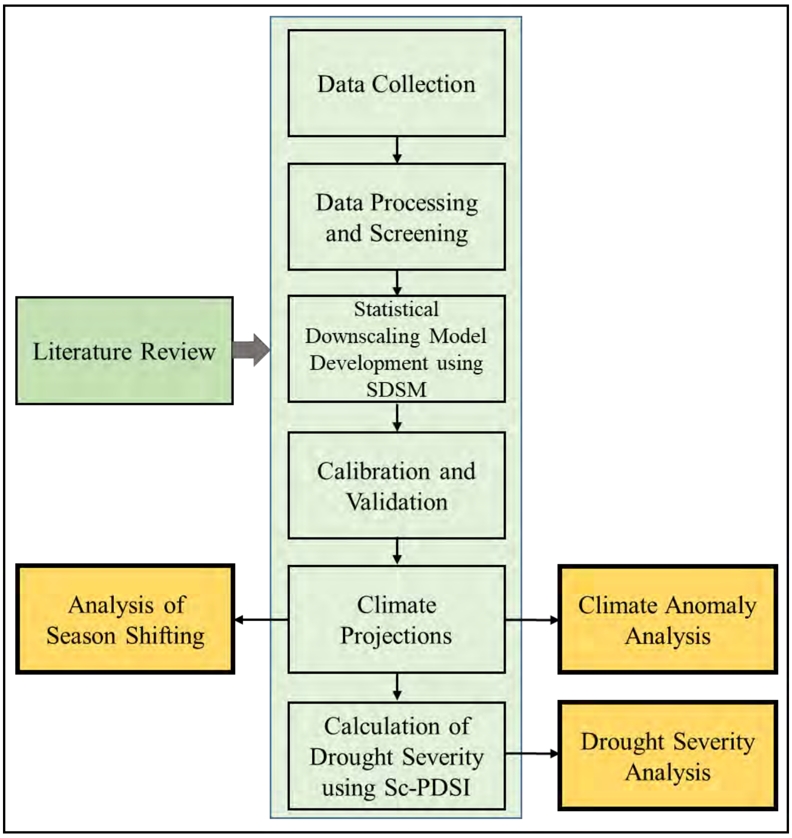


Figure 3.1: Overall approach of the study

3.2 Data Collection

Three types of data are found necessary for this study 1) local climate data 2) large scale atmospheric variable and 3) soil moisture data. Collection status of available data is described below:

3.2.1 Local climate data

Effort has been made to collect available local climate data i.e. maximum temperature, minimum temperature, rainfall and solar radiation for 31 stations of Bangladesh

Meteorological Department (BMD). Figure 3.2 shows the spatial distribution of BMD stations. Data of maximum and minimum temperature and rainfall has been collected for 1971-2013 period for all of the BMD stations. But, solar radiation data has been found for only 7 stations containing and for 1985-2005 period. All available collected data contained substantial amount of missing data. Table 3.1 shows the details of collected local climate data for different BMD stations from Bangladesh Meteorological Department (BMD).

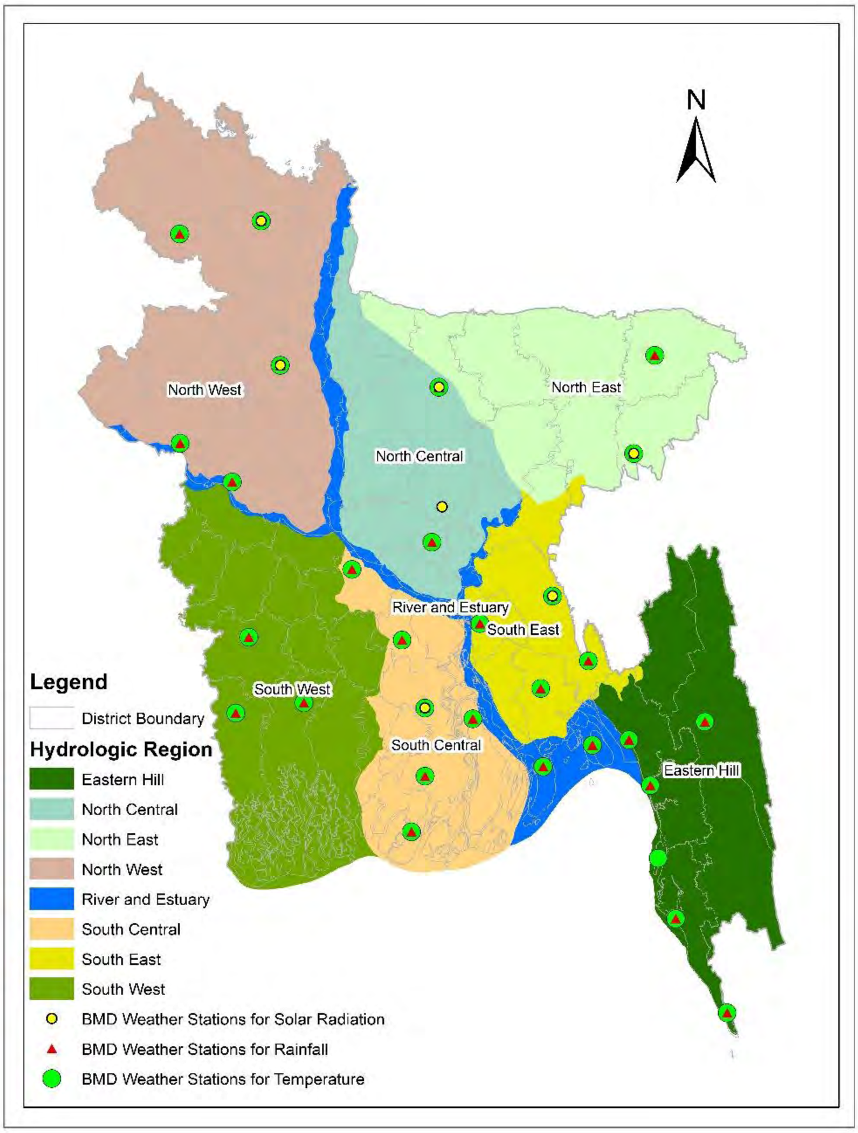


Figure 3.2: Meteorological stations of BMD (Source: CEGIS)

Table 3.1: Local Climate Data Used in this Study from BMD Stations

ID	Station	Lat	Long	Mean MaxT (^{0}C)	Mean MinT (^{0}C)	Mean Rain (mm)	Mean Radiation (MJ/Sq.m/Day)
11704	Barisal	22.7	90.4	30.4	21.1	2116	9.3
11706	Bhola	22.7	90.7	30.3	21.4	2328	-
10408	Bogra	24.9	89.4	30.6	20.7	1837	10.7
11316	Chandpur	23.2	90.7	30.2	21.6	2119	-
11921	Chittagong	22.3	91.8	30.2	21.6	2897	-
11313	Comilla	23.5	91.2	30.1	22.0	3474	8.5
11927	Coxs bazar	21.4	92.0	30.1	20.9	2046	-
11111	Dhaka	23.8	90.4	30.6	21.5	2139	-
10120	Dinajpur	25.6	88.7	30.0	19.6	2004	-
11505	Faridpur	23.6	89.8	30.4	21.0	1935	-
11805	Feni	23.0	91.4	30.3	22.3	3057	-
11814	Hatiya	22.4	91.1	29.5	22.2	2967	-
10910	Ishwardi	24.1	89.1	30.9	20.2	1650	-
11407	Jessore	23.2	89.2	31.4	20.9	1607	-
41917	Joydevpur	24.0	90.5	-	-	-	9.9
12110	Khepupara	22.0	90.2	30.1	22.2	2725	-
11604	Khulna	22.8	89.6	31.1	21.6	1759	-
11925	Kutubdia	21.8	91.9	29.8	22.1	-	-
11513	Madaripur	23.2	90.2	30.9	21.2	2090	-
11809	Maijdee court	22.8	91.1	29.9	21.6	3092	-
10609	Mymensingh	24.7	90.4	30.0	20.6	2195	9.1
12103	Patuakhali	22.3	90.3	30.3	22.0	2687	-
10320	Rajshahi	24.4	88.6	31.1	20.5	1536	-
12007	Rangamati	22.7	92.2	30.2	21.4	2541	-
10208	Rangpur	25.7	89.2	29.6	19.8	2232	9.5
11916	Sandwip	22.5	91.4	29.4	22.3	3468	-
11610	Satkhira	22.7	89.1	31.5	21.4	1695	-
11912	Sitakunda	22.6	91.7	30.2	21.1	3052	-
10724	Sreemangal	24.3	91.7	30.4	19.4	2339	9.3
10705	Sylhet	24.9	91.9	29.6	20.2	4161	-
11929	Teknaf	20.9	92.3	30.1	22.0	3943	-

3.2.2 Large scale atmospheric variable

Required large scale atmospheric variables for both historical period and future periods have been collected from Canadian Climate Data and Scenarios (CCDS) website (http://climate-scenarios.canada.ca/), where large scale predictor variable data has been shared under Coupled Model Intercomparison Project 5 (CMIP5) experiment of IPCC. The obtained predictor variables are found at spatial resolution of 2.81^o x 2.81^o. Historical data are found for 1961-2005 period and CanESM2 GCM future data are found for 2006-2100 for three different RCPs as RCP2.6, RCP4.5 and RCP8.5 in separate files. Historical predictor variables data obtained are actually produced by US National Centers for Environmental Prediction (NCEP). The NCEP reanalysis data set is gridded data set representing the state of the Earth's atmosphere, incorporating observations and Numerical Weather Prediction (NWP) model output dating back to 1948, which are normalised over the complete 1961-2005 period. Total 26 normalized daily predictors (describing atmospheric circulation, thickness and moisture content at the surface, geopotential heights at 850 and 500 hPa etc.) are obtained for the downscaling. Table 3.2 list of predictors obtained from NCEP and CanESM2 datasets.

Table 3.2: List of Predictor Variables from NCEP Re-analysis and CanESM2 Datasets

Predictor Code	Daily Predictor Variable	Predictor Code	Daily Predictor Variable
p500	500 hPa Geopotential height	**p_th**	1000 hPa Wind direction
p8_v	850 hPa Meridional velocity	**p5_f**	500 hPa Wind speed
s500	500 hPa Specific humidity	**p5_z**	500 hPa Vorticity
shum	1000 hPa Specific humidity	**p8_f**	850 hPa Wind speed
p5_u	500 hPa Zonal velocity	**p5zh**	500 hPa Divergence
p_u	1000 hPa Zonal velocity	**p8_z**	850 hPa Vorticity
p5_v	500 hPa Meridional velocity	**p_f**	1000 hPa Wind speed
s850	850 hPa Specific humidity	**temp**	Surface air (2m) temperature
p_v	1000 hPa Meridional velocity	**p8zh**	850 hPa Divergence
p8_u	850 hPa Zonal velocity	**p_z**	1000 hPa Vorticity
mslp	Mean Sea Level pressure	**p8th**	850 hPa Wind direction

Predictor Code	Daily Predictor Variable	Predictor Code	Daily Predictor Variable
p850	850 hPa Geopotential height	**p1_zh**	1000 hPa Divergence
p5th	500 hPa Wind direction	**prcp**	Precipitation

3.2.3 Available Water Content

Available Water Content (AWC) data is the most important input for PDSI calculation, which varies significantly from one location to another. This AWC for every BMD stations has been collected from the UNDP & FAO reports (1988a, 1988b) and (Datta, 2005). Table 3.3 shows AWC data for BMD stations used in this study.

Table 3.3: Available Water Content (AWC) used in this Study for BMD Stations

Station	Available Water Content (in)	Station	Available Water Content (in)
Barisal	22.8	**Khulna**	22.8
Bhola	30.3	**Madaripur**	20.1
Bogra	21.0	**Maijdeecourt**	30.3
Chandpur	25.8	**Mymensingh**	21.7
Chittagong	21.0	**Patuakhali**	22.8
Comilla	20.3	**Rajshahi**	21.1
Coxs Bazar	21.0	**Rangamati**	19.6
Dhaka	18.3	**Rangpur**	30.6
Dinajpur	30.6	**Sandwip**	30.3
Faridpur	20.1	**Satikhira**	22.8
Feni	27.2	**Sitakunda**	21.0
Ishawrdi	21.1	**Sreemangal**	20.3
Jessore	21.1	**Sylhet**	20.3
Khepupara	22.8	**Teknaf**	21.0

3.3 Statistical Downscaling using SDSM

3.3.1 Rationale

Statistical downscaling using SDSM provides the opportunity to establish low cost multiple and single site scenarios for daily surface weather variables under present and future climate change scenarios (Wilby, 2000). SDSM 4.2 was developed by Wilby (2000), a decision support tool and uses a hybrid approach i.e. combination of stochastic weather generator and transfer functions method which involves establishing linear or nonlinear relation between large scale ‘predictors’ of GCM and ‘predictands or local climate variables' (Christensen et al., 2007; Wilby et al., 2002). Since then SDSM has become popular among researchers of many countries including Europe, North America, Southeast Asia specially in and around of Bangladesh (Wilby et al., 1999, 2000; Hay et al., 2000, Hassan et al., 2012; Belay, 2011; Salvi et al., 2011; Nury et al., 2014; Pervez et al; 2014; Rahaman et al., 2015; Ali et al., 2016; Dorji et al., 2017) for meteorological, hydrological or environmental assessments. Robustness, easy to implement and computationally inexpensive techniques of SDSM provides superiority over other methods e.g. direct use of GCM output, dynamic downscaling or sensitivity analysis etc.

In addition, Coulibaly et al., (2004) and Liu et al., (2008) showed that SDSM satisfactorily can estimate extreme temperatures. It is capable of skillfully simulate rainfall occurrence indices than intensity (Haylock et al., 2006). Although SDSM model is able to capture most of the monthly and annual rainfall with a good agreement between observed and simulated rainfall, several studies (Dibike et al., 2005; Harun et al., 2008; Chu et al., 2010 and Hassan et al., 2012) found that SDSM is poor in predicting daily rainfall. A daily rainfall is the most difficult variables for prediction and it is a condition process which involves an inter-connected with many factors/variables (Wilby and Dawson, 2007). Statistical Downscaling Model (SDSM) is intended to bridge the gap between accessibility and sophistication. SDSM can also be used as a stochastic weather generator or to fill in gaps in hydro meteorological time series (Wilby, 2002).

3.3.2 Concept

SDSM model contains two separate sub-models to determine occurrence and amount of conditional meteorological variables (or discrete variables) such as precipitation and amount model for unconditional variables (or continues variables) such as temperature or evaporation. Therefore, SDSM can be classified as a conditional weather generator in which regression equations are used to estimate the parameters of daily precipitation occurrence and amount, separately, so it is slightly more sophisticated than a straightforward regression model (Tavakol-Davani et al., 2013). Occurrence of rainfall can be represented by equation (3.1).

$$w_t = \alpha_0 + \sum_{j=1}^{n} \alpha_j \hat{u}_t^{(j)} + \alpha_{t-1} w_{t-1} \tag{3.1}$$

where, t is time (days), w_t is the conditional possibility of rain occurrence on day t, $\hat{u}_t$ is the normalized predictor, α_j is the regression parameter deduced by an ordinary least square method and w_{t-1} and α_{t-1} are the conditional probabilities of rain occurrence on day *t-1* and lag-1 day regression parameter respectively. Last two parameters are optional, depending on the study region and predictand. Uniformly distributed random number r_t ($0 \leq r_t \leq 1$) is used to determine the rain occurrence and supposed the rain would happen if $r_t \leq w_t$. Again, the amount of rainfall or unconditional variable like temperature can be estimated through following equation (3.2).

$$Z_t = \beta_0 + \sum_{j=1}^{n} \beta_j \hat{u}_t^{(j)} + \beta_{t-1} Z_{t-1} + \varepsilon \quad (3.2)$$

in which Z_t is the z-score on day *t*, β_j is the calculated regression parameter, and β_{t-1} and Z_{t-1} are the regression parameter and the z-score on day *t-1* respectively. The model error ε is assumed to follow a Gaussian distribution and is stochastically generated from normally distributed random numbers and added on a daily basis to the deterministic component (Nury et al., 2014).

Figure 3.3 shows steps of downscaling through SDSM.

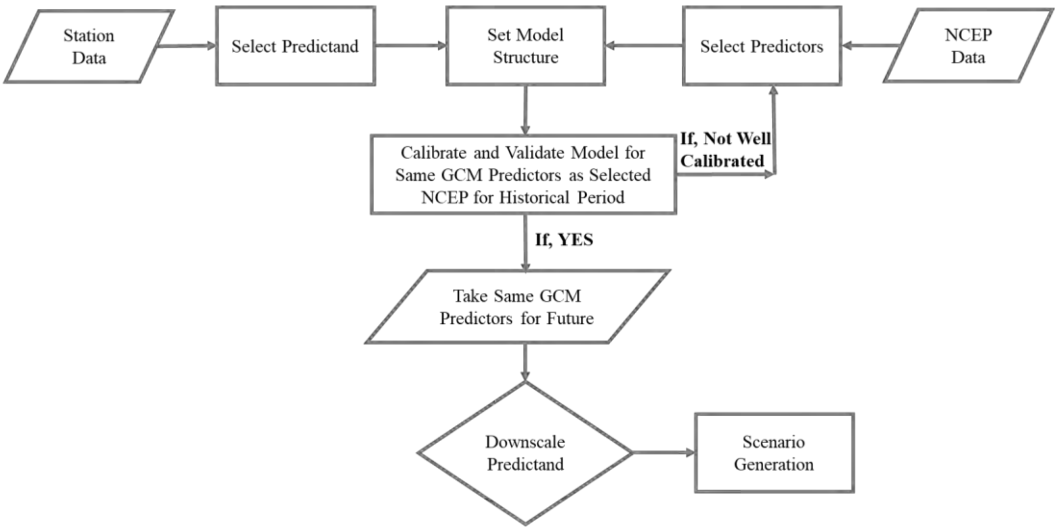


Figure 3.3: Structure of SDSM (adopted from Wilby et al, 2000)

The detailed steps followed in this study for development of Statistical Downscaling Model are described in Chapter 4, where SDSM 4.2.9 has been used for all downscaling.

3.3.3 Assumptions

Reliable and high resolution location specific future climate change data than raw GCM can be produced if and else downscaling techniques satisfy some assumptions. The assumption made in statistical downscaling is that stable statistical relationships occur at different temporal and spatial scales (Wilby et al., 1998). Statistical downscaling using SDSM is based and conceptualized on three assumptions (Tripathi et al., 2006, Ali et al., 2016). First, suitable relationships can be developed between larger-scale versus smaller-scale predictor variables. Second, the empirical relationship between the predictand and the predictor will remain the same under present and future conditions. It actually differs the method from dynamic downscaling where change in physical process is considered for future periods also. Third, it is assumed that the predictors accurately represent climate changes and their indications, which means that the predictors used for establishing relation between local climate and large scale variables of GCM have been modeled realistically by GCM.

3.3.4 Limitations

Some major weaknesses of statistical downscaling using SDSM adopted from Wilby and Dawson (2007) are as following:

- SDSM is Dependent on the realism of GCM boundary forcing
- Choice of domain size and location affects results
- Requires high quality data for model calibration
- Predictor–predictand relationships are often non–stationary
- Choice of predictor variables affects results
- Choice of empirical transfer scheme affects results
- Low–frequency climate variability problematic
- Always applied off-line, therefore, results do not feedback into the host GCM

3.4 Self-calibrating Palmer Drought Severity Index (Sc-PDSI)

3.4.1 Rationale

Palmer Drought Severity Index (PDSI) was developed by Palmer (Palmer, 1965), which is one of the most prominent index of meteorological drought. It was developed to measure the cumulative departure (relative to local mean condition) in atmospheric moisture supply and demand at the surface. It incorporates antecedent precipitation, moisture supply, and moisture demand into a hydrological accounting system (Collier, 2016). It is most effective measuring impacts sensitive to soil moisture conditions, such as agriculture (Willeke et al., 1994). Use of PDSI as drought monitoring tool is quite popular in United States to trigger actions associated with drought contingency plans (Willeke et al., 1994). Three positive characteristics of Palmer Index have been identified by Alley (1984), which seem to contribute to its popularity i.e. (1) if facilitates decision makers with measurement of the abnormality of recent weather for a region; (2) it provides an opportunity to place current conditions in historical perspective; and (3) it provides spatial and temporal representations of historical droughts. Palmer method is also found to produce satisfactory results in north-west region of Bangladesh in terms of drought occurrences and severity by Datta (2005) in comparison with Standardized Precipitation Index (SPI) and Herbst methods.

However, Wells et al. (2004) adopted a new calculation algorithm slightly modifying classic PDSI which is called Self-calibrated PDSI (Sc-PDSI) after spatial comparability problem identified by several researchers identified by several researchers Karl (1985), Alley (1984), Heddinghaus and Sabol (1991), and Guttman et al. (1992). The self-calibrated PDSI automatically calibrates the behaviour of the index at any location by replacing empirical constants (climatic characteristics and duration factor) in the index computation with dynamically calculated values based on the input data (Wells et al., 2004), which actually resolves the inconsistent behavior of the index and more realistically represent the climates of diverse locations without altering the actual objective of Palmer’s original procedure.

3.4.2 Concept

The Palmer Drought Severity Index (PDSI) is basically based on primitive water balance model. It defines the drought period as an interval of time during which the actual moisture supply at given site falls from its potential demand, that is Climatically Appropriate for Existing Conditions (CAFEC) to maintain the normal water balance level of that location. Therefore, PDSI is calculated based on precipitation and temperature data, as well as the local Available Water Content (AWC) of the soil. From the inputs, all the basic terms of the water balance equation can be determined, including evapotranspiration, soil recharge, runoff, and moisture loss from the surface layer. In addition, PDSI also accounts climatic differences of locations and seasons of the year (Wells et al., 2004). On the basis of this, Palmer fixed a scale of 11 classes of severity of drought to compare both spatially and temporally. Table 3.4 shows the classification of the PDSI values, which is same for Sc-PDSI.

Table 3.4: Classification of PDSI value

PDSI Value	PDSI Category
Above 4.00	Extreme Wet
3.00 – 3.99	Severe Wet
2.0 – 2.99	Moderate Wet
1.00 - 1.99	Mild Wet

PDSI Value	PDSI Category
0.50 – 0.99	Incipient West
0.49 to -0.49	Normal
-0.50 to -0.99	Incipient Drought
-1.00 to -1.99	Mild Drought
-2.00 to -2.99	Moderate Drought
-3.00 to -3.99	Severe Drought
Below -4.00	Extreme Drought

Palmer expressed the severity of drought as a function of both duration and magnitude of the moisture deficiency (Datta, 2005) taking consideration the fact that a series of months with near-normal precipitation following a serious drought does not mean that the drought is over or abnormally wet month in between of longer duration of dry spell should not affect the drought,. Therefore, Palmer developed criteria for determining when a drought or a wet spell begins and ends, which adjust the PDSI accordingly. A given PDSI value represents not only the current conditions but also recent past conditions to a certain extent. Sc-PDSI can be calculated following seven steps which is described in detailed in Wells et al. (2004):

1. Calculate all moisture departures from four values related to the soil moisture four values related to their complementary potential values. These eight values are evapotranspiration (ET), recharge (R), runoff (RO), loss (L), potential evapotranspiration (PE), potential recharge (PR), potential runoff (PRO), and potential loss (PL)
2. Calculate all moisture anomalies using calculated moisture departures
3. Calculate the automatically calculated dynamic duration factors using the moisture anomalies computed in step 2.
4. Calculate the PDSI using the moisture anomalies and dynamic duration factors computed in steps 2 and 3, respectively.
5. Find the 98th and 2nd percentile values of the PDSI.
6. Compute the new moisture anomalies using updated techniques of climatic characteristics assessment based solely on how the climate of the location form the range of its moisture departures instead of empirical constant value
7. Calculate the Sc-PDSI

Albeit The Palmer Drought Severity Index (PDSI) is one of the first procedures to demonstrate success at quantifying the severity of meteorological droughts across different climates (Wells et al., 2004), it incorporates temperature along with precipitation and water holding capacity of a location very prudentially to make the hydrological accounting more sophisticated. It allows effect of potential loss of moisture from the soil due to temperature effects. Human impacts on the water balance, such as irrigation, are not considered.

3.4.3 Assumptions

Following assumptions have been considered by Palmer (1965) for developing drought assessment tool in different climatic regions,

1. The soil is divided into two layers where the upper layer is called the surface layer and other is called the underlying layer.
2. Availability of water in the soil is the combined available capacity of both surface and underlying layers of soil
3. Surface layer of the soil is assumed to contain 1 inch of available moisture at field capacity
4. Potential evapotranspiration is the measure of amount of moisture to be used when supply is not limited
5. It is assumed that evaporation takes place at potential rate from the surface layer until all the available moisture is removed
6. Potential loss is assumed as the amount of moisture lost from the soil when precipitation is zero
7. There is no recharge to the underlying soil layer until the surface layer is brought to the field capacity
8. Potential recharge is assumed as the amount of moisture required to bring the soil to field capacity
9. No rainfall occurs until the both layers of soil reach field capacity
10. Potential runoff is assumed as maximum runoff when potential evapotranspiration is zero
11. Potential precipitation is equal to available water holding capacity of soil.

3.4.4 Limitations

There are several noteworthy limitations which are described in detail by Alley (1984). Drawbacks of the Sc-PDSI include:

- The values quantifying the intensity of drought, the starting and ending of a drought or wet spell are arbitrarily selected based on Palmer's study of central Iowa and western Kansas and have little scientific meaning.
- It is sensitive to the Available Water Content (AWC) of a soil type, which is location specific, pose obligations on not to select a region.
- The two soil layers within the water balance computations are simplified and may not accurately represent the site specific condition.
- Precipitation is treated as rainfall only neglected snowfall, snow cover, and frozen ground which may be variable with spatial and temporal extent
- The natural lag between when rainfall and the resulting runoff is not considered. In addition, no runoff is allowed to take place in the model until the water capacity of the surface and subsurface soil layers is reach field capacity, leading to an underestimation of runoff.
- Potential evapotranspiration is estimated using the Thornthwaite method. This technique has wide acceptance, but it is still only an approximation.
- Any kind of human interventions like irrigation are not considered during water balance calculation

In addition to these specific limitations, many researchers have found numerous additional weakness like it represent better results if missing data is there (WMO, 2013) "extreme" and "severe" classifications of drought occur with a greater frequency in some parts of the country than in others (Willeke et al., 1994), which is avoided in PDSI calculation. According to McKee et al. (1995), PDSI is designed for agriculture but does not accurately represent the hydrological impacts resulting from longer droughts. This limitations in some cases make difficulties for decision makers to use this as desired tool for drought monitoring.

Chapter 4 Statistical Downscaling Model Development

4.1 Introduction

Development of statistical downscaling model using SDSM is performed in this study through seven (7) major steps. They are

Step 1: Evaluation of selected General Circulation Model (GCM) whether it realistically represents the climate pattern of the concerned area or not.

Step 2: Selection of base period or climate normal period for the study area, because the length of record of this period significantly influences the future climate anomaly.

Step 3: Selection of desired climate change scenarios or Representative Concentration Pathways (RCPs) for which future scenario will be generated.

Step 4: Fourth step is the necessary data processing to make the database of predictors as well as predictands as desired format of SDSM and ensure quality control of database.

Step 5: This is the most important and challenging step of this study to screen and select suitable combination of predictors for selected GCM in Step 1.

Step 6: Calibration of the model through establishing relation between predictor and predictand using weather generator tool of SDSM and later validation of the model.

Step 7: Climate projections for different RCPs using scenario generator tool of SDSM.

Following sections of this chapter describes the detailed worked done for above mentioned steps to develop model and future climate projections.

4.2 Evaluation of Selected GCM

In this study, Canadian GCM CanESM2 has been selected for downscaling as future predictors up to 2100 are readily available for this model including base period. The second generation of Earth System Model CanESM2 is the fourth generation coupled global climate model developed by the Canadian Centre for Climate Modelling and Analysis (CCCMA) of Environment and Climate Change Canada. This model has special resolution along the longitude of 2.8125° and along the latitude of roughly 2.8125° covering with 128x64 grid cells. The new model couples together an Atmosphere-Ocean General Circulation Model (AOGCM), a land-vegetation model and 5 terrestrial and oceanic interactive carbon cycles. It simulates well the observed 20th century Arctic temperature variability that includes the early and late 20th century warming periods and the intervening (1940–1970) period of substantial cooling. The addition of the land-vegetation model and the terrestrial and oceanic interactive carbon cycle to the coupled AOGCM improves the agreement with observations from 1900–1970.

There are 61 General Circulation Models (GCMs) under Coupled Model Intercomparison Project-Phase 5 (CMIP5) of IPCC from different countries. All of these GCMs do not represent best output for all of the regions of the world due to their system biases. Therefore, GCM representing which represent most realistic the climate pattern of the area of interest should be selected. Recent study by Mukherjee et al. (2011) has illustrated that CCCMA-31 is the best suited GCM out of 8 best fit GCMs for future scenario generation in Bangladesh. Suitability was done one the basis of their skill criteria, flux adjustment and convergence criteria. Although, those best fit GCMs were representing actually IPCC SRES AR4 scenarios. Later, Alam (2015) also found that CCCMA model has well fit for future scenario projection on Brahmaputra Basin. Moreover, McSweeney et al. (2015) illustrated a methodology for selecting a set of 8–10 GCMs for use in regional climate change assessments from the available CMIP5 models. In that research, CanESM2 by CCCMA has been found showing satisfactory results for Southeast Asia region with some system biases in summer monsoon indices assessment, means the position and timing of features are realistic but magnitude is relatively less well than almost all other models in the ensemble. Figure 4.1 shows the CMIP5 model performance summary according to McSweeney et al. (2015) where, Green color represents ‘Satisfactory’ performance, yellow means has some ‘Biases’, orange means ‘Significant Biases’ are in the model to represent realistic situation and pink means ‘Implausible’ or very poor performance. Grey shading indicates that the data were not available at the time of analysis. All these previous analysis reveal that CanESM2 GCM can be used for scenario generation of Bangladesh with satisfactory performance.

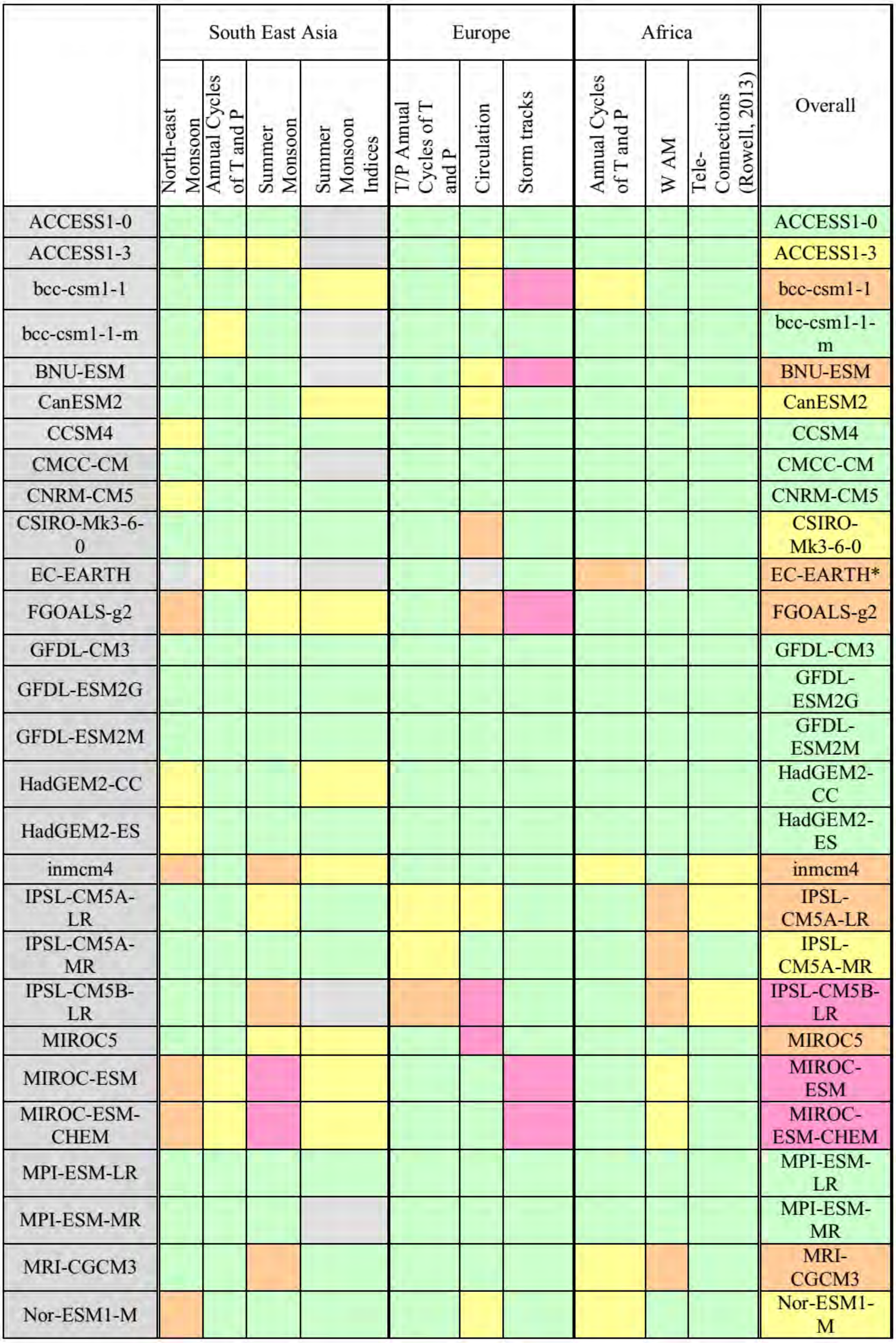


Figure 4.1: CMIP5 model performance summary (from McSweeney et al., 2015)

4.3 Selection of Base Period

Future climate anomaly analysis demands significant period of time at least 30 years which is also called as 'Climate Normal' period to compare future data with historical observed data. Climate Normals are used for two principal purposes. First, they serve as a benchmark against which recent or current observations can be compared, including providing a basis for many anomaly-based climate datasets (for example, global mean temperatures). They are also widely used, implicitly or explicitly, as a prediction of the conditions most likely to be experienced in a given location. The World Meteorological Organization (WMO) has defined Climatological Standard Normal as the most-recent 30-year period starting in a year ending with 1 and finishing in a year ending with 0 (1981-2010 at the time of writing), rather than to non-overlapping 30-year periods (1901-1930, 1931-1960, 1961-1990, and in the future 1991-2020) as was the case previously under WMO Guidelines (WMO, 2017). This climate normal has to be updated after every ten years. However, the period from 1961 to 1990 has been retained as a standard reference period for long-term climate change assessments recognizing the need for a stable base for long-term climate change and variability assessment.

In this study, the period of 1981-2010 should be the ideal base year for downscaling purposes according to WMO. But, the predictor variables from GCM CanEMS2 is available only of 1961-2005 period, which does not allow to select base period as desired going beyond 2005. Therefore, immediately previous climate normal period of one decade before i.e. 1971-2000 has been selected as base period for the downscaling purposes in this study, except solar radiation data. For solar radiation, base period has been selected as 1986-2000, due to unavailability of historical data for desired period as mentioned in Section 3.2.1.

4.4 Selection of Scenarios

Among four Representation Concentration Pathways (RCPs), three RCPs i.e. RCP2.6, RCP4.5 and RCP8.5 has been selected for future scenario generation in SDSM which represent low GHGs concertation level with peak at mid-century and decline by 2100, medium GHGs concentration level without overshoot beyond 2100 and high GHGs concentration level with rising trend up to 2100 respectively.

4.5 Data Processing and Quality Control

Observed daily data for maximum temperature, minimum temperature, rainfall of 30 years (1971-2000) and solar radiation of 15 years (1986-2000) have been piled up as time series data for each of the meteorological stations over Bangladesh following Gregorian calendar. These time series values have been used as the input file of SDSM. Any missing values in the time series data has been filled with -999 code, which is actually skipped by SDSM during calculation process if faces.

Quality check tool of SDSM provides the opportunity to check any gross data errors and outliers prior to model development. SDSM assumes that all the input data are normally distributed. After quality checking, input data of 30 meteorological stations are found alright for maximum and minimum temperature, 29 stations for rainfall and only 7 stations for solar radiation among 34 meteorological stations of BMD. Rejection has been done on the basis that the missing data available in the time series should not be greater than half of the available data in the time series. Table 3.1 provides the meteorological station details selected for different climate parameters in this study.

4.6 Screening of Predictor Variables

Screening of predictor variables of selected GCM is the most important and crucial task of Statistical Downscaling Modeling (Wilby et al., 2002; Huang et al., 2011; Rahaman et al., 2015). Because based on consistent relationship of the selected predictors and predictand, future scenarios will be generated in SDSM. Several methods are available to select best combination of predictors like correlation analysis, partial correlation analysis, stepwise regression analysis or combination of these methods. The main criterion for the selection of suitable predictors for downscaling is that they should be strongly correlated with the predictands. Consequently, correlation analysis is the most widely used approach for picking useful predictors from the potential predictors (Chen et al., 2010; Huang et al., 2012; Mahmood et al., 2013; Hassan et al., 2014; Pervez et al., 2014). In this study, combination of correlation analysis, partial correlation and P-value has been used to select combination of best predictors from 26 NCEP predictors whose steps are described in detailed by Ali et al. (2016). Firstly, couple of predictors (maximum 7 to 8) has been selected on the basis of strong correlation value i.e. high Partial r value and less P-value (P-value with zero value has got high preferences). Explained variance has also been checked for each of the month against each of the selected predictors which makes strong correlation with respective months. For rainfall, the selections of predictor variables are performed by transforming to the fourth root without any lag time. However, for the case of temperature and solar radiation, normal distribution was considered and hence no transformation function is applied. Secondly, again same process has been performed to find out best 2 or 3 predictor variables, when physical process of variables with predictands and study area of interest is also considered for screening. Researchers (Wilby et al., 2002; Chu et al., 2010; Mahmood and Babel, 2013) found that mostly 1-3 large scale variables are believed to be enough to capture the variation of a predictand during calibration. Increased number of selected variables can increase the chance of multiple co-linearity during regression process. Table 4.1 shows selected predictor variables for different parameters for the study area. It has been found that mostly are found having good correlation with maximum temperature. Table 4.1 shows selected NCEP predictors among 26 which have good correlation with respective predictands for each of the parameter against BMD station.

Table 4.1: Selected Combination of Predictor Variables for SDSM

Station	Maximum Temperature	Minimum Temperature	Rainfall	Solar Radiation
Barisal	s850, temp	mslp, temp	p8_z	mslp
Bhola	s850, temp	mslp, temp	p8_z	-
Bogra	s850, temp	s850, temp	p1_zh, p5_v	p850
Chandpur	s850, temp	mslp, temp	p8_z	-
Chittagong	p8_z, temp	mslp, temp	p8_z	-
Comilla	p8_z, temp	mslp, temp	p8_z	p5th
Coxs Bazar	mslp, temp	mslp, temp	p8_z	-
Dhaka	s850, temp	mslp, temp	p8_z	-
Dinajpur	s850, temp	p500, temp	p1_zh, p5_v	-
Faridpur	s850, temp	shum, temp	p5_u, p5_z	-
Feni	temp, p8_z	mslp, temp	p8_z	-
Hatiya	temp, mslp	mslp, temp	p8_z	-
Ishawrdi	s850m, temp	s850, temp	p1_zh, p5_v	-
Jessore	s850, temp	shum, temp	p5_z	-
Joydevpur	-	-	-	prcp

Station	Maximum Temperature	Minimum Temperature	Rainfall	Solar Radiation
Khepupara	temp, p8_z	mslp, temp	p8_z	-
Khulna	temp	shum, temp	p5_z	-
Kutubdia	temp, p8_z	mslp, temp	-	-
Madaripur	temp, p8_z	mslp, temp	p5_z, p8_u	-
Maijdee court	s850, temp	mslp, temp	p8_z	-
Mymensingh	p500, prcp	p500, temp	p8_z	prcp
Patuakhali	s850, temp	mslp, temp	p8_z	-
Rajshahi	s850, temp	p500, temp	p1_zh, p5_v, p8_z	-
Rangamati	s850, temp	s850, temp	p8_z	-
Rangpur	s850, temp	s850, temp	p1_zh, p5_v	p850
Sandwip	mslp, temp	mslp, temp	p8_z	-
Satkhira	s850, temp	shum, temp	p5_z	-
Sitakunda	mslp, temp	mslp, temp	p5_z	-
Sreemangal	p500, prcp	s850, temp	p8_z	prcp
Sylhet	p500, prcp	p500, temp	p8_z	-
Teknaf	mslp, temp	mslp, temp	p5_z, p8_u	-

The upper air temperature and specific humidity (both 850 hPa and 1000 hPa) are found as best predictors for both maximum and minimum temperature in most of the stations. 500 hPa Geopotential height is also found among suitable predictors list for mostly northern part of Bangladesh. However, mean sea level pressure is found along with upper air temperature in and around the coastal area of Bangladesh for both maximum and minimum temperature. The upper air temperature obviously has direct connection to the surface air temperature, so the explained variances are higher than for other predictors. Specific humidity has higher correlation may be due to the effect of southwest Indian monsoon through which moisture content in air varies and consequently surface air temperature. The geopotential height is also strongly connected to the predictand, because variation in geopotential height reflects variation in air pressure, which in turn is affected by surface temperature through vertical energy transfer and air movement (Li et al., 2017). Mean sea level pressure is predominant in coastal areas due to its geophysical characteristics which ultimately relates specific humidity with surface air temperature.

For most of the stations, 850 hPa vorticity or 500 hPa vorticity have been found as most influential predictors against rainfall, except north-western parts of Bangladesh. Fujinami et al (2014) found presence of strong low-level westerly/southwesterly flows around the plain and a center of cyclonic vorticity over Bangladesh, which causes heavy rainfall over eastern portion of Bangladesh due to orography. Roy et al (2018) also found low level vorticity support vigorous updraft followed by wind pattern changes and cause heavy rainfall over Bangladesh. On the other hand, Pervez et al (2014) found meridional velocity is one of the most influence predictors for Ganges basin rainfall, which was supported by Bawiskar et al (2005) and Parthasarathy et al (1991). Accordingly, 500 hPa meridional velocity has been found as most suitable predictor for rainfall of north-west Bangladesh along with low level (1000 hPa) divergence or convergence as, orography of northern and eastern sides of Bangladesh helps overturning of the low level warm moist air coming from Bay of Bengal and hence convergence takes place in northwestern side of Bangladesh (Rafiuddin et al., 2010).

For solar radiation, precipitation has been found in northeastern side and 850 hPa geopotential height has been found in north western portion as most suitable predictors. In southern portion near Bay of Bengal, mean sea level pressure has been found more consistent with solar radiation. All of these predictors have been selected on the basis of statistical value of explained variance and R-squared value, rather emphasizing on physical linkage of selected predictors and predictand solar radiation. However, solar radiation is more governed by the local variables such as cloud cover and difference of maximum and minimum temperature, which were not in the list of predictors of NCEP and CanESM2. Although, cloud cover has been indirectly represented in the analysis by precipitation. Felay (2008) strongly recommended to use combination of both large scale and local climate variables i.e. cloud cover and difference of maximum and minimum temperature as predictors during selection of predictors for solar radiation, which are not considered in this study.

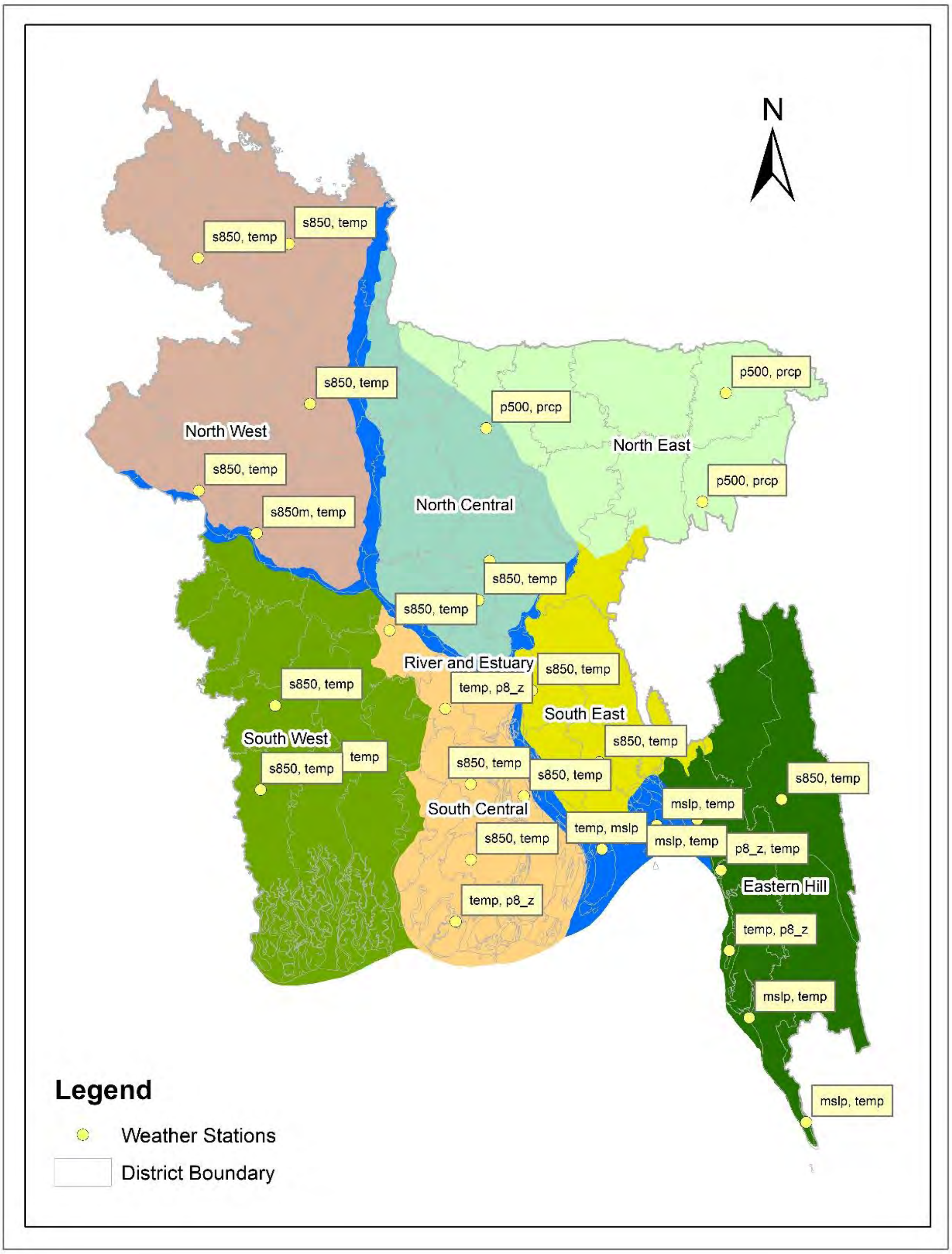


Figure 4.2: Selected predictor variables for maximum temperature over Bangladesh

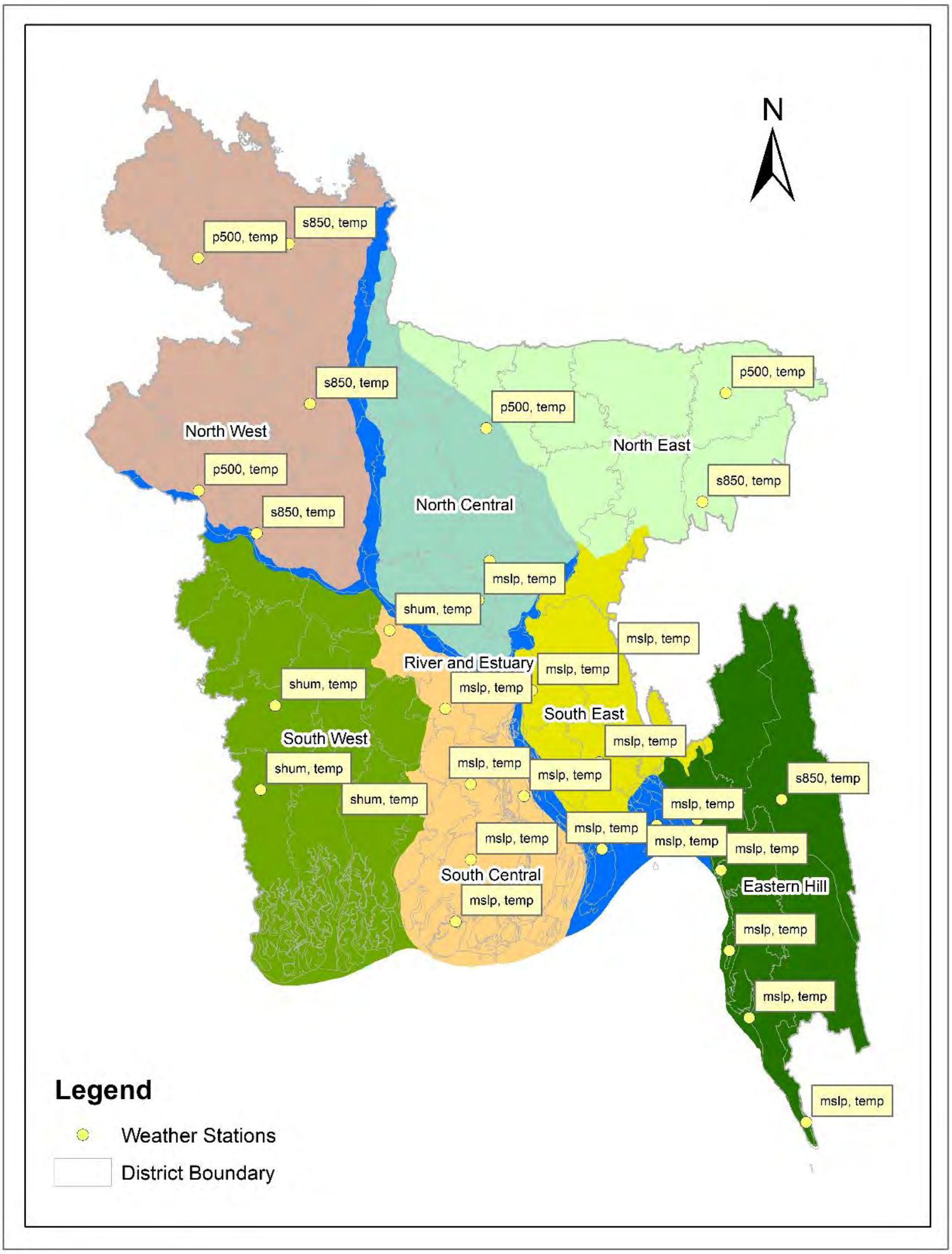


Figure 4.3: Selected predictor variables for minimum temperature over Bangladesh

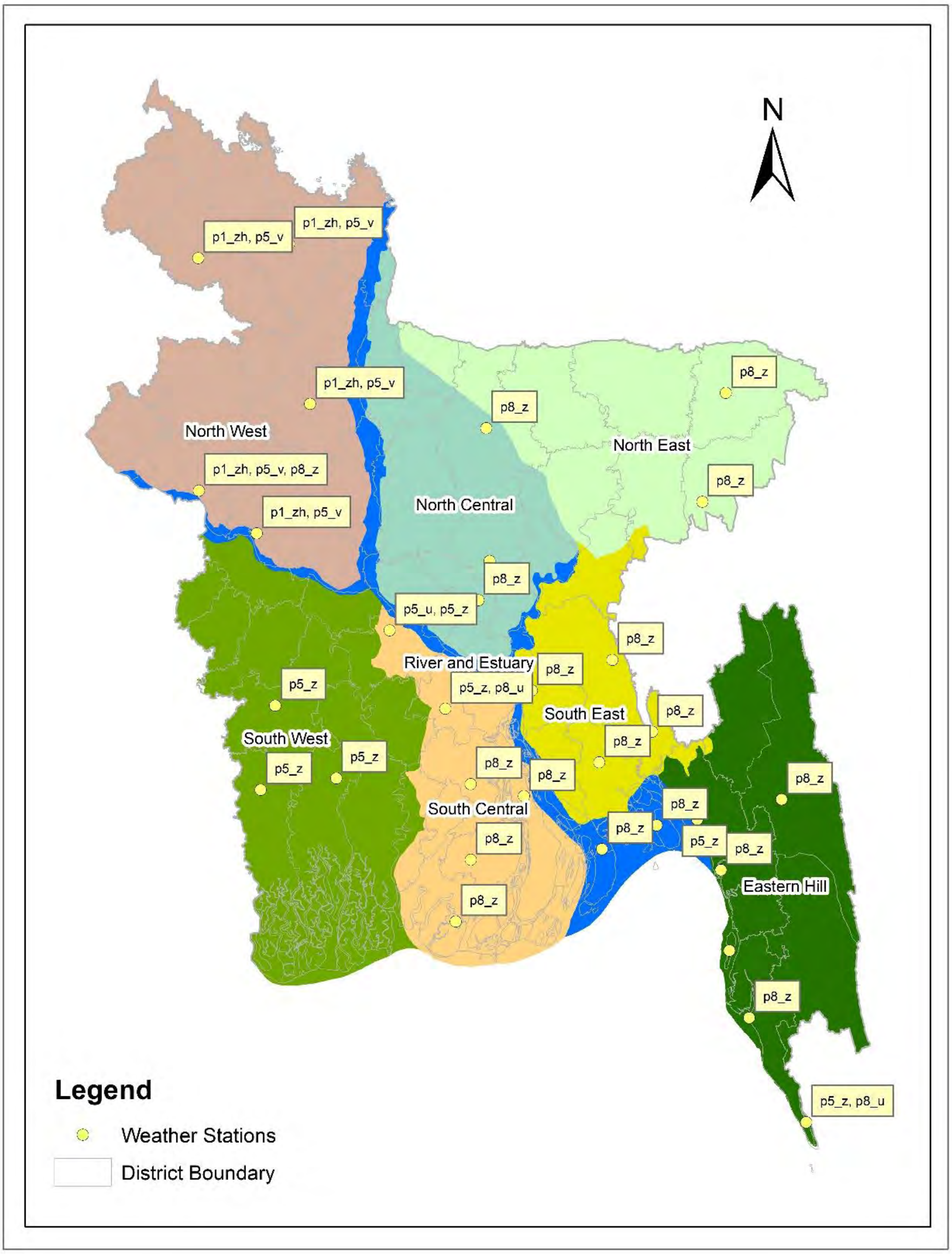


Figure 4.4: Selected predictor variables for rainfall over Bangladesh

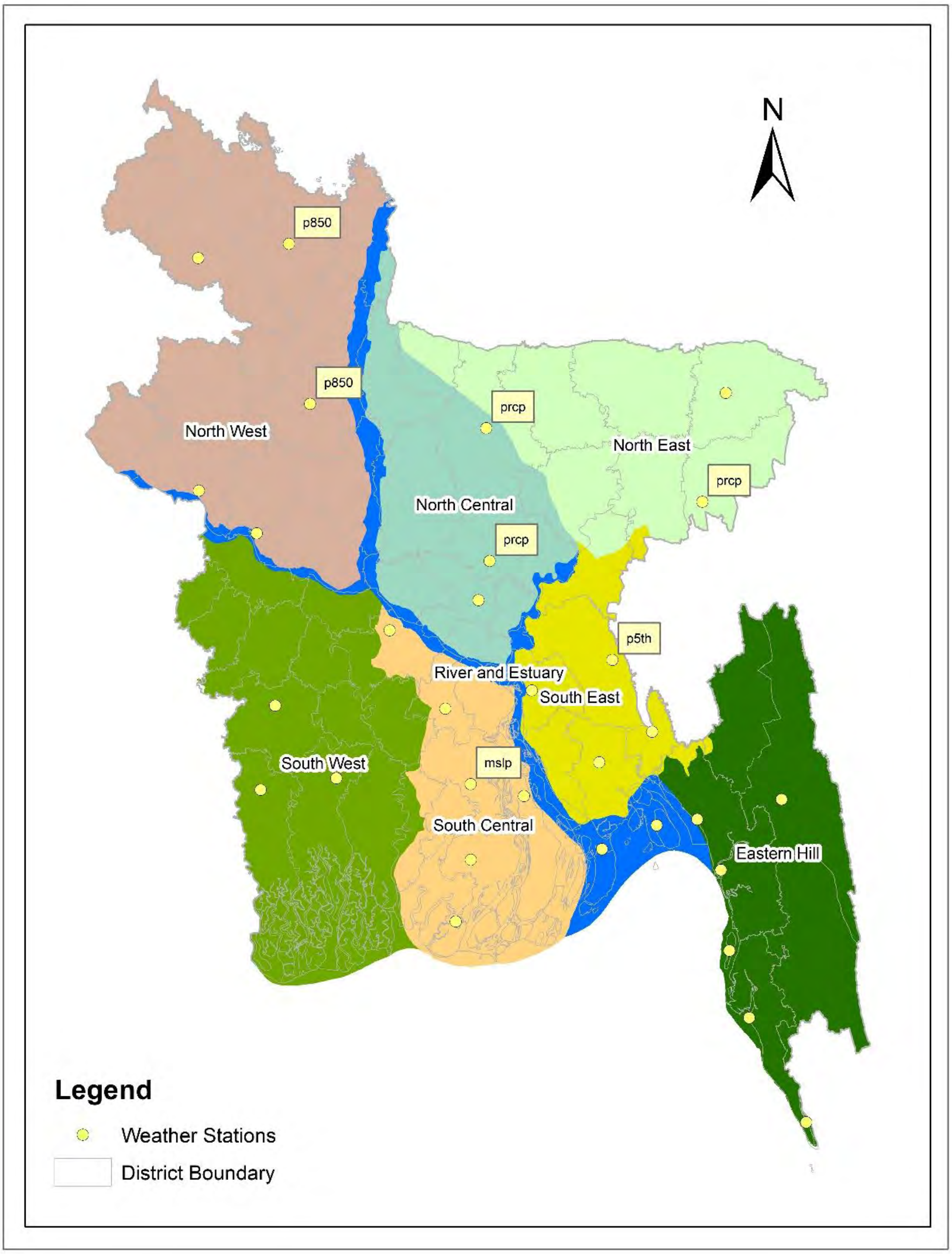


Figure 4.5: Selected predictor variables for solar radiation over Bangladesh

4.7 Calibration and Validation

Calibration and validation has been done using weather generator and scenario generator tool of the SDSM. Firstly, synthetic weather data has been generated for selected period using the relationship of selected combination of NCEP predictors with predictands (i.e. maximum or minimum temperature, rainfall or solar radiation) using the stochastic weather generator tool through combination of a multiple linear regression technique and transfer function. Secondly, generated weather data is again adjusted by selecting same predictor variable of CanESM2 GCM as NCEP predictors for historical period using scenario generator tool. It generates 20 ensembles of downscaled model data of CanESM2 GCM of same historical period. Calibration and validation is then performed comparing the observed data and generated ensemble mean of downscaled model data of CanESM2 GCM for same historical period. Typically, half of the total period should be taken as calibration period and rest of the period for validation. In this study, half of the base period i.e. 1971-1985 for maximum temperature, minimum temperature, rainfall and 1986-1995 for solar radiation has been considered as calibration period and rest of the period has been considered as validation period. Calibration and validation has been performed by both visual inspection and statistical analysis on the basis of monthly data. Three statistical indices i.e. the Nash-Sutcliffe efficiency (NSE), Percentage bias (P-bias) and coefficient of determination (R^2) have been used to evaluate the performance of the model. Details of these three statistical performance indicators are described below which are taken from Ali et al. (2016):

a) Nash-Sutcliffe efficiency (NSE)

The Nash-Sutcliffe efficiency (NSE) is a normalized statistic that determines the relative magnitude of the residual variance (noise) compared to the measured data variance (information). NSE indicates how well the plot of observed versus simulated data fits the 1:1 line. NSE is computed as shown in equation 4.1.

$$NSE = 1 - \left[\frac{\sum_i^n (xobs(i) - ymod(i))^2}{\sum_i^n (xobs(i) - \overline{xobs})^2}\right] \quad (4.1)$$

Where *xobs(i)* is the i^{th} observation for the constituent being evaluated, *ymod(i)* is the i^{th} simulated value for the constituent being evaluated, $\overline{xobs}$ is the mean of observed data for the constituent being evaluated, and n is the total number of observations. NSE ranges between −∞ and 1.0 (1 inclusive), with NSE =1 being the optimal value. Values between 0.0 and 1.0 are generally viewed as acceptable levels of performance, whereas values <0.0 indicates that the mean observed value is a better predictor than the simulated value, which indicates unacceptable performance.

b) Percent of bias (PBIAS)

Percent of bias (PBIAS) measures the average tendency of the simulated data to be larger or smaller than their observed counterparts. The optimal value of PBIAS is 0.0, with low-magnitude values indicating accurate model simulation. Positive values indicate model underestimation bias, and negative values indicate model overestimation bias. The percent of bias (PBIAS) defined as

$$PBIAS = \left[\frac{\sum_i^n (xobs(i) - ymod(i))}{\sum_i^n xobs(i)}\right] \tag{4.2}$$

Where *xobs(i)* is the i^{th} observation for the constituent being evaluated, *ymod(i)* is the i^{th} simulated value for the constituent being evaluated and PBIAS is the deviation of data being evaluated, expressed as a percentage.

c) Coefficient of determination (R^2)

Coefficient of determination (R^2) describes the degree of collinearity between simulated and measured data. R^2 ranges from 0 to 1, with higher values indicating less error variance and typically values greater than 0.5 are considered acceptable (Moriasi et al. 2007). R^2 has been widely used for model evaluation; these statistics are oversensitive to high extreme values (outliers) and insensitive to additive and proportional differences between model predictions and measured data. Coefficient of determination (R^2) can be expressed as,

$$R^2 = \left[\frac{[\sum_i^n (xobs(i) - \overline{xobs})(ymod(i) - \overline{ymod})]^2}{[\sum_i^n (xobs(i) - \overline{xobs})^2 \sum_i^n (ymod(i) - \overline{ymod})^2]}\right] \tag{4.3}$$

Where *xobs* is the observation and *ymod* is the simulated value for the constituent being evaluated. Table 4.2 summarizes the model performance evaluation category for three statistical indicators (Rossi et al, 2008).

Table 4.2: Performance Evaluation Criteria

Performance Rating	NSE	PBIAS (%)	R^2
Very Good	0.75 < NSE <1.00	PBIAS < ±10	$R^2 > 0.90$
Good	0.65 < NSE <0.75	±10 <PBIAS < ±15	$0.60 < R^2 < 0.90$
Satisfactory	0.50 < NSE <0.65	±15 <PBIAS < ±25	$R^2 > 0.50$
Unsatisfactory	NSE <0.50	PBIAS > ±25	$R^2 < 0.50$

Performance evaluation of model using these three statistical indicators is discussed in Chapter 6.

4.8 Climate Projections

Climate projections have been performed using scenario generator tool of calibrated and validated SDSM model. For climate projections, predictors of CanESM2 for future periods under different scenarios has been fed into the model and daily time series data has been generated from 2006 to 2100. In this study, climate projections have been performed for three time slices 2030s (2016-2045), 2050s (2046-2065) and 2080s (2066-2095) under three RCPs i.e. RCP2.6, RCP4.5 and RCP8.5. Climate projections have been performed for mentioned timeframe and scenarios for each of the parameters under each of the BMD meteorological stations over Bangladesh.

4.9 Climate Anomaly Analysis

Analysis of climate anomaly has been performed comparing project climate data with base period. Climate anomaly has been performed for monthly, seasonal and annual basis. For maximum and minimum temperature changes in monthly temperature, seasonal temperature and annual temperature are analyzed. On the other hand, percentages changes of monthly, seasonal and annual rainfall and solar radiation are analyzed for rainfall and solar radiation. Detailed analysis results are illustrated and discussed in Chapter 6 and Appendix-A to Appendix-F.

Chapter 5 Drought Severity Analysis using Sc-PDSI

5.1 Introduction

Drought severity analysis using Sc-PDSI techniques has been performed in this study to understand future drought severity condition for different climate change scenarios over Bangladesh. In this chapter, different steps of drought severity analysis i.e. selection of base period, selection of scenarios, calculation of Sc-PDSI values using Sc-PDSI program have been discussed in detail. This analysis has been performed as a part of afterwards analysis of statistically downscaled future climate data generated by calibrated and validated SDSM tool avoiding separate calibration and validation for drought assessment again.

5.2 Selection of Base Period

Base period for drought analysis has been selected on the basis of continuous data availability for each of the stations. Since the PDSI is an accumulating index (that is, one value depends directly on the previous value), large gaps in the data creates adverse effects. The PDSI also depends on long-term averages (of at least 25 years data and not more than five consecutive years of missing data) used in the water balance equation, so using a small amount of data hampers the ultimate PDSI value. Therefore, it was not possible to use the same baseline data which were used during Statistical Downscaling i.e. 1971-2000. More than eight stations in this period among 31 were with less than of 25 years of monthly observed data, which may impact the overall result. Thus, base period has been selected as next 30 years i.e. 1981-2010. Twenty eight stations are found satisfying the data period criteria after screening in the selected period of 1981-2010. However, PDSI value has dependency on length of record means, index value of 2000 will be different if length of record varies from 1981-2010 to 1990-2010. Therefore, it is important to note the period of record used in the analysis of the PDSI (Wells et al., 2004).

5.3 Selection of Scenario

Two climate change scenarios i.e. RCP4.5 and RCP 8.5 which expresses moderate scenario and extreme scenario respectively, have been selected for this analysis to compare future drought with base period and among two scenarios. SDSM generated statistically downscaled data for two time slices i.e. 2050s (2046-2065) and 2080s (2066-2095) has been taken for the considered scenarios for this analysis.

5.4 Calculation of Sc-PDSI using Sc-PDSI program

Sc-PDSI values over Bangladesh has been calculated for 28 meteorological stations of Bangladesh Meteorological Department (BMD) using Sc-PDSI program (Version 2.0) developed by Wells et al. (2003). This Sc-PDSI program was firstly written based on a FORTRAN program that calculated the monthly PDSI that was received from the National Climatic Data Center (NCDC). The program was than translated to C++ and several modifications were made, including making the index Self-Calibrating. This PDSI program is capable of calculating the Original Monthly PDSI, the Self-Calibrating Monthly and Weekly PDSI, as well as the Weekly Crop Moisture Index (CMI). In this study, only monthly Sc-Calibrating PDSI has been calculated for base period (1981-2010) and future periods (2050s and 2080s) under RCP4.5 and RCP8.5. Statistically downscaled data using SDSM for mentioned future periods and scenarios generated under this study has been used for future drought severity analysis.

The input files include monthly temperature and rainfall data, and monthly temperature normal. The monthly temperature or rainfall is the average monthly temperature for each of the 12 months (52 weeks) of that year and monthly normal temperature is the average temperature for over all the years on record for each of 12 months. The parameters include the local available water content (AWC) data for soil and latitude of the station in decimal degrees. AWC is the most important parameters for this calculation. AWC for the BMD weather station locations have been estimated based on the UNDP & FAO reports (1988a, 1988b). Table 3.3 shows AWC values for different meteorological stations which are used in the Sc-PDSI calculation in this study.

Missing data is represented in the input files by using the value –99.00. This causes the program to skip that period as if it does not exist. The program requires at least 25 years of data in order to do any calculations, but it does not have the capability to check to see how many holes in the data there are, or how big they are. Following argument is used to calculate Sc-PDSI for each of the stations and scenario in Windows Command Prompt.

```
./pdsi –x all –f both
```

Pressing ‘Enter’ button generates automatically Sc-PDSI monthly values for the data period given for each of the month in a location using built-in algorithm inside it developed by Wells et al. (2003). Figure 5.1 and Figure 5.2 show screen shot of Sc-PDSI program calculation performed for this study.

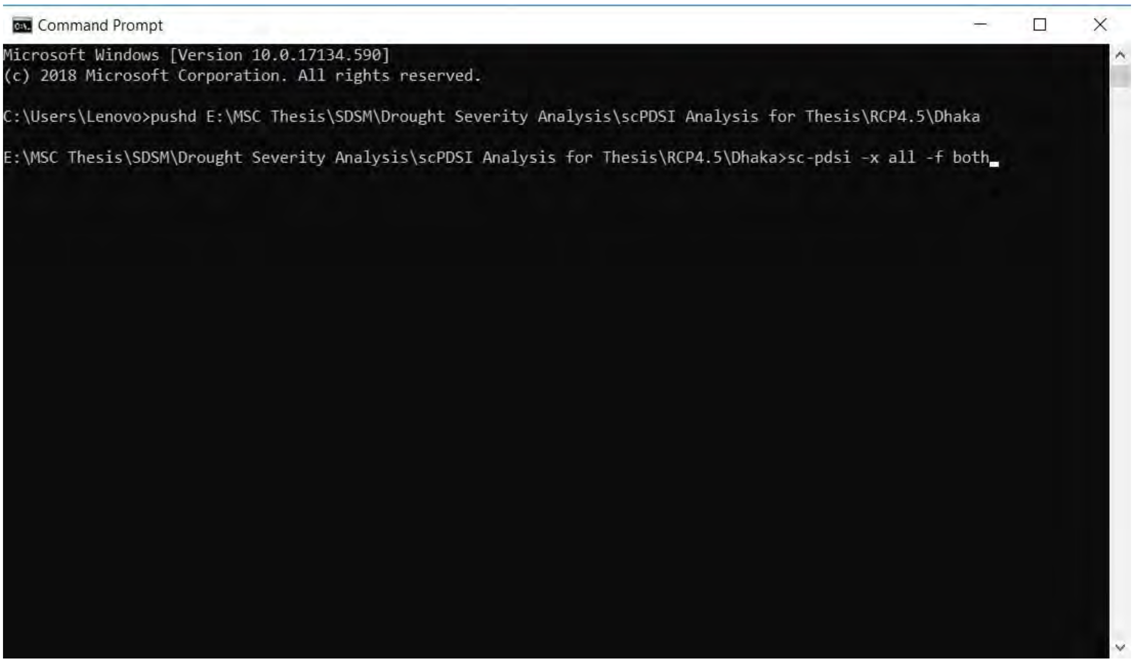


Figure 5.1: Screenshot 1 of calculation Sc-PDSI through Sc-PDSI program

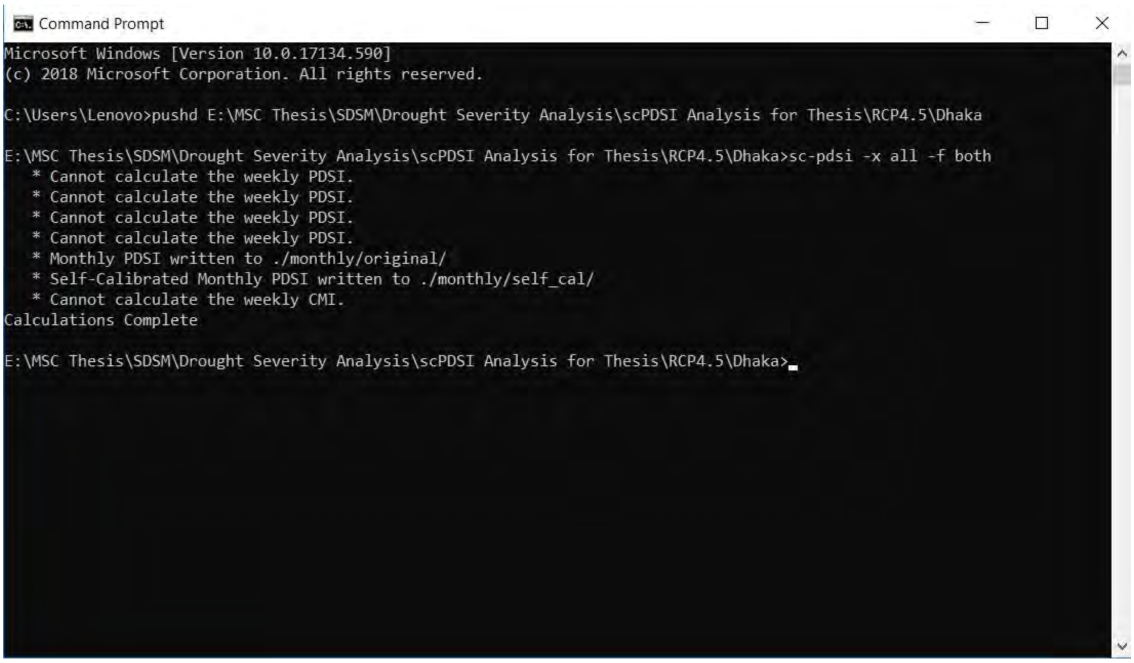


Figure 5.2: Screenshot 2 of calculation Sc-PDSI through Sc-PDSI program

5.5 Drought Severity Analysis

Drought severity analysis has been performed using MS Excel 2013 amalgamating all generated Sc-PDSI values for each of the stations. During analysis, Sc-PDSI values of only four drought class i.e. mild drought, moderate drought, severe drought and extreme drought has been considered and drought spell length less than 6 months has been discarded from the analysis, as Sc-PDSI is more suitable to represent long term droughts (Zhao et a., 2015). Drought severity analysis has been performed in terms of occurrence of different categories of drought in total drought period and total drought occurrence during selected 30 years period. Drought occurrence has been calculated summing each of the drought spell having at least 6 months or more for each of the station and each of the time slices i.e. base, 2050s and 2080s under two RCPs. Detailed results of severity analysis has been illustrated and discussed in Chapter 6 and Appendix F.

Chapter 6 Results and Discussions

6.1 Introduction

Climate anomalies of Bangladesh is assessed through analysis of statistically downscaled climate projections for different Representative Concentration Pathways (RCPs) and discussed in this Chapter. Both spatial i.e. regional and countrywide, and temporal variations of climate anomalies have been discussed as part of the analysis. Anomalies have been calculated assessing change in future Maximum Temperature, Minimum Temperature, Rainfall and Solar Radiation with respect to historical period or base period. Hydrologic regions i.e. North East (NE), North Central (NC), North West (NW), South East (SE), South Central (SC), South West (SW) and Eastern Hills (EH) have been taken as spatial boundary for regional analysis. Three time slices i.e. 2030s (2016-2045), 2050s (2036-2065) and 2080s (2066-2095) have been considered for temporal variations. Besides, shifting of season and drought severity due to climate change for future periods over the country have also been discussed.

6.2 Calibration and Validation of SDSM

Calibration and validation of developed SDSM model has been performed in two ways i.e. 1) using monthly data of full times series or every year and 2) using mean monthly data for full regime or average year of calibration and validation period. Calibration and validation period is 1971-2000 for maximum temperature, minimum temperature and rainfall, and 1986-2000 for solar radiation. Full regime means average year of 1971-2000 period or 30 years in case of temperature and rainfall, and average year of 1986-2000 or 15 years in case of solar radiation. Table 6.1 shows summary of statistical performance of SDSM. Table 6.2 and Table 6.3 show statistical performance of SDSM model for each of the stations in two ways.

According to Table 6.1, calibration and validation are found more satisfactory in full regime basis rather than monthly calibration and validation for full time series. Coefficient of determination (R^2) values are found satisfactory for most of the stations against temperature and rainfall for monthly calibration of full time series. Lowest value of R^2 has been found 0.48 in Chandpur station, all other stations are of greater than 0.5 value. But R^2 value has been found in unsatisfactory range for all of the stations against solar radiation in calibration for full time series. This may be due to the presence of higher concentration of missing values in observed data and not taking consideration the local climate variables i.e. cloud cover and difference in maximum temperature and minimum temperature which was strongly recommended by Felay (2008). Although, R^2 value has been found more than good for all of the solar radiation stations in full regime calibration and validation.

In respect to PBIAS value, most of the stations are found within satisfactory range for temperature, rainfall and solar radiation, which are found more improved i.e. in very good range for calibration and validation of full regime. This means that developed SDSM model for four parameters have generated simulated values having satisfactory biases for most of the stations as investigated by McSweeney et al. (2015). Table 6.2 and Table 6.3 show that most the stations are having negative values of PBIAS, which means most of the stations are overestimating than observed value.

Although, Nash Sutcliffe Efficiency (NSE) have not been found within satisfactory range in full time series calibration, depicts the presence of dispersed noise in the simulated value. However, it has been improved in full regime analysis. Presence of higher concentration of missing data against total available data is one of the major reasons for degrading performance of SDSM in most of the case.

In a nutshell, it is revealed that developed SDSM is capable of generating satisfactory results with some biases up to monthly level for maximum temperature, minimum temperature and rainfall, but not for solar radiation which is subject to add local climate variable as predictors. Previous studies (Mahmood and Babel, 2014; Pervez et al, 2014) also found that SDSM model can perform better in monthly, seasonal or annual scale than daily scale. Therefore, this model generated results will be more useful to assess future water resources, water balance or impact rather directly using for any extremity analysis.

Station specific graphs of calibration and validation using monthly data of full time series for each of the parameter are shown in Appendix A.

Table 6.1: Summary of Statistical Performance of SDSM

Performance Rating	Indices	No. of BMD Stations Fall within the Range							
		Monthly Calibration and Validation for Full Time Series				Mean Monthly Calibration for Full Regime			
		MaxT	MinT	Rain	Srad	MaxT	MinT	Rain	Srad
R^2									
Very Good	$R^2 > 0.90$	0	8	0	0	30	30	28	5
Good	$0.60 < R^2 < 0.90$	30	22	18	0	0	0	1	2

Performance Rating	Indices	No. of BMD Stations Fall within the Range							
		Monthly Calibration and Validation for Full Time Series				Mean Monthly Calibration for Full Regime			
		MaxT	MinT	Rain	Srad	MaxT	MinT	Rain	Srad
Satisfactory	**$R^2 > 0.50$**	0	0	10	0	0	0	0	0
Unsatisfactory	**$R^2 < 0.50$**	0	0	1	7	0	0	0	0
PBIAS									
Very Good	**PBIAS < ±10**	17	17	12	4	30	30	29	7
Good	**±10 <PBIAS < ±15**	4	2	5	1	0	0	0	0
Satisfactory	**±15 <PBIAS < ±25**	2	4	6	0	0	0	0	0
Unsatisfactory	**PBIAS > ±25**	7	7	6	2	0	0	0	0
NSE									
Very Good	**0.75 < NSE <1.00**	0	1	0	0	30	30	29	6
Good	**0.65 < NSE <0.75**	0	2	0	0	0	0	0	0
Satisfactory	**0.50 < NSE <0.65**	0	5	13	0	0	0	0	1
Unsatisfactory	**NSE <0.50**	30	22	16	7	0	0	0	0

Table 6.2: Statistical Performance of SDSM Model during Monthly Calibration and Validation for Full Time Series

Station	Maximum Temperature			Minimum Temperature			Rainfall			Solar Radiation		
	NSE	PBIAS	R^2	NSE	PBIAS	R^2	NSE	PBIAS	R^2	NSE	PBIAS	R^2
Barisal	0.25	-1.04	0.82	0.66	-0.51	0.83	0.65	-3.17	0.66	0.10	-3.59	0.22
Bhola	0.08	-4.19	0.79	0.39	-3.46	0.81	0.54	-2.68	0.56	-	-	-
Bogra	0.15	-4.84	0.70	0.57	-3.94	0.84	0.64	8.54	0.67	0.27	-0.85	0.29
Chandpur	0.02	-14.55	0.84	0.16	-14.83	0.92	0.26	-23.54	0.48	-	-	-
Chittagong	0.22	-1.20	0.77	0.57	-0.51	0.84	0.55	-6.89	0.63	-	-	-
Coxsbazar	0.18	-0.97	0.71	0.59	-0.14	0.79	0.55	-9.03	0.62	-	-	-
Comilla	0.15	-4.25	0.78	0.43	-3.34	0.84	0.55	-7.01	0.60	-0.02	-9.44	0.16
Dhaka	0.15	-3.71	0.77	0.45	-2.77	0.81	0.58	-5.04	0.64	-	-	-
Dinajpur	-0.01	-41.55	0.74	0.07	-40.98	0.81	-0.22	-54.06	0.53	-	-	-
Faridpur	0.26	-1.58	0.82	0.56	0.03	0.81	0.48	-11.08	0.57	-	-	-
Feni	0.04	-11.74	0.74	0.30	-5.91	0.79	0.39	-21.59	0.67	-	-	-
Hatiya	0.02	-37.40	0.82	0.08	-36.41	0.91	0.28	-38.51	0.64	-	-	-
Ishwardi	0.10	-7.95	0.77	0.50	-6.05	0.86	0.42	-6.87	0.50	-	-	-
Jessore	0.17	-4.89	0.78	0.44	-1.88	0.81	0.55	-11.22	0.63	-	-	-
Joydevpur	-	-	-	-	-	-	-	-	-	-0.06	-42.75	0.15
Khepupara	0.04	-20.99	0.82	0.16	-20.65	0.94	0.43	-18.78	0.68	-	-	-
Khulna	0.13	-8.21	0.80	0.26	-9.22	0.85	0.41	-17.87	0.59	-	-	-
Kutubdia	0.02	-86.18	0.79	0.03	-85.99	0.93	-	-	-	-	-	-
Madaripur	0.03	-34.73	0.86	0.10	-35.41	0.94	0.30	-35.70	0.65	-	-	-
Maijdeecourt	0.08	-10.38	0.77	0.19	-11.12	0.82	0.55	-14.82	0.69	-	-	-
Mymensingh	0.07	-8.15	0.76	0.20	-18.23	0.81	0.49	-4.62	0.54	0.00	-25.94	0.21
Patuakhali	0.03	-21.37	0.81	0.11	-22.12	0.94	0.36	-30.06	0.67	-	-	-

Station	Maximum Temperature			Minimum Temperature			Rainfall			Solar Radiation		
	NSE	PBIAS	R^2	NSE	PBIAS	R^2	NSE	PBIAS	R^2	NSE	PBIAS	R^2
Rajshahi	0.25	-3.96	0.80	0.79	-1.77	0.84	0.47	-4.05	0.54	-	-	-
Rangamati	0.24	-1.20	0.73	0.66	-0.13	0.76	0.64	-3.44	0.65	-	-	-
Rangpur	-0.01	-25.16	0.70	0.12	-25.05	0.87	0.36	-19.02	0.60	0.12	-8.80	0.37
Sandwip	0.10	-6.13	0.75	0.30	-5.93	0.79	0.64	-11.23	0.70	-	-	-
Satkhira	0.21	-2.45	0.78	0.59	-0.50	0.86	0.47	-13.58	0.62	-	-	-
Sitakunda	0.04	-25.43	0.74	0.17	-25.08	0.94	0.22	-35.60	0.53	-	-	-
Sreemangal	0.02	-13.94	0.77	0.22	-15.35	0.80	0.35	-15.81	0.57	0.02	-11.79	0.05
Sylhet	0.11	-4.01	0.63	0.30	-7.44	0.83	0.61	-9.83	0.68	-	-	-
Teknaf	0.03	-25.08	0.69	0.09	-25.01	0.93	0.53	-25.24	0.75	-	-	-

Table 6.3: Statistical Performance of SDSM Model during Monthly Calibration and Validation for Full Regime

Station	Maximum Temperature			Minimum Temperature			Rainfall			Solar Radiation		
	NSE	PBIAS	R^2	NSE	PBIAS	R^2	NSE	PBIAS	R^2	NSE	PBIAS	R^2
Barisal	0.98	0.43	0.98	0.98	1.13	0.98	0.99	-2.38	0.99	0.96	2.20	0.97
Bhola	0.97	0.39	0.97	0.98	1.23	0.98	0.99	-1.30	0.99	-	-	-
Bogra	0.95	-0.82	0.96	0.99	-0.27	0.99	0.91	-5.58	0.95	0.94	0.55	0.95
Chandpur	0.98	0.58	0.98	0.98	1.20	0.98	0.98	-3.19	0.99	-	-	-
Chittagong	0.96	0.74	0.97	0.98	1.25	0.98	0.95	-5.33	0.97	-	-	-
Coxsbazar	0.95	0.98	0.96	0.97	1.28	0.97	0.92	-8.27	0.97	-	-	-
Comilla	0.96	0.80	0.97	0.98	1.36	0.98	0.97	-3.10	0.98	0.97	1.52	0.97
Dhaka	0.97	0.61	0.98	0.98	1.38	0.98	0.99	-0.84	0.99	-	-	-
Dinajpur	0.95	-1.01	0.97	0.99	-0.22	0.99	0.77	-9.46	0.88	-	-	-
Faridpur	0.96	0.72	0.97	0.97	2.49	0.98	0.85	-9.48	0.94	-	-	-

Station	Maximum Temperature			Minimum Temperature			Rainfall			Solar Radiation		
	NSE	PBIAS	R^2	NSE	PBIAS	R^2	NSE	PBIAS	R^2	NSE	PBIAS	R^2
Feni	0.95	0.70	0.96	0.98	0.81	0.98	0.96	-6.12	0.98	-	-	-
Hatiya	0.97	0.70	0.97	0.98	1.07	0.98	0.96	-7.07	0.98	-	-	-
Ishwardi	0.95	-1.21	0.97	0.99	-0.60	0.99	0.93	-3.96	0.95	-	-	-
Jessore	0.95	0.91	0.96	0.97	2.97	0.98	0.95	-6.41	0.99	-	-	-
Joydevpur	-	-	-	-	-	-	-	-	-	0.86	0.68	0.87
Khepupara	0.97	0.72	0.98	0.98	1.08	0.98	0.97	-4.76	0.98	-	-	-
Khulna	0.96	0.95	0.97	0.97	2.44	0.98	0.92	-9.12	0.99	-	-	-
Kutubdia	0.96	0.98	0.98	0.97	1.24	0.97	-	-	-	-	-	-
Madaripur	0.98	0.76	0.99	0.98	1.08	0.98	0.99	-2.25	0.99	-	-	-
Maijdeecourt	0.96	0.45	0.96	0.97	1.60	0.98	0.99	-4.39	0.99	-	-	-
Mymensingh	0.97	0.47	0.97	0.99	0.37	0.99	0.99	-0.33	0.99	0.93	0.68	0.94
Patuakhali	0.98	0.45	0.98	0.98	1.05	0.98	0.78	-20.13	0.94	-	-	-
Rajshahi	0.96	-1.12	0.98	0.99	-0.81	0.99	0.90	-3.78	0.94	-	-	-
Rangamati	0.97	0.48	0.97	0.98	1.05	0.98	0.99	-2.65	0.99	-	-	-
Rangpur	0.91	-1.43	0.95	0.99	0.25	0.99	0.89	-11.36	0.96	0.96	1.57	0.97
Sandwip	0.96	0.91	0.97	0.98	0.79	0.98	0.97	-7.32	0.99	-	-	-
Satkhira	0.96	0.66	0.96	0.97	2.66	0.98	0.89	-9.79	0.98	-	-	-
Sitakunda	0.93	1.24	0.96	0.97	1.48	0.98	0.95	-8.04	0.97	-	-	-
Sreemangal	0.97	0.69	0.97	0.99	0.18	0.99	0.94	-4.06	0.96	0.62	1.43	0.77
Sylhet	0.93	1.06	0.95	0.99	0.28	0.99	0.96	-5.09	0.96	-	-	-
Teknaf	0.90	1.19	0.94	0.99	1.26	0.99	0.96	0.93	0.96	-	-	-

6.3 Climate Anomalies of Bangladesh

6.3.1 Maximum temperature

6.3.1.1 Seasonal

Maximum temperatures for different seasons has been found increasing for three time slices and all of the RCPs i.e. RCP2.6, RCP4.5 and RCP8.5. Countrywide mean average maximum temperature anomaly of DJF, MAM, JJAS and ON season will be 1.7ºC, 1.1ºC, 2.6ºC and 2.4ºC for 2080s under extreme climate change scenario RCP8.5. Highest maximum temperature anomaly will be 2.4ºC in Khulna for DJF, 2.4ºC in Ishawrdi for MAM, 4.6ºC in Feni for JJAS and 3.9ºC in Rangamati for ON. Figure 6.1 to Figure 6.4 show anomalies in average maximum temperature over Bangladesh and Figure 6.5 to Figure 6.8 show anomalies in average maximum temperature for different seasons and different regions of Bangladesh. Figure 6.5 reveals that south-west and north-west region of Bangladesh will face highest increment of average maximum temperature for DJF season, whereas increment of average maximum temperature will be lowest in north-east region. For MAM season, highest increment will be in north-west region and lowest in south-central region. South-east region will face highest increment of average maximum temperature in JJAS season, but lowest in north-west region. Highest average maximum temperature increment will be in eastern hill region for ON season. Variation of increment of temperature is found very less in north-east region for all four seasons. Average maximum temperature anomaly between three RCPs illustrate highest temperature anomaly are in RCP8.5 and lowest in RCP2.6. Seasonal temperature increase is found higher in monsoon (4.5ºC) and post-monsoon season (up to 4.0ºC) considering all scenarios.

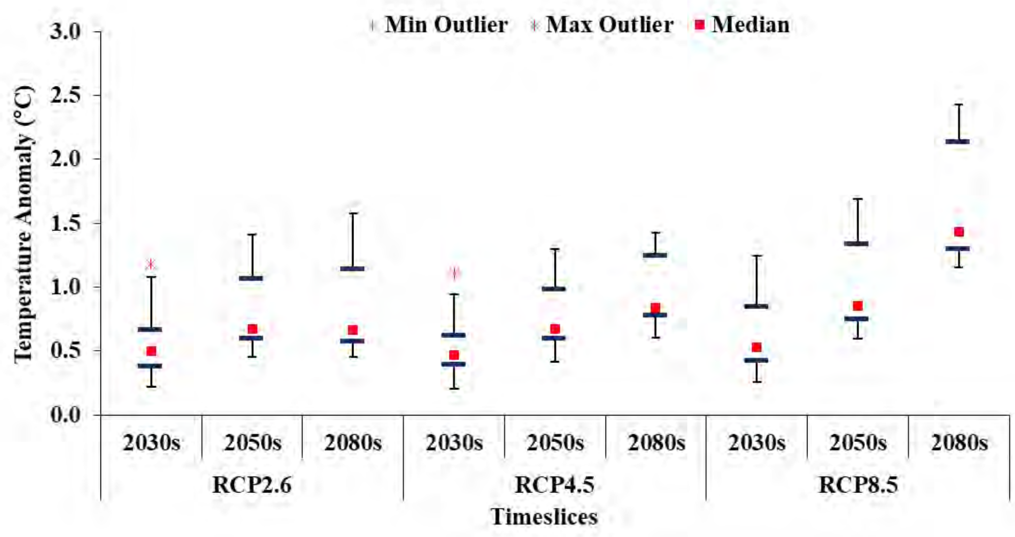


Figure 6.1: Anomalies of average maximum temperature for December-January-February (DJF) over Bangladesh

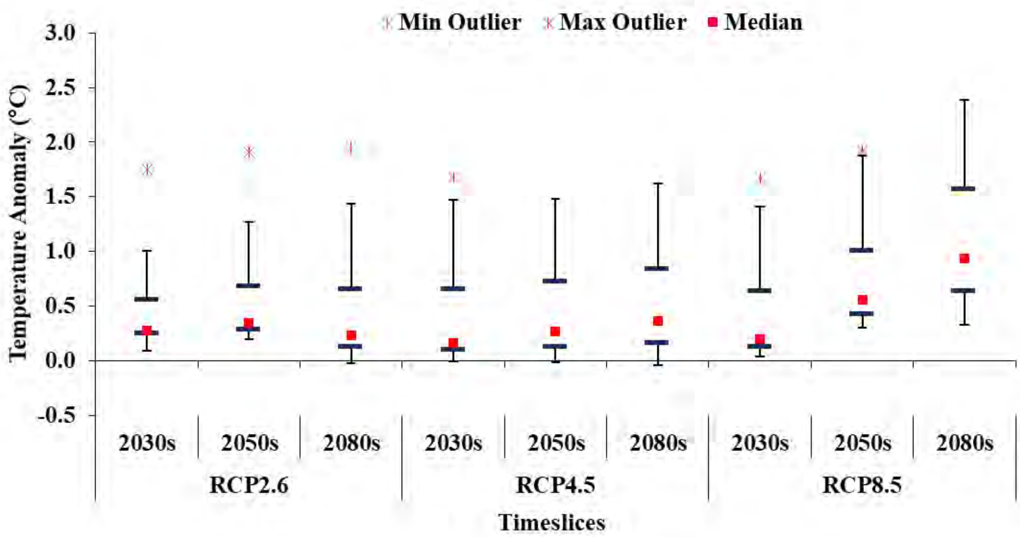


Figure 6.2: Anomalies of average maximum temperature for March-April-May (MAM) over Bangladesh

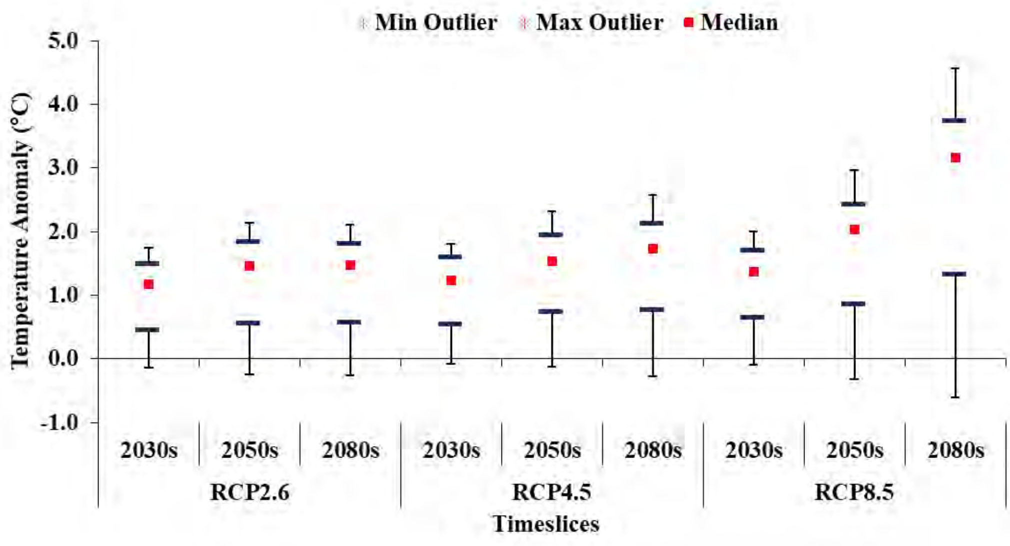


Figure 6.3: Anomalies of average maximum temperature for June-July-August-September (JJAS) over Bangladesh

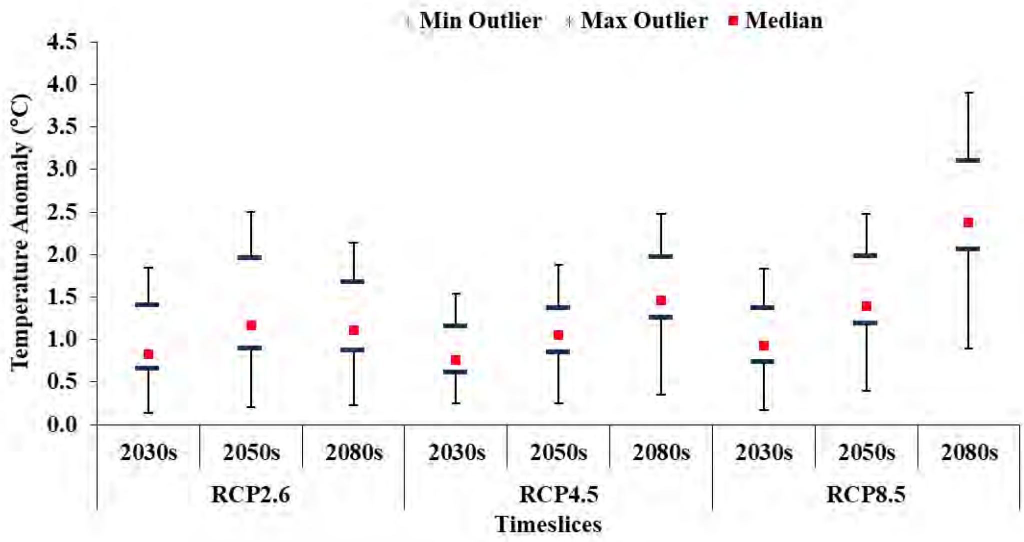


Figure 6.4: Anomalies of average maximum temperature for October-November (ON) over Bangladesh

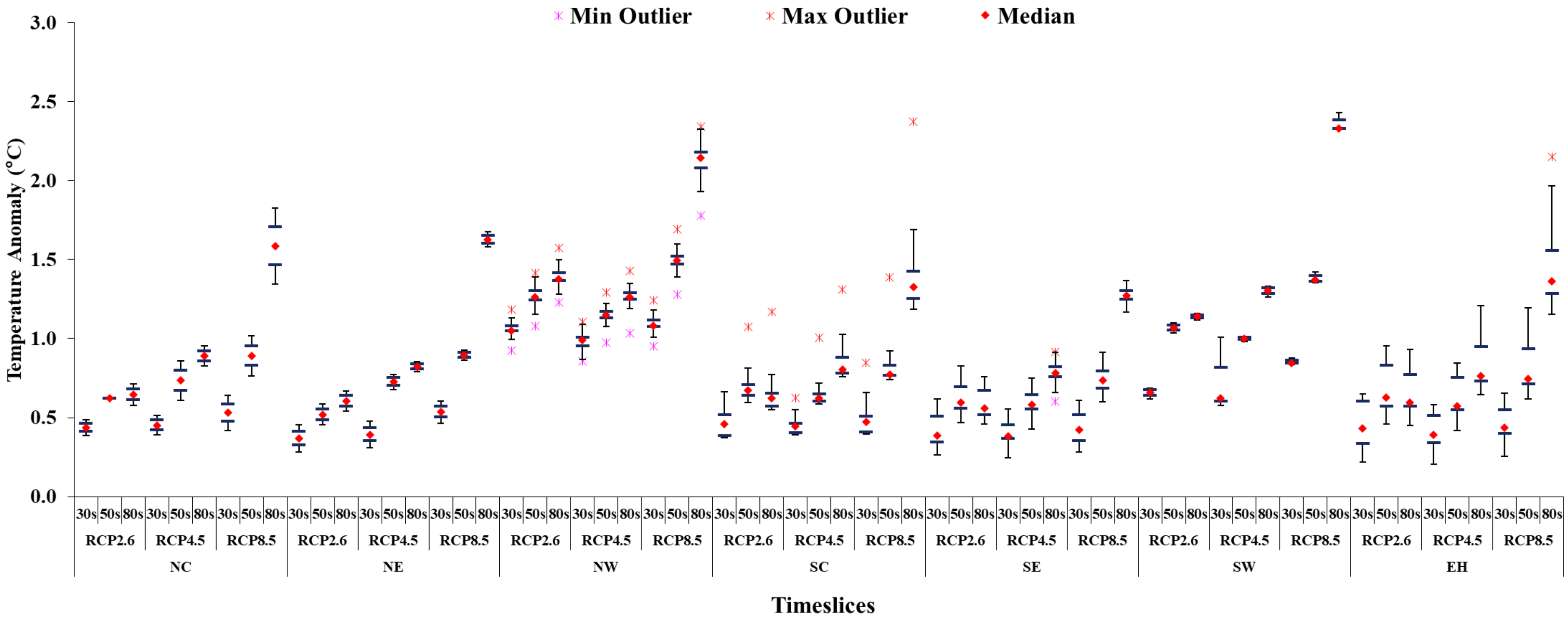


Figure 6.5: Anomalies of average maximum temperature for December-January-February (DJF) in different regions of Bangladesh

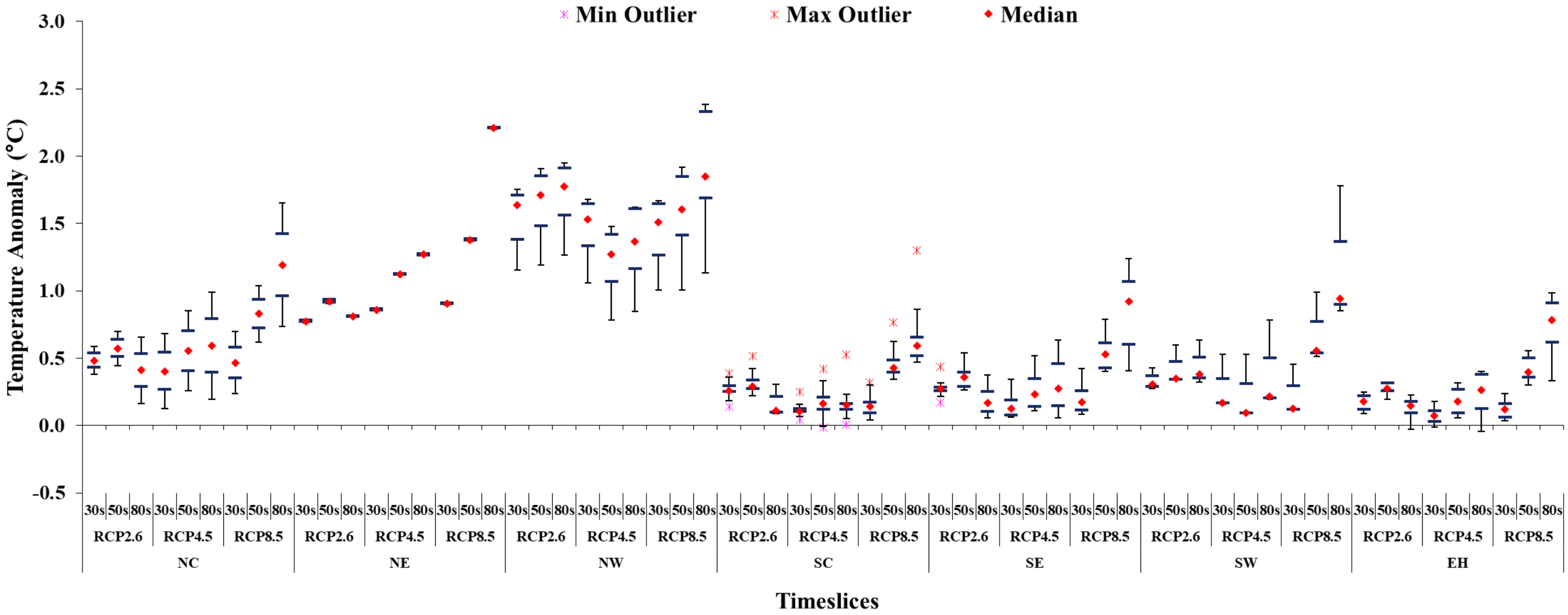


Figure 6.6: Anomalies of average maximum temperature for March-April-May (MAM) in different regions of Bangladesh

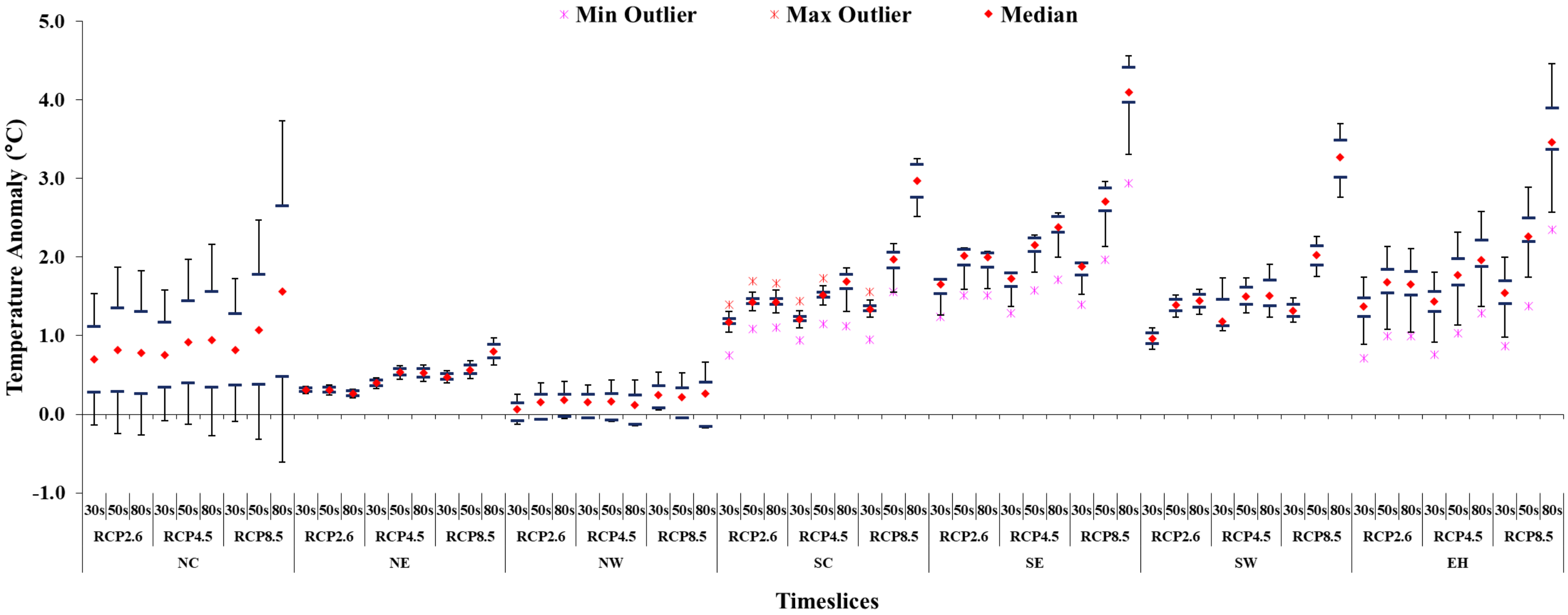


Figure 6.7: Anomalies of average maximum temperature for June-July-August-September (JJAS) in different regions of Bangladesh

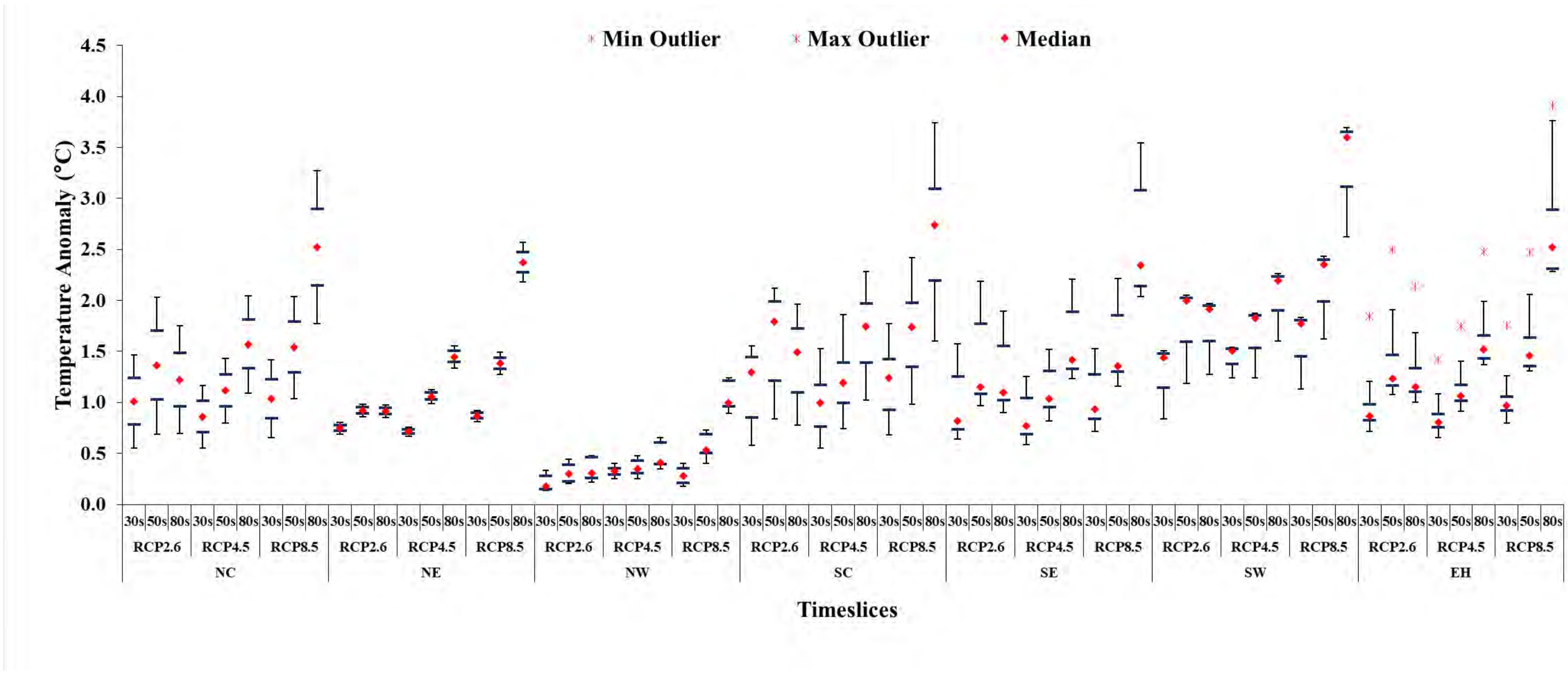


Figure 6.8: Anomalies of average maximum temperature for October-November (ON) in different regions of Bangladesh

6.3.1.2 Annual

Increase of mean annual average maximum temperature has been found 1.8ºC for 2080s under RCP8.5 scenario. Highest annual average maximum temperature increase will be 2.7ºC in Khulna as well as in south west region. Figure 6.10 to Figure 6.12 illustrate spatial distribution of annual average maximum temperature anomaly over Bangladesh for three time slices under RCP2.6, RCP4.5 and RCP8.5 scenarios. These figures depict that southern part of Bangladesh will be hotter gradually than northern part. Dhaka will face 2.3ºC increase of annual average maximum temperature in 2080s for RCP8.5. Table 6.4 represents annual average maximum temperature anomalies over different regions of Bangladesh. Although Bangladesh contribute only 0.3% of global of Green House Gas (GHGs) emission, it is becoming the worst victim of climate change rising temperature all over the country due to its geographical position (GED, 2018).

Table 6.4: Annual Average Maximum Temperature Anomalies over Bangladesh

Region	Change in Temperature, ^{o}C (Mean [Min-Max])								
	RCP2.6			RCP4.5			RCP8.5		
	2030s	2050s	2080s	2030s	2050s	2080s	2030s	2050s	2080s
North Central	0.6 [0.3-0.9]	0.8 [0.4-1.2]	0.7 [0.4-1.1]	0.6 [0.4-0.9]	0.8 [0.5-1.1]	0.9 [0.6-1.3]	0.7 [0.4-1.0]	1.0 [0.6-1.5]	1.6 [1.0-2.3]
North East	0.5 [no variation]	0.6 [no variation]	0.6 [0.6-0.7]	0.6 [no variation]	0.8 [no variation]	1.0 [0.9-1.0]	0.6 [no variation]	1.0 [0.9-1.0]	1.6 [1.5-1.7]
North West	0.7 [0.5-0.8]	0.8 [0.6-1.0]	0.8 [0.6-1.0]	0.7 [0.5-0.9]	0.7 [0.5-0.9]	0.7 [0.5-1.0]	0.7 [0.5-0.9]	0.9 [0.6-1.1]	1.2 [0.8-1.5]
South Central	0.8 [0.6-0.9]	1.0 [0.8-1.1]	0.9 [0.8-1.0]	0.7 [0.6-0.8]	0.9 [0.8-1.0]	1.1 [1.0-1.2]	0.8 [0.7-0.9]	1.2 [1.1-1.4]	2.0 [1.8-2.2]
South East	0.9 [0.7-1.0]	1.1 [1.0-1.3]	1.0 [0.9-1.2]	0.8 [0.7-0.9]	1.1 [0.9-1.2]	1.3 [1.1-1.4]	0.9 [0.8-1.0]	1.4 [1.3-1.6]	2.2 [2.0-2.5]
South West	0.8 [no variation]	1.1 [1.1-1.2]	1.1 [1.1-1.2]	1.0 [0.8-1.2]	1.1 [1.0-1.2]	1.3 [1.2-1.4]	1.0 [0.9-1.0]	1.5 [1.4-1.6]	2.5 [2.3-2.7]
Eastern Hill	0.8 [0.6-0.9]	1.1 [0.9-1.2]	1.0 [0.8-1.1]	0.7 [0.6-0.9]	1.0 [0.8-1.2]	1.3 [1.1-1.4]	0.8 [0.7-1.0]	1.3 [1.1-1.5]	2.3 [2.0-2.5]
Countrywide	0.6 [0.3-1.0]	0.8 [0.4-1.3]	0.8 [0.4-1.2]	0.8 [0.4-1.2]	0.8 [0.5-1.2]	1.0 [0.5-1.4]	0.7 [0.4-1.0]	1.1 [0.6-1.6]	1.8 [0.8-2.7]

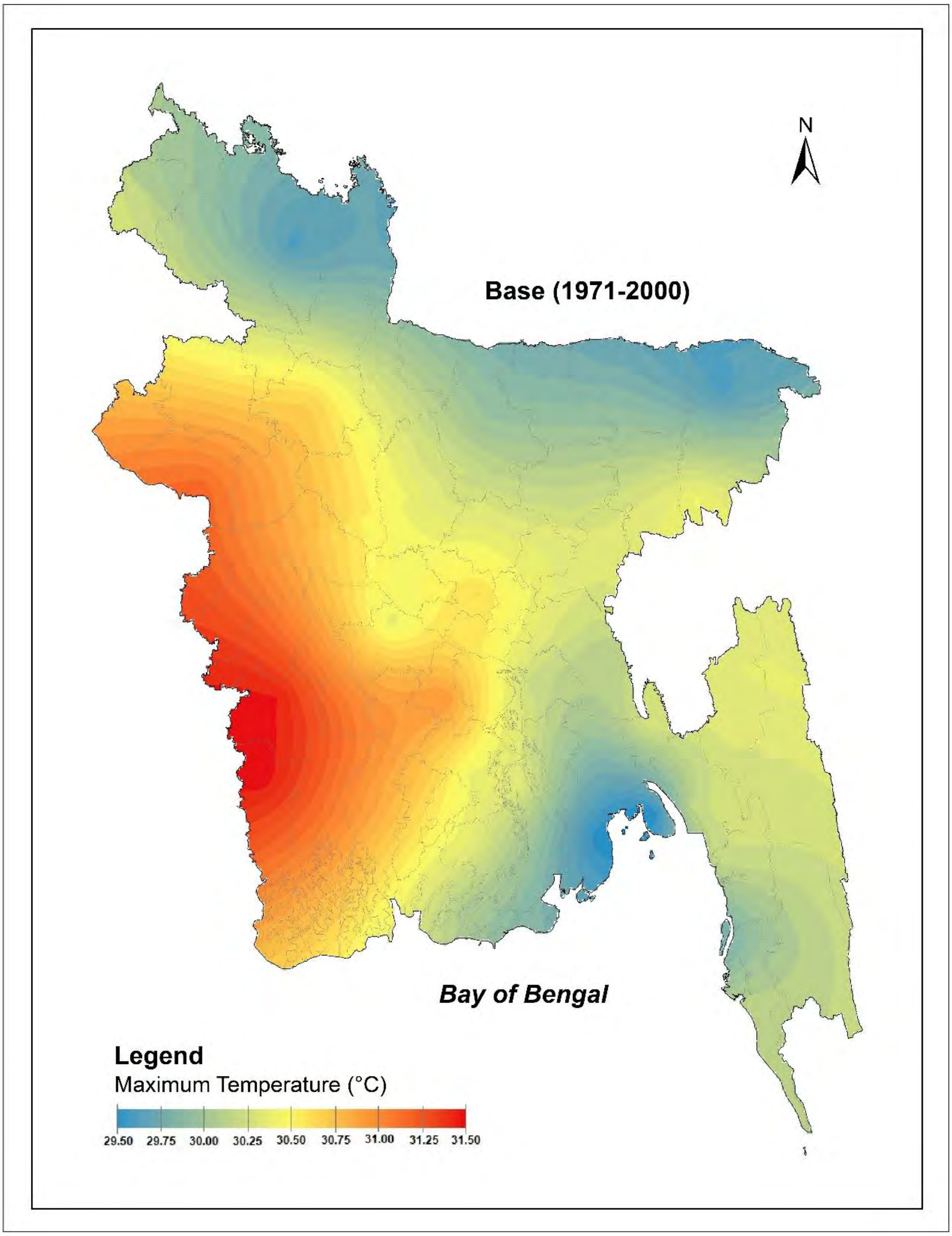


Figure 6.9: Spatial distribution of annual average maximum temperature over Bangladesh for base period (1971-2000)

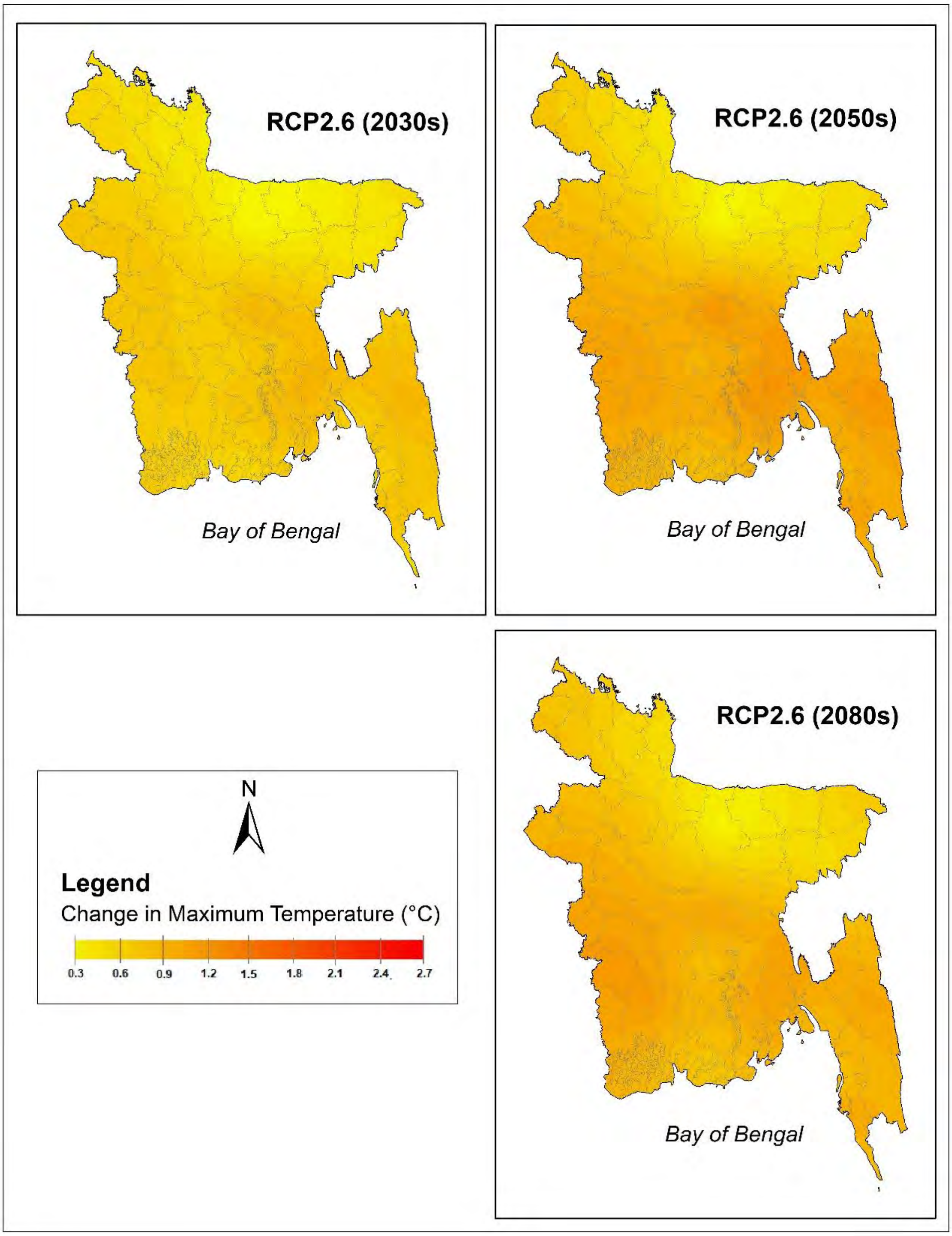


Figure 6.10: Spatial distribution of annual average maximum temperature anomalies over Bangladesh for RCP2.6

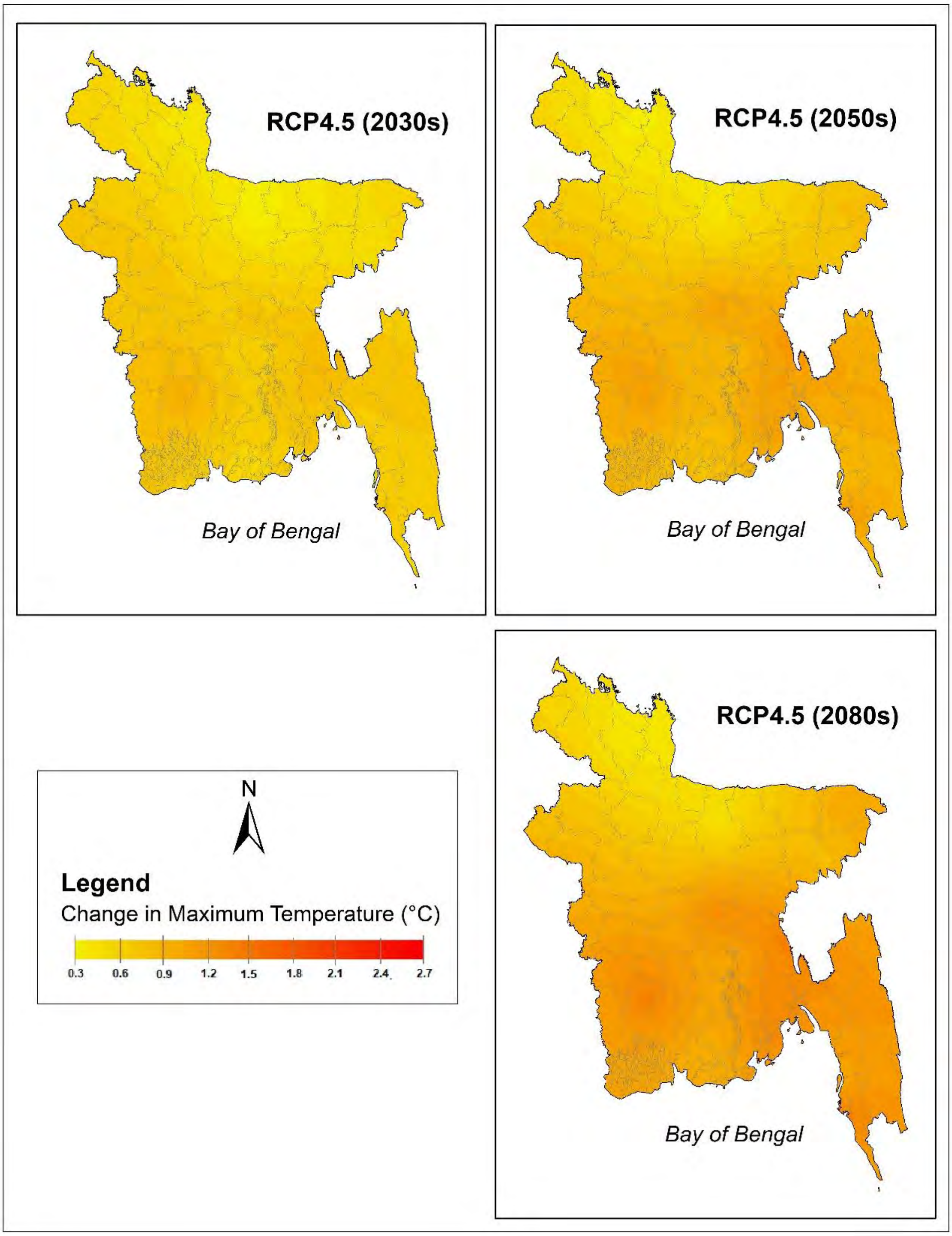


Figure 6.11: Spatial distribution of annual average maximum temperature anomalies over Bangladesh for RCP4.5

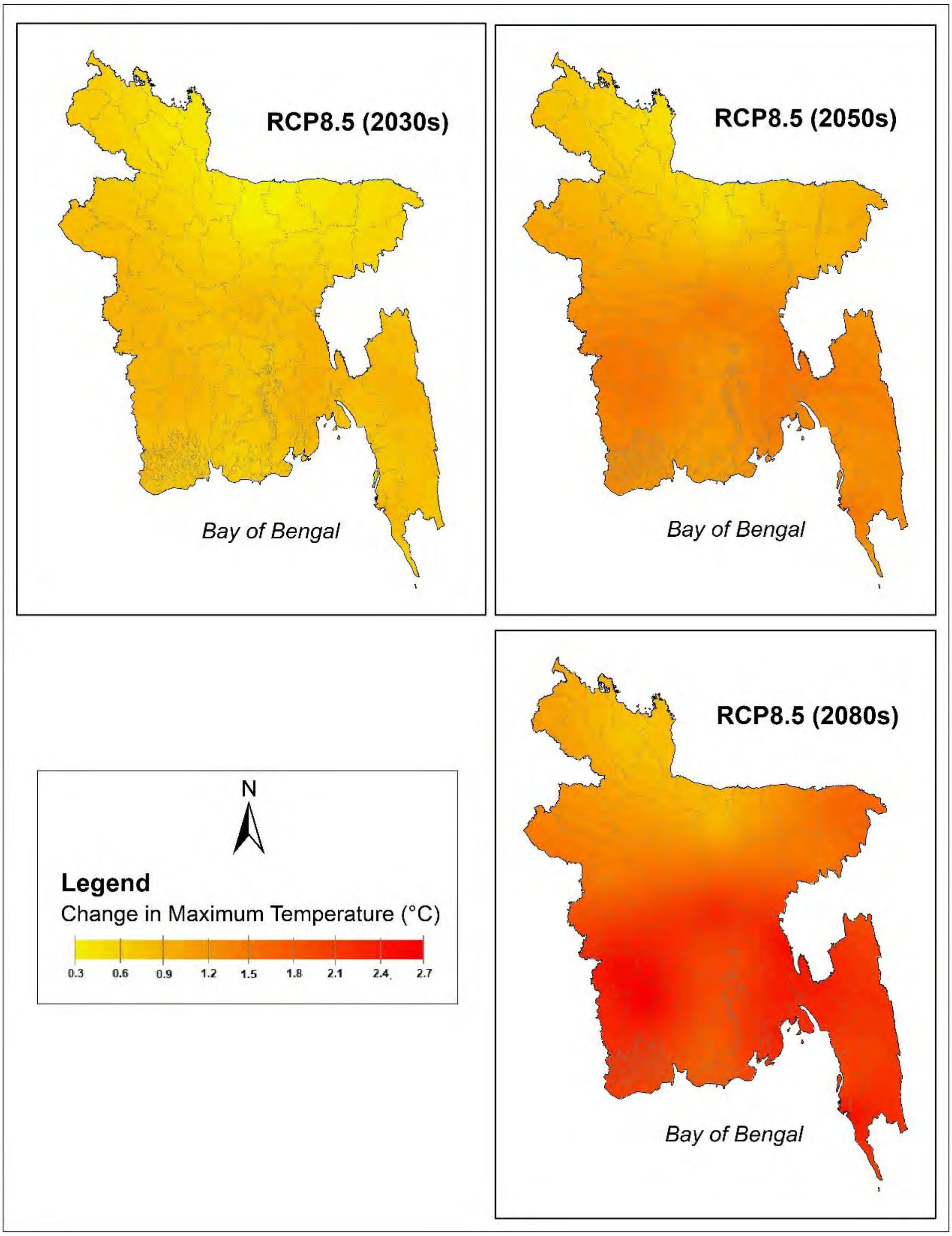


Figure 6.12: Spatial distribution of annual average maximum temperature anomalies over Bangladesh for RCP8.5

6.3.2 Minimum temperature

6.3.2.1 Seasonal

Minimum temperatures for different seasons has also been found increasing for three time slices and all of the RCPs i.e. RCP2.6, RCP4.5 and RCP8.5 like maximum temperature. Countrywide mean average minimum temperature anomaly of DJF, MAM, JJAS and ON season will be 2.2ºC, 2.0ºC, 2.1ºC and 3.8ºC for 2080s under extreme climate change scenario RCP8.5. Highest average minimum temperature anomaly will be 4.0ºC in Jessore for DJF, 3.4ºC in Mymensingh for MAM, 3.1ºC in Bhola for JJAS and 5.2ºC in Satkhira for ON. Lowest average minimum temperature anomaly will be 1.4ºC in Hatiya for DJF, 1.0ºC in Teknaf for MAM, 0.2ºC in Dinajpur for JJAS and 2.5ºC in Bogra for ON under RCP8.5 scenarios for 2080s. Figure 6.13 to Figure 6.16 show anomalies in average minimum temperature over Bangladesh and Figure 6.17 to Figure 6.20 show anomalies in average minimum temperature for different seasons and different regions of Bangladesh. Figure 6.17 reveals that south-west region of Bangladesh will face highest increment of average minimum temperature for DJF season, whereas increment of average minimum temperature will be lowest in south-east region. For MAM season, highest increment will be in north-central region and lowest in eastern hill region. South-central region will face highest increment of average minimum temperature in JJAS season, but lowest in north-west region. Highest average minimum temperature increment will be in south-west region and lowest will be in the same region for ON season. Variation of increment of average minimum temperature is found very less in north-east region for all four seasons. Average minimum temperature anomaly between three RCPs illustrate highest temperature anomaly are in RCP8.5 and lowest in RCP2.6 as like as maximum temperature.

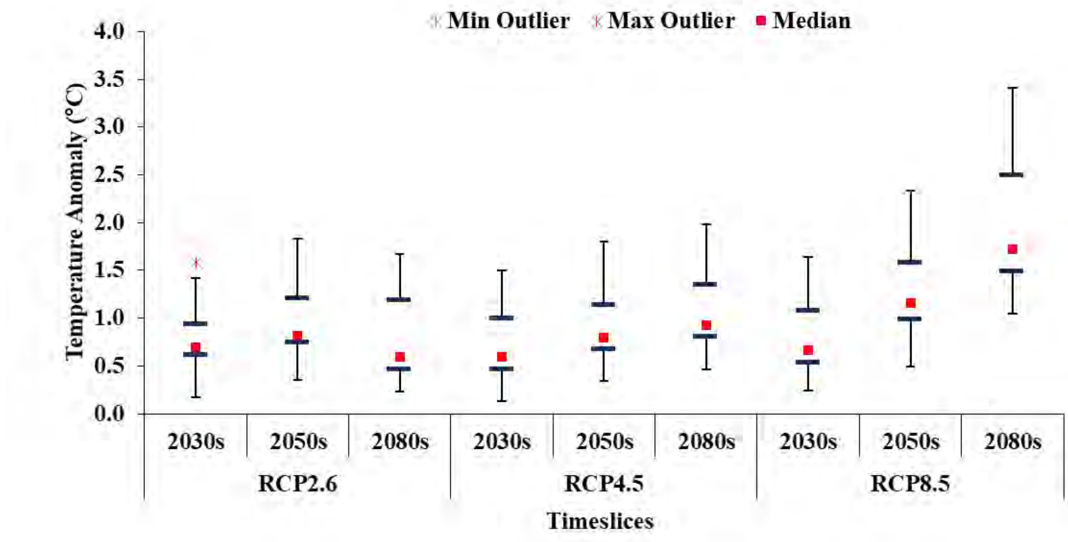


Figure 6.13: Anomalies of average minimum temperature for December-January-February (DJF) over Bangladesh

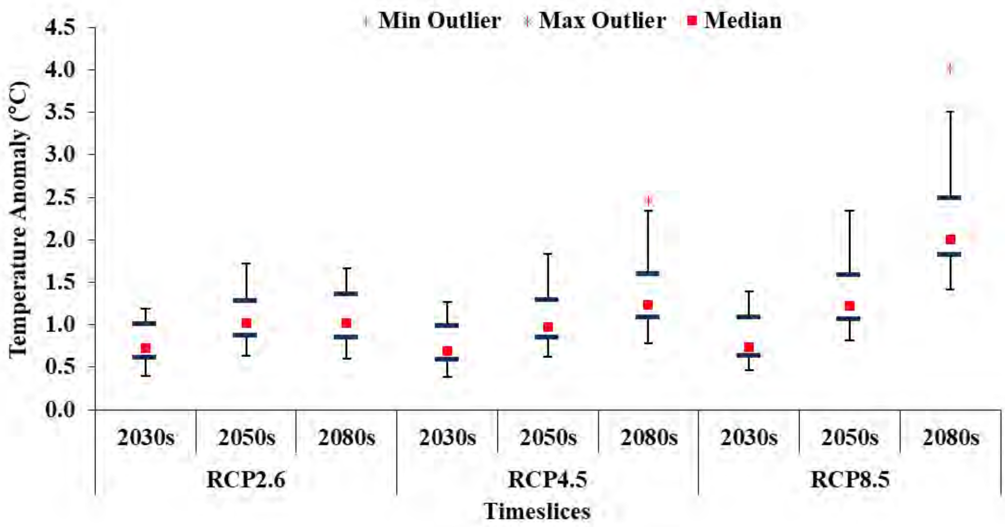


Figure 6.14: Anomalies of average minimum temperature for March-April-May (MAM) over Bangladesh

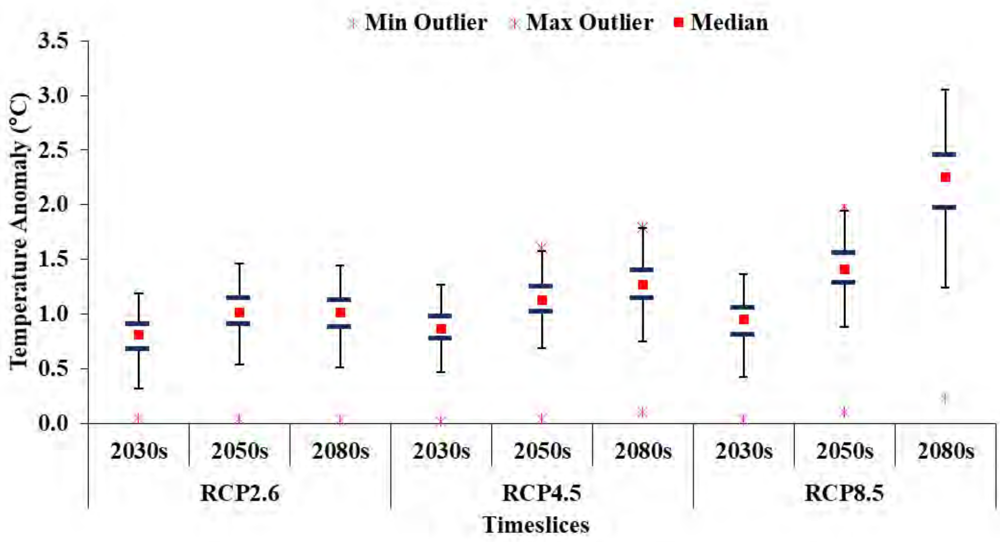


Figure 6.15: Anomalies of average minimum temperature for June-July-August-September (JJAS) over Bangladesh

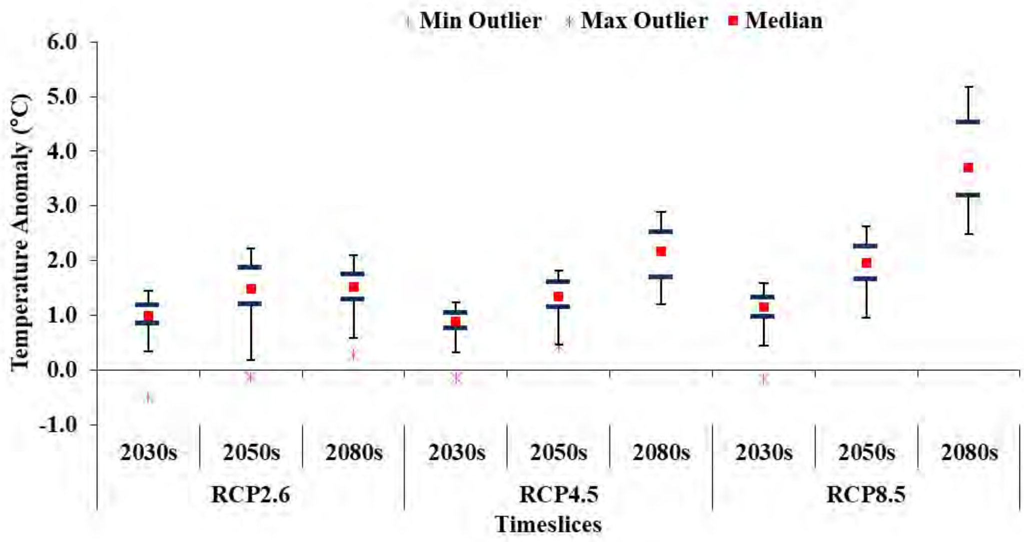


Figure 6.16: Anomalies of average minimum temperature for October-November (ON) over Bangladesh

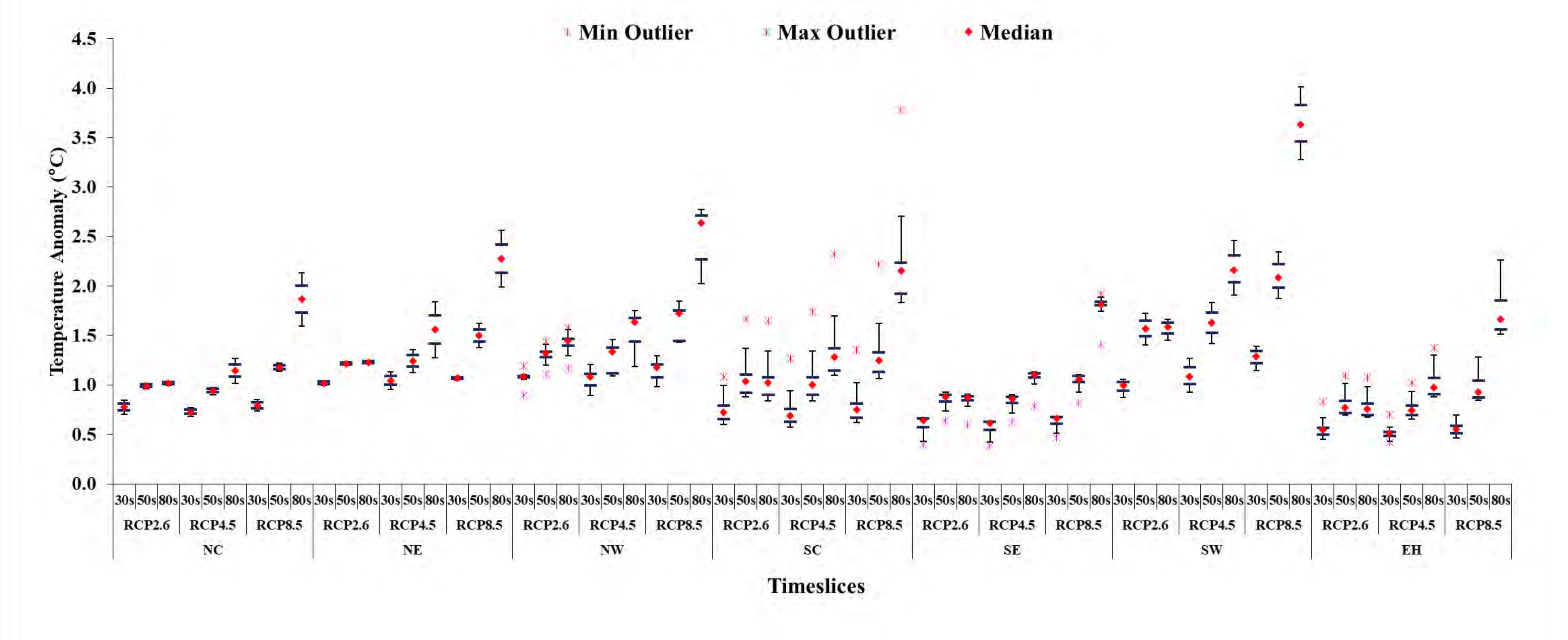


Figure 6.17: Anomalies of average minimum temperature for December-January-February (DJF) in different regions of Bangladesh

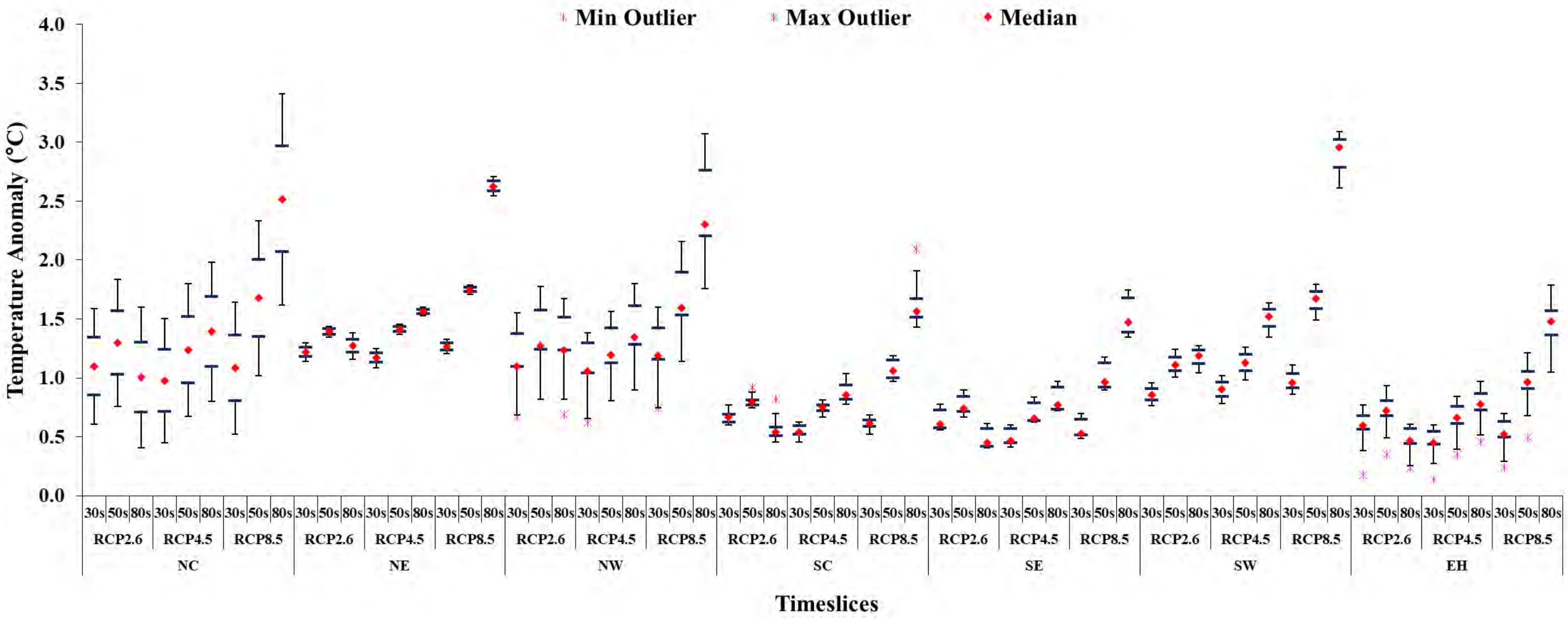


Figure 6.18: Anomalies of average minimum temperature for March-April-May (MAM) in different regions of Bangladesh

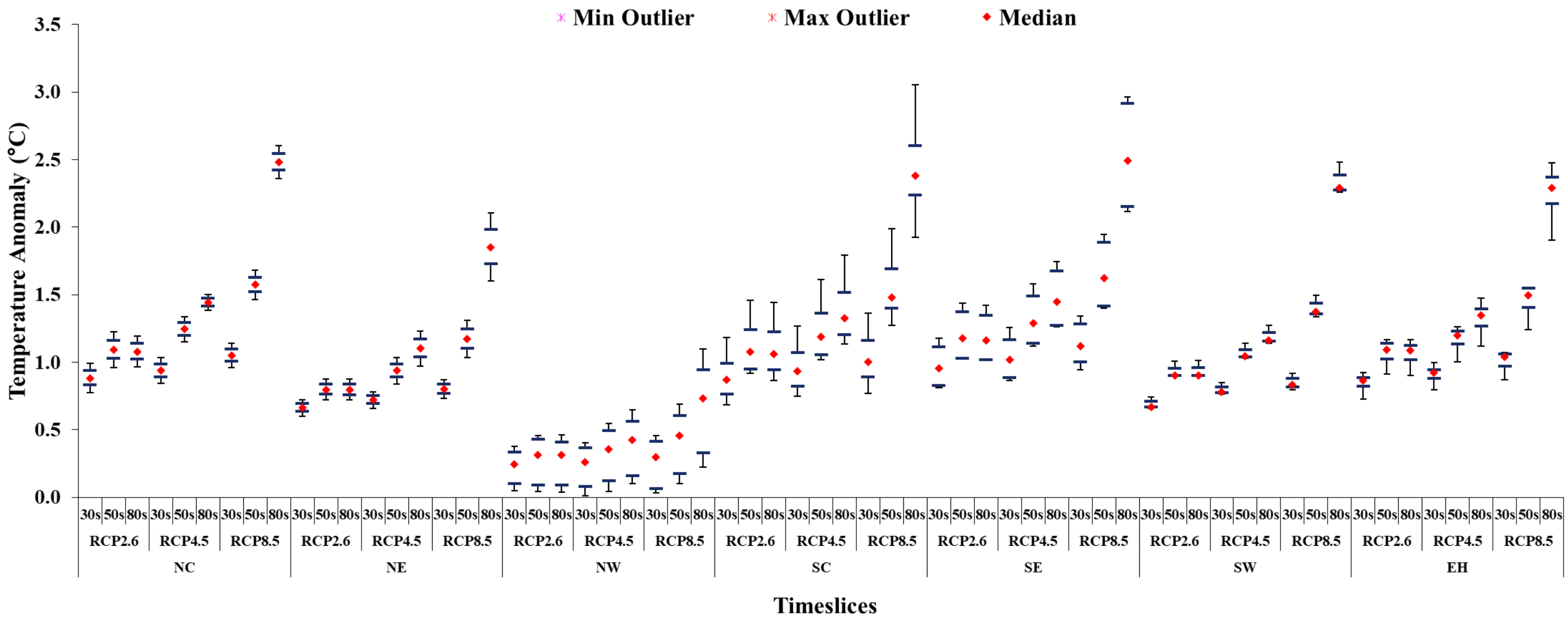


Figure 6.19: Anomalies of average minimum temperature for June-July-August-September (JJAS) in different regions of Bangladesh

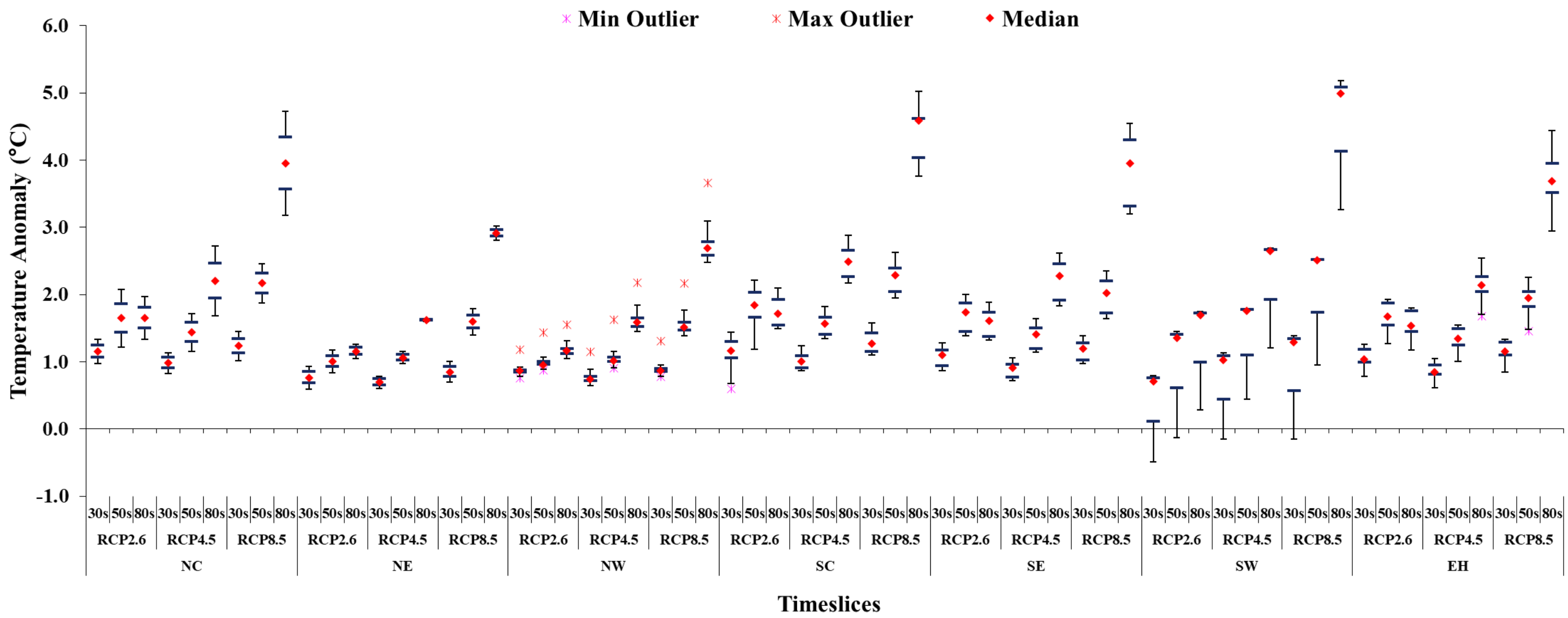


Figure 6.20: Anomalies of average minimum temperature for October-November (ON) in different regions of Bangladesh

6.3.2.2 Annual

Increase of mean annual average minimum temperature has been found 2.4ºC for 2080s under RCP8.5 scenario. Highest annual average minimum temperature increase will be 3.3ºC in Satkhira as well as in south west region. Figure 6.22 to Figure 6.24 illustrate spatial distribution of annual average minimum temperature anomaly over Bangladesh for three time slices under RCP2.6, RCP4.5 and RCP8.5 scenarios. These figures depict that southern part of Bangladesh will be hotter gradually and will aggravate to northern part. Dhaka will face 2.6ºC increase of annual average minimum temperature and Rangpur will face 1.5ºC increase of annual average minimum temperature which is lowest among all stations in 2080s for RCP8.5. Table 6.5 represents annual average minimum temperature anomalies over different regions of Bangladesh. Changes in sea surface temperature and associated atmospheric ocean circulation triggered by GHGs emission are the main cause of both maximum and minimum temperature rising. However, inter seasonal variability or between ranges of maximum and minimum temperature change may be either due to natural process or anthropogenic activities (FAO, 2007).

Table 6.5: Annual Average Minimum Temperature Anomalies over Bangladesh

Region	Change in Temperature, ⁰C (Mean [Min-Max])								
	RCP2.6			RCP4.5			RCP8.5		
	2030s	2050s	2080s	2030s	2050s	2080s	2030s	2050s	2080s
North Central	1.0 [0.9-1.0]	1.2 [no variation]	1.1 [1.1-1.2]	0.9 [0.8-1.0]	1.2 [1.1-1.3]	1.5 [no variation]	1.0 [0.9-1.1]	1.6 [1.5-1.7]	2.6 [no variation]
North East	0.9 [no variation]	1.1 [1.0-1.1]	1.1 [no variation]	0.9 [no variation]	1.2 [1.1-1.2]	1.4 [1.4-1.5]	1.0 [no variation]	1.5 [1.4-1.5]	2.3 [2.3-2.4]
North West	0.8 [0.6-1.0]	0.9 [0.7-1.2]	0.9 [0.7-1.2]	0.7 [0.5-0.9]	0.9 [0.7-1.1]	1.1 [0.9-1.3]	0.8 [0.6-1.0]	1.2 [0.9-1.5]	1.9 [1.5-2.3]
South Central	0.8 [0.8-0.9]	1.1 [1.0-1.3]	1.1 [0.9-1.2]	0.8 [0.7-0.9]	1.1 [1.0-1.2]	1.4 [1.3- 1.6]	0.9 [0.8-1.0]	1.5 [1.3-1.7]	2.6 [2.2-3.0]
South East	0.7 [0.7-0.9]	1.1 [1.0-1.2]	1.0 [0.9-1.0]	0.7 [0.7-0.8]	1.0 [0.9-1.1]	1.3 [1.2-1.5]	0.9 [0.8-0.9]	1.4 [1.2-1.5]	2.3 [2.1-2.5]
South West	0.7 [0.6-0.8]	1.1 [1.1-1.3]	1.2 [1.1-1.3]	0.9 [0.8-1.0]	1.3 [1.2-1.4]	1.7 [1.6-1.8]	1.0 [0.9-1.1]	1.7 [1.6-1.9]	3.2 [3.1-3.3]
Eastern Hill	0.7 [0.7-0.8]	1.0 [0.9-1.1]	0.9 [0.8-1.0]	0.7 [0.6-0.7]	0.9 [0.9-1.0]	1.2 [1.1-1.4]	0.8 [0.7-0.9]	1.3 [1.1-1.4]	2.1 [1.9-2.4]
Countrywide	0.8 [0.6-1.0]	1.0 [0.7-1.3]	1.0 [0.7-1.3]	0.8 [0.5-1.0]	1.0 [0.7-1.4]	1.3 [0.9-1.8]	0.9 [0.6-1.1]	1.4 [0.9-1.9]	2.4 [1.5-3.3]

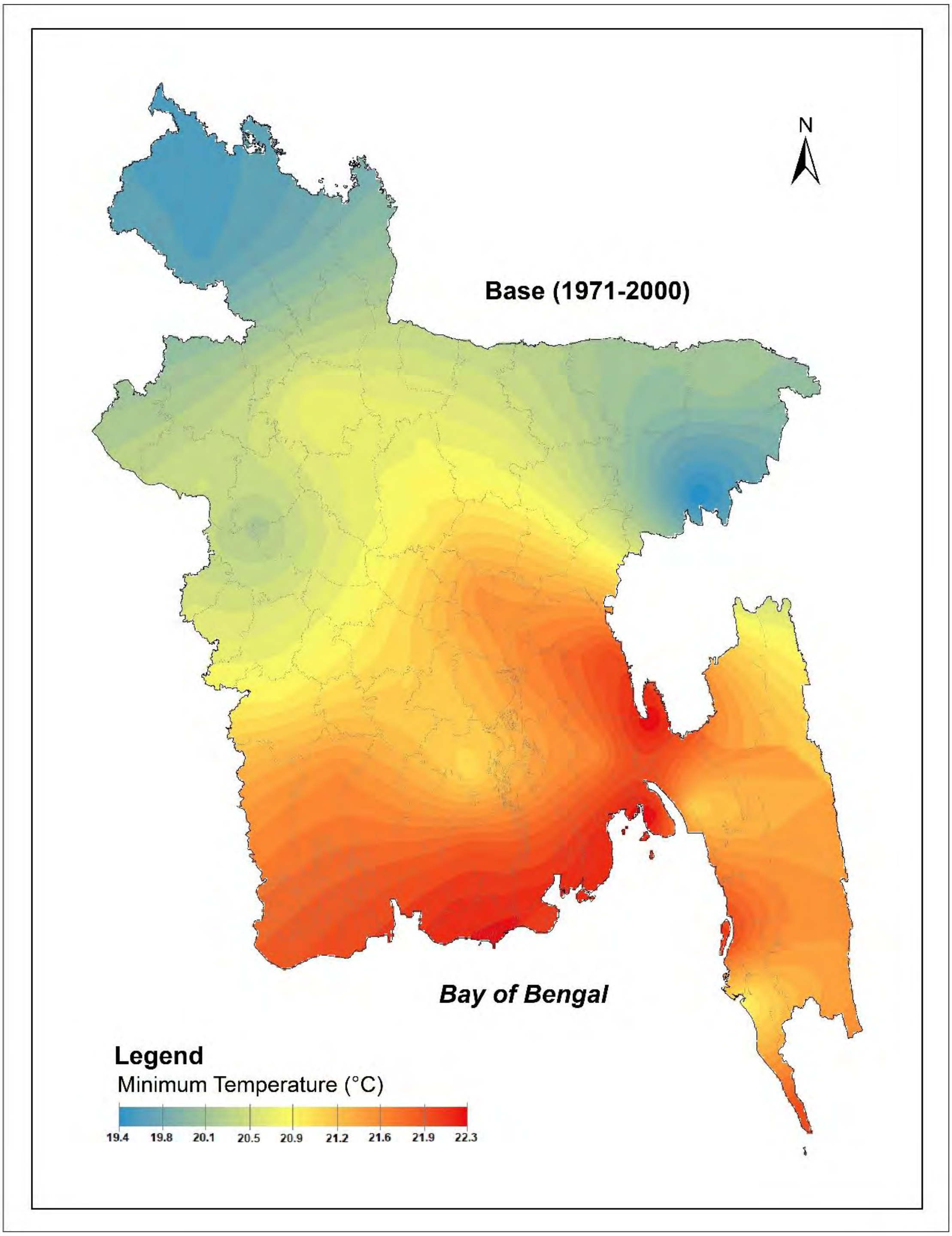


Figure 6.21: Spatial distribution of annual average minimum temperature over Bangladesh for base period (1971-2000)

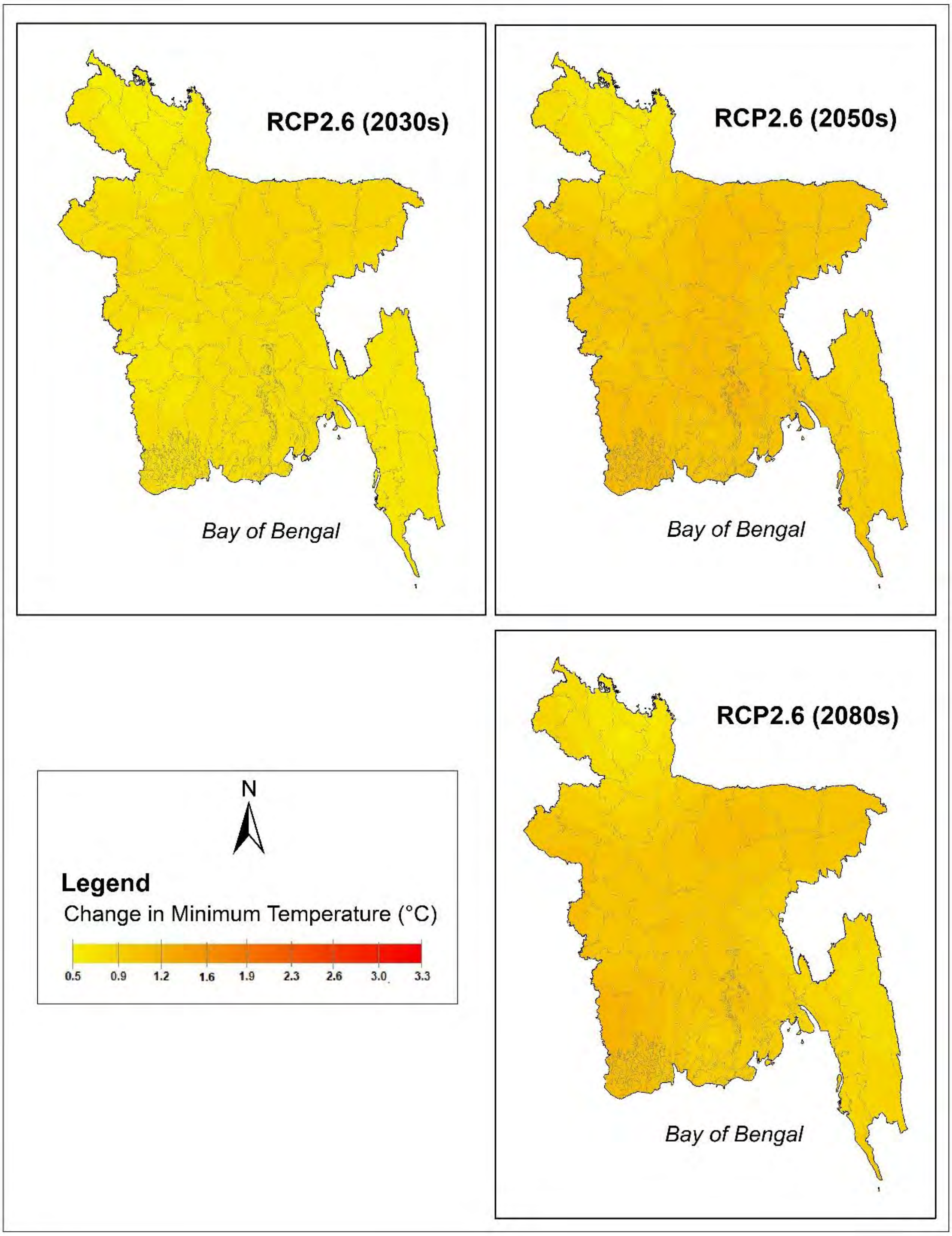


Figure 6.22: Spatial distribution of annual average minimum temperature anomalies over Bangladesh for RCP2.6

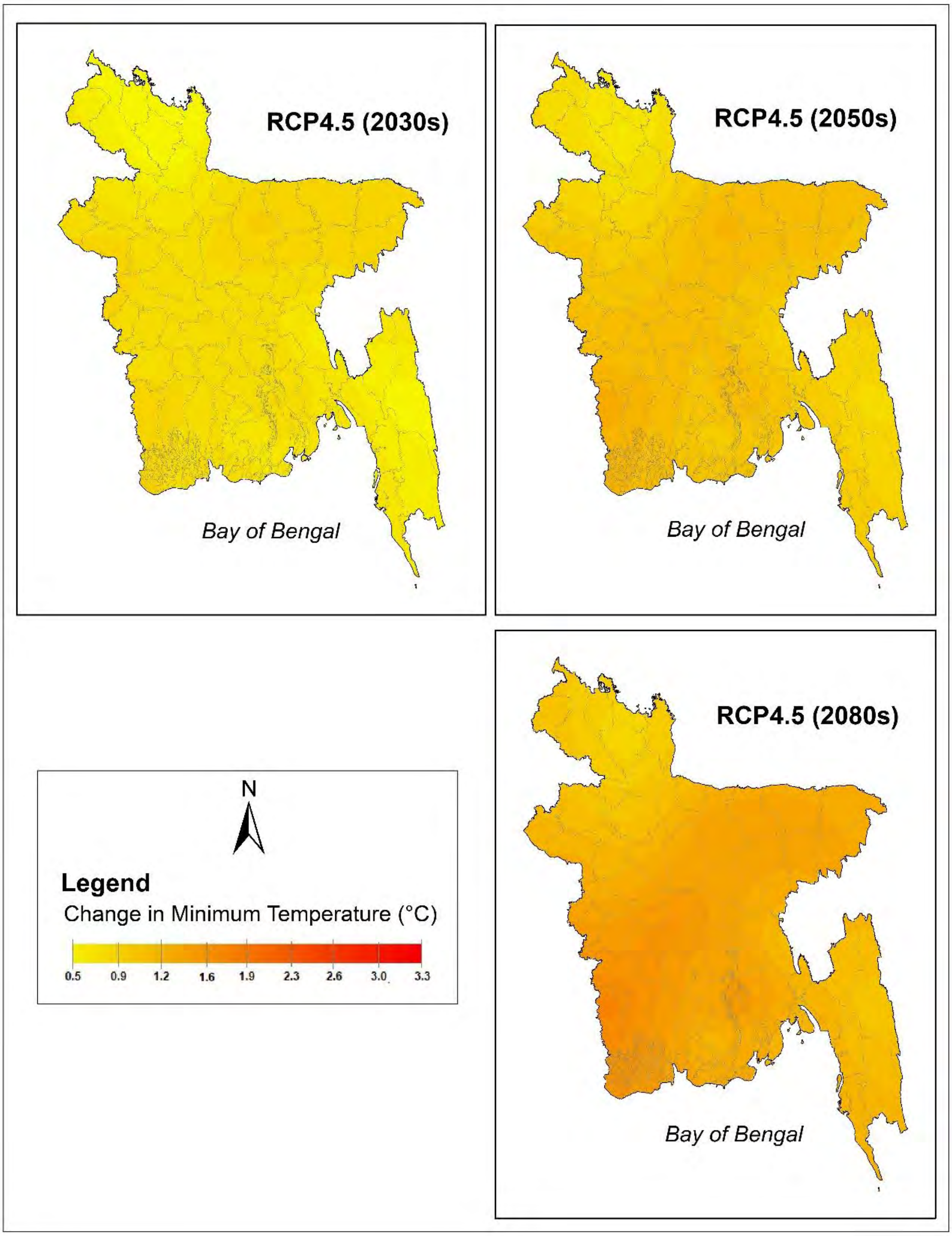


Figure 6.23: Spatial distribution of annual average minimum temperature anomalies over Bangladesh for RCP4.5

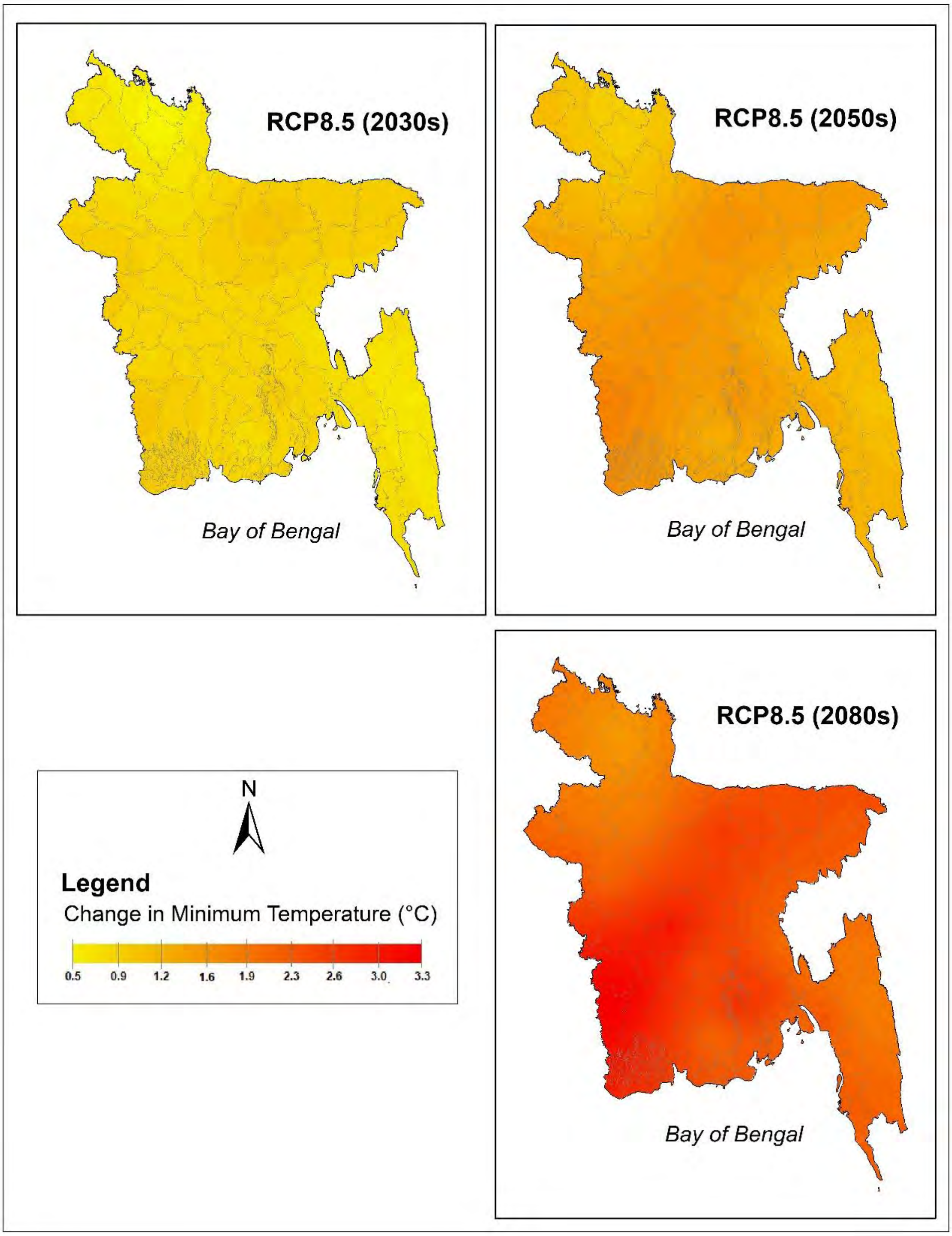


Figure 6.24: Spatial distribution of annual average minimum temperature anomalies over Bangladesh for RCP8.5

6.2.3 Rainfall

6.3.3.1 Seasonal

Rainfall anomaly has been found erratic, sometimes increasing and sometimes decreasing for three time slices and all of the RCPs i.e. RCP2.6, RCP4.5 and RCP8.5. Countrywide mean average rainfall anomaly of DJF, MAM, JJAS and ON season will be -7% to -8%, 10% to 22%, 10% to 16% and -15% to -17% for 2080s considering RCP2.6, RCP4.5 and RCP8.5. Therefore, seasonal average rainfall will be decreased in DJF and ON season and increased in MAM and JJAS season making dry season more drier and wet season more wetter due to increase of temperature.

In DJF season, average rainfall will be increased only in Sylhet, Sreemangal and Teknaf stations and in ON season, average rainfall will be increased only in Khulna, Satkhira, Teknaf and Faridpur stations for all timescales and RCPs. In MAM season, highest increase of average rainfall will be in Teknaf and Sitakunda station around 48% to 57%. Sylhet and Sreemangal will face 29% to 37% increment of average rainfall in this season. Highest decrease will be up to 32% in north-west and up to 9% in south-west regions. In JJAS season, highest increase of average rainfall will be up to 33% in Dinajpur and on an average 24% in north-west region and 21% in both south west and eastern hill regions for 2080s considering RCP2.6, RCP4.5 and RCP8.5.

Figure 6.25 to Figure 6.28 show anomalies in average rainfall over Bangladesh and Figure 6.29 to Figure 6.32 show anomalies in average rainfall for different seasons and different regions of Bangladesh. Figure 6.29 reveals that all of the regions of Bangladesh will face decrease of average rainfall amount for DJF season, except north-east region where DJF rainfall will be slightly increased. Highest decrease will be in south-west region of Bangladesh in DJF season. For MAM season, highest increment will be in eastern hill region and highest decrease will be in north-west region. In monsoon i.e. in JJAS season, average rainfall will be increased all over Bangladesh with highest increase in eastern hill and north-west region. Lowest increase will be in north-east region. Average rainfall will be decreased all over Bangladesh except south-west region in ON season as represented by Figure 6.32. In monsoon season, variation of average rainfall anomaly will be more erratic in north-west, south-central and eastern hill regions. Variation of average rainfall anomaly is found very less in south-west region for all four seasons. Average rainfall anomaly between three RCPs illustrate highest rainfall anomaly are found very unpredictable for different season and regions. Range of average rainfall anomaly is found almost same for all of the three RCPs for DJF season. For MAM season, highest average rainfall anomaly is found in RCP4.5 rather RCP8.5. Highest average rainfall anomaly is found in RCP8.5 for JJAS season. Range of variation of average rainfall anomaly is also found almost similar for three RCPs in ON season as like as DJF season.

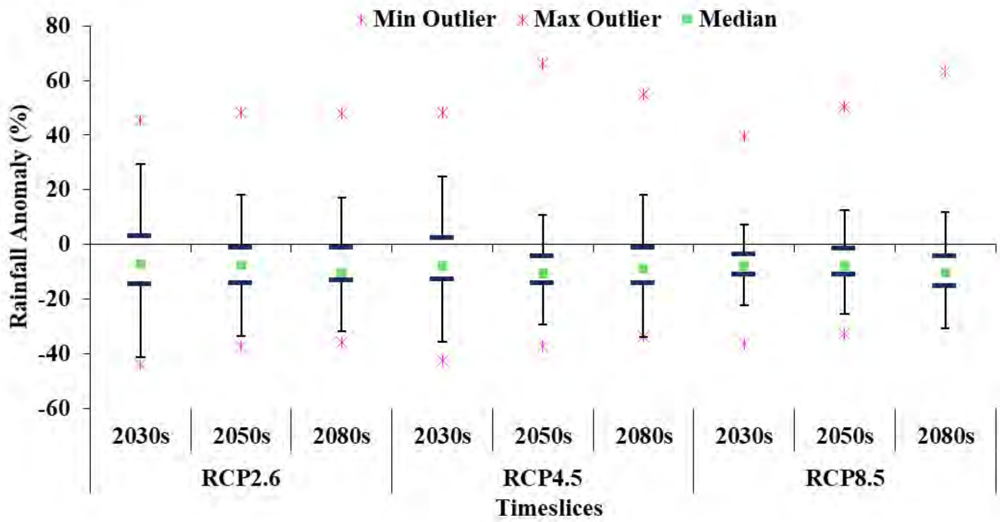


Figure 6.25: Anomalies of average rainfall for December-January-February (DJF) over Bangladesh

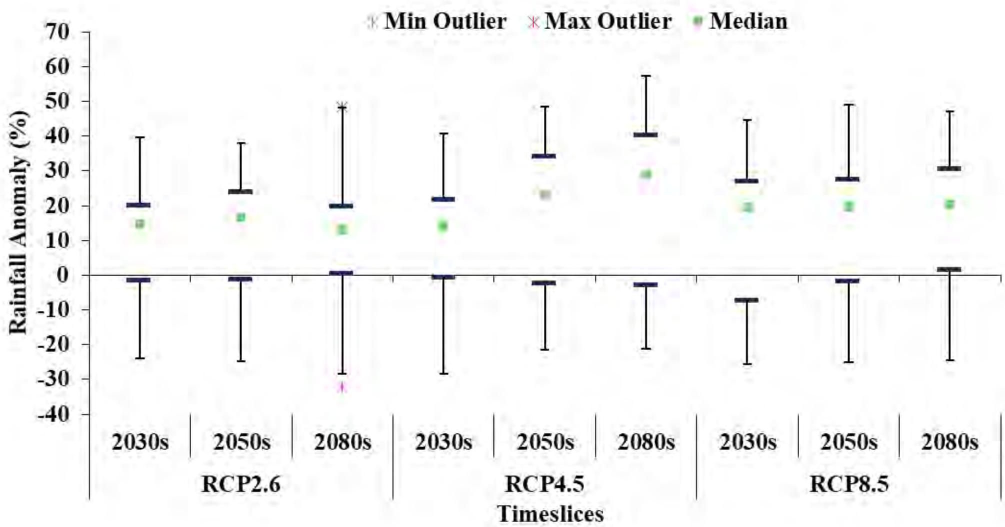


Figure 6.26: Anomalies of average rainfall for March-April-May (MAM) over Bangladesh

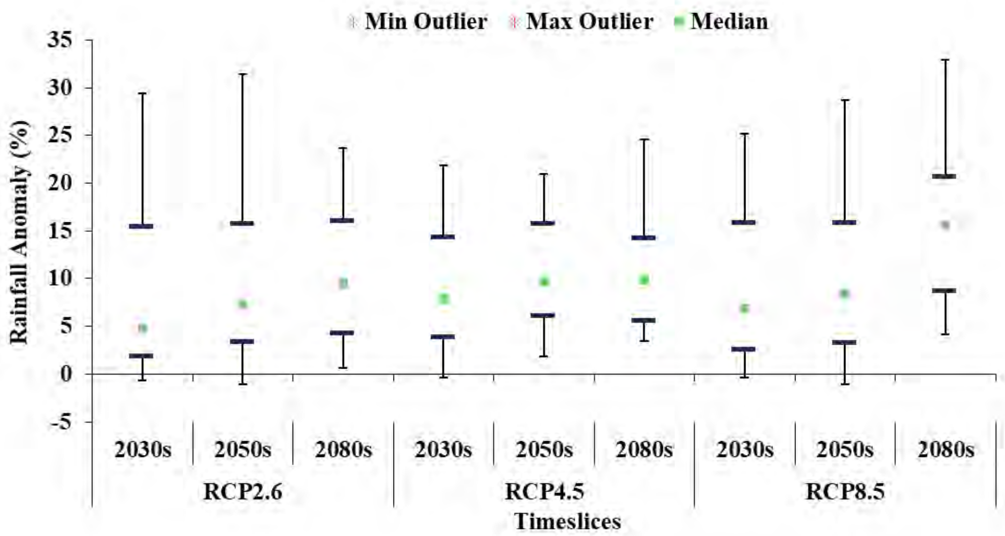


Figure 6.27: Anomalies of average rainfall for June-July-August-September (JJAS) over Bangladesh

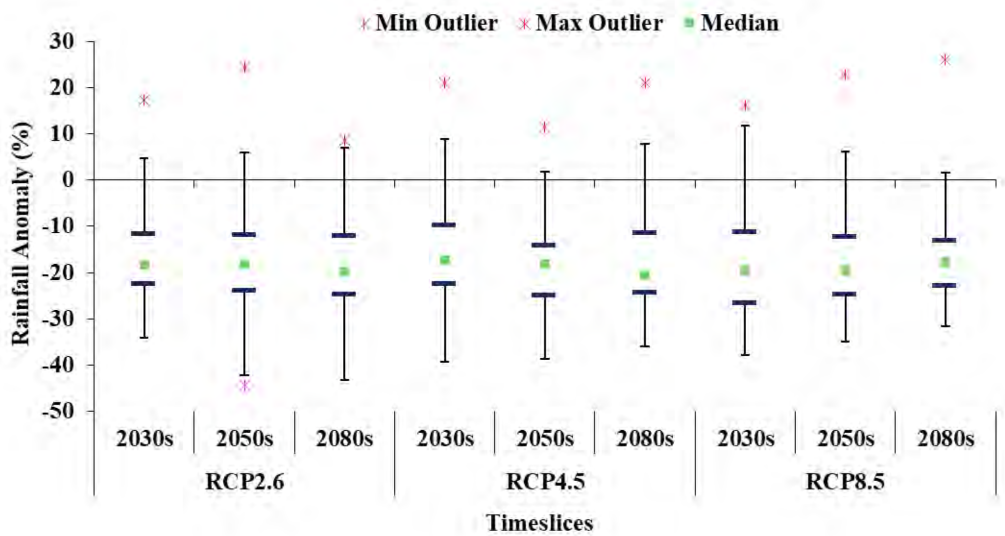


Figure 6.28: Anomalies of average rainfall for October-November (ON) over Bangladesh

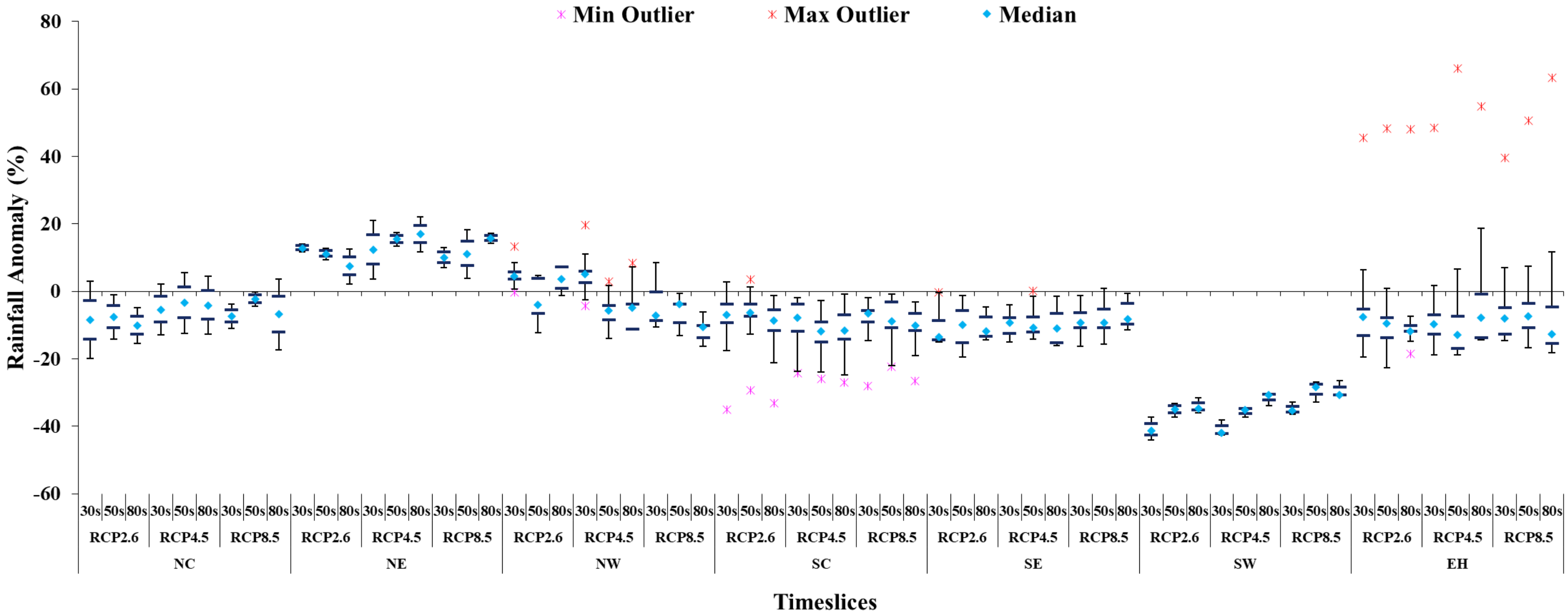


Figure 6.29: Anomalies of average rainfall for December-January-February (DJF) in different regions of Bangladesh

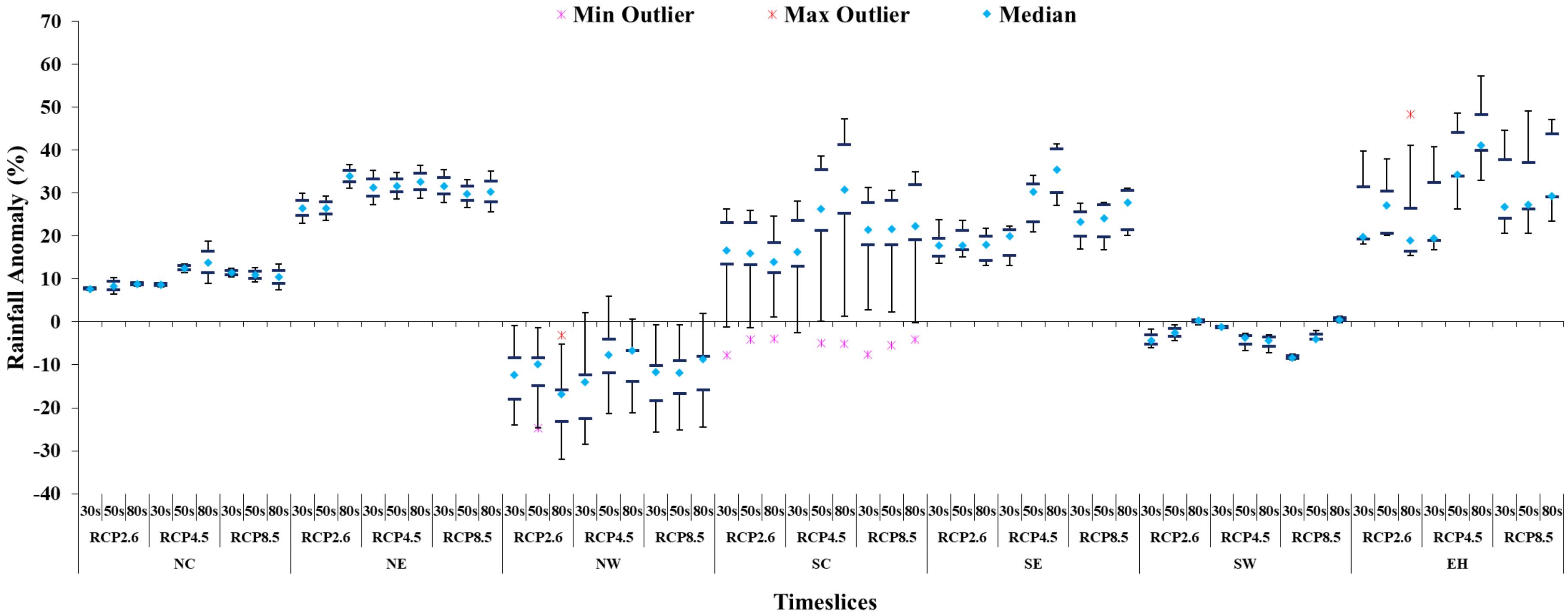


Figure 6.30: Anomalies of average rainfall for March-April-May (MAM) in different regions of Bangladesh

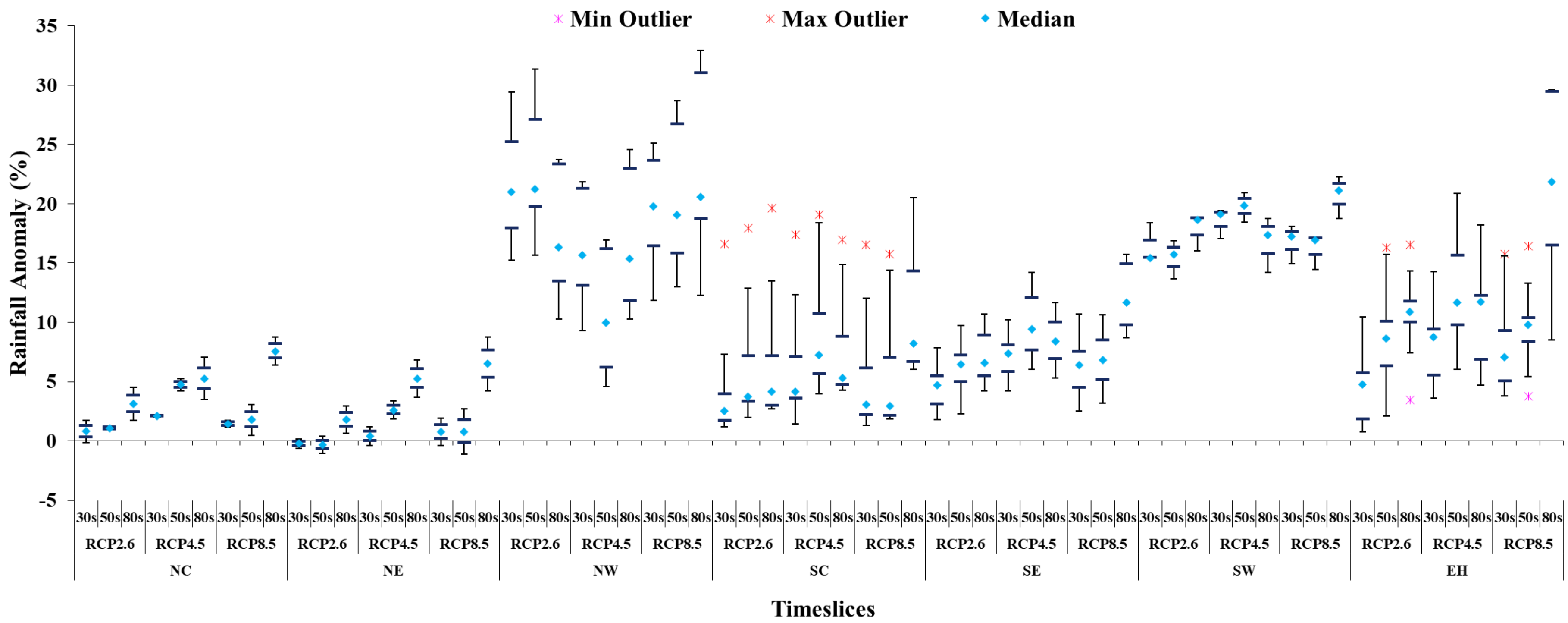


Figure 6.31: Anomalies of average rainfall for June-July-August-September (JJAS) in different regions of Bangladesh

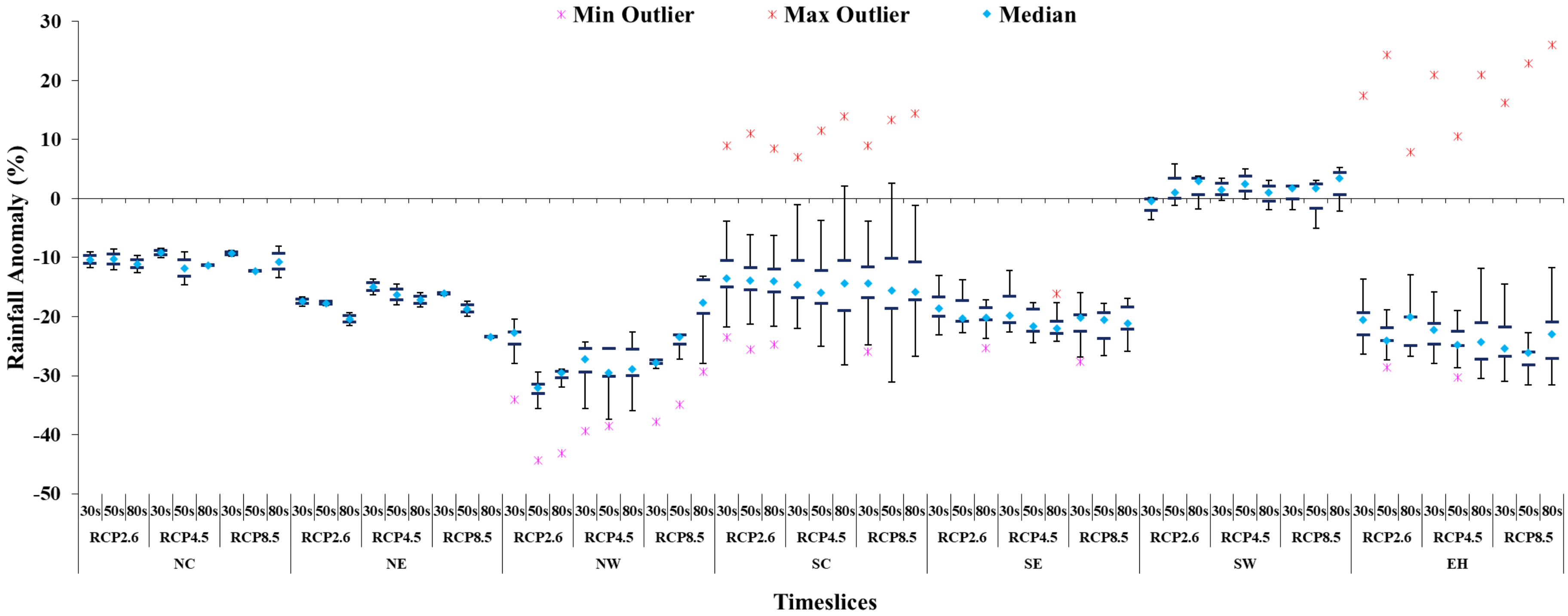


Figure 6.32: Anomalies of average rainfall for October-November (ON) in different regions of Bangladesh

6.3.3.2 Annual

Increase of mean annual average rainfall has been found 20% for 2080s under RCP8.5 scenario. Highest annual average rainfall will be increased up to 31% in Teknaf as well as in eastern hill region. Figure 6.34 to Figure 6.36 illustrate spatial distribution of annual average rainfall anomaly over Bangladesh for three time slices under RCP2.6, RCP4.5 and RCP8.5 scenarios. These figures depict that northern part of north-west region, south west portion, north east portion and eastern hill region of Bangladesh will get increased annual average rainfall in far future.

Table 6.6 represents annual average rainfall anomalies over different regions of Bangladesh.

Table 6.6: Annual Average Rainfall Anomalies over Bangladesh

Region	Change in Rainfall, % (Mean [Min-Max])								
	RCP2.6			RCP4.5			RCP8.5		
	2030s	2050s	2080s	2030s	2050s	2080s	2030s	2050s	2080s
North Central	1.0 [1.0-2.0]	2.0 [1.0-2.0]	3.0 [2.0-4.0]	2.0 [no variation]	5.0 [no variation]	6.0 [no variation]	3.0 [no variation]	3.0 [2.0-3.0]	6.0 [no variation]
North East	6.0 [6.0-7.0]	6.0 [6.0-7.0]	9.0 [9.0-10.0]	8.0 [7.0-9.0]	10.0 [9.0-10.]	12.0 [10.0-13.0]	8.0 [7.0-9.0]	8.0 [7.0-9.0]	11.0 [9.0-14.0]
North West	13.0 [9.0-17.0]	13.0 [9.0-17.0]	9.0 [5.0-12.0]	9.0 [5.0-12.0]	5.0 [1.0-9.0]	9.0 [5.0-14.0]	10.0 [6.0-13.0]	12.0 [7.0-16.0]	14.0 [8.0-20.0]
South Central	5.0 [2.0-9.0]	7.0 [3.0-11.0]	7.0 [2.0-12.0]	7.0 [3.0-11.0]	9.0 [6.0-12.0]	9.0 [6.0-13.0]	6.0 [3.0-9.0]	6.0 [3.0-10.0]	11.0 [6.0-15.0]
South East	6.0 [4.0-8.0]	9 [6.0-13.0]	9.0 [5.0-12.0]	8.0 [6.0-11.0]	13.0 [8.0-17.0]	13.0 [9.0-16.0]	9 [5.0-12.0]	9.0 [6.0-13.0]	16 [10.0-23.0]
South West	9.0 [8.0-11.0]	9.0 [8.0-10.0]	11 [10.0-12.0]	11 [10.0-13.0]	12.0 [10.0-13.0]	10.0 [7.0-12.0]	9.0 [7.0-10.0]	9.0 [8.0-11.0]	14.0 [12.0-15.0]
Eastern Hill	5.0 [3.0-7.0]	7.0 [3.0-11.0]	9.0 [4.0-15.0]	7.0 [5.0-10.0]	12.0 [9.0-15.0]	13.0 [9.0-17.0]	7.0 [4.0-10.0]	10.0 [5.0-14.0]	20.0 [10.0-31.0]
Countrywide	**9.0 [1.0-17.0]**	**9.0 [1.0-17.0]**	**8.0 [2.0-15.0]**	**8.0 [2.0-13.0]**	**9.0 [1.0-17.0]**	**11.0 [5.0-17.0]**	**8.0 [3.0-13.0]**	**9.0 [2.0-16.0]**	**19.0 [6.0-31.0]**

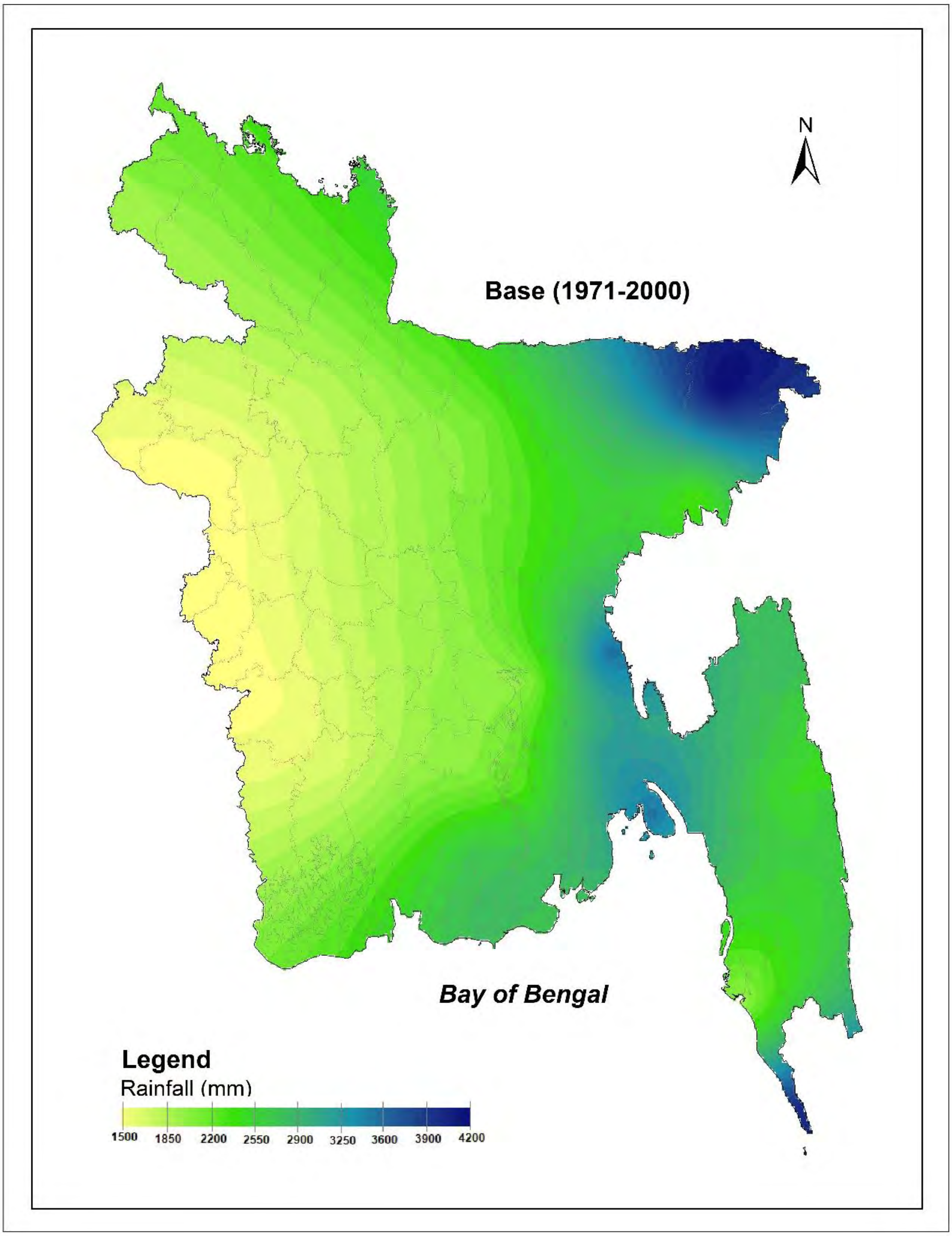


Figure 6.33: Spatial distribution of annual average rainfall over Bangladesh for base period (1971-2000)

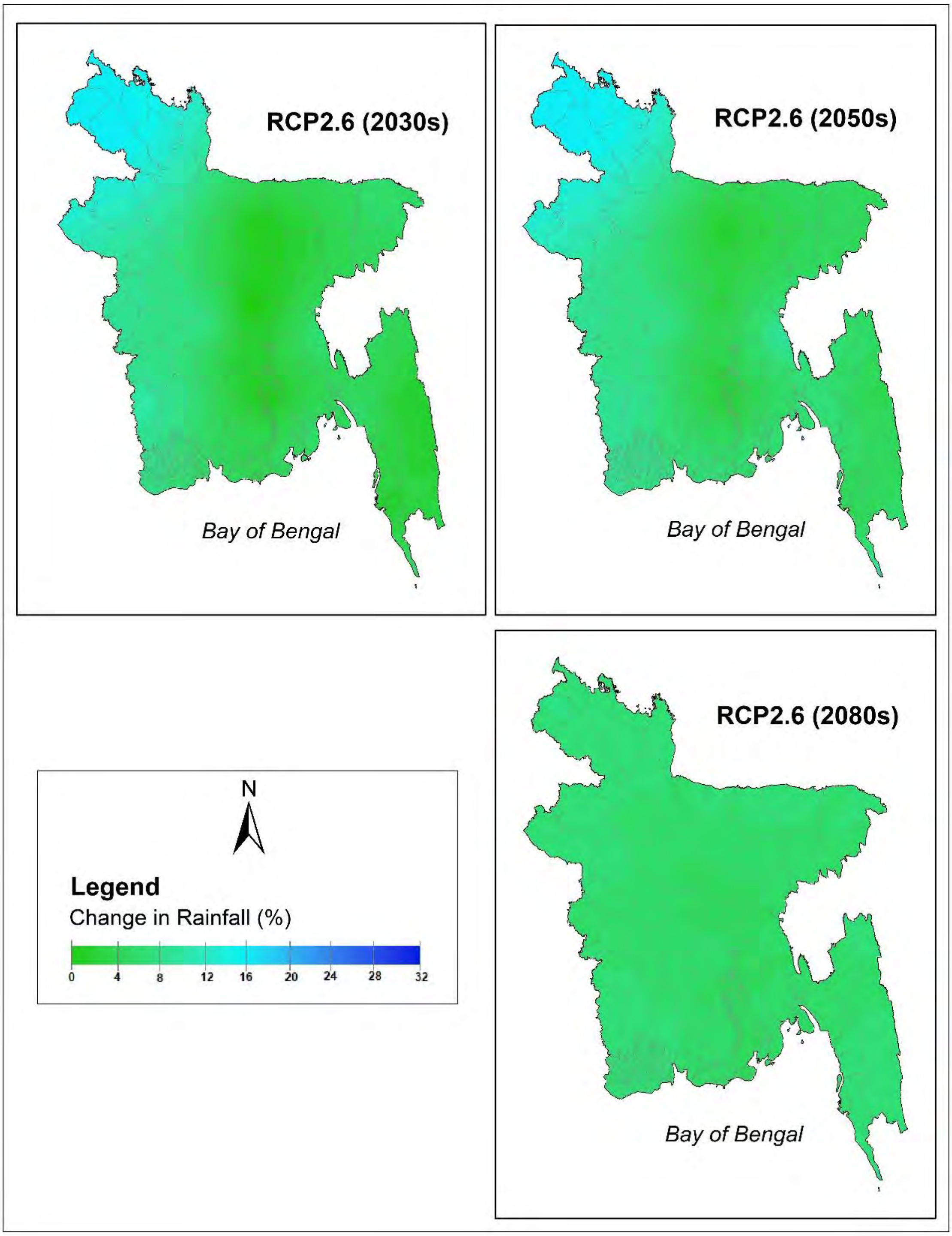


Figure 6.34: Spatial distribution of annual average rainfall anomalies over Bangladesh for RCP2.6

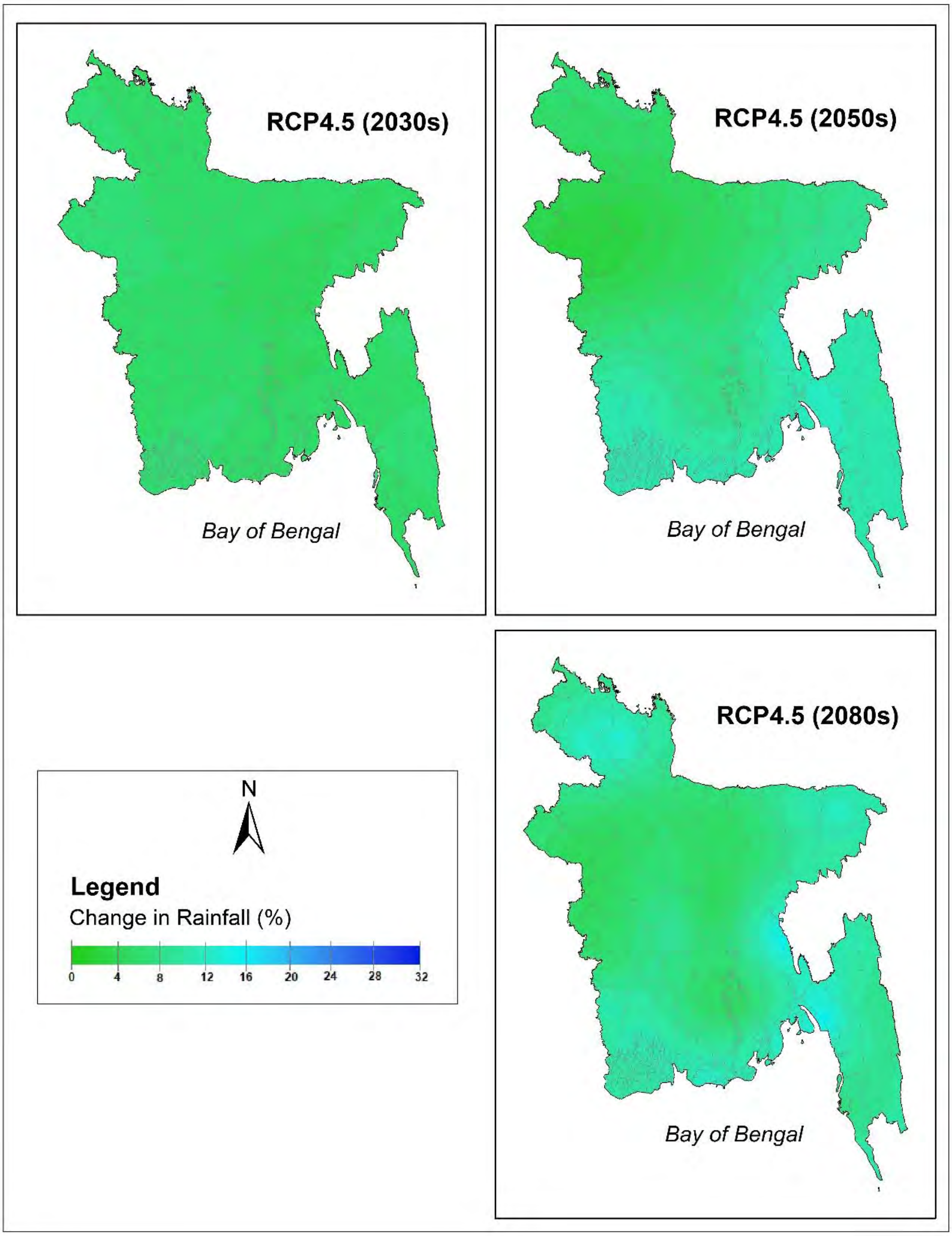


Figure 6.35: Spatial distribution of annual average rainfall anomalies over Bangladesh for RCP4.5

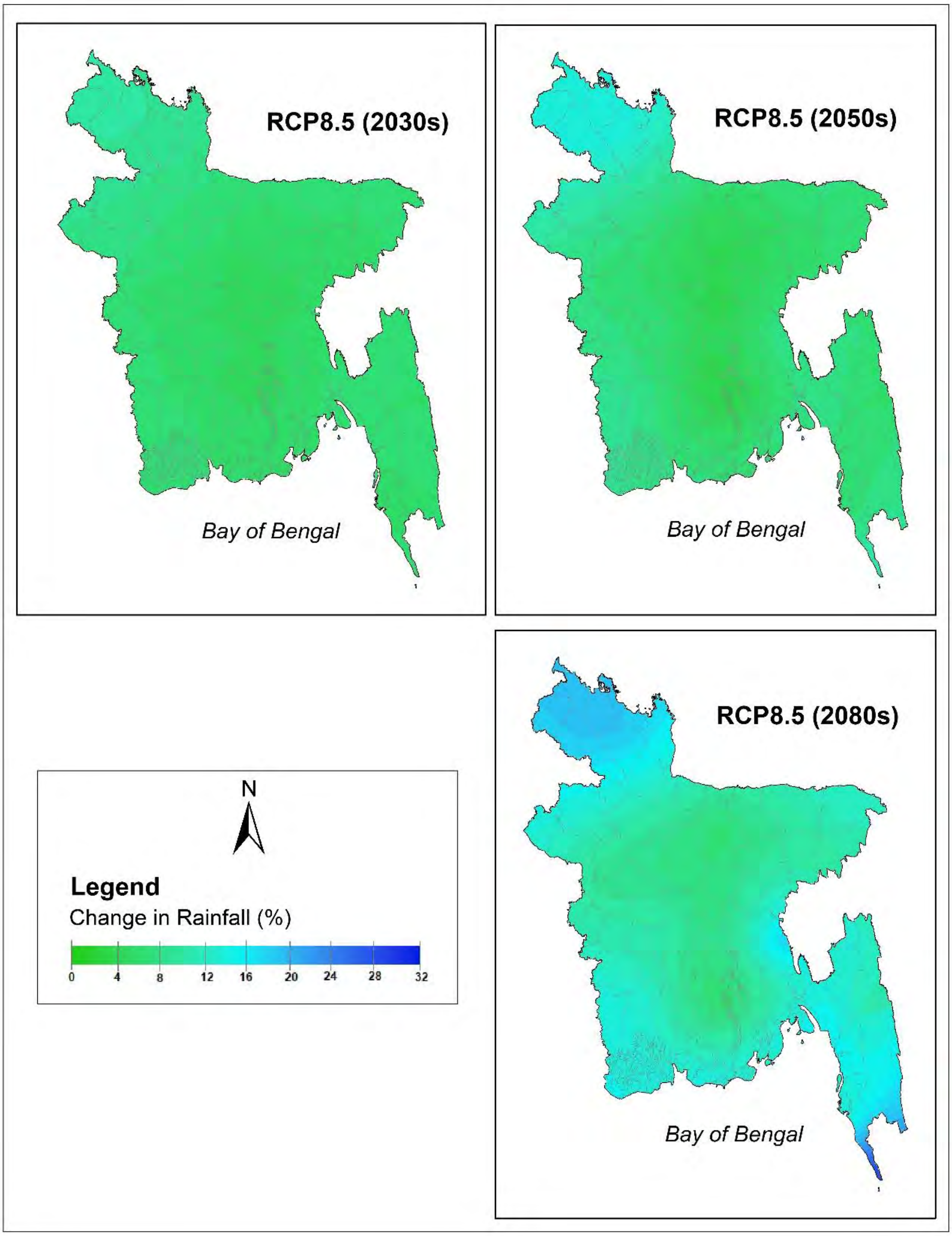


Figure 6.36: Spatial distribution of annual average rainfall anomalies over Bangladesh for RCP8.5

6.3.4 Solar radiation

6.3.4.1 Seasonal

Seasonal average solar radiation anomaly analysis illustrates that countrywide mean average solar radiation will be decreased on an average 0.3% to 0.8% in DJF season considering all time slices and RCPs. Countrywide mean average solar radiation will be increased on an average 0.2% to 0.9% in MAM season and 0.2% to 0.5% in ON season. In JJAS season, countrywide mean average solar radiation will be decreased in RCP2.6 scenario, but will be increased in other two scenarios up to 0.8%. Region wise analysis of average solar radiation is discarded due to insufficiently sparse available data. However, cloud cover and differential heating are the main reasons of variation of solar radiation. Formation of more cloud cover reduces the radiation and vice versa, means solar radiation should be higher in dry or winter than monsoon. But, it is difficult to set physical linkage on inter-seasonal variations of cloud cover and solar radiation as formation of clouds or occurrence of rainfall are very uncertain and conditional of other large scale atmospheric variables.

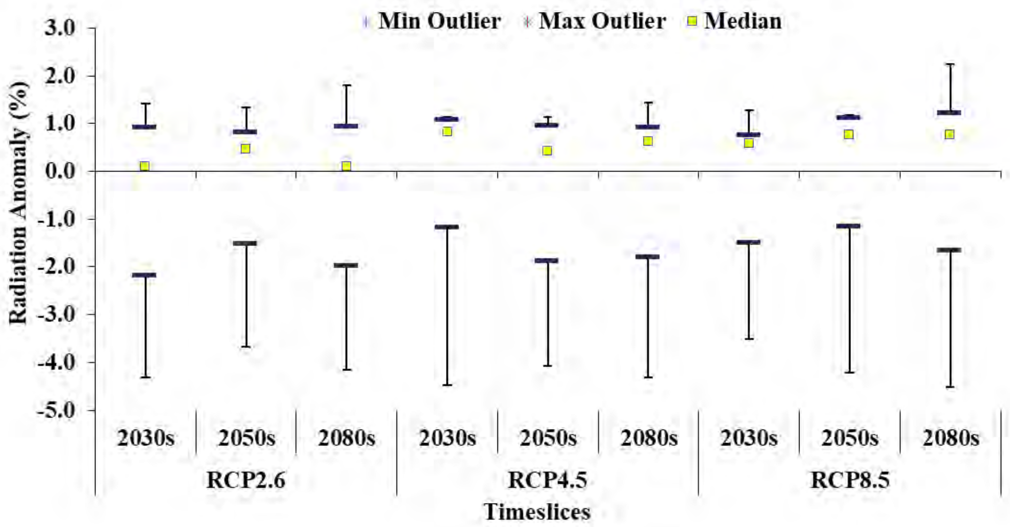


Figure 6.37: Anomalies of average solar radiation for December-January-February (DJF) over Bangladesh

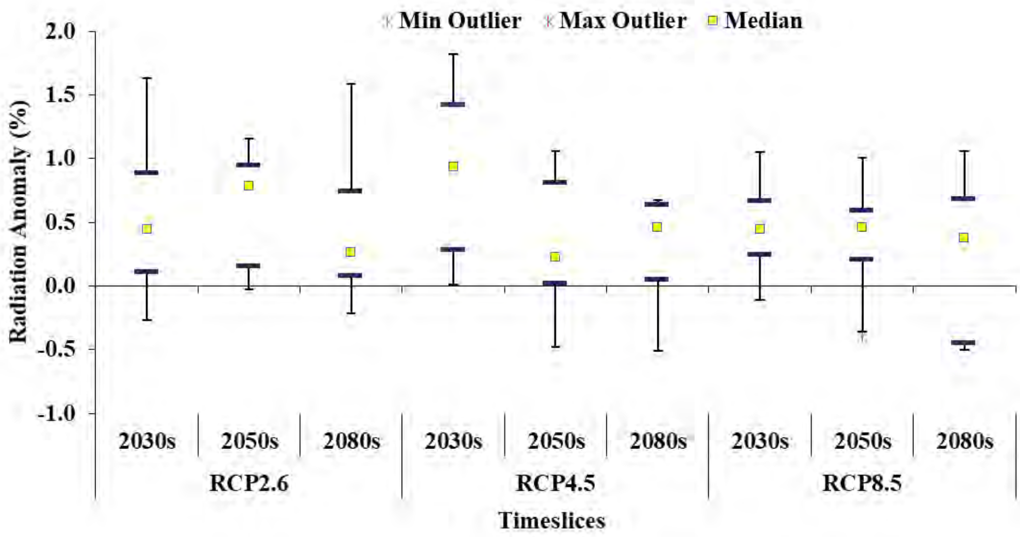


Figure 6.38: Anomalies of average solar radiation for March-April-May (MAM) over Bangladesh

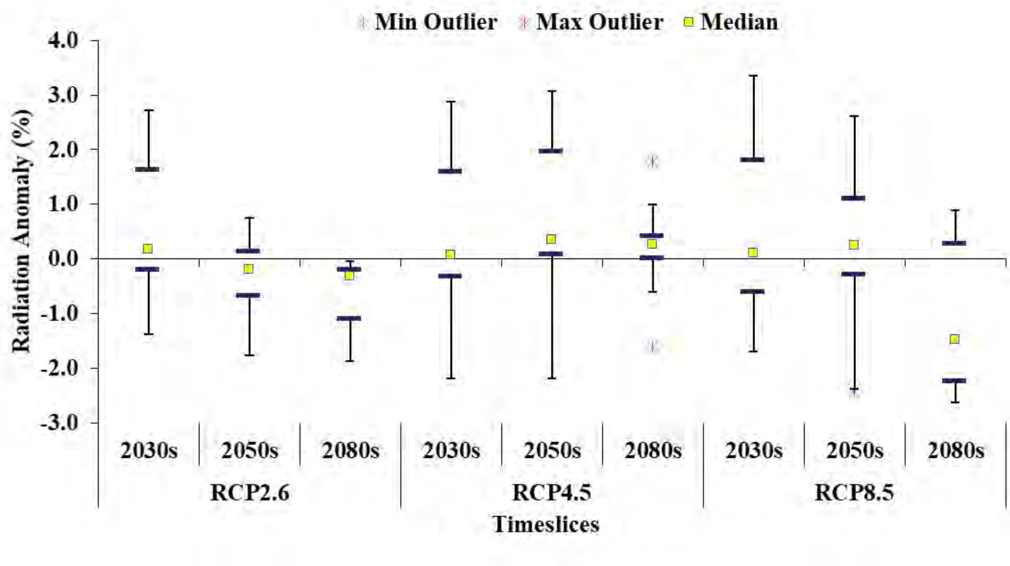


Figure 6.39: Anomalies of average solar radiation for June-July-August-September (JJAS) over Bangladesh

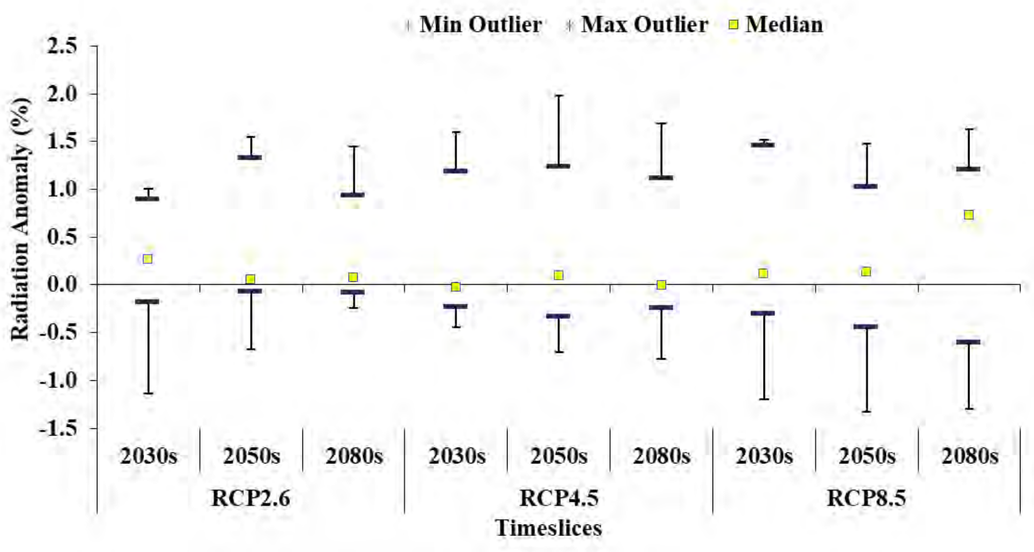


Figure 6.40: Anomalies of average solar radiation for October-November (ON) over Bangladesh

6.3.4.2 Annual

Annual average solar radiation anomalies shown in Table 6.7 depicts that mean annual average solar radiation will be decreased for all of the time slices and RCPs except 2030s in RCP4.5 and RCP8.5. Although, change of mean annual average radiation is very less in between -0.1% to -0.4%, which may be due to scarcity of observed data in considered period. Figure 6.42 to Figure 6.44 show spatial distribution of annual average solar radiation anomaly, which illustrates that annual average solar radiation is increasing up to 1.5% in north central portion which further aggravates to northern portion of north-west region. On the other hand, annual average solar radiation is decreasing in south central portion up to 2.0% in 2080s under RCP8.5. As annual average rainfall will be increased in future all over the country means cloud formation will be increased, which may be the cause of slight decrease of solar radiation. However, increasing pollution can also trigger decreasing of solar radiation, which is not considered in the model.

Table 6.7: Annual Average Solar Radiation Anomalies over Bangladesh

Time slices	Change in Radiation, % (Mean [Min-Max])		
	RCP2.6	RCP4.5	RCP8.5
2030s	-0.1 [-1.5 ~ 1.3]	0.1 [-1.3 ~ 1.5]	0.1 [-1.3 ~ 1.5]
2050s	-0.3 [-1.3 ~ 0.7]	-0.1 [-1.7 ~ 1.5]	-0.2 [-1.6 ~ 1.2]
2080s	-0.6 [-1.6 ~ 0.4]	-0.3 [-1.6 ~0.9]	-0.4 [-2.0 ~ 1.2]

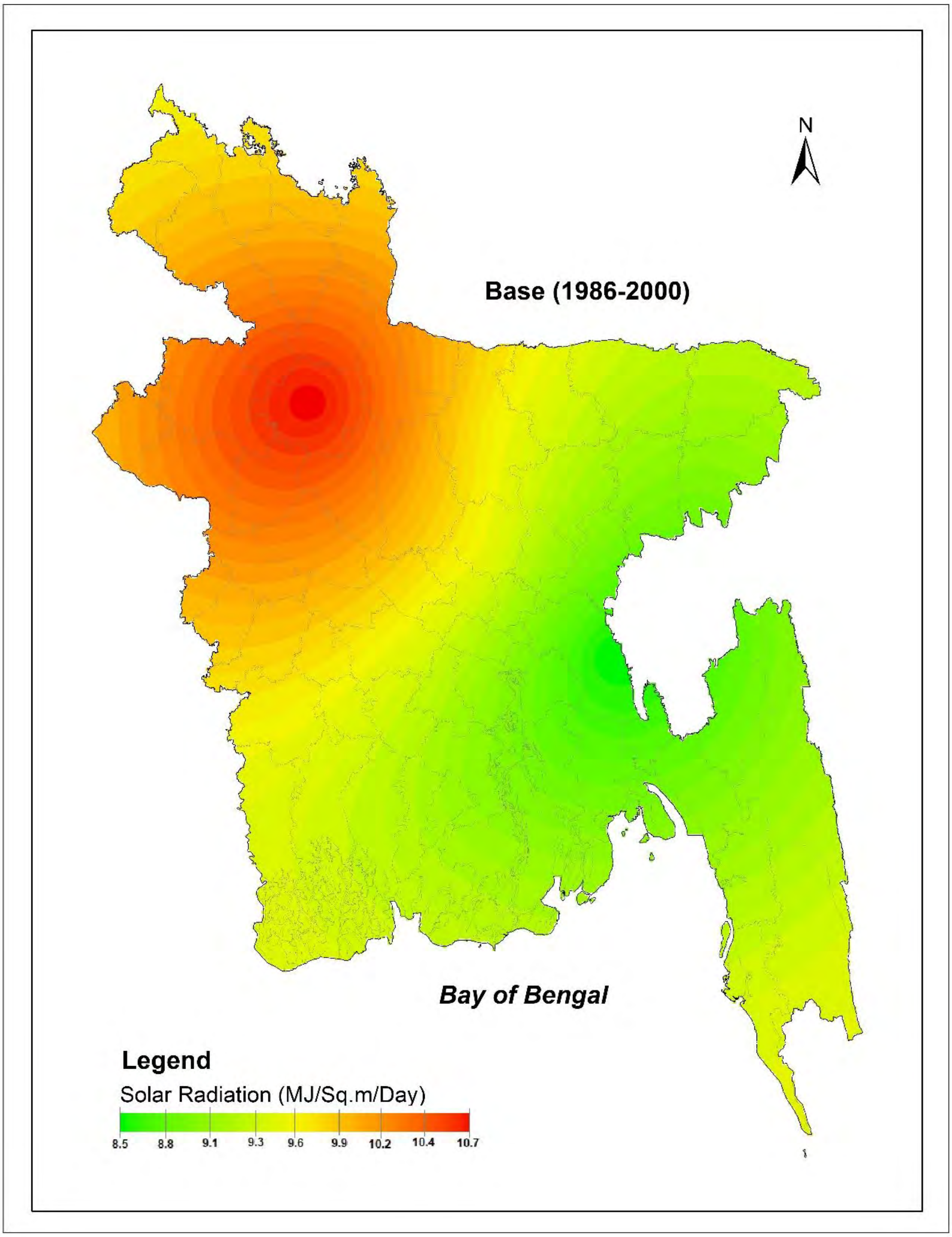


Figure 6.41: Spatial distribution of annual average solar radiation over Bangladesh for base period (1986-2000)

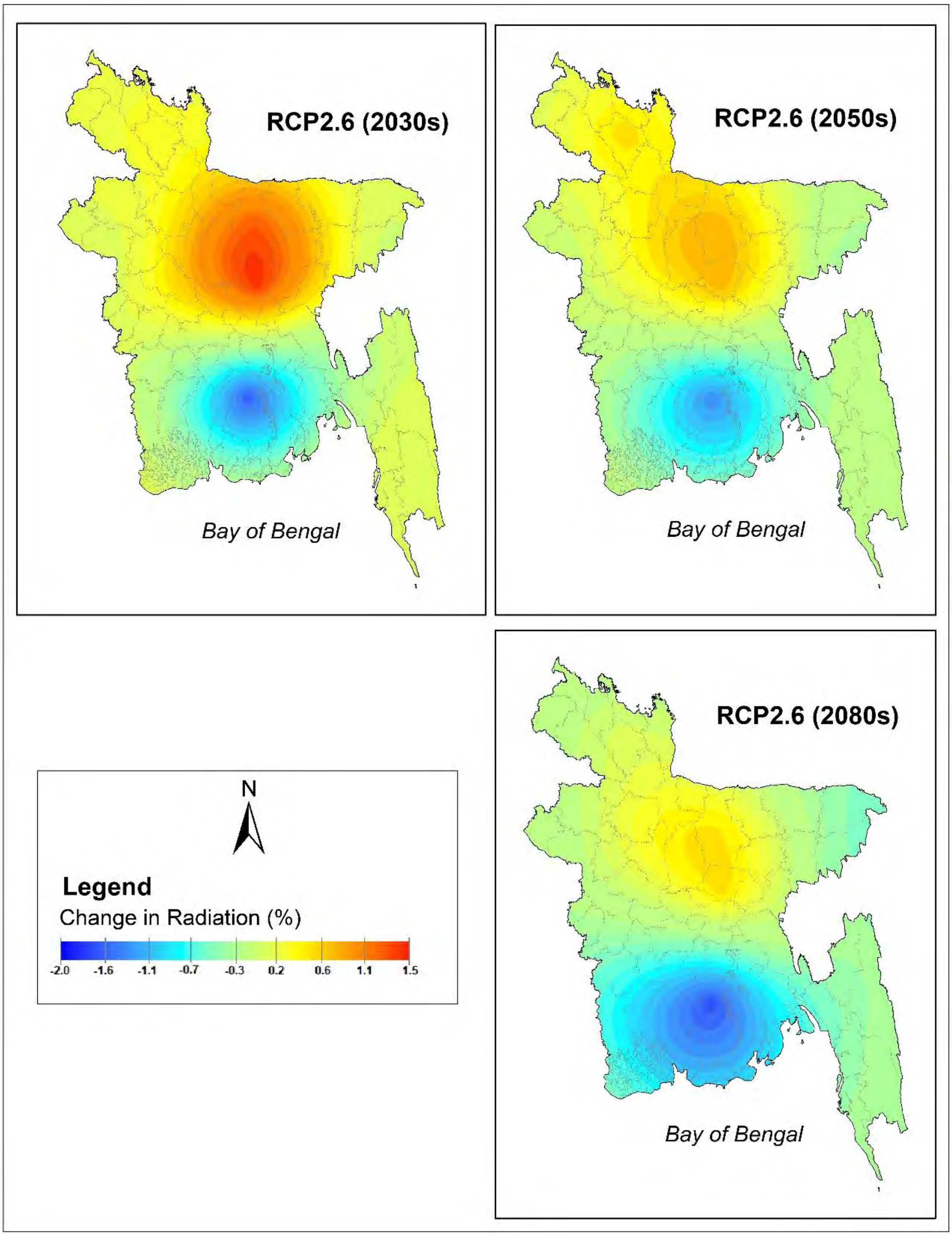


Figure 6.42: Spatial distribution of annual average solar radiation anomalies over Bangladesh for RCP2.6

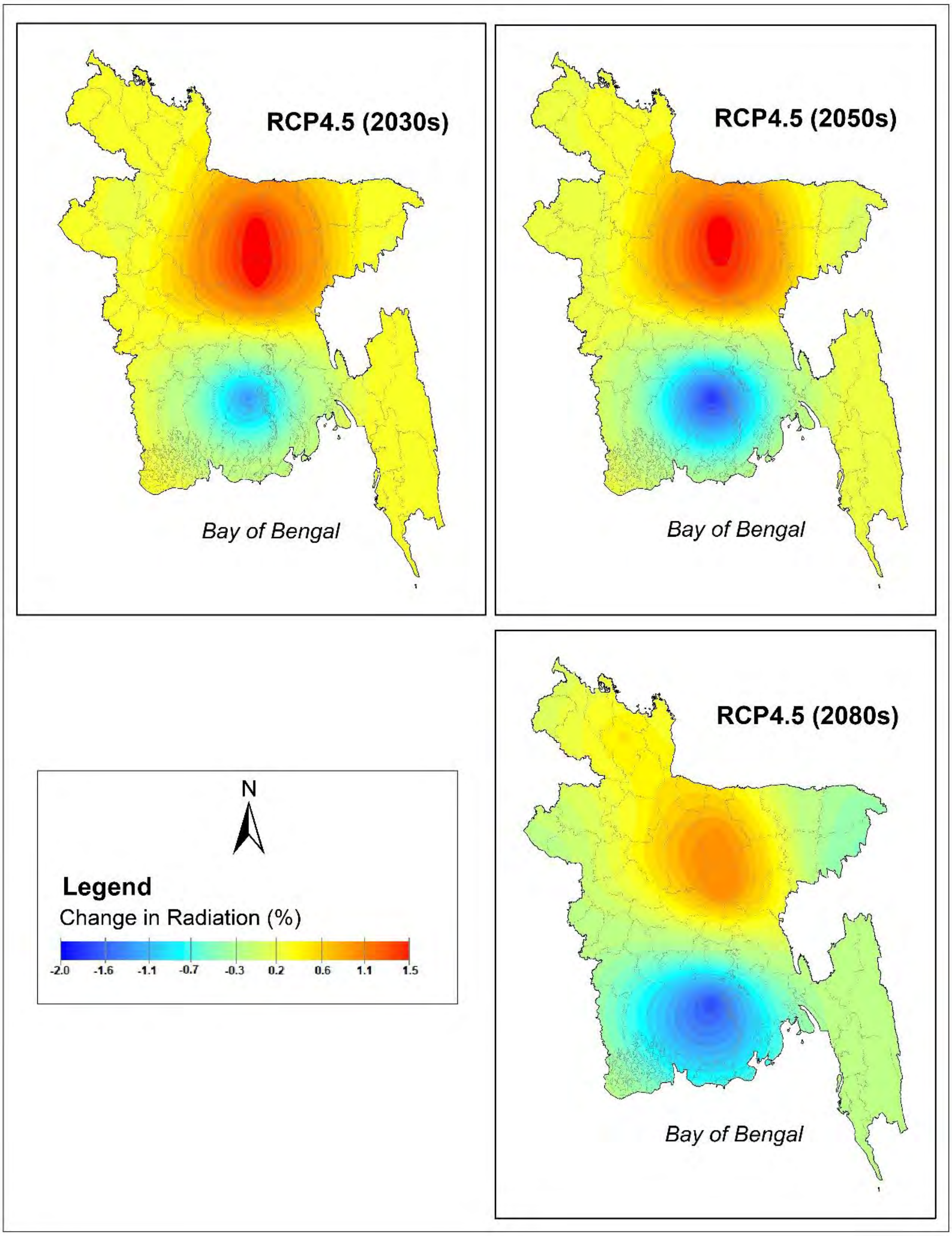


Figure 6.43: Spatial distribution of annual average solar radiation anomalies over Bangladesh for RCP4.5

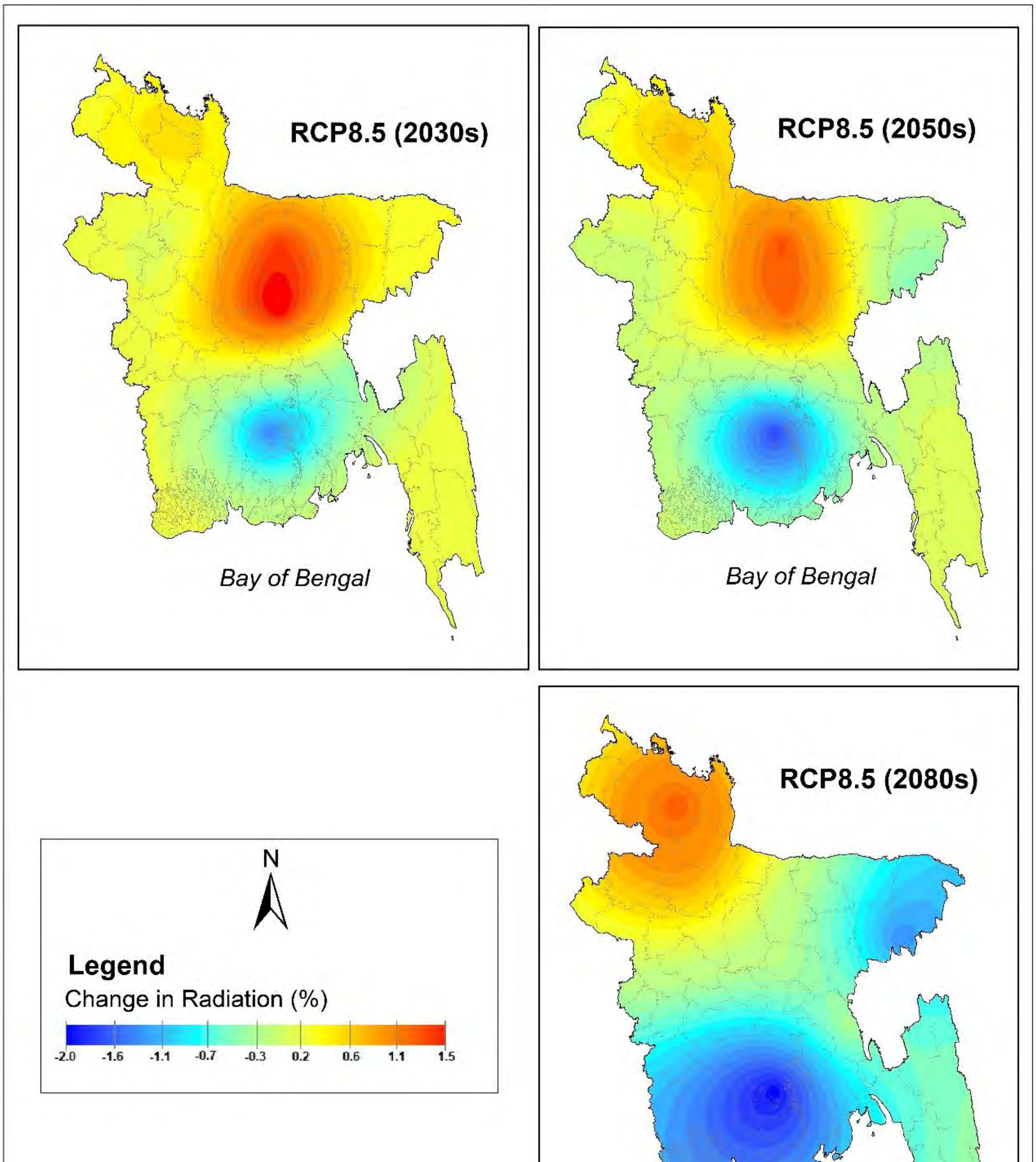


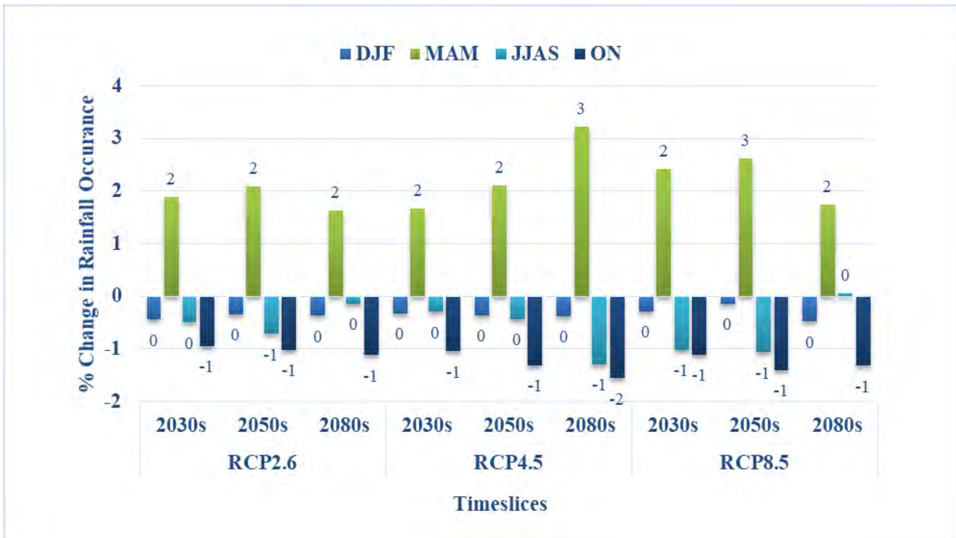
Figure 6.44: Spatial distribution of annual average solar radiation anomalies over Bangladesh for RCP8.5

6.4 Shifting of Season

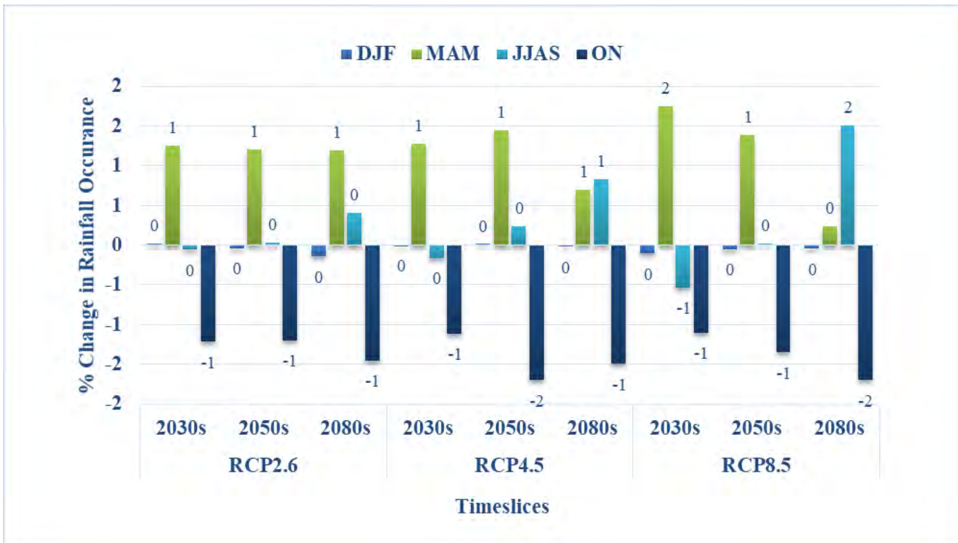
Shifting of season has been identified analyzing seasonal rainfall pattern over different regions of Bangladesh. In most of the regions, rainfall pattern will change in similar fashion for three time slices under all of the three RCPs. Rainfall occurrence will increase in pre-monsoon season i.e. March-April-May (MAM) in most of the regions decreasing rainfall occurrence in monsoon i.e. June-July-August-September (JJAS) and post-monsoon i.e. October-November (ON) except north west and south west region. Rainfall occurrence in winter i.e. December-January-February (DJF) will remain more or less unchanged in future periods except south-west region.

Specially, pre-monsoon rainfall occurrence will be increased around 1%-3% in north-central region and around 5%-6% increase in north-eastern region than base period, which clearly depicts that haor area of Bangladesh will be more prone to early rainfall as well as early flash floods in future periods. Inversely, same amount of rainfall occurrence will be decreased dominantly in post-monsoon (ON) season in the north-central region. In north-eastern region, 2%-5% monsoon (JJAS) rainfall occurrence and 1%-2% post-monsoon (ON) rainfall occurrence will be decreased in the north-eastern region.

Figure 6.45 and Figure 6.46 show change in rainfall distribution in north-central and north-eastern regions respectively for three time slices (2030s, 2050s and 2080s) under three RCPs i.e. RCP2.6, RCP4.5 and RCP8.5.

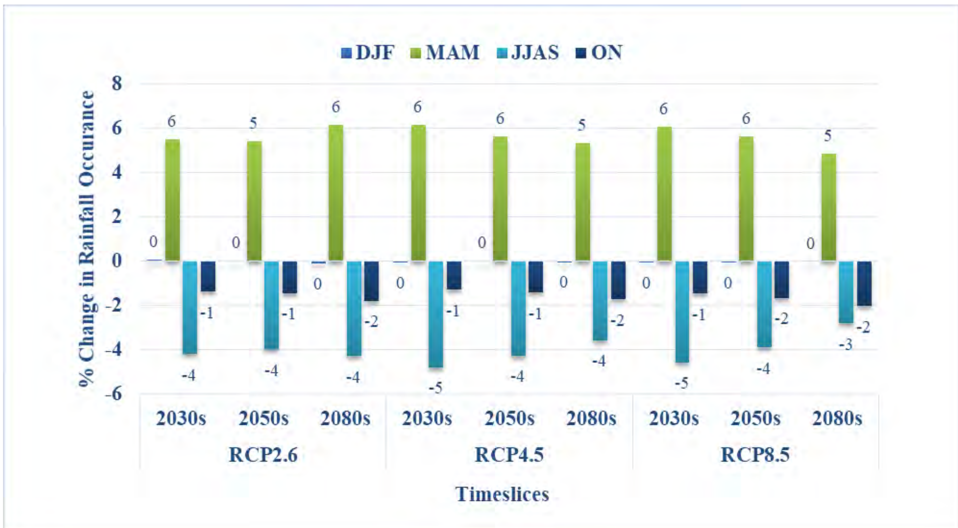


Dhaka

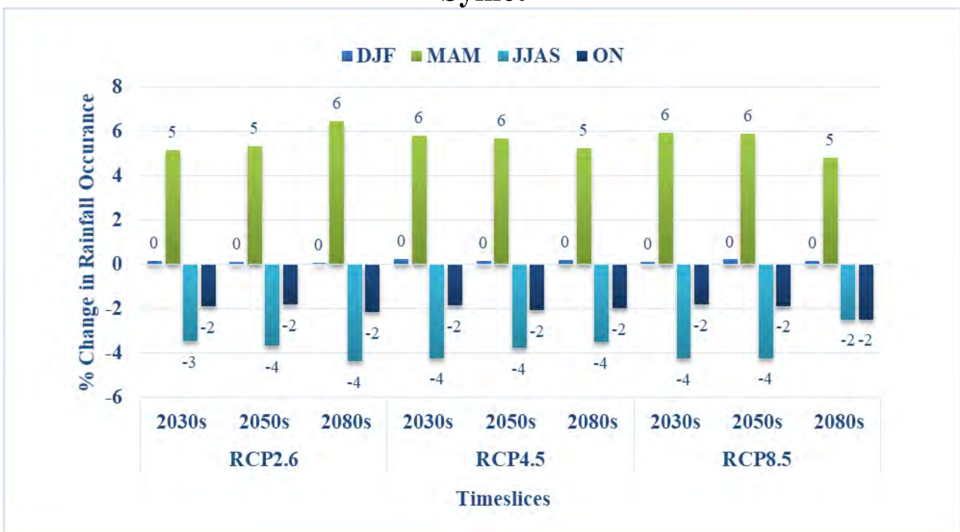


Mymensingh

Figure 6.45: Change of future occurrence of rainfall in north-central region



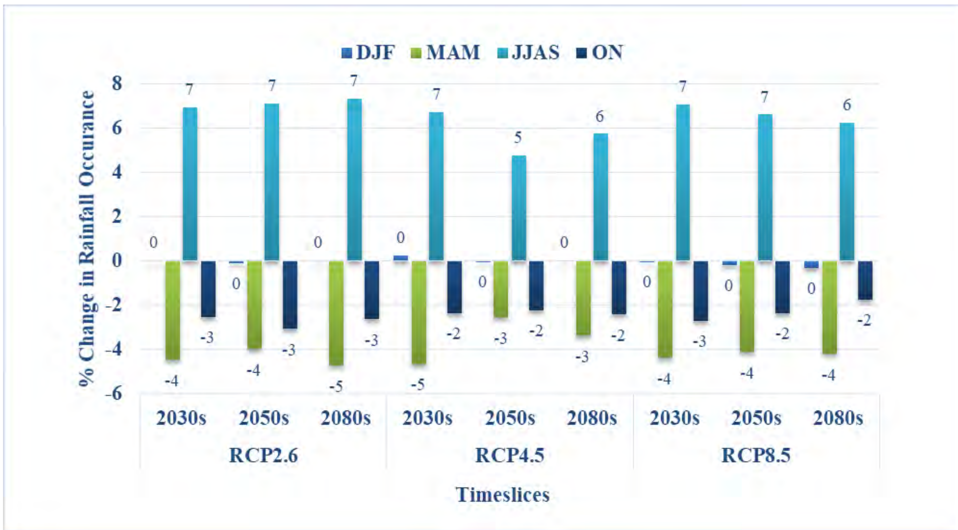
Sylhet



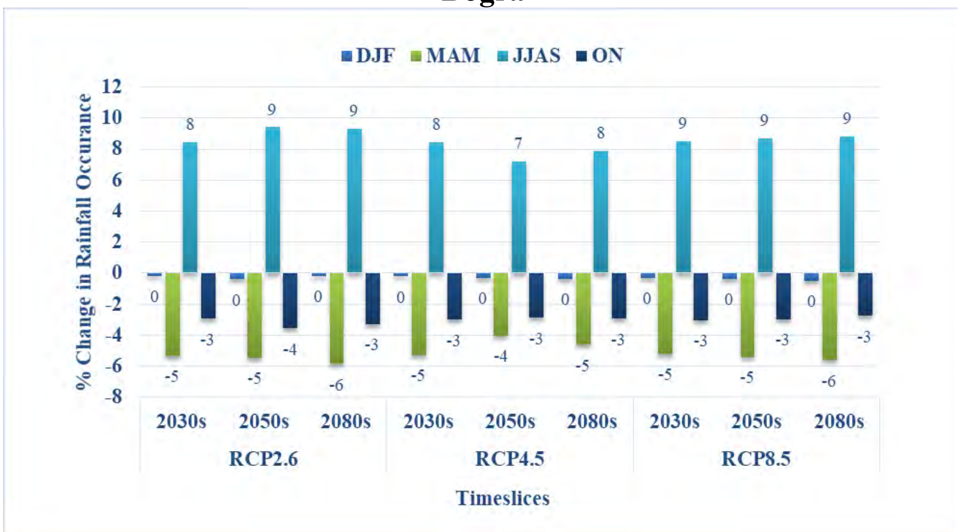
Sreemangal

Figure 6.46: Change of future occurrence of rainfall in north-east region

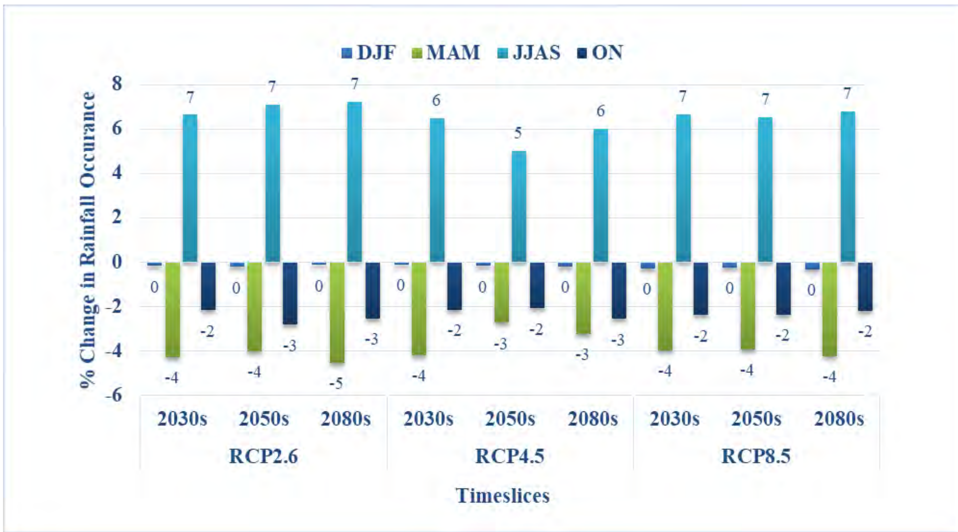
In north-west region occurrence of rainfall will be different from other regions. Wet season will be wetter and dry season will be dryer in this region. Monsoon (JJAS) rainfall occurrence will be increased 2%-9%, whereas pre-monsoon (MAM) rainfall occurrence will be decreased 1%-6% and post-monsoon (ON) rainfall occurrence will be decreased 1%-4% than base period. Decrease of rainfall occurrence will be higher in pre-monsoon than post-monsoon season and winter (DJF) rainfall occurrence will be remained unchanged as other regions. Figure 6.47 shows change of future rainfall occurrence in north-west region for different scenarios.



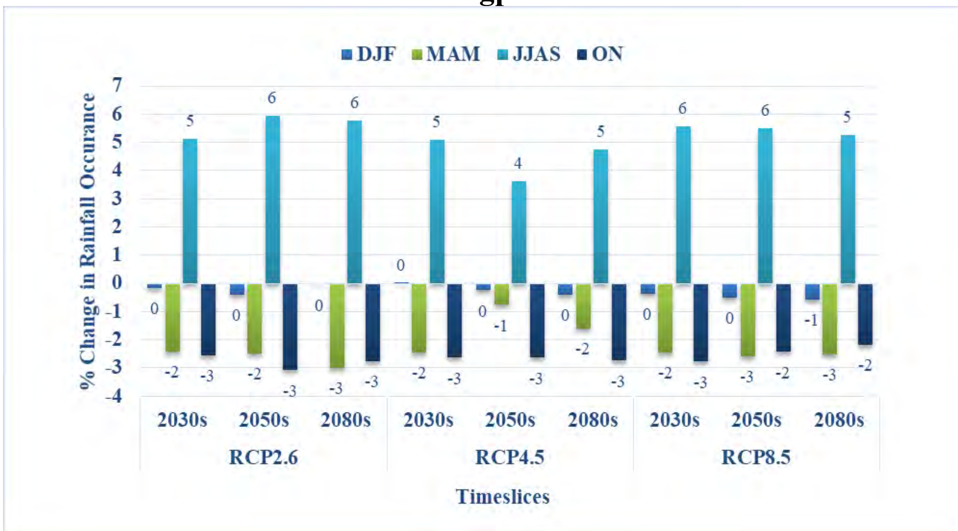
Bogra



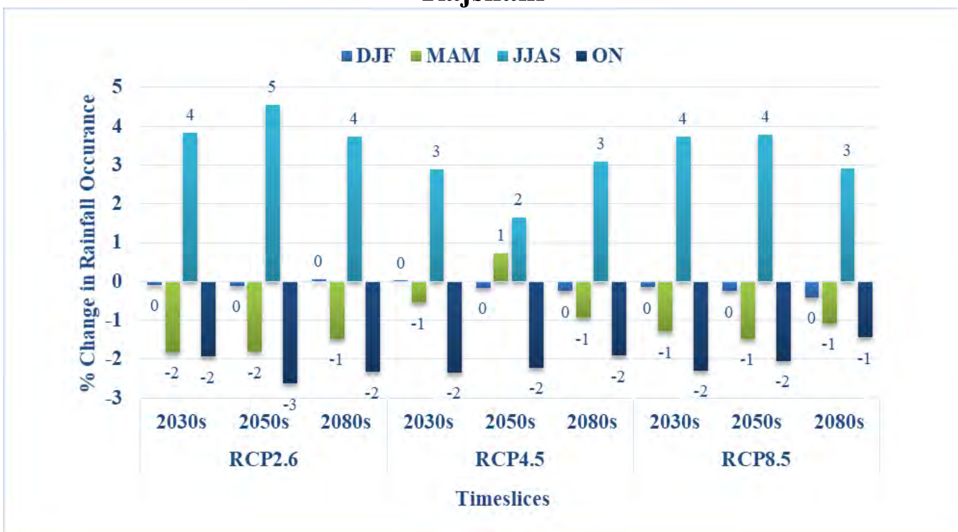
Dinajpur



Rangpur



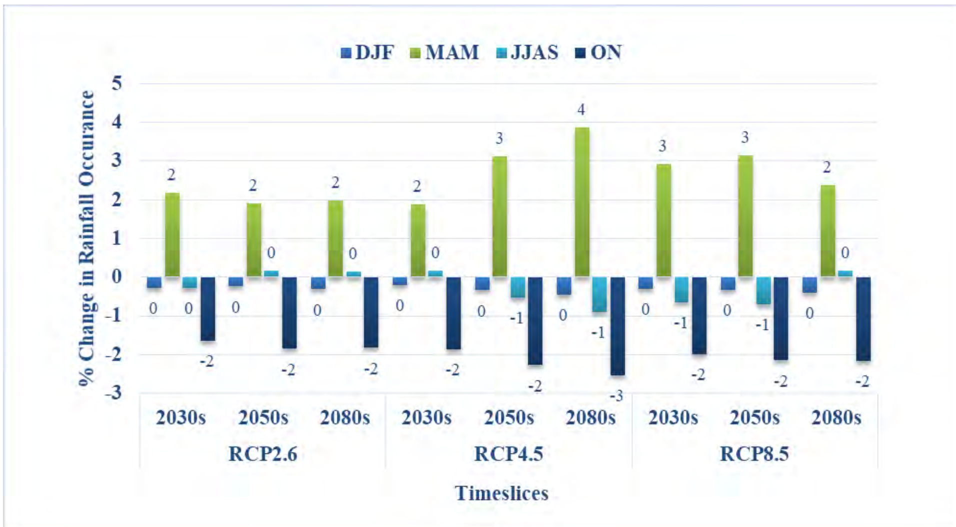
Rajshahi



Ishawrdi

Figure 6.47: Change of future occurrence of rainfall in north-west region

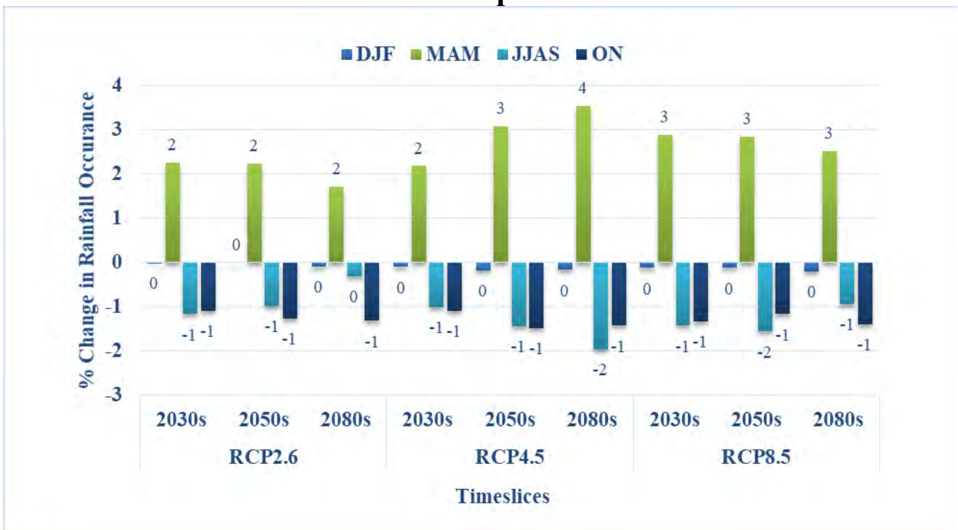
Pre-monsoon (MAM) rainfall occurrence will be increased 2%-5% and 1%-5% in south-central and south-eastern regions respectively except Faridpur where, monsoon (JJAS) rainfall occurrence will be increased 4%-5% as like other areas of north-west region. Therefore, these two regions will also face early rainfall occurrence than base period (1971-2000) as like as north-central and north-eastern regions. Less rainfall will be occurred in monsoon (JJAS) and post-monsoon seasons in both of the regions. Exceptionally, Faridpur will face less pre-monsoon rainfall occurrence than base period. This may be due to the geographical position of Faridpur station which is nearby of Rajshahi and Ishawrdi stations of north-west region. Figure 6.48 and Figure 6.49 show change in occurrence of rainfall for south central and south eastern regions.



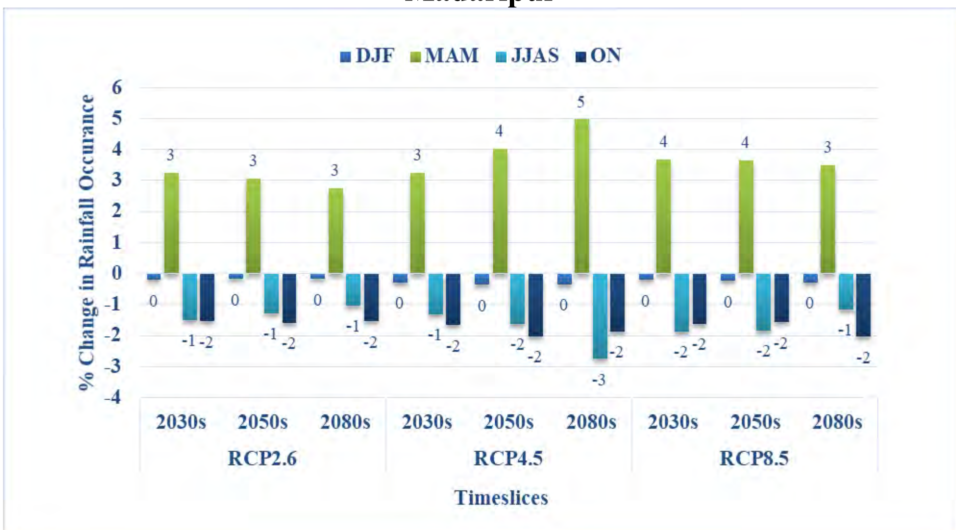
Barisal

Bhola

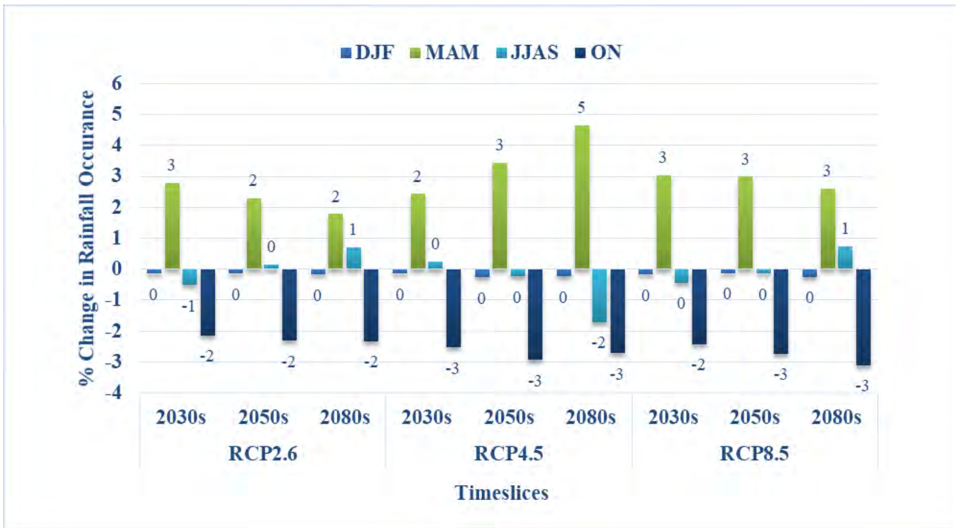
Faridpur



Madaripur

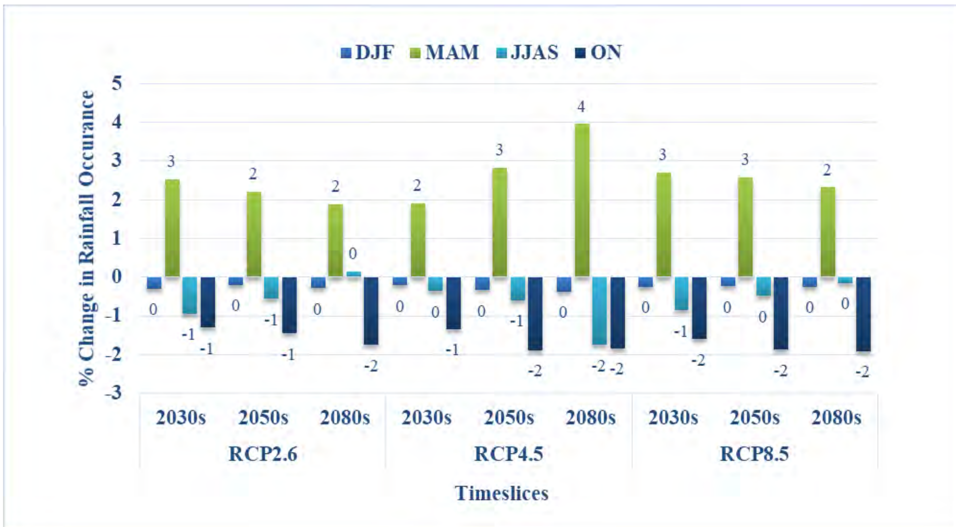


Patuakhali

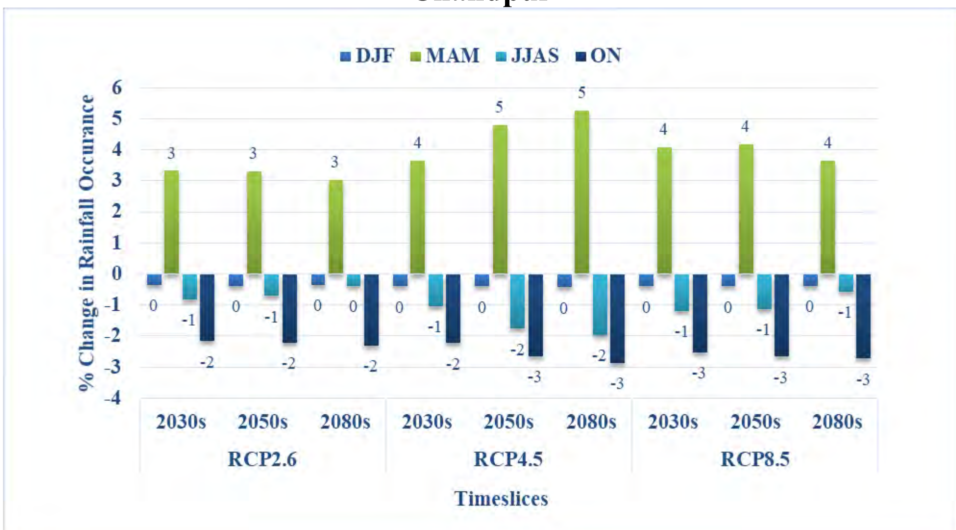


Khepupara

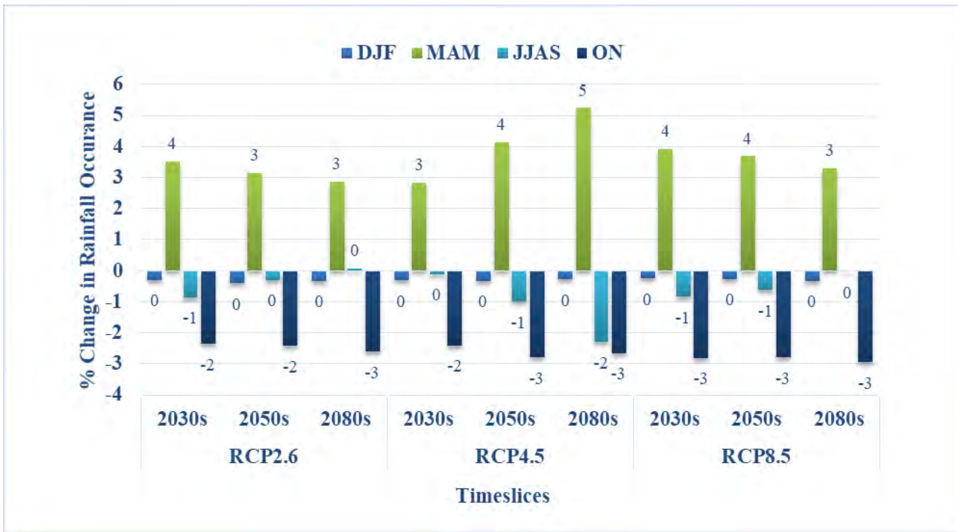
Figure 6.48: Change of future occurrence of rainfall in south-central region



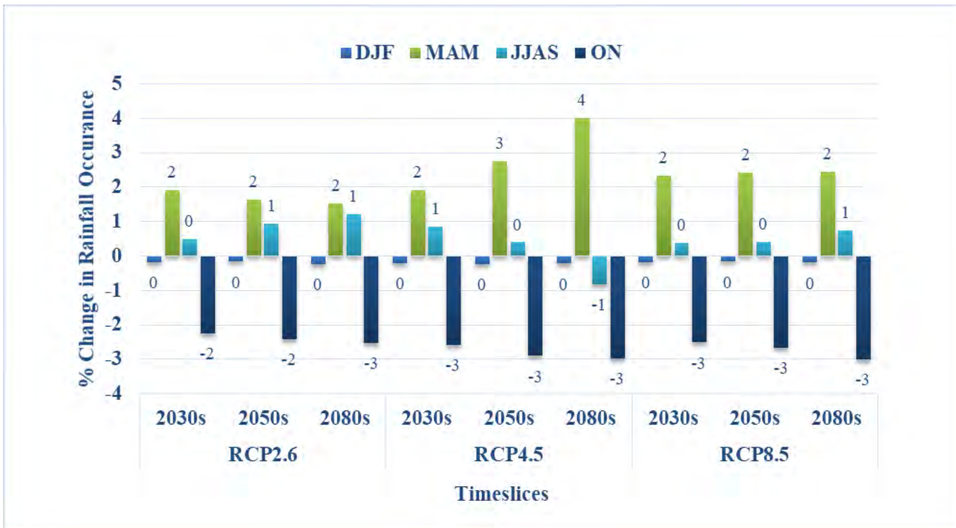
Chandpur



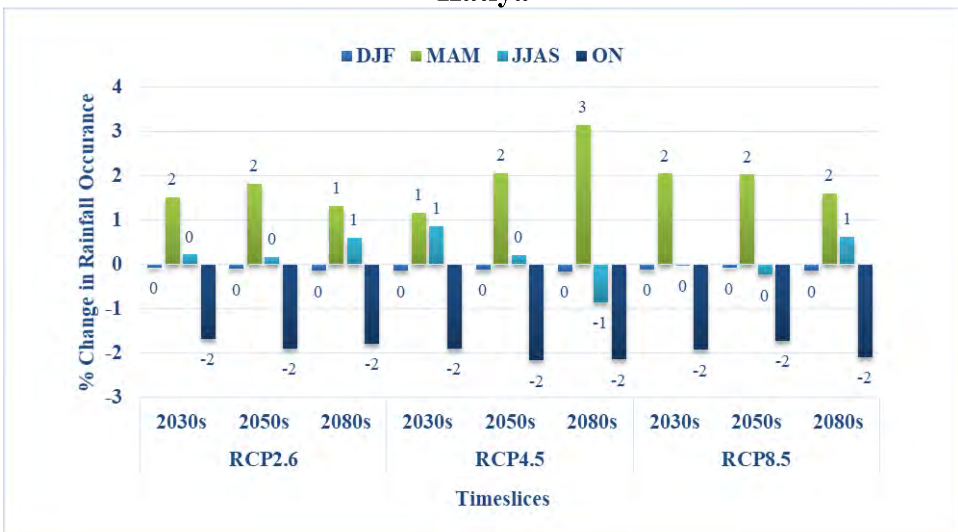
Comilla



Feni



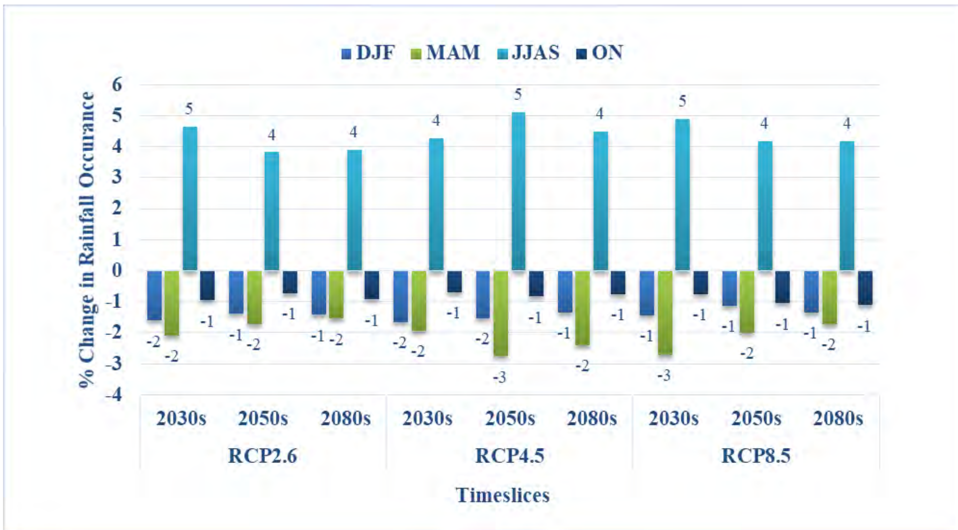
Hatiya



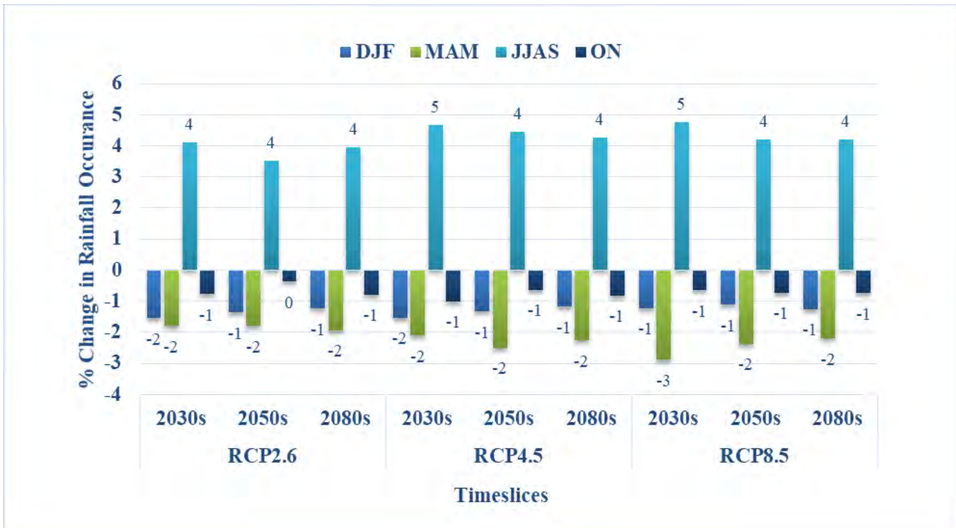
Maijdeecourt

Figure 6.49: Change of future occurrence of rainfall in south-east region

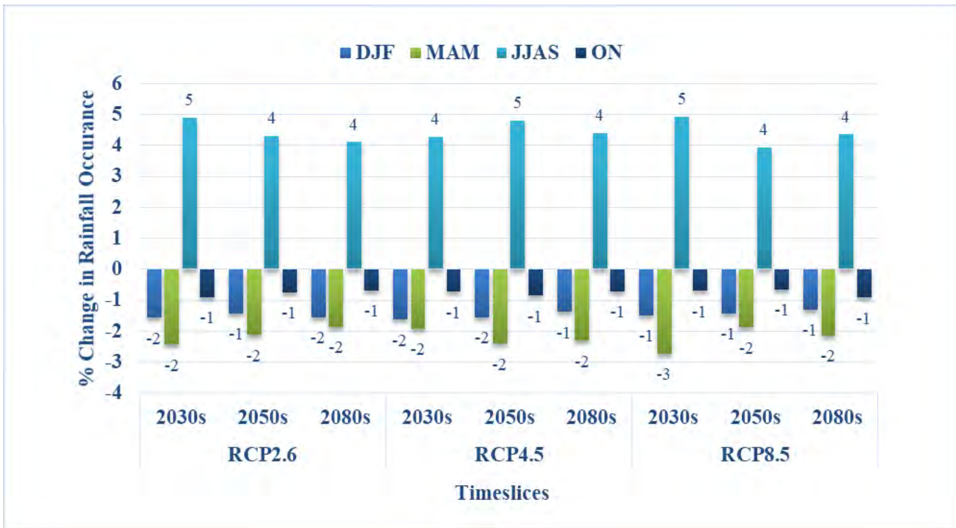
In south-west region, monsoon (JJAS) rainfall occurrence will be increased 4%-5% as like north-west region, whereas occurrence in pre-monsoon (MAM), post-monsoon (ON) and winter (DJF) rainfall will be decreased in this region. Pre-monsoon, post-monsoon and winter rainfall occurrence will be decreased 2%-3%, 1% and 1%-2% respectively. On the other hand, 1%-7% pre-monsoon rainfall occurrence will be increased in eastern hill region. Monsoon rainfall occurrence will be increased in 1%-4% Chittagong and Cox's Bazar and 1%-4% will be decreased in Sandwip, Sitakunda, Rangamati and Teknaf stations. Post-monsoon rainfall occurrence will be decreased 2%-4% in all over areas of eastern hill region. Figure 6.50 and Figure 6.51 show change in future occurrence of rainfall in south-west and eastern hill region respectively.



Jessore

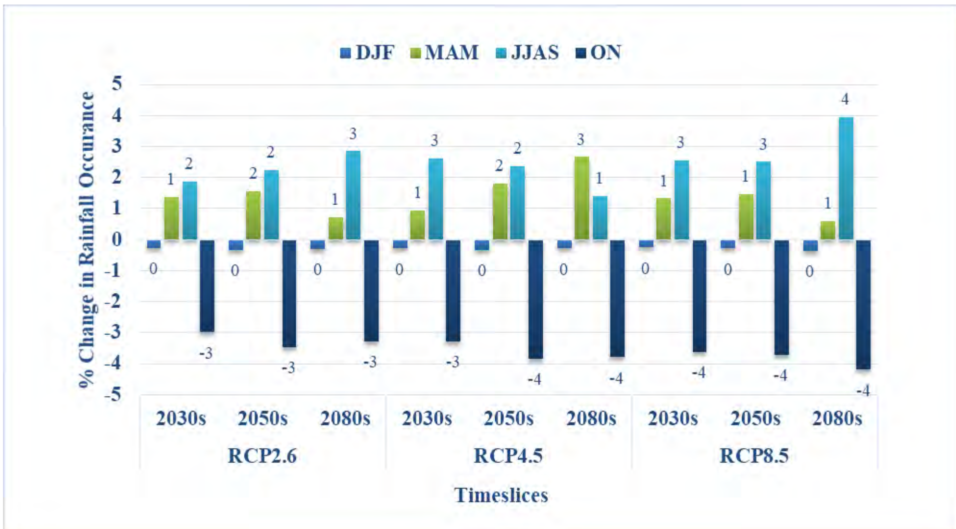


Khulna



Satkhira

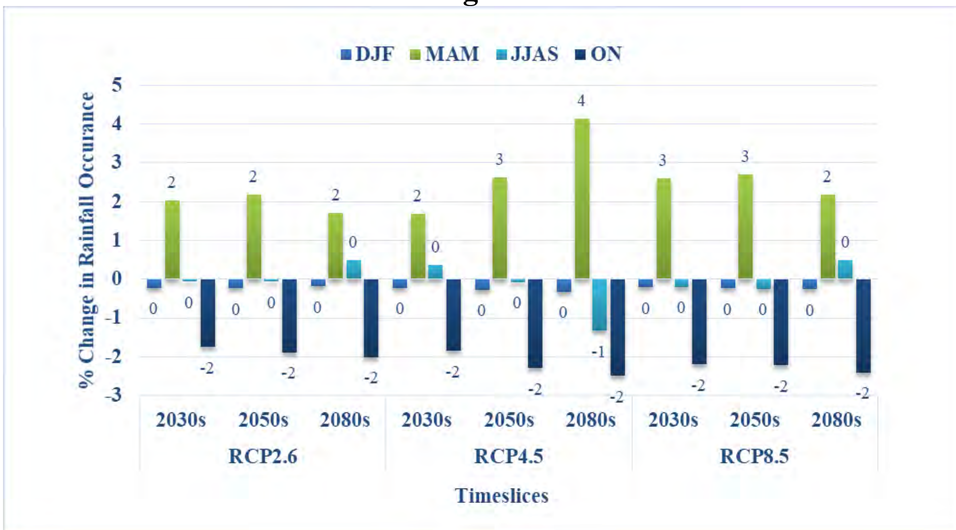
Figure 6.50: Change of future occurrence of rainfall in south-west region



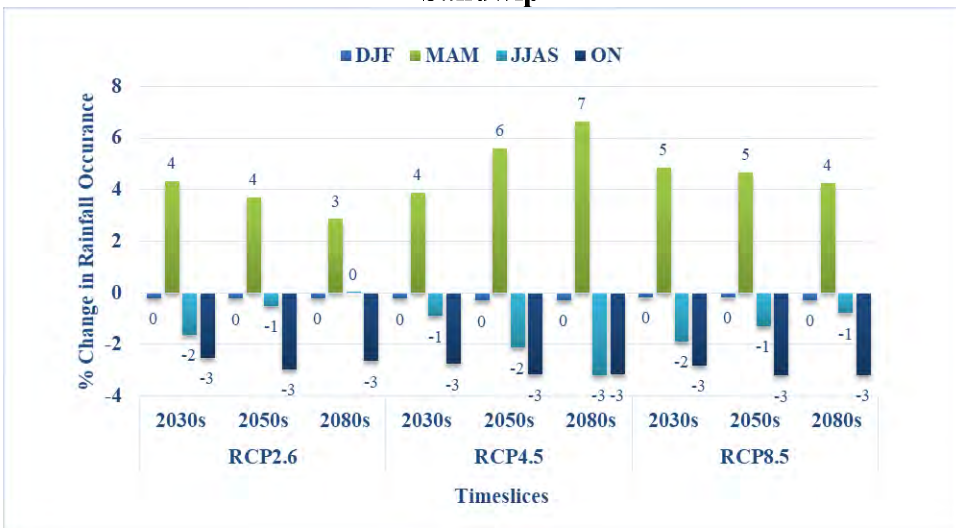
Cox's Bazar

Chittagong

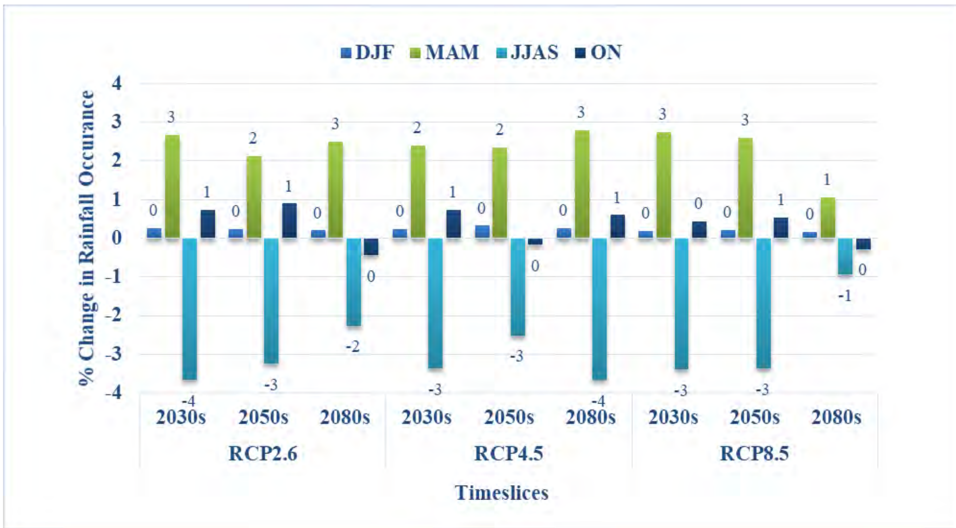
Rangamati



Sandwip



Sitakunda



Teknaf

Figure 6.51: Change of future occurrence of rainfall in eastern hill region

In a nutshell, pattern of rainfall occurrence is erratic all over Bangladesh. Eastern portion of Bangladesh will face more rainfall occurrence than base period in pre-monsoon decreasing monsoon rainfall occurrence, whereas western Bangladesh will face more rainfall occurrence in monsoon season decreasing pre-monsoon and post-monsoon rainfall occurrence for all of the future climate scenarios i.e. RCP2.6, RCP4.5 and RCP8.5. Shifting of season in terms of rainfall occurrence is evident except north-west and south-west regions of Bangladesh. Stephen et al. (2001) showed weakening of Indian monsoon circulation which may be the possible cause of reducing monsoon rainfall in eastern side of Bangladesh, whether increased monsoon rainfall in western part of Bangladesh represents the unusual pattern of rainfall or erratic rainfall due to changes in atmospheric circulation.

6.5 Drought Severity over Bangladesh

6.5.1 Historical Occurrence of Drought

Historically north-west region of Bangladesh mainly faced severe drought over the years being low rainfall area. In this region, severe droughts occurred in 1981, 1982, 1984, 1989, 1994, 1995, 2000, 2006, 2009 (Selvaraju et al., 2006, BBS, 2017 and Mardy et al., 2018) in the period of 1981-2010. Simulated Sc-PDSI value for the same historical period has successfully matched the severe drought (Sc-PDSI value greater than -2.0) in this region for 1982, 1994, 1995, 2000, 2006 and 2009 (Figure 6.52). This comparison has been made taking considerations of occurrence of severe drought for at least two stations among five stations of north-west region. This means simulated Sc-PDSI matches around

67% of historical observance, which is quite reasonable. However, presence of missing values in input data may be one of the causes of not matching for rest of the years. Figure 6.53 to Figure 6.57 show simulated Sc-PDSI for different stations of north-west region of Bangladesh for the period 1981-2010.

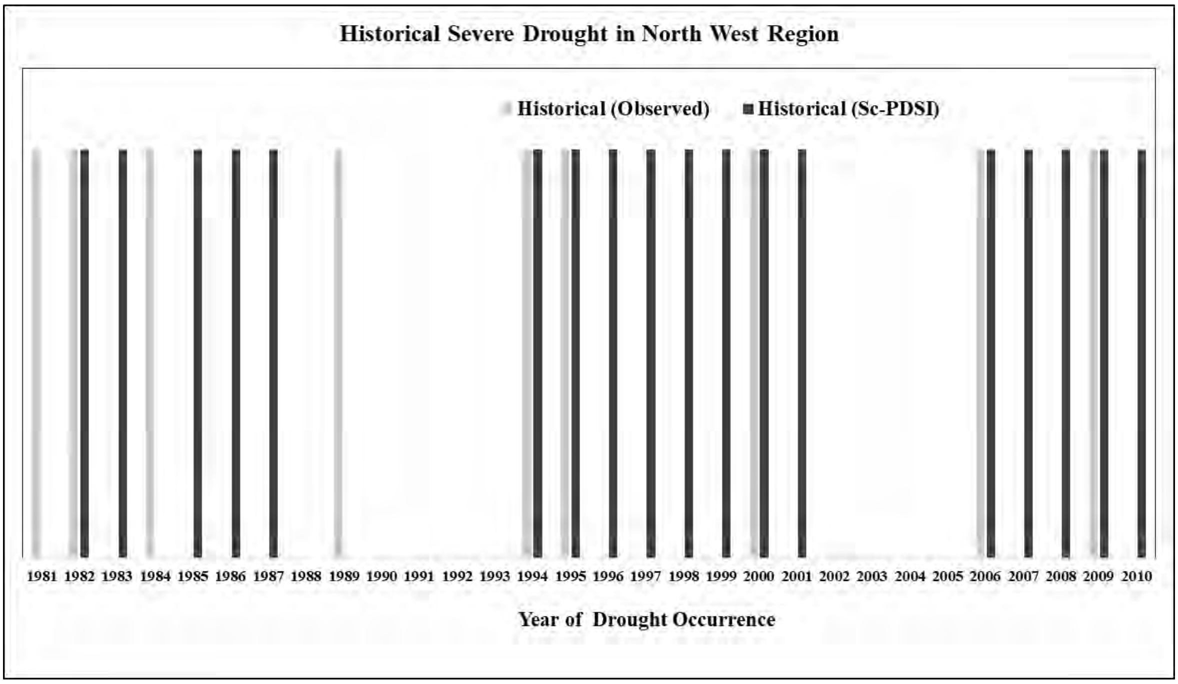


Figure 6.52: Comparison of historical severe drought occurrence with Sc-PDSI for 1981-2010

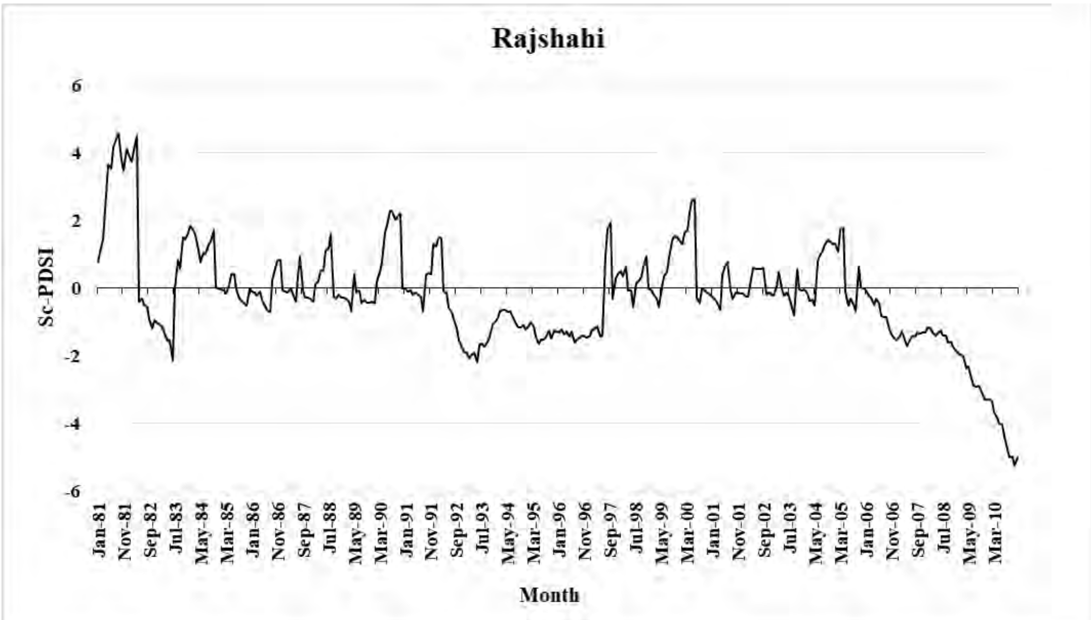


Figure 6.53: Simulated Sc-PDSI of Rajshahi for historical period (1981-2010)

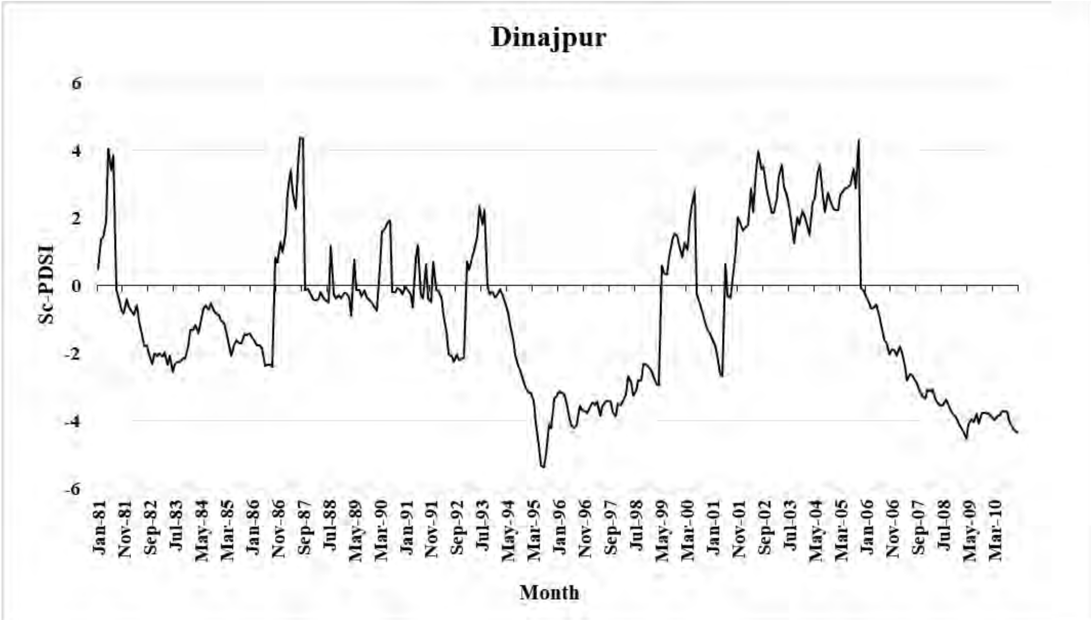


Figure 6.54: Simulated Sc-PDSI of Dinajpur for historical period (1981-2010)

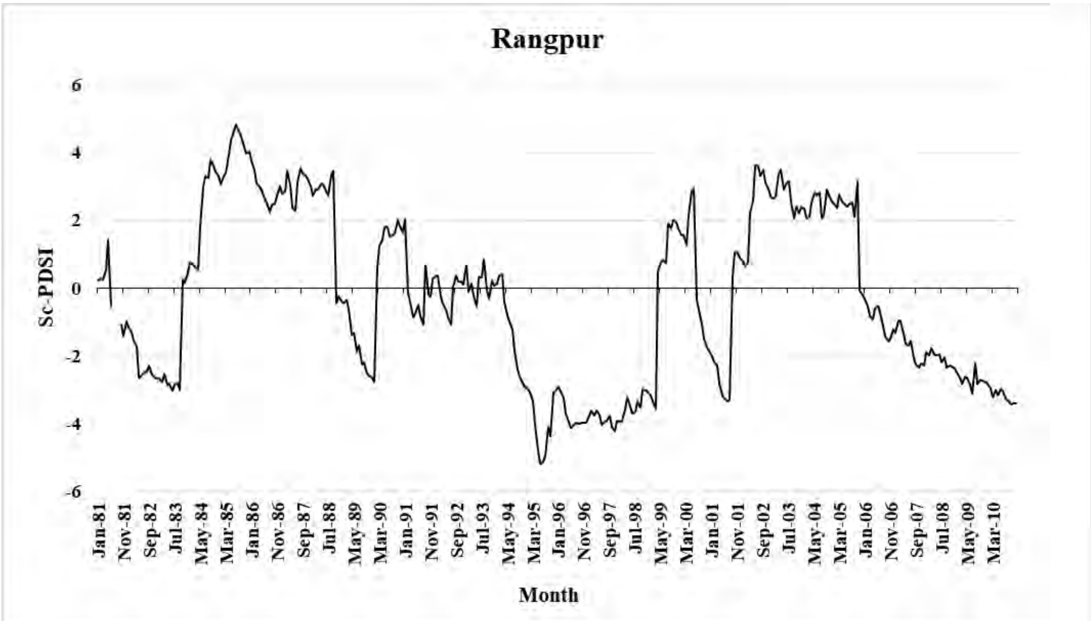


Figure 6.55: Simulated Sc-PDSI of Rangpur for historical period (1981-2010)

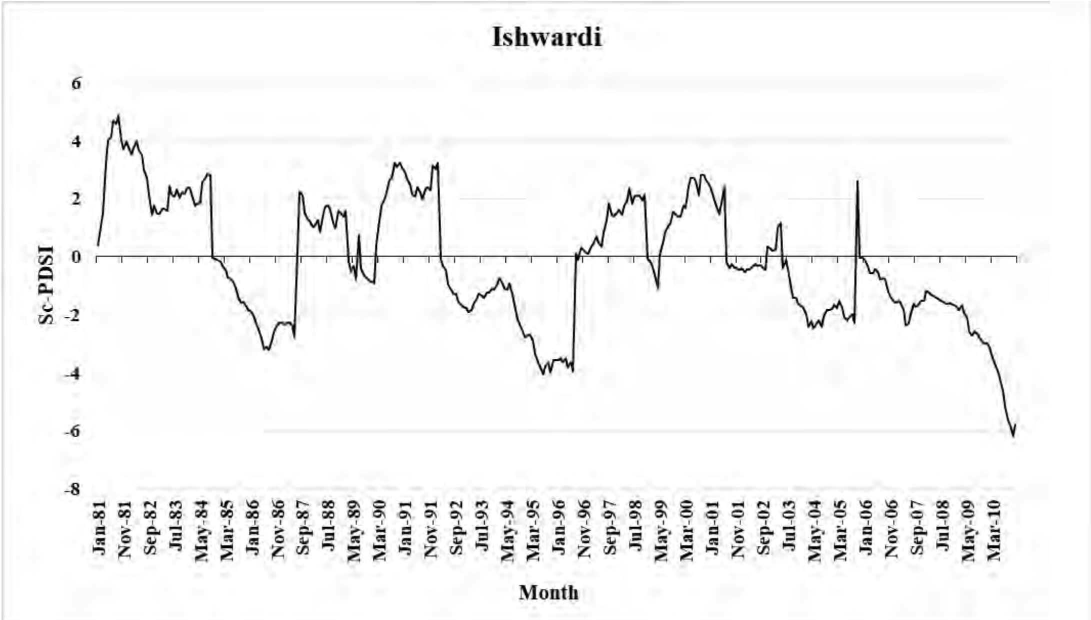


Figure 6.56: Simulated Sc-PDSI of Ishwardi for historical period (1981-2010)

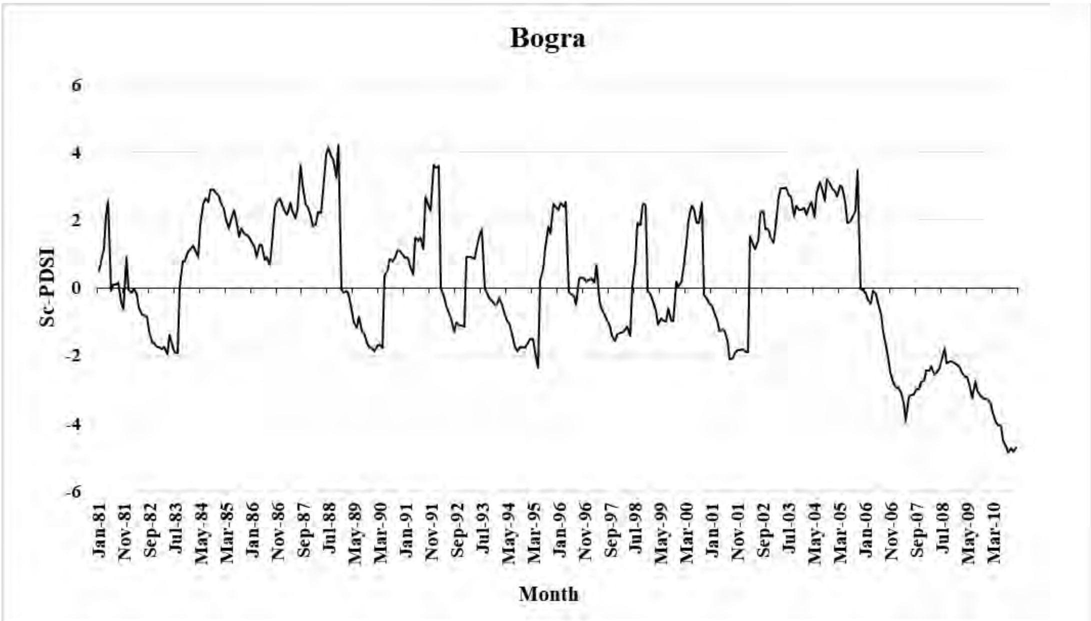


Figure 6.57: Simulated Sc-PDSI of Bogra for historical period (1981-2010)

6.5.2 Occurrence of Different Types of Drought

Analysis of occurrence of different types of long term drought (at least 6 month spell) with respect to total drought time through self-calibrating PDSI reveals that, in extreme climate change scenario i.e. RCP8.5, occurrence of severe and extreme meteorological drought will be increased almost all over Bangladesh in 2080s through decreasing occurrence of mild and moderate drought. Chance of decreasing of occurrence of mild drought is higher than moderate drought and chance of increasing occurrence of severe drought is higher than extreme drought in both RCP4.5 and RCP8.5 scenarios. In most of the regions, occurrence of mild drought will be increased in 2050s and later decreased in 2080s for both RCPs. Overall occurrence of severe and extreme drought will be decreased in 2050s, later will be increased again in 2080s with respect to total drought period.

Figure 6.58 shows distribution of future drought occurrence among total drought months with relative to base period (1981-2010) in north central region for RCP8.5. Distribution for RCP4.5 scenario is given in Figure F1 to Figure F2 of Appendix F and total drought month of each stations for base and future has been shown in Table F1 and Table F2 of same Appendix. In north-central region, occurrence of mild drought will be decreased 5%-11% and 11%-22% for 2050s and 2080s respectively. Occurrence of moderate drought will be increased 4%-19% in 2050s, whereas will be decreased up to 6% in 2080s for RCP8.5. Change of occurrence of severe drought will be -8% to 8% in 2050s and 10% to 12% in 2080s. In 2050s, occurrence of extreme drought will be decreased 1%-6% but will be increased in 2080s as 5%-9%.

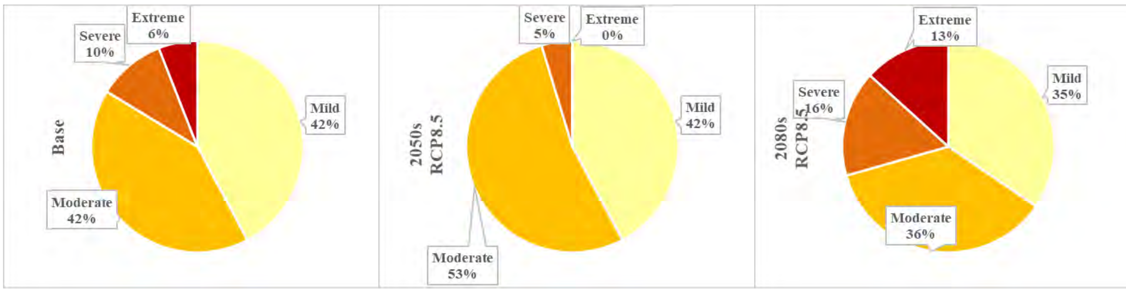
In north-eastern region, 2%-13% of occurrence of mild drought will be increased in 2050s but will be decreased up to 17% in 2080s. Occurrence of moderate drought will be decreased 2%-14% and 4%-6% in 2050s and 2080s respectively. But occurrence of severe and extreme drought will be increased up to 13% and 10% respectively considering both RCPs.

North-west region is the most drought prone in the country, which will remain drought prone in future. Occurrence of moderate, severe and extreme drought will be increased in future considering both RCP4.5 and RCP8.5 scenarios. Although occurrence of mild drought will be decreased up to 20% and 14% in 2050s and 2080s respectively, occurrence of moderate drought will be increased up to 14%, severe drought up to 7% and extreme drought up to 4%. Chance of increasing occurrence of severe drought is higher than extreme drought in this region. Table 6.8 shows change in future drought occurrence over different regions of Bangladesh considering both RCPs.

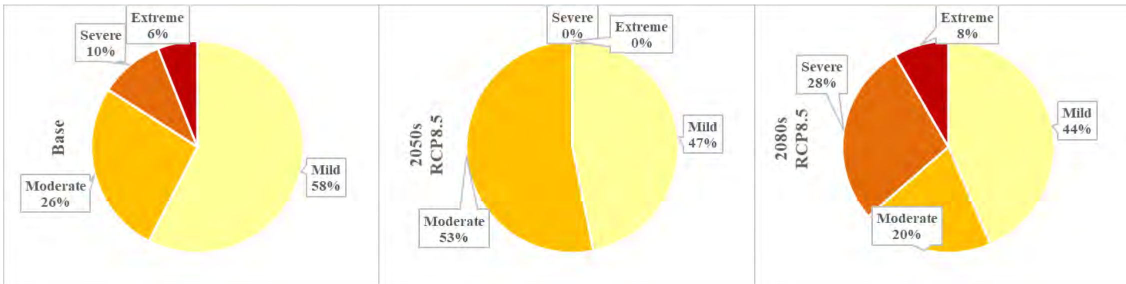
Table 6.8: Change in Future Drought Occurrence over Different Regions of Bangladesh Considering both RCPs (RCP4.5 and RCP8.5)

Hydrologic Region	% Change in Occurrence of Drought							
	2050s				2080s			
	Mild Drought	Moderate Drought	Severe Drought	Extreme Drought	Mild Drought	Moderate Drought	Severe Drought	Extreme Drought
NC	-5 to -11	**4 to 19**	-8 to 8	-1 to -6	-11 to -22	-6 to 2	**10 to12**	**5 to 9**
NE	**2 to 13**	-2 to -14	-1 to 1	-2 to 1	-17 to 1	-4 to -6	-2 to 13	**5 to 10**
NW	-20 to 12	**0 to 13**	**1 to 7**	-3 to 0	-10 to -14	**5 to 14**	**1 to 4**	-4 to 4
SC	**3 to 4**	-3 to 0	-8 to 3	-3 to -5	-4 to -8	-3 to 2	**4 to 8**	-2 to 4
SE	**13 to 14**	-5 to -7	-8 to 1	-1 to -2	**2 to 5**	-6 to -9	**0 to 1**	**3 to 5**
SW	-13 to 8	**6 to 7**	-4 to 3	-2 to 4	-1 to -6	**6 to 17**	-5 to -11	-5 to 5
EH	-1 to 7	**1**	-5 to 0	-1 to -3	-5 to -6	**1 to 2**	**0 to 3**	**2 to 4**

Occurrence of mild drought will be increased 3%-4% in south central region in 2050s, but will be decreased up to 8% in 2080s. Occurrence of severe and extreme drought will be increased up to 8% and 4% respectively in 2080s, although there is chance of decreasing in 2050s.

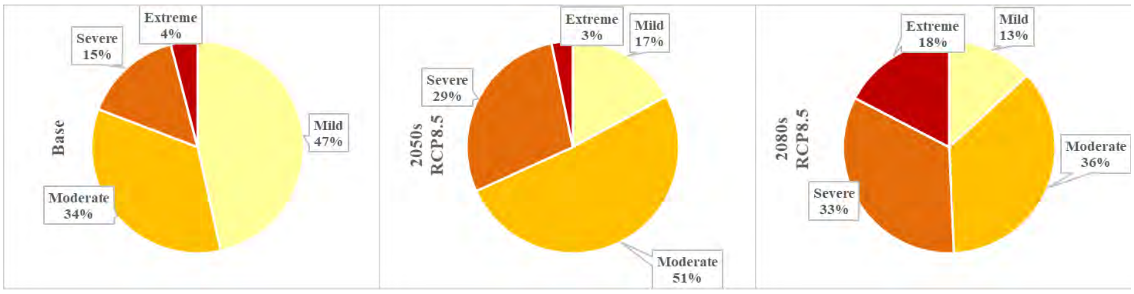


Dhaka

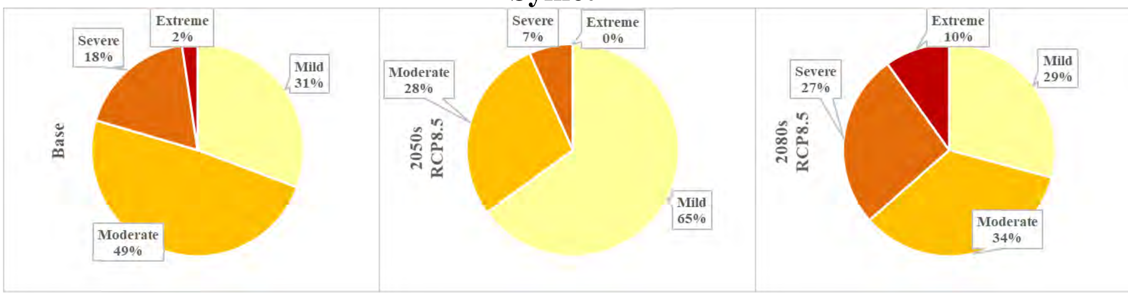


Mymensingh

Figure 6.58: Distribution of future occurrence of drought in north-central region for RCP8.5



Sylhet



Sreemangal

Figure 6.59: Distribution of future occurrence of drought in north-east region for RCP8.5

Similarly, occurrence of mild drought will also be increased 13%-14% in 2050s and 2%-5% in 2080s than base period in south-east region. Occurrence of severe and extreme drought will be increased up to 1% and 5% respectively in 2080s considering both RCPs.

In south-west region, occurrence of increasing moderate drought will be higher than other types of drought up to maximum 17%. Occurrence of moderate, severe and extreme drought in eastern hill region will also be increased up to 2%, 3% and 4% respectively in 2080s, maintaining similar decreasing trend of all droughts in 2050s.

Severity of meteorological drought will be changed from moderate to extreme in most of the stations analysed. Although, pattern of change of future occurrence of drought is found very irregular between two RCPs and among different regions. However, north-west, south-west and eastern hill regions are found prone to moderate drought, north-west, north-central, south-central, south-east and eastern hill regions are found more prone to severe drought and north-central, north-east, south-east and eastern hill regions are found more prone to extreme drought for future periods and scenarios.

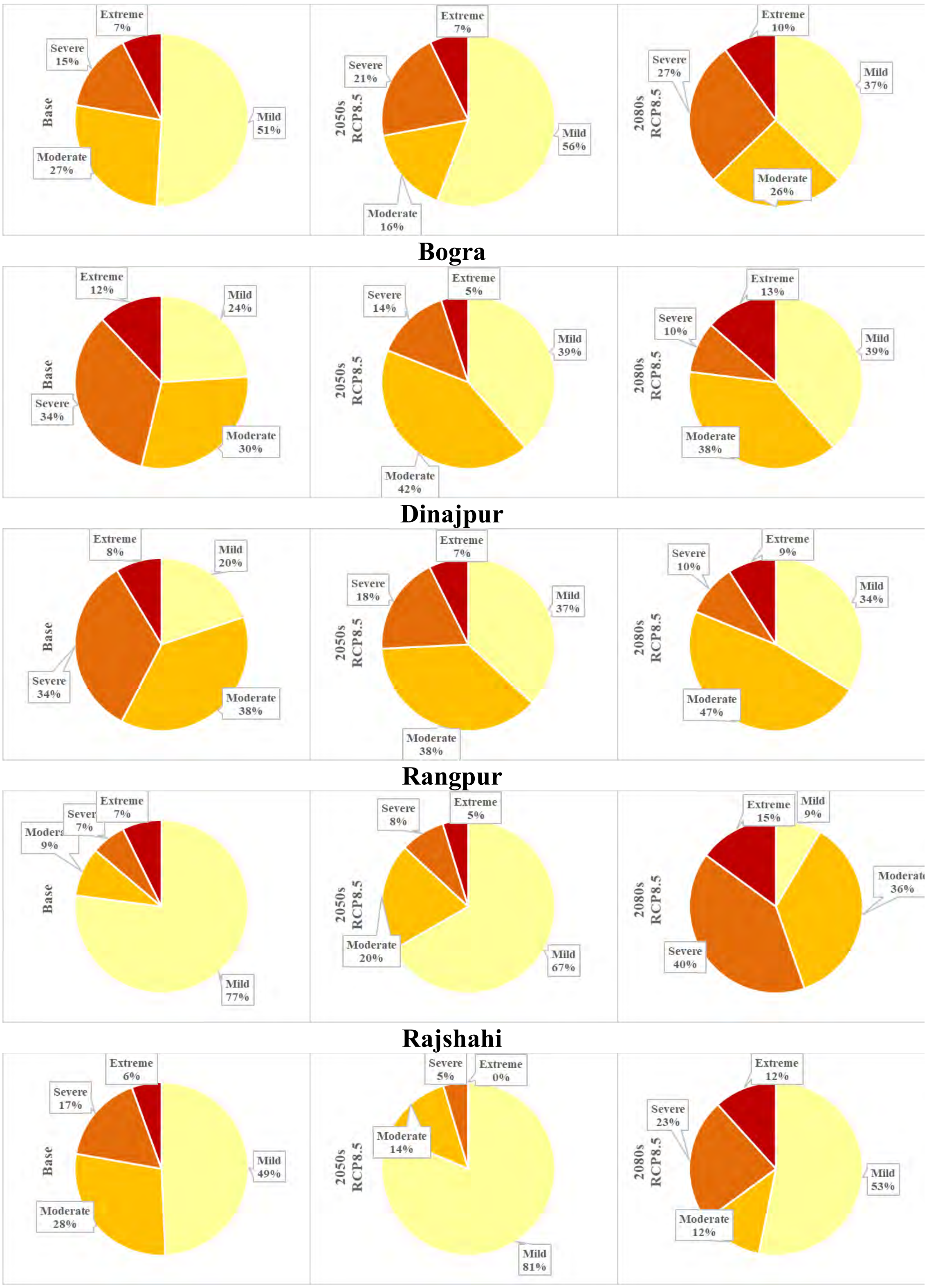
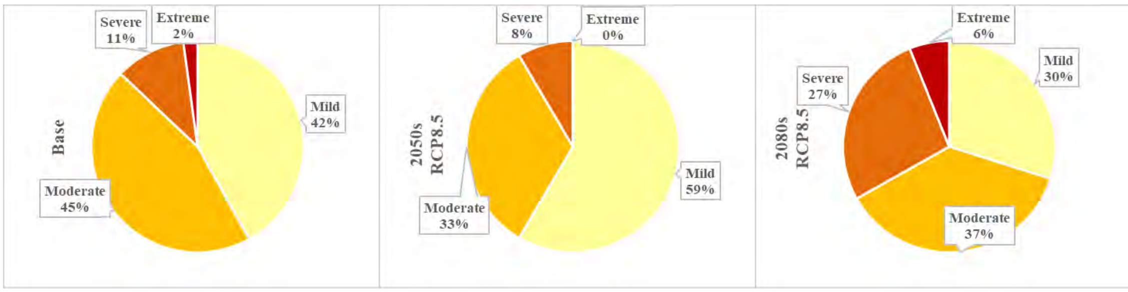
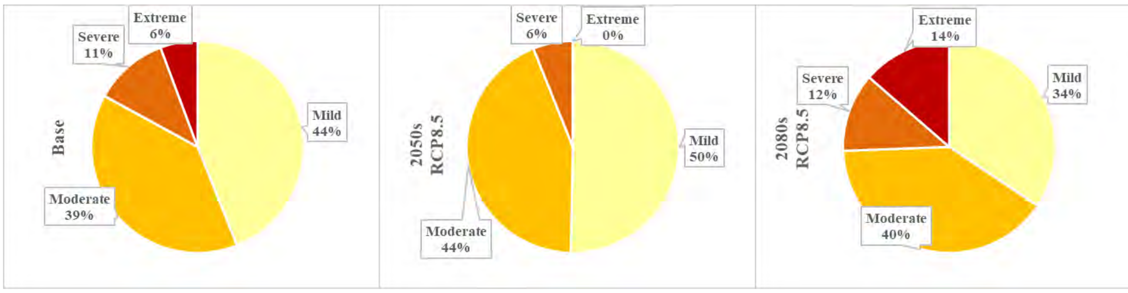


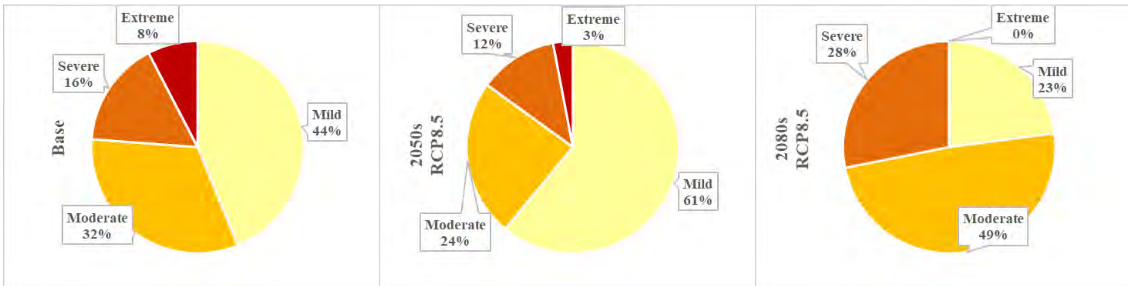
Figure 6.60: Distribution of future occurrence of drought in north-west region for RCP8.5



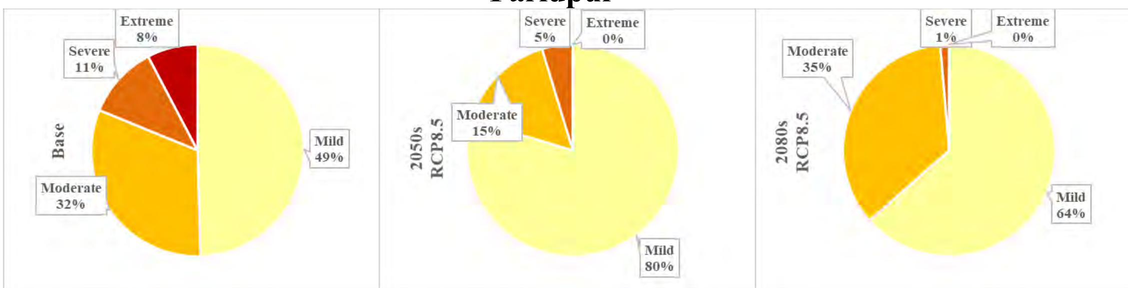
Barisal



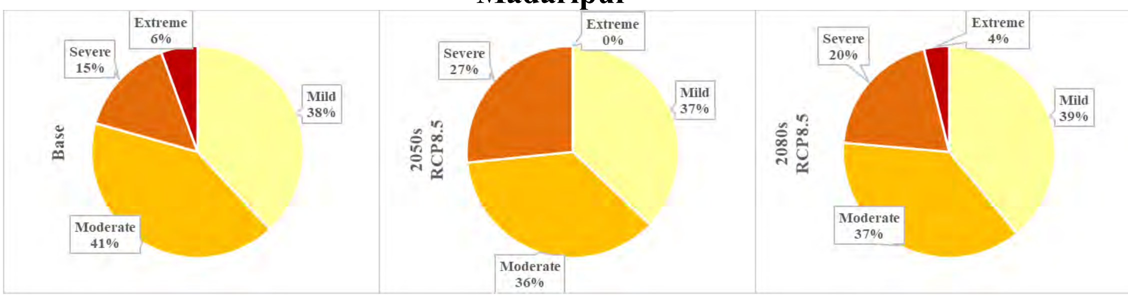
Bhola



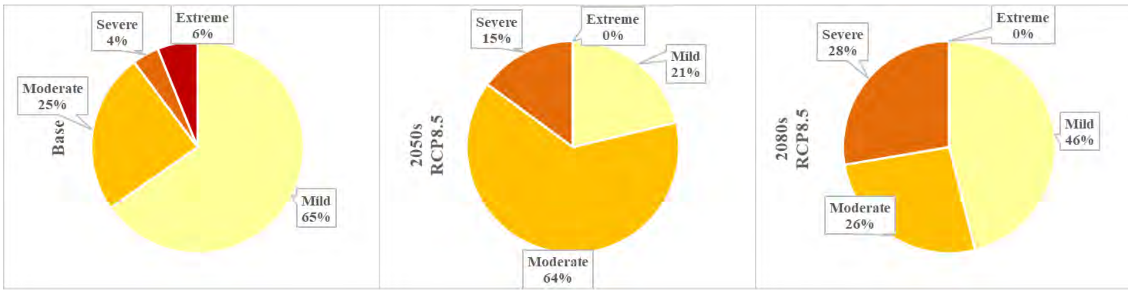
Faridpur



Madaripur

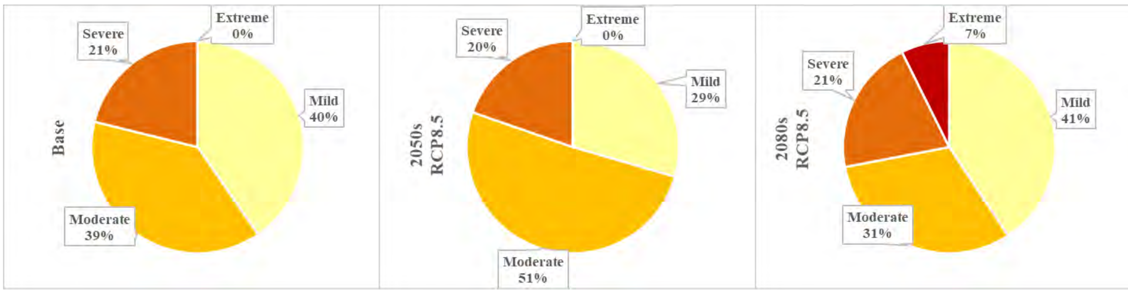


Khepupara

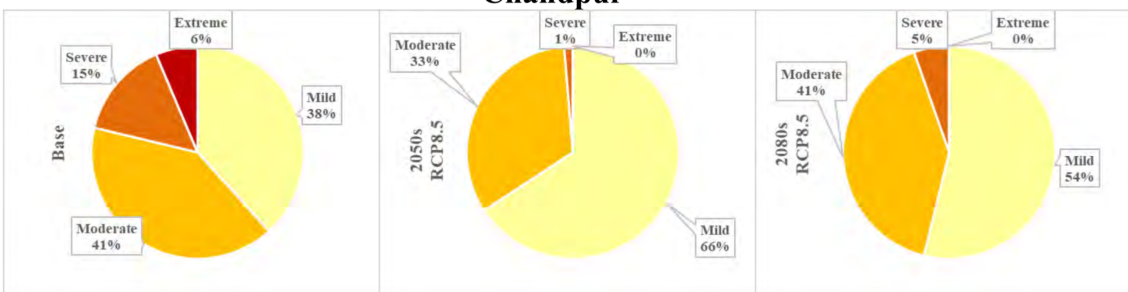


Patuakhali

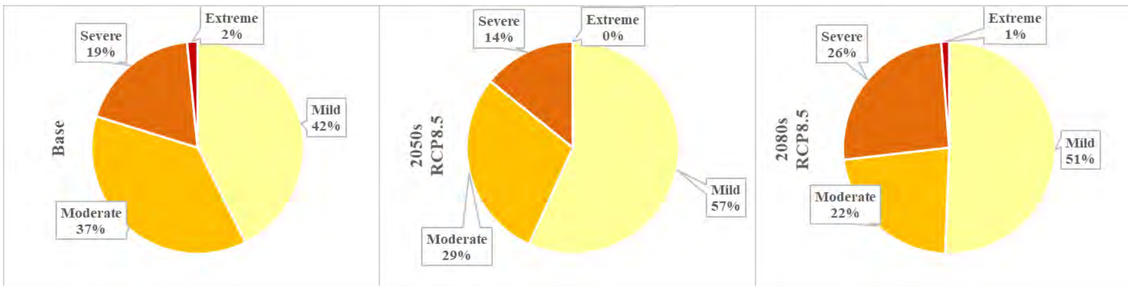
Figure 6.61: Distribution of future occurrence of drought in south-central region for RCP8.5



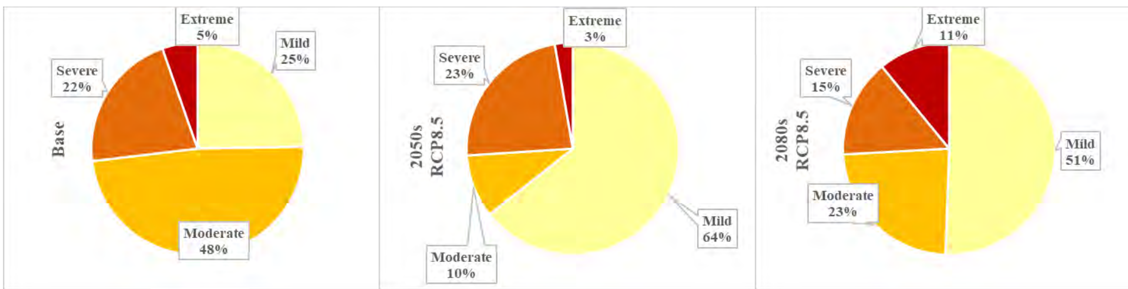
Chandpur



Comilla

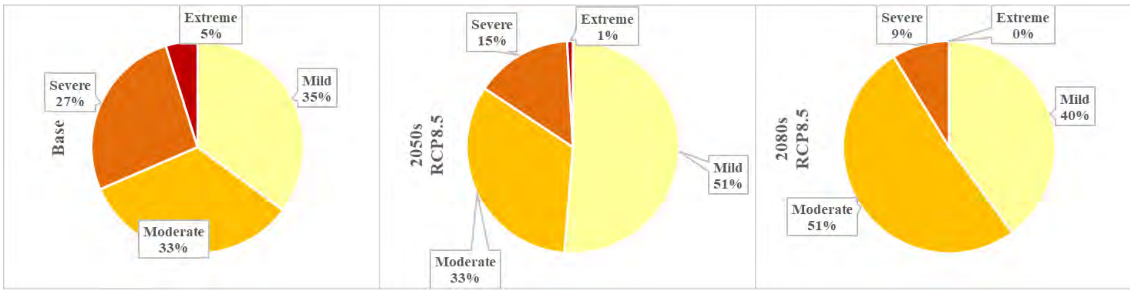


Feni

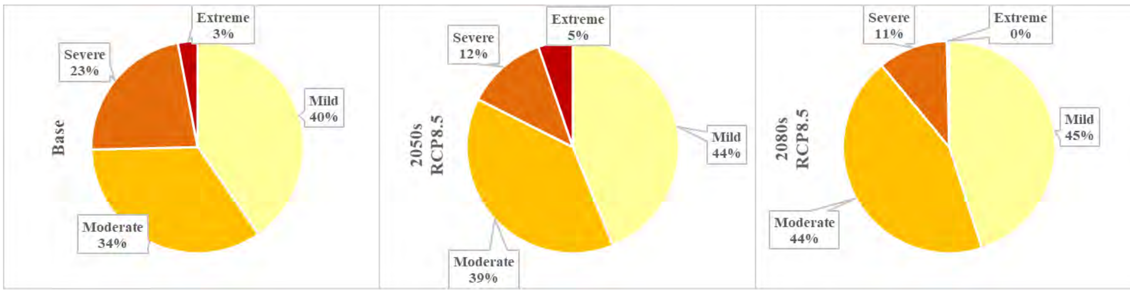


Maijdeecourt

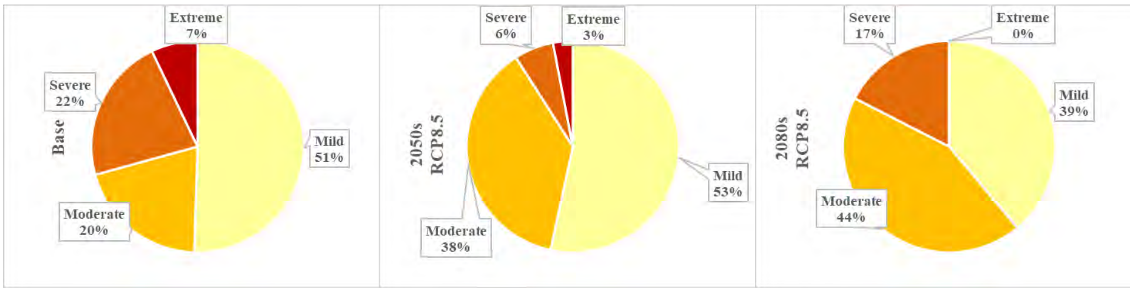
Figure 6.62: Distribution of future occurrence of drought in south-east region for RCP8.5



Jessore

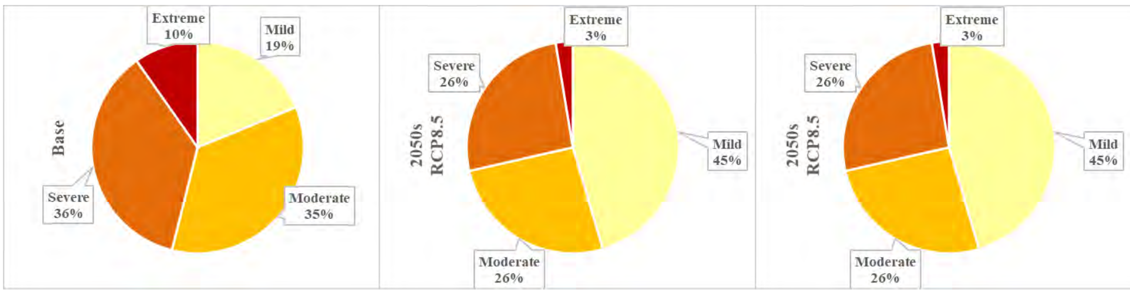


Khulna

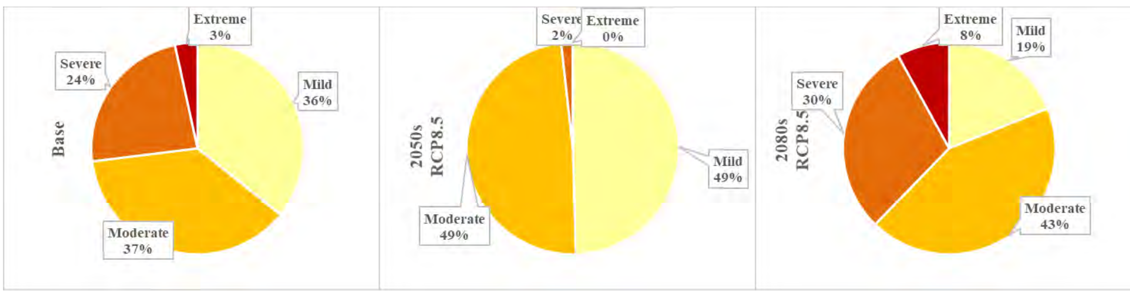


Satkhira

Figure 6.63: Distribution of future occurrence of drought in south-west region for RCP8.5



Cox's Bazar



Chittagong

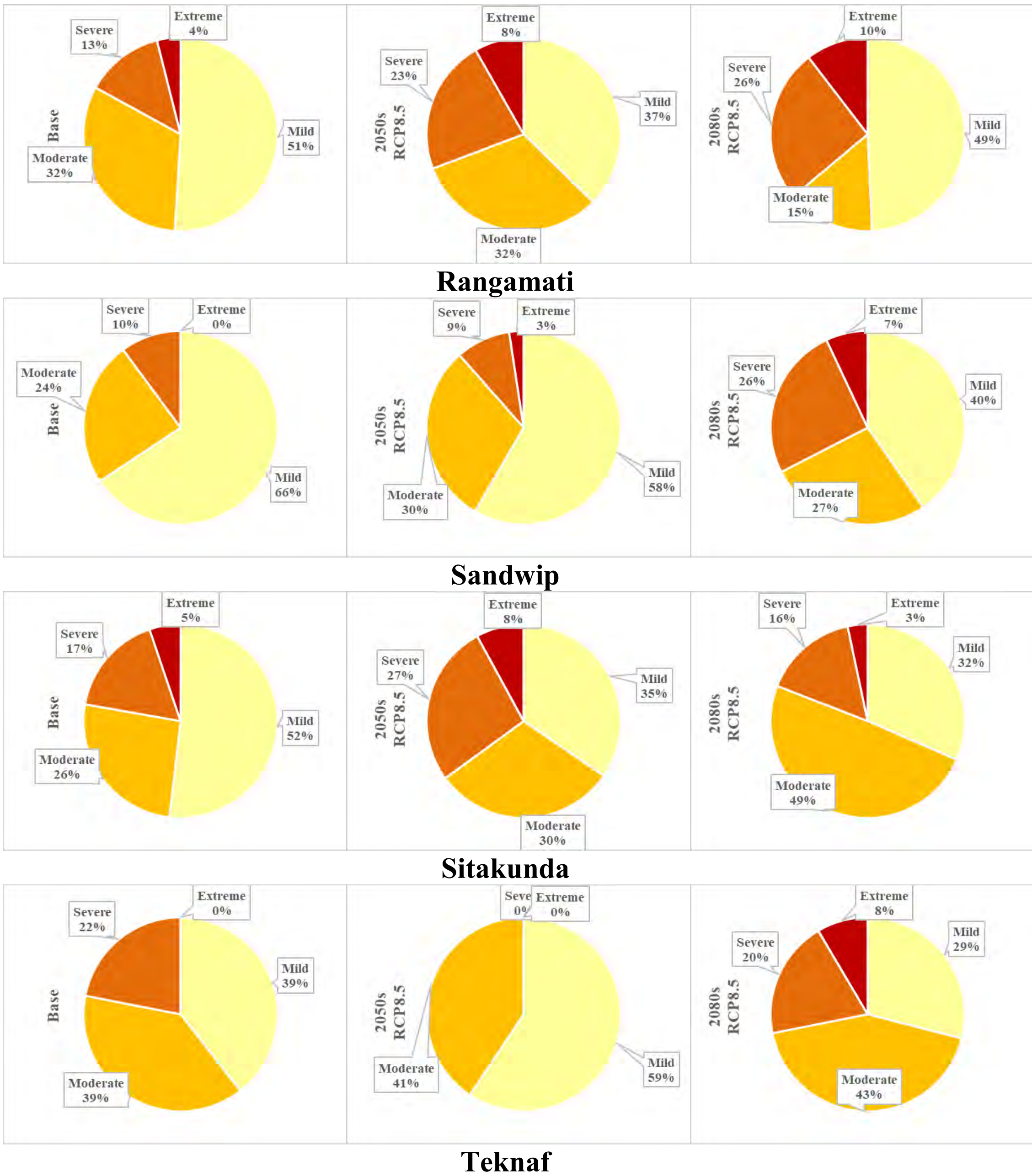


Figure 6.64: Distribution of future occurrence of drought in eastern hill region for RCP8.5

6.5.3 Total Drought Occurrence

From the analysis of total drought occurrence over the 30 years period of base period (1981-2010) and future three time slices i.e. 2050s (2016-2045), 2050s (2046-2065) and 2080s (2066-2095), it has been found from zonal average analysis that duration of total drought occurrence will be decreased in 2050s, but will increase up to 8% throughout the country in 2080s considering both RCPs. Table 6.9 shows total occurrence of drought over 30 years period.

In north central region, total drought occurrence will be decreased up to 17% in 2050s, but will be increased up to 15% in 2080s with relative to base period (1981-2010). In north-eastern region, overall pattern of long term drought (6 months or more than 6 months) occurrence is decreasing except 11% increase in 2080s for extreme climate change scenarios.

Surprisingly, zonal average of total duration of long term drought occurrence in north-west region is found increasing up to 4% under RCP4.5 scenarios but decreasing up to 10% under RCP8.5 scenarios. Again from Table 6.6 from previous section, both severe and extreme drought will be increased in this region, which depict that severity and intensity of drought will be increased in north-west region.

Total drought occurrence will be increased by any means in south central region up to ranges from 2%-3% in RCP4.5 and 3%-21% in RCP8.5. Similar findings are also found for south east region except 2050s under RCP4.5 scenario. South-west region will be more drought prone with respect to 1981-2010. Almost 30%-50% increment of drought occurrence is found in this region except 2050s under RCP4.5 scenario. In eastern hill region, occurrence of drought is also found decreasing except 12% increase in 2080s under RCP8.5.

From regional analysis of drought occurrence it has been revealed that total drought occurrence will be increased all over the western Bangladesh than other parts of the country. North-west region will face intensive severe drought spell than historical period (1981-2010). South west portion of Bangladesh will become prone to longer term drought with relative to 1981-2010. Drought occurrence will be decreased in eastern hill and north east regions. However, it is also clear that there is very insignificant correlation exist between overall rainfall pattern and long term drought over Bangladesh which also analogous to the findings of Shahid (2007 and 2008). However, seasonality of drought and rainfall distribution are not considered in this analysis.

Table 6.9: Total Occurrence of Drought over 30 Years Period

Hydrologic Region	Station	Occurrence of Drought (% of 30 Years Period)					% Change of Occurrence			
		Base (1981-2010)	RCP4.5		RCP8.5		RCP4.5		RCP8.5	
			2050s	2080s	2050s	2080s	2050s	2080s	2050s	2080s
NC	Dhaka	38	38	65	18	38	-4	15	-17	15
	Mymensingh	37	28	39	22	66				
NE	Sreemangal	35	18	39	17	65	-19	-7	-3	11
	Sylhet	48	27	31	60	40				
NW	Bogra	30	27	55	21	57	4	3	-7	-10
	Dinajpur	49	53	39	44	29				
	Ishwardi	40	46	46	30	45				
	Rajshahi	30	42	30	21	50				
	Rangpur	42	36	38	45	37				
SC	Barisal	26	16	41	36	59	2	4	3	21
	Bhola	39	39	42	46	35				
	Faridpur	29	26	29	28	53				
	Madaripur	33	28	24	36	62				
	Khepupara	35	46	20	34	51				
	Patuakhali	14	34	45	13	39				
SE	Chandpur	29	38	30	17	42	-4	1	1	9
	Comilla	26	28	48	21	36				
	Feni	52	25	37	45	46				
	Maijdeecourt	26	28	26	20	48				
	Sandwip	28	21	27	58	36				
SW	Jessore	46	19	92	32	63	-8	55	3	30
	Khulna	19	21	67	32	78				
	Satkhira	28	29	99	37	41				

<table>
<tr><th rowspan="3">Hydrologic Region</th><th rowspan="3">Station</th><th colspan="5">Occurrence of Drought (% of 30 Years Period)</th><th colspan="4">% Change of Occurrence</th></tr>
<tr><th rowspan="2">Base (1981-2010)</th><th colspan="2">RCP4.5</th><th colspan="2">RCP8.5</th><th colspan="2">RCP4.5</th><th colspan="2">RCP8.5</th></tr>
<tr><th>2050s</th><th>2080s</th><th>2050s</th><th>2080s</th><th>2050s</th><th>2080s</th><th>2050s</th><th>2080s</th></tr>
<tr><td rowspan="5">**EH**</td><td>**Chittagong**</td><td>57</td><td>25</td><td>35</td><td>31</td><td>49</td><td rowspan="5">-10</td><td rowspan="5">-5</td><td rowspan="5">-4</td><td rowspan="5">12</td></tr>
<tr><td>**Coxsbazar**</td><td>43</td><td>33</td><td>61</td><td>21</td><td>53</td></tr>
<tr><td>**Rangamati**</td><td>43</td><td>27</td><td>27</td><td>51</td><td>40</td></tr>
<tr><td>**Sitakunda**</td><td>38</td><td>22</td><td>27</td><td>59</td><td>67</td></tr>
<tr><td>**Teknaf**</td><td>32</td><td>54</td><td>39</td><td>27</td><td>62</td></tr>
</table>

Chapter 7 Conclusions and Recommendations

7.1 Conclusions

In this section, conclusion has been made summarizing major findings of the study on climate anomalies, season shifting in terms of rainfall occurrence and drought severity analysis over Bangladesh. Climate anomalies has been analyzed developing statistical downscaling model using SDSM for maximum temperature, minimum temperature, rainfall and solar radiation under three climate change scenarios RCP2.6, RCP4.5 and RCP8.5. Seasonal rainfall analysis has been performed to quantify changes in rainfall distribution through which shifting of season has been identified. Later, future occurrence of drought and changes of severity has been analyzed calculating and analyzing Self-calibrated Palmer Drought Severity Index (Sc-PDSI).

Major findings revealed by this study are as following:

Developed SDSM is capable of generating satisfactory results with some biases up to monthly level for maximum temperature, minimum temperature and rainfall, but not for solar radiation which is subject to add local climate variable as predictors. Previous studies (Mahmood and Babel, 2014; Pervez et al, 2014) also found that SDSM model can perform better in monthly, seasonal or annual scale than daily scale. Therefore, this model generated results will be more useful to assess future water resources, water balance or impact rather directly using for any extremity analysis. However, presence of missing data obviously hampers the overall performance of model.

Increase of mean annual average maximum temperature has been found 1.8^{o}C for 2080s under RCP8.5 scenario. Highest annual average maximum temperature increase will be 2.7^{o}C in Khulna as well as in south west region. Southern part of Bangladesh will be hotter gradually than northern part. Countrywide mean average maximum temperature anomaly of DJF, MAM, JJAS and ON season will be 1.7^{o}C, 1.1^{o}C, 2.6^{o}C and 2.4^{o}C for 2080s under extreme climate change scenario RCP8.5. Variation of increment of average maximum temperature is found very less in north-east region for all four seasons. Seasonal average maximum temperature increase is found higher in monsoon (4.5^{o}C) and post-monsoon season (up to 4.0^{o}C) considering all scenarios.

Highest annual average minimum temperature increase will be 3.3^{o}C in Satkhira as well as in south west region. Bangladesh will face highest increment of average minimum temperature for ON (post-monsoon) season, which is 5.2^{o}C. Spatial distribution indicates that southern part of Bangladesh will be hotter gradually and will aggravate to northern part. Increase of temperature is found higher for average minimum temperature than average maximum temperature which is also supported by Biswas et al. (2017).

Rainfall anomaly has been found erratic, sometimes increasing and sometimes decreasing for three time slices and all of the RCPs. However, mean annual average rainfall increase has been found 8%, 9% and 19% for 2030s, 2050s and 2080s respectively under RCP8.5 scenario, whereas maximum increase is 11% for 2080s under RCP4.5, which fully similar to the findings of several studies (Met Office, 2011, CDMP, 2012 and CIAT, 2017). Countrywide mean average rainfall anomaly of DJF, MAM, JJAS and ON season will be -7% to -8%, 10% to 22%, 10% to 16% and -15% to -17% for 2080s considering RCP2.6, RCP4.5 and RCP8.5. Therefore, seasonal rainfall are found to be decreased in DJF (winter) and ON (post-monsoon) season and increased in MAM (pre-monsoon) and JJAS (monsoon) season, which is also analogous with study findings of Hasan et al. (2014 and 2015). In JJAS (monsoon) season, highest increase of average rainfall will be up to 33% in Dinajpur and on an average 24% in north-west region for 2080s considering RCP2.6, RCP4.5 and RCP8.5. Second highest increase would be up to 21% in both south-west and eastern hill region.

Mean annual average solar radiation will be decreased for all of the time slices and RCPs except 2030s in RCP4.5 and RCP8.5. Although, change of mean annual average radiation is very less in between -0.1% to -0.4%, which may be due to scarcity of observed data in considered period. However, findings of this study regarding solar radiation satisfies indication of CDMP (2012) and PKSF (2014). Spatial distribution of annual average solar radiation shows it will increase up to 1.5% in north central portion which further aggravates to northern portion of north-west region. On the other hand, annual average solar radiation is found decreasing in south central portion up to 2.0% in 2080s under RCP8.5. Increase of annual average precipitation indicates the chances of more cloud formation which may be the cause of overall decrease of solar radiation along with other external factors like increased air pollution.

Season of rainfall has been found shifting towards pre-monsoon in the eastern portion of Bangladesh than base period decreasing monsoon rainfall occurrence, whereas western Bangladesh will face more rainfall occurrence in monsoon season for all of the future climate scenarios i.e. RCP2.6, RCP4.5 and RCP8.5. Shifting of season in terms of rainfall occurrence is evident except north-west and south-west regions of Bangladesh. Highest increase in occurrence of pre-monsoon rainfall is found to be increased 5%-6% in north-eastern region than base period, which clearly depicts that haor area of Bangladesh will be more prone to early rainfall as well as early flash floods in future period.

However, changes in atmospheric circulation or Indian monsoon circulation triggered by surface temperature increase and sea-surface temperature increase due to increased global GHGs emission is the prime cause of inter-seasonal or inter-annual climate variability.

Historically, north-west region of Bangladesh faced severe droughts in 1981, 1982, 1984, 1989, 1994, 1995, 2000, 2006, 2009 (Selvaraju et al., 2006, BBS, 2017 and Mardy et al., 2018) during 1981-2010. Simulated Sc-PDSI value for the same historical period has successfully matched the severe drought in this region for 1982, 1994, 1995, 2000, 2006 and 2009. Therefore simulated Sc-PDSI matches around 67% of historical observance, which is quite reasonable.

Occurrence of severe and extreme long term (at least 6 months spell length) drought will be increased almost all over Bangladesh in 2080s through decreasing occurrence of mild and moderate drought. Chance of decreasing of occurrence of mild drought is higher than moderate drought and chance of increasing occurrence of severe drought is higher than extreme drought in both RCP4.5 and RCP8.5 scenarios. In most of the regions, occurrence of mild drought will be increased in 2050s and later decreased in 2080s for both RCPs. Overall occurrence of severe and extreme drought will be decreased in 2050s, later will be increased again in 2080s with respect to total drought period. North-west region is the most drought prone area in the country, which will remain drought prone in future. Occurrence of moderate, severe and extreme drought will be increased in future considering both RCP4.5 and RCP8.5 up to 14%, up to 7% and up to 4% respectively. Chance of increasing occurrence of severe drought is higher than extreme drought in this region.

It has been found from zonal average analysis that total drought occurrence will be decreased in 2050s, but will increase up to 8% throughout the country in 2080s considering both RCPs with relative to 1981-2010. Duration of total drought occurrence will be increased all over the western Bangladesh than other parts of the country. North-west region will face intensive severe drought spell than historical period. South west portion of Bangladesh will become prone to longer term drought. Total drought occurrence will be decreased in eastern hill and north east regions. However, it is also clear that there is very insignificant correlation exist between overall rainfall pattern and long term drought over Bangladesh which also analogous to the findings of Shahid (2007 and 2008).

7.2 Limitations of the Study

Major limitations of the study are as following:

- This study developed statistical downscaling model using predictors of only one GCM CanESM2, although this GCM is found giving satisfactory performance to capture climate pattern of Bangladesh with some system biases.
- Longer term data of solar radiation is not found from meteorological stations due to lack of long term historical measurements for most of the meteorological stations of BMD.
- Climate anomaly analysis has been done based on the model generated results, but downscaled climate data may have higher uncertainties especially in rainfall.
- Available water content data is considered same for future period during drought severity value calculation using Sc-PDSI tool.

7.3 Recommendations

This study generates numerous information on climate anomalies, season shifting and drought severity condition over Bangladesh for future period, which will be definitely useful in future for different impact studies and decision making process. However, this study has opened up some new research horizon which can be done in future. They are:

This study is conducted using only one GCM output. Any climate change studies with ensemble of GCMs can give better output than single GCM over a region. Therefore, reanalysis of other suitable CMIP5 GCMs should be done and used in statistical downscaling model to compare results of all GCM and ensembles.

Uncertainty analysis of model generated data can be done in future to get the high confidence of climate projections as developed SDSM model performs well up to monthly scale. Moreover, more detailed study can be done to improve the daily data simulation by SDSM.

SDSM model can be updated for solar radiation with continuous long term data and taking local climate variables i.e. cloud cover and difference in maximum and minimum temperature as predictors along with large scale predictors.

Drought severity analysis can be done for Standardized Precipitation Index (SPI) or other available indices to assess meteorological drought characteristics. Sensitivity of different methods to developed model can be assessed. There is also scope to do further research on customization of Palmer Drought Severity Index in the context of Bangladesh critically analyzing the threshold for a staring or ending of wet spell or dry spell, as established index value generates too long period of spell which is quite unexpected in case of Bangladesh.

Available water content is taken constant in future period as historical period. Therefore, effort should be made to assess future available water content and incorporate in Sc-PDSI program to get better estimation of drought severity of Bangladesh.

Calibration and validation is not performed for PDSI calculation in this study, which is recommended to do further to get better output. Furthermore, seasonality of drought occurrence should also be investigated.

References

Agrawala, S., Ota, T., Ahmed, A.U., Smith, J., Aalst, M.V., 2003. Development and Climate Change in Bangladesh: Focus on Coastal Flooding and the Sundarbans. OECD Publication COM/ENV/EPOC/DAC (2003)3/FINAL.

Ahmed, A.U., Alam, M., 1999. Development of climate change scenarios with General Circulation Models. In: Huq, S., Karim, Z., Asaduzzaman, M., Mahtab, F.(Eds.), Vulnerability and Adaptation to Climate Change for Bangladesh. Kluwer Academic Publishers, Dordrecht.

Alam, S., 2015. Impact of climate change on future flow of Brahmaputra river basin using SWAT model, M.Sc Thesis. Department of Water Resources Engineering, Bangladesh University of Engineering and Technology (BUET), Bangladesh.

Ali, A., 1999. Climate Change Impacts and Adaptation Assessment in Bangladesh. Climate Research 12:109-116 pp.

Ali, M.M., Zobeyer, H., Khan, M.F.A., Ludwig, Fulco., Rahman, M., and Paul, G.C., 2016. "CAR5 report on Statistical Downscaling of Selected GCM results for GBM Basin, Scenario Development in Integrated Water Resources Management: coping with future challenges in Bangladesh (NICHE/BGD/155)", Dhaka, Bangladesh.

Alley, W.M. (1984). “Palmer Drought Severity Index: Limitations and assumptions”, J. Climate Appl. Meteor., 23, 1100–1109.

Azad, S., 2015. Comparison of Statistical Downscaling Techniques for Development of Future Climate Change Scenarios for the Coastal Areas of Bangladesh, Post Graduate Diploma in Water Resources Development, Institute of Water and Flood Management, Bangladesh University of Engineering and Technology (BUET), Dhaka, Bangladesh.

Bari, S. H., Rahman, M. T. U., Hoque, M.A., Hussain, M.M., 2016. Analysis of seasonal and annual rainfall trends in the northern region of Bangladesh, Atmospheric Research (2016), doi: 10.1016/j.atmosres.2016.02.008.

Bawiskar, S.M., Chipade, M.D., Puranik, P.V., Bhide, U.V., 2005. Energetics of lower tropospheric planetary waves over mid latitudes: precursor for Indian summer monsoon. J. Earth Syst. Sci. 114 (5), 557–564.

BBS, 2017. Statistical Year Book of Bangladesh (37th Edition), Bangladesh Bureau of Statistics, Statistics & Informatics Division (SID), Ministry of Planning Government of the People's Republic of Bangladesh, Dhaka, Bangladesh. ISBN-978-984-519-112-8.

BCCRF, 2014. "Climate Downscaled Data to Support Impact Risk Assessments in Bangladesh, A guide on how to access data derived from models used in the IPCC 5th Assessment Report using the World Bank Climate Analysis Tool", Bangladesh Climate Change Resilience Fund, Bangladesh.

Belay, H., 2011. Evaluation of Climate Change impacts on hydrology on selected catchments of Abbay Basin, M.Sc Thesis in Partial Fulfillment of the Requirements for the Degree of Masters of Science in Hydraulics Engineering, Addis Ababa University.

Bengtsson, L., 1996. The climate response to the changing greenhouse gas concentration in the atmosphere. In: Decadal Climate Variability, Dynamics And Variability [Anderson, D.L.T., and J. Willebrand (eds.)]. NATO ASI Series 44, Springer, Berlin, 493 pp.

Bhuyan, M.D.I., Islam, M. M., and Bhuiyan, M.E.K., 2018. A Trend Analysis of Temperature and Rainfall to Predict Climate Change for Northwestern Region of Bangladesh, American Journal of Climate Change, 2018, 7, 115-134.

Biswas, J.C., Maniruzzaman, M., Naher, U. A., Haque, M. M., Hossain, M. B., Rahman, M. M., Miah, M. M. U., Choudhury, A. K., Akhter, S., Ahmed, F., Hamid, M. A., Kalra, N., and Furuya, J., 2017. Future Climate Change Scenarios and Anticipated Performance of Major Cereals in Bangladesh, International Journal of Agriculture and Environmental Research, Volume:03, Issue:06 "November-December 2017".

Brammer H., 2014. Climate Change, Sea Level Rise and Development in Bangladesh, UPL, Dhaka

Busuioc, A., H. von Storch and R. Schnur, 1999: Verification of GCM generated regional precipitation and of statistical downscaling estimates. J. Climate, 12: 258–272.

CDMP, 2012. Spatial and Temporal Distribution of Temperature, Rainfall, Sunshine and Humidity in Context of Crop Agriculture, Ministry of Food and Disaster Management, Government of the People's Republic of Bangladesh. 179pp.

CDMP, 2013. Vulnerability to Climate Induced Drought: Scenario and Impact, Comprehensive Disaster Management Program II, Ministry of Disaster and Relief, Government of the People's Republic of Bangladesh, Bangladesh.

Chen, S.T., Yu, P.S., Tang, Y.H., 2010. Statistical downscaling of daily precipitation using support vector machines and multivariate analysis. J. Hydrol. 385 (1–4), 13–22

Choudhury, B. U., Das, Anup, Ngachan, S. V., Slong, A., Bordoloi, L. J. and Chowdhury, P., 2012. "Trend analysis of long term weather variables in mid altitude Meghalaya, North-East India", Journal of Agricultural Physics, 12, 1, 12-22

Christensen, J.H., B. Hewitson, A. Busuioc, A. Chen, X. Gao, I. Held, R. Jones, R.K. Kolli, W. T. Kwon, R. Laprise, V. Magaña Rueda, L. Mearns, C.G. Menéndez, J. Räisänen, A. Rinke, A. Sarr and P. Whetton, 2007. Regional Climate Projections. In: Climate Change 2007: The Physical Science Basis. Contribution of Working Group I to the Fourth Assessment Report of the Intergovernmental Panel on Climate Change [Solomon, S., D. Qin, M. Manning, Z. Chen, M. Marquis, K.B. Averyt, M. Tignor and H.L. Miller (eds.)]. Cambridge University Press, Cambridge, United Kingdom and New York, NY, USA.

Christopher G. Collier, 2016. Hydrometerology (P 250), Chickester, Uk, Hoboken, NJ, John Wiley and Sons, 2016, ISBN 9781118414972

Chu JT, Xia J, Xu CY, Singh VP., 2010. Statistical downscaling of daily mean temperature, pan evaporation and precipitation for climate change scenarios in Haihe, China. Theoretical and Applied Climatology 99: 149–161.

Chu, J., Xia, J., Xu, C.Y., and Singh,V., 2009. Statistical downscaling of daily mean temperature, pan evaporation and precipitation for climate change scenarios in Haihe River, China. Theoretical and Applied Climatology, 99(1): 149-161.

CIAT, 2017. Climate-Smart Agriculture in Bangladesh. CSA Country Profiles for Asia Series. International Center for Tropical Agriculture (CIAT); World Bank. Washington, D.C. 28 p.

Clarke LE, Edmonds JA, Jacoby HD, Pitcher H, Reilly JM, Richels R., 2007. Scenarios of greenhouse gas emissions and atmospheric concentrations. Subreport 2.1a of Synthesis and Assessment Product 2.1. Climate Change Science Program and the Subcommittee on Global Change Research, Washington DC.

Collins, M.; Knutti, R.; Arblaster, J.; Dufresne, J.L.; Fichefet, T.; Friedlingstein, P.; Gao, X.; Gutowski, W.J.; Johns, T.; Krinner, G.; Shongwe, M.; Tebaldi, C.; Weaver, A.J.; and Wehner, M., 2013. Long Term climate change: Projections, commitments and irreversibility. In: Climate change. The physical science basis. Contribution of Working Group I to the Fifth Assessment Report of the Intergovernmental Panel on Climate Change. [Stocker, T.F.; Qin, D. ; Plattner, G.K.; Tignor, M.; Allen, S.K.; Boschung, J.; Nauels, A.; Xia, Y.; Bex, V.; Midgley, P.M. (eds.)]. Cambridge University Press, Cambridge, United Kingdom and New York, NY, USA. pp. 1029 1036. DOI: 10.1017/ CBO9781107415324.024

Cook, E.R., Meko, D.M., Stahle, D.W., Cleaveland, M.K. (1999) "Drought reconstructions for the continental United States". Journal of Climate 12 (4): 1145–1162.

Coulibaly, P., 2004. Downscaling daily extreme temperatures with genetic programming. Geophysical Research Letters 31: L16203.

Dai, A., Trenberth, K.E. and Qian, T.T. (2004) "A global dataset of Palmer drought severity index for 1870–2002: relationship with soil moisture and effects of surface warming". Journal of Hydrometeorology 5(6): 1117–1130.

Das, S.R., 2015. Monsoon Rainfall Forecasting for Different Hydrological Regions of Bangladesh Using Climate Predictability Tool (CPT), M.Sc Thesis in Water Resources Development, Institute of Water and Flood Management, Bangladesh University of Engineering and Technology (BUET), Dhaka, Bangladesh.

Dash SK., Shekhar MS., Singh GP., 2006. Simulation of Indian summer monsoon circulation and rainfall using RegCM3. Theor. and App. Clim. 86(1-4): 161-172.

Dash, B. K., Khanam, M.R.F., and Islam, M.N., Characteristics of meteorological drought in Bangladesh, Nat Hazards (2012) 64:1461–1474, DOI 10.1007/s11069-012-0307-1.

Datta, A.R., 2005. Application of Palmer Method in Analyzing Drought in Northwest Region of Bangladesh, M.Sc Thesis, Department of Water Resources Engineering, BUET, Dhaka, Bangladesh.

Debbarma, S. and Choudhury, P., 2016. "Uncertainty analysis of downscaled daily precipitation using climate scenarios of different story line", Journal of Scientific Research and Development 3 (3): 22-29, ISSN 1115-7569.

Déqué, M., and A.L. Gibelin, 2002. High versus variable resolution in climate modelling. In: Research Activities in Atmospheric and Oceanic Modelling [Ritchie, H. (ed.)]. WMO/TD No. 1105, Report No. 32, World Meteorological Organization, Geneva, pp. 74–75.

Dibike, YB., Coulibaly, P., 2005. Hydrologic impact of climate change in the Saguenay watershed: comparison of downscaling methods and hydrologic models. Journal of Hydrology 307: 145–163

Dorji, S., Herath, S., and Mishra, B.K., 2017. Future Climate of Colombo Downscaled with SDSM-Neural Network, Climate 2017, 5, 24; doi:10.3390/cli5010024.

Fahad, G.R., Islam, A.K.M.S., Nazari, R., Hasan, A., Islam, G.M.T., and Bala, S.K., 2017. "Regional changes of precipitation and temperature over Bangladesh using bias-corrected multi-model ensemble projections considering high-emission pathways," Int. J. Climatol. (2017); DOI: 10.1002/joc.5284.

FAO, 2007. Climate variability and change: adaptation to drought in Bangladesh: A resource book and training guide, Asian Disaster Preparedness Center, Food and Agriculture Organizations of the United Nations, Viale delle Terme di Caracalla, 00153 Rome, Italy. ISBN 978-92-5-105782-7.

Felay, R., and Sweeney, J., 2008. Statistical downscaling of temperature, radiation and potential evapotranspiration to produce a multiple GCM ensemble mean for a selection of sites in Ireland, Irish Geography · March 2008, DOI: 10.1080/00750770801909235

Fowler, H.J., Blenkinsop, S., Tebaldi, C., 2007. Linking climate change modelling to impacts studies: Recent advances in downscaling techniques for hydrological modelling. Int. J. Climatol., 27, 1547-157.

Fujinami, H., Yasunari, T., and Morimoto, A., 2014. Dynamics of distinct intraseasonal oscillation in summer monsoon rainfall over the Meghalaya–Bangladesh–western Myanmar region: covariability between the tropics and mid-latitudes, Clim Dyn (2014) 43:2147–2166, DOI 10.1007/s00382-013-2040-1

Fujino J, Nair R, Kainuma M, Masui T, Matsuoka Y., 2006. Multigas mitigation analysis on stabilization scenarios using aim global model. The Energy Journal Special issue, 3,343–354.

GED, 2018. Bangladesh Delta Plan 2100, Baseline Studies on Disaster and Environment Management (Volume 2), Bangladesh Planning Commission, Ministry of Planning, Government of the People’s Republic of Bangladesh, Bangladesh.

Guttman, N. B., J. R. Wallis, and J. R. M. Hosking, 1992. Spatial Comparability of the Palmer Drought Severity Index, Water Resources Bulletin,28,1111–1119.

Guttman, N.B., 1999. “Accepting the standardized precipitation index: a calculation algorithm”. Journal of the American Water Resources Association 35(2): 311–322.

Harun, S., Hanapi, M. N., Shamsuddin, S., Mohd Amin, M. Z., and Ismail, N. A., 2008. Regional Climate Scenarios Using a Statistical Downscaling Approach. Technical Report, Universiti Teknologi Malaysia, Skudai. 1-91pp.

Hasan, M.A., Islam, A.K.M.S., and Bokhtiar, S.M., 2013. Future Changes of Meteorological Drought over Bangladesh using High Resolution Climate Scenarios, International Conference on Climate Change Impact and Adaptation (I3CIA-2013), Center for Climate Change and, Sustainability Research (3CSR), Department of Civil Engineering, DUET - Gazipur, Bangladesh.

Hasan, M.A., Islam, G.M.S., Islam, T., Bala, S.K., Paul, S., Billah, M., Rahman, M.M. and Fahad, M.G.R., 2015. A Comparative Analysis of CMIP3 and CMIP5 Climate Projections over Bangladesh. 5th International Conference on Water and Flood Management, Dhaka, 6-8 March 2015, 573-580.

Hasan, M.A., Paul, S., Islam, A.K.M. S., Islam, G.M.T., Bala, S.K., Billah, M., Md. Rahman, M.M., Fahad, M.G.R., and Pavel, M.A.A., 2014. Changes of Rainfall in The Future over Bangladesh Simulated by a High Resolution Regional Climate Model Considering The RCP Scenarios, 2nd International Conference on Advances in Civil Engineering 26 –28 Dec, 2014 CUET, Chittagong, Bangladesh.

Hasan, MA, Islam, AS, and Bhaskaran, B., 2013. Predicting change of future climatic extremes over Bangladesh in high resolution climate change scenarios, In Proceedings 4th International Conference on Water & Flood Management (ICWFM-2013). Dhaka, Bangladesh: 4-6th October 2013a. 583-590 p.

Hassan, Z., and Harun, S., 2012. Application of Statistical Downscaling Model for Longlead Rainfall Prediction in Kurau River Catchment of Malaysia, Malaysian Journal of Civil Engineering 24(1):1-12 (2012).

Hay, L.E., Wilby, R.L. and Leavesley, G.H., 2000. A comparison of delta change and downscaled GCM scenarios for three mountainous basins in the United States. Journal of the American Water Resources Association, 36, 387–397.

Haylock MR, Cawley GC, Harpham C, Wilby RL, Goodess CM., 2006. Downscaling heavy precipitation over the UK: a comparison of dynamical and statistical methods and their future scenarios. International Journal of Climatology 26: 1397–1415.

Heddinghaus, T.R. & Sabol, P., 1991. A Review of the Palmer Drought Severity Index and Where Do We go from Here? Proceedings of the 7th Conference on Applied Climatology, ‘91, American Meteorological Society, Boston, 242-246.

Hibbard KA, Meehl G, Cox P, Friedlingstein P, 2007. A strategy for climate change stabilization experiments. Eos 88, 217–221.

Hijioka Y et al., 2008. Global GHG emission scenarios under GHG concentration stabilization targets. J Glob Environ Eng 13:97–108.

Hossain, B.M.T.A., Rahaman, A.Z., Ahmed, T., Rashid, M.A., Haq, M.M.U., 2017, Assessment of Drought Characteristics in Bangladesh, 6th International Conference on Water and Flood Management, Institute of Water and Flood Management, BUET, Dhaka, Bangladesh.

Huang, J., Zhang, J., Zhang, Z., Xu, C.,Wang, B., Yao, J., 2011. Estimation of future precipitation change in theYangtze River basin by using statistical downscaling method. Stoch. Environ. Res. Risk A25(6), 781–792.

Huntingford, C. and J. Gash, 2005. Climate equity for all. Science, 309, 1789.

Huq, S., 2001. Climate Change and Bangladesh, Science

IPCC, 2007. Climate Change 2007: Impacts, Adaptation and Vulnerability: Contribution of Working Group II to the Fourth Assessment Report of the Intergovernmental Panel on Climate Change, Cambridge University Press, Cambridge, U.K. and New York, NY.

IPCC, 2013. Climate Change 2013: The Physical Science Basis, Summary for Policymakers. Contribution of the Working Group I to the Fifth Assessment Report of the Intergovernmental Panel on Climate Change, Cambridge University Press, Cambridge.

Islam, AS, and Hasan, MA., 2012. Climate induced changes of precipitation extremes over Bangladesh. In Proceedings of 3rd International Conference on Environmental Aspects of Bangladesh (ICEAB 2012). Japan: 2012. 67-105 p.

Islam, M.N., 2009. Rainfall and Temperature Scenario for Bangladesh, The Open Atmospheric Science Journal, 2009, 3, 93-103, 294 (5547), 1617. [doi: 10.1126/science.294.5547.1617]

Islam, M.N., Rafiuddin, M., Ahmed, A. U., and Kolli, R.K., 2008. Calibration of PRECIS in employing future scenarios in Bangladesh, Int. J. Climatol. 28: 617–628.

Israt, A., Matin, I., Rahman, M., and Banu D.A., 2012. Analysis of Drought in Eastern Part of Bangladesh, Daffodil International University Journal of Science and Technology, Volume 7, Issue 1, January 2012.

Karim, Z., Ibrahim, A., Iqbal, A. and Ahmed, M., 1990. Drought in Bangladesh agriculture and irrigation schedule for major crops, Bangladesh Agricultural Research Center (BARC) Publication No. 34, Dhaka, Bangladesh.

Karl, T.R. & Knight, R.W., 1985, Atlas of Monthly Palmer Hydrological Drought Indices (1931-1983) for the Contiguous United States, Historical Climatology Series 3-7, National Climatic Data Center, Asheville, NC.

Kreft, S., Eckstein, D., Dorsch, L. and Fischer, L., 2016. "Global Climate Risk Index 2016, Who Suffers Most From Extreme Weather Events? Weather related Loss Events in 2014 and 1995 to 2014", Germanwatch, ISBN 978-3-943704-37-2.

Li, Y., and Yan, X., 2017. Statistical downscaling of monthly mean temperature for Kazakhstan in Central Asia, Climate Research, Vol. 72: 101–110, 2017, https://doi.org/10.3354/cr01456

Liu XL, Coulibaly P, Evora N., 2008. Comparison of data-driven methods for downscaling ensemble weather forecasts. Hydrology and Earth System Sciences 12: 615–624

Liu Z, Xu Z, Charles SP, Fu G, Liu L., 2011. Evaluation of two statistical downscaling models for daily precipitation over an arid basin in China. International Journal of Climatology 31: 2006–2020.

Mahmood, R., Babel, M., 2013. Evaluation of SDSM developed by annual and monthly sub-models for downscaling temperature and precipitation in the Jhelum basin, Pakistan and India. Theor. Appl. Climatol. 113(1–2), 27–44.

Mardy, T., Uddin, M.N., Sarker, M.A., Roy, D., Emily, D., and Dunn, S., 2018. Assessing Coping Strategies in Response to Drought: A Micro Level Study in the North-West Region of Bangladesh, Climate2018, 6, 23; doi: 10.3390/cli6020023.

May, W., and E. Roeckner, 2001. A time-slice experiment with the ECHAM4 AGCM at high resolution: The impact of horizontal resolution on annual mean climate change. Clim. Dyn., 17, 407–420.

McKee TB, Doesken NJ, Kleist J., 1995. Drought monitoring with multiple time scales. Ninth Conference on Applied Climatology, American Meteorological Society, 15–20 Jan, 1995, Dallas TX, pp 233–236.

McSweeney, C.F., Jones, R.G., Lee, R.W.,·Rowell, D.P., 2015. Selecting CMIP5 GCMs for downscaling over multiple regions, Clim Dyn (2015) 44:3237–3260, DOI 10.1007/s00382-014-2418-8.

Met Office, 2011. Climate: Observations, projections and impacts: Bangladesh, FitzRoy Road, Exeter, Devon, EX1 3PB, United Kingdom.

MoEF, 2005. National Adaptation Programme of Action, Ministry of Environment and Forests, Government of the People's Republic of Bangladesh, Bangladesh.

MoEF, 2009. Bangladesh Climate Change Strategy and Action Plan, Ministry of Environment and Forests, Government of the People's Republic of Bangladesh, Bangladesh.

Mohammed, Y., 2009. "Climate Change Impact Assessment on Soil Water Availability and Crop Yield in Anjeni Watershed Blue Nile Basin", Master Thesis, Arba Minch University, Ethiopia. 1 123pp..

Mondol, M.A.H., Al-Mamun, Iqbal, M., and Jang, D.H., 2018. Precipitation Concentration in Bangladesh over Different Temporal Periods, Hindawi Advances in Meteorology Volume 2018, Article ID 1849050, 18 pages, **https://doi.org/10.1155/2018/1849050**.

Mondol, M.A.H., Ara, I., and Das, S.C., 2017. Meteorological Drought Index Mapping in Bangladesh Using Standardized Precipitation Index during 1981–2010. Hindawi, Advances in Meteorology, Volume 2017, Article ID 4642060, 17 pages, https://doi.org/10.1155/2017/4642060

Moriasi, D. N., Arnold J. G., Van Liew M. W. and R. D. Bingner, 2002. Model evaluation guidelines for systematic quantification of accuracy in watershed simulations. Trans. ASABE 50(0), 885{890}.

Moriasi, D., Arnold, J., Van Liew, M., Bingner, R., Harmel, R., & Veith, T., 2007. Model evaluation guidelines for systematic quantification of accuracy in watershed simulations. Trans. ASABE, 50(3), 885-900. **http://dx.doi.org/10.13031/2013.23153**

Moss RH, Edmonds JA, Hibbard KA, Manning MR, Rose SK, van Vuuren DP, Carter TR, Emori S, Kainuma M, Kram T et al., 2010. The next generation of scenarios for climate change research and assessment. Nature 463,747–756.

Mukherjee, N., Khan, M. F. A., Hossain, B. M. T., Islam, A. K. M. S., Aktar, M. N., & Rahman, S., 2011. A hybrid approach for climate change scenario generation for Bangladesh using GCM model results. In Third International Conference on Water & Flood Management, Institute of Water and Flood Management (IWFM), BUET, Dhaka.

Nowreen, S., Murshed, S.B., Islam, A. K. M. S., Bhaskaran, and Hasan, M.A., 2014. Changes of rainfall extremes around the haor basin areas of Bangladesh using multi-member ensemble RCM, Theor Appl Climatol. DOI 10.1007/s00704-014-1101-7.

Nury, A.H., and Alam, M.J.B., 2014. Performance Study of Global Circulation Model HADCM3 Using SDSM for Temperature and Rainfall in North-Eastern Bangladesh, Journal of Scientific Research, J. Sci. Res. 6 (1), 87-96 (2014).

NWMP, 2001. National Water Management Plan, Water Resources Planning Organization, Government of the People’s Republic in Bangladesh.

Palmer, W.C. (1965). Meteorological drought. Research Paper 45, U.S. Dept. of Commerce, 58 pp.

Parthasarathy, B., Kumar, K.R., Deshpande, V.R., 1991. Indian summer monsoon rainfall and 200-mbar meridional wind index: application for long-range prediction. Int. J. Climatol. 11 (2), 165–176

Pervez, M.S. and Henebry, G.M., 2014. "Projections of the Ganges–Brahmaputra precipitation Downscaled from GCM predictors", Journal of Hydrology 517 (2014) 120–134, DOI: http://dx.doi.org/10.1016/j.jhydrol.2014.05.016.

PKSF, 2014. Development of National and Sub-national Model for Long Term Water Availability Assessment in Ganges-Brahmaputra-Meghna (GBM) Basins due to Climate Change Impact, Palli Karma Sahayak Foundation, Agargaon, Dhaka, Bangladesh.

Rafiuddin, M., Uyedaa, H., and Islam, M.N., 2010. Characteristics of monsoon precipitation systems in and around Bangladesh, Int. J. Climatol.30: 1042 – 1055 (2010).

Rahaman, A.Z., Khan, M.F.A., Aktar, M.N., Hossain, B.M.T.A., Akand, M.K. and Noor, F., 2015. "Climate change scenarios of Bangladesh using statistical downscaling model (SDSM)" in 5th International Conference on Water & Flood Management (ICWFM-2015), Institute of Water and Flood Management (IWFM), BUET, Dhaka, Bangladesh.

Rahaman, K.M., Ahmed, F.R.S., and Islam, M.N., 2016. Modeling on climate induced drought of north-western region, Bangladesh, Model. Earth Syst. Environ. (2016) 2:45, DOI 10.1007/s40808-016-0089-7.

Rahman, M. A., Kamal, S. M., and Billah, M. M., 2016. "Rainfall Variability and Linear Trend Models on North-West Part of Bangladesh for the Last 40 Years," American Journal of Applied Mathematics, 2016; 4(3): 158-162.

Rahman, M. A., Kamal, S. M., and Billah, M. M., 2017. "Prediction and Trends of Rainfall Variability over Bangladesh," American Journal of Applied Mathematics, 2017; 5(1): 54-59, 2017.

Rahman, M.R., and Lateh, H., 2016. Meteorological drought in Bangladesh: assessing, analyzing and hazard mapping using SPI, GIS and monthly rainfall data, Environ Earth Sci (2016) 75:1026, DOI 10.1007/s12665-016-5829-5

Rahman, MM, Islam, MN, Ahmed, AU, and Georgi, F., 2012. Rainfall and temperature scenarios for Bangladesh for the middle of 21st century using RegCM. Journal of earth system science, 121(2): 287-295.

Rajib, M.A., and Rahman, M.M., 2012. A Comprehensive Modeling Study on Regional Climate Model (RCM) Application — Regional Warming Projections in Monthly Resolutions under IPCC A1B Scenario, Atmosphere 2012, 3, 557-572; doi:10.3390/atmos3040557.

Rajib, MA, Rahman, MM, Islam, AS, and McBean, EA., 2011. Analyzing the Future Monthly Precipitation Pattern in Bangladesh from Multi-Model Projections Using Both GCM and RCM. In Proceedings Reston, VA: ASCE copyright Proceedings of the 2011 World Environmental and Water Resources Congress; May 22. 26, 2011, Palm Springs, California| d 201100002011. American Society of Civil Engineers.

Ramamasy, S., and Baas, S., 2007. Climate Variability and Change: Adaptation to Drought in Bangladesh; Asian Disaster Preparedness Centre and Food and Agriculture Organization of the United Nations: Rome, Italy.

Ramírez-Villegas, J. and Thornton, P. K., 2015. Climate change impacts on African crop production. Working Paper No. 119. CGIAR Research Program on Climate Change, Agriculture and Food Security (CCAFS), Copenhagen, Denmark. Available at: **http://hdl.handle**. net/10568/66560.

Rashid HE. 1991. Geography of Bangladesh. University Press Ltd:, Dhaka; 579

Riahi K, Grübler A, Nakicenovic N., 2007. Scenarios of long-term socio-economic and environmental development under climate stabilization. Technol Forecast Soc Chang 74,887–935.

Rossi, C. G., Dybala, T. J., Moriasi, D. N., Arnold, J. G., Amonett, C., & Marek, T., 2008. Hydrologic calibration and validation of the Soil and Water Assessment Tool for the Leon River watershed. Journal of soil and water conservation, 63(6), 533-541.

Rouf, M. A., Uddin, M. K., Debsarma, S. K., and Rahman, M.M., 2011. Climate of Bangladesh: An Analysis of Northwestern and Southwestern Part Using High Resolution Atmosphere-Ocean General Circulation Model (AOGCM), The Agriculturists 9(1&2): 143-154(2011), ISSN-1729-5211.

Roy, D., Samad, M.A., and Hassan, S.M., 2018. Simulation of Monsoon Low Pressure System and its Associated Rainfall Over Bangladesh Using WRF Model, Dhaka Univ. J. Sci. 66(1): 29-35, 2018 (January).

Salvi, K., Kannan, S., and Ghosh, S., 2011. International Conference on Environmental and Computer Science IPCBEE vol.19 (2011), Singapore.

Selvaraju, R., Subbiah, A. R., Baas, S. andJuergens, I., 2006. Livelihood adaptation to climate variability and change in drought-prone areas of Bangladesh. Developing institutions and options. Institutions for Rural Development (FAO).

Shahid S., 2008. Spatial and Temporal Characteristics of Droughts in the Western Part of Bangladesh. Hydrol. Proc., 22(13), 2235-2247.

Shahid S., 2010. Recent trends in the climate of Bangladesh. Climate Res., 42, 185-193.

Shahid, S., 2010a. Probable impacts of climate change on public health in Bangladesh. Asia-Pacific Journal of Public Health, 22(3): 310-319.

Shahid, S., 2010b. Rainfall variability and the trends of wet and dry periods in Bangladesh. International Journal of Climatology, 30(15): 2299-2313.

Shahid, S., 2011. Trends in extreme rainfall events of Bangladesh. Theoretical and applied climatology, 104(3-4): 489-499.4

Solomon, S., Qin, D., Manning, M., Chen, Z., Marquis, M., Averyt, K.B., Tignor, M. and Miller H.L.(eds.), 2007. "Climate Change 2007: The Physical Science Basis. Contribution of Working Group I to the Fourth Assessment Report of the Intergovernmental Panel on Climate Change", Cambridge University Press, Cambridge, United Kingdom and New York, NY, USA.

Stephenson DB., Douville H., Rupa Kumar K., 2001. Searching for a fingerprint of global warming in the Asian summer monsoon. MaUSm 52: 213–220.

Stocker, T.F., Qin, D., Plattner, G.K., Tignor, M., Allen, S.K., Boschung, J., Nauels, A., Xia, Y., Bex, V. and Midgley, P.M. (eds.), 2013. "Evaluation of Climate Models. In: Climate Change 2013: The Physical Science Basis. Contribution of Working Group I to the Fifth Assessment Report of the Intergovernmental Panel on Climate Change", Cambridge University Press, Cambridge, United Kingdom and New York, NY, USA.

Tavakol-Davani, H., Nasserib, M., and Zahraiec, B., 2013. Improved statistical downscaling of daily precipitation using SDSM platform and data-mining methods, Int. J. Climatol. 33: 2561–2578 (2013).

Tripathi, S., Srinivas, V.V., Nanjundiah, R.S., 2006. Downscaling of precipitation for climate change scenarios: A support vector machine approach. Journal of Hydrology, 330, 621-640.

UNDP, FAO (1988a). Land Resources appraisal of Bangladesh for agricultural development, Report 2, Agroecological regions of Bangladesh, Dhaka, Ministry of Agriculture.

UNDP, FAO (1988b). Land Resources appraisal of Bangladesh for agricultural development, Report 6, Land suitability assessment, Dhaka, Ministry of Agriculture.

Van Vuuren ,Jae Edmonds, Mikiko Kainuma, Keywan Riahi, Allison Thomson, Kathy Hibbard, George C. Hurtt, Tom Kram, Volker Krey, Jean-Francois Lamarque, Toshihiko Masui, Malte Meinshausen, Nebojsa Nakicenovic, Steven J. Smith, Steven K. Rose, 2011a.The representative concentration pathways, an overview, Climatic Change, 109, 5–31.

Van Vuuren DP, Riahi K, 2011b. The relationship between short-term emissions and long-term concentration targets—a letter. Climatic Change 104, Issue 3–4, 793–801.

von Storch, H., and F.W. Zwiers, 1999. Statistical Analysis in Climate Research, Cambridge University Press, ISBN 0 521 45071 3, 528 pp.

Wells, N. (2003) PDSI Users Manual, Version 2.0, National Agricultural Decision Support System (**http://nadss.unl.edu**), University of Nebraska-Lincoln, USA.

Wells, N., Goddard, S. and Hayes, M.J. (2004). “A self-calibrating Palmer Drought Severity Index”. Journal of Climate, 17: 2335–2351.

Wilby, R. L., & Dawson, C. W., 2013. The Statistical DownScaling Model: insights from one decade of application. International Journal of Climatology 33(7), 1707-1719.

Wilby, R. L., Dawson, C. W., and Barrow, E. M., 2007. "SDSM 4.2 - A decision support tool for the assessment of regional climate change impacts", User Manual. Environment (2007), 17 (2): 1-94.

Wilby, R. L., Dawson, C. W., Murphy, C., O'Connor, P. and Hawkins, E., 2014. "The Statistical Downscaling Model − Decision Centric (SDSM-DC): conceptual basis and applications", Climate Research, Vol. 61: 259–276, 2014, DOI: 10.3354/cr01254.

Wilby, R. L., Troni, J., Biot, Y., Tedd, L., Hewitson, B. C., Smith, D. M., & Sutton, R. T., 2009. "A review of climate risk information for adaptation and development planning." International Journal of Climatology 29(9), 1193-1215.

Wilby, R.L. and Dawson, C.W., 2007. SDSM 4.2-A Decision Support Tool for the Assessment of Regional Climate Change Impacts, Version 4.2 User Manual. Lancaster University, Lancaster/Environment Agency of England and Wales, Lancaster, 1-94.

Wilby, R.L. and Wigley, T.M.L. 2000. Precipitation predictors for downscaling: observed and General Circulation Model relationships. International Journal of Climatology, 20, 641–661.

Wilby, R.L., Conway, D. and Jones, P.D. 2002. Prospects for downscaling seasonal precipitation variability using conditioned weather generator parameters. Hydrological Processes, 16, 1215-1234.

Wilby, R.L., Hay, L.E., Gutowski, W.J., Arritt, R.W., Tackle, E.S., Leavesley, G.H. and Clark, M. 2000. Hydrological responses to dynamically and statistically downscaled General Circulation Model output. Geophysical Research Letters, 27, 1199–1202.

Wilby, R.L., Tomlinson, O.J. and Dawson, C.W. 2003. Multi-site simulation of precipitation by conditional resampling. Climate Research, 23, 183-194.

Willeke, G., Hosking, J.R.M., Wallis, J.R. & Guttman, N.B., 1994. The National Drought Atlas. Institute for Water Resources Report 94-NDS-4, U.S. Army Corps of Engineers.

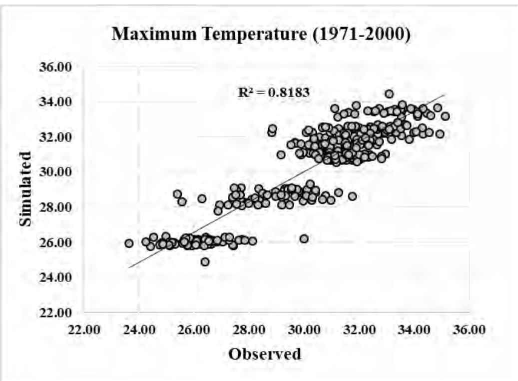
WMO and GWP, 2016. Handbook of Drought Indicators and Indices (M. Svoboda and B.A. Fuchs). Integrated Drought Management Programme (IDMP), Integrated Drought Management Tools and Guidelines Series 2. Geneva.

WMO, 2017. WMO Guidelines on the Calculation of Climate Normals, World Meteorological Organization, WMO No. 1203. CH-1211 Geneva 2, Switzerland.

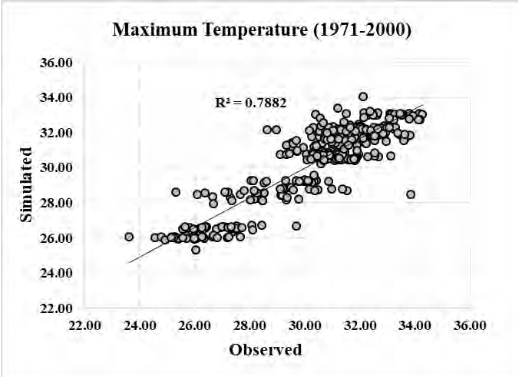
Zhao, H., Gao, G., An, W., Zou, X., Li, H., Hou, M., 2015. Timescale Differences between SC-PDSI and SPEI for Drought Monitoring in China, Physics and Chemistry of the Earth (2015), DOI: 10.1016/j.pce.2015.10.02

Appendix A: Calibration and Validation of SDSM

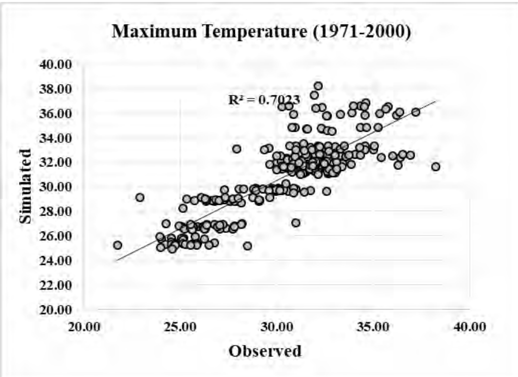
Table A1: Graphs of Performance of SDSM for Maximum Temperature in Calibration and Validation Period (1971-2000) for Full Time Series



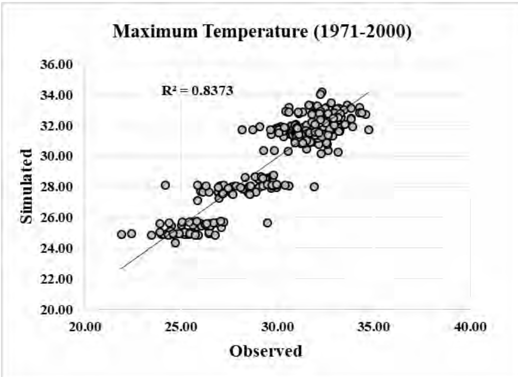
Barisal



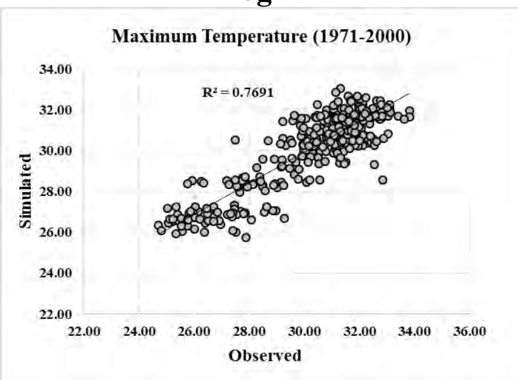
Bhola



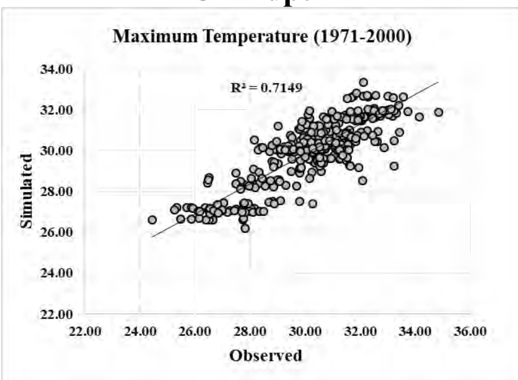
Bogra



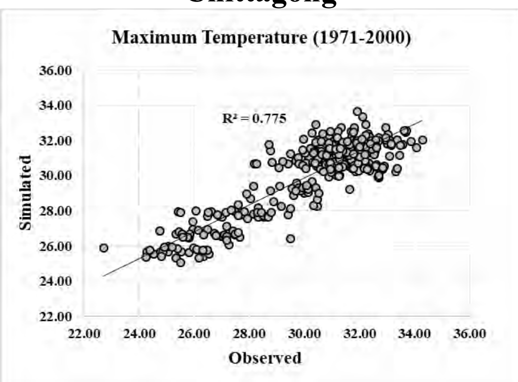
Chandpur



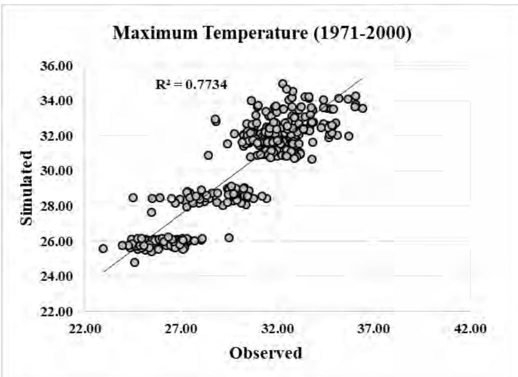
Chittagong



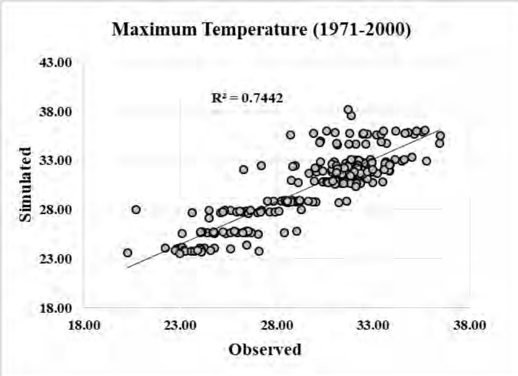
Cox's Bazar



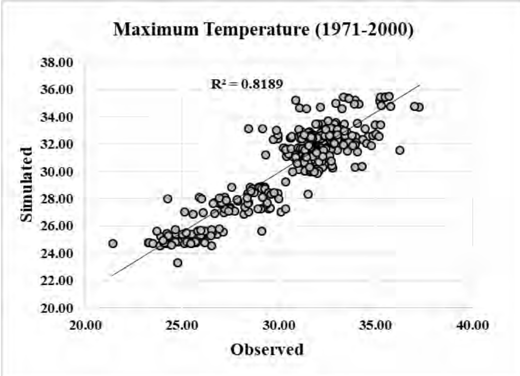
Comilla



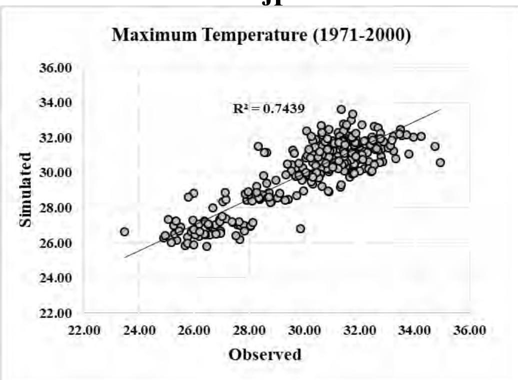
Dhaka



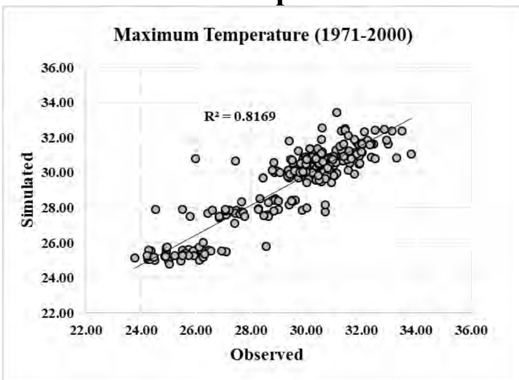
Dinajpur



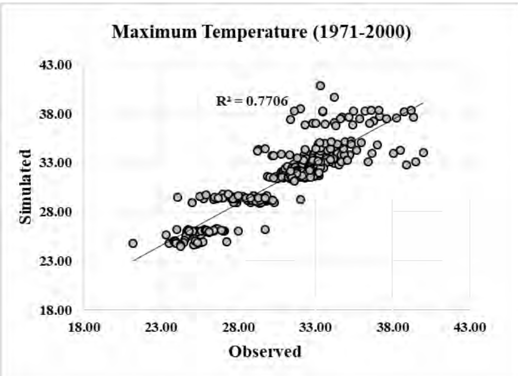
Faridpur



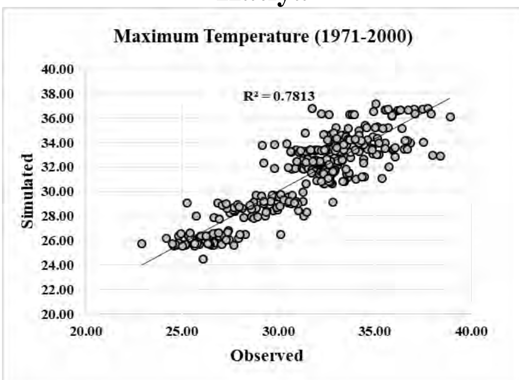
Feni



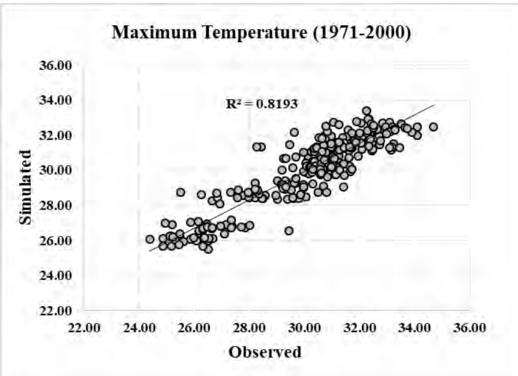
Hatiya



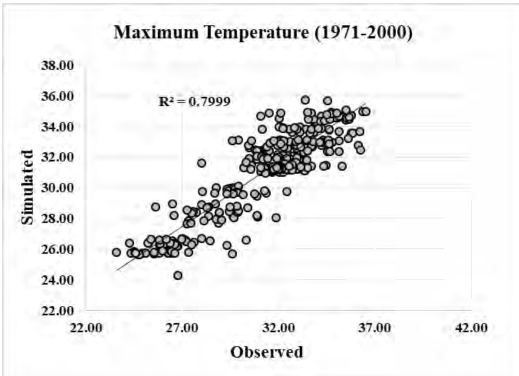
Ishawrdi



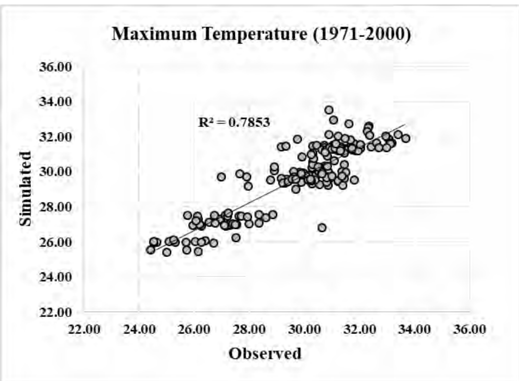
Jessore



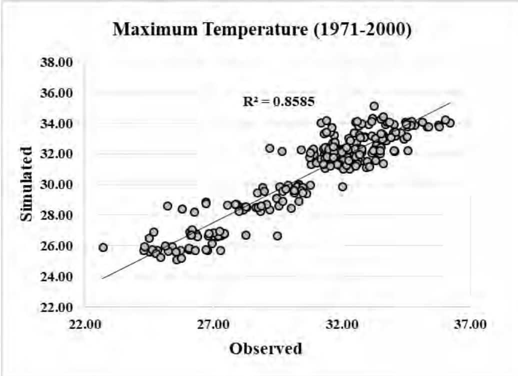
Khepupara



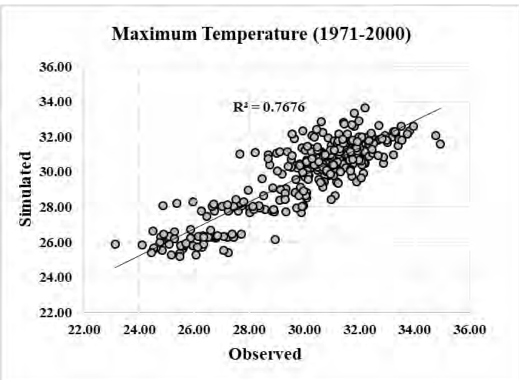
Khulna



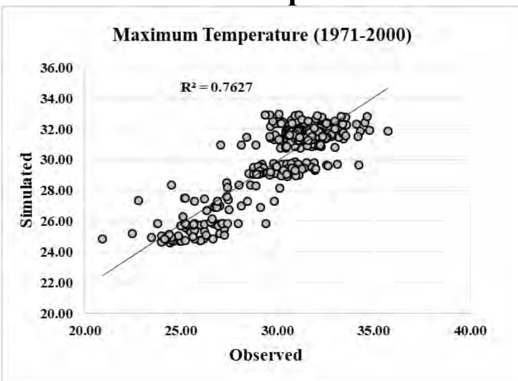
Kutubdia



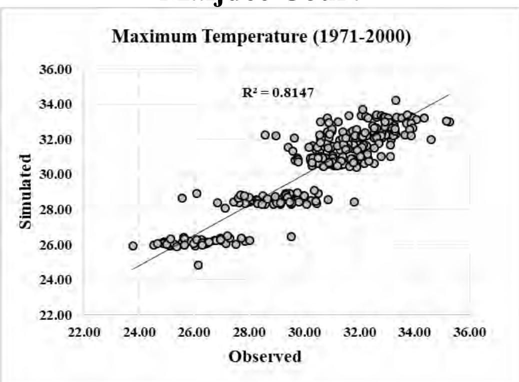
Madaripur



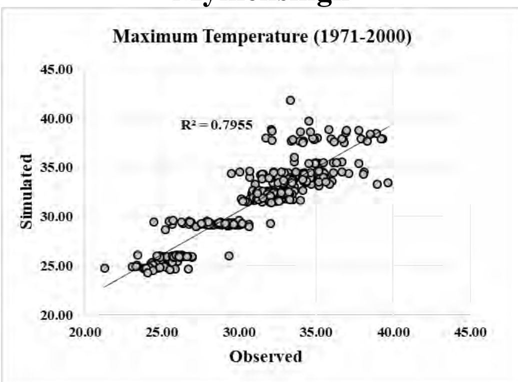
Maijdee Court



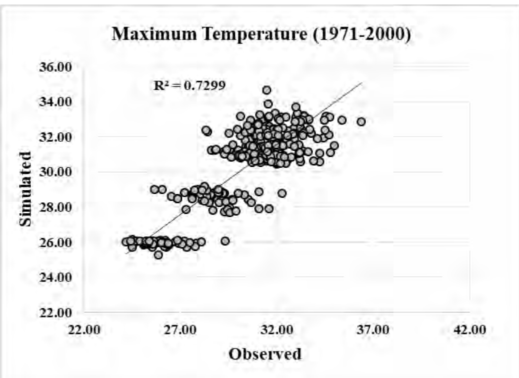
Mymensingh



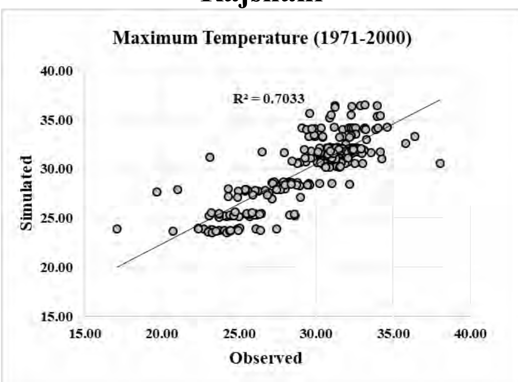
Patuakhali



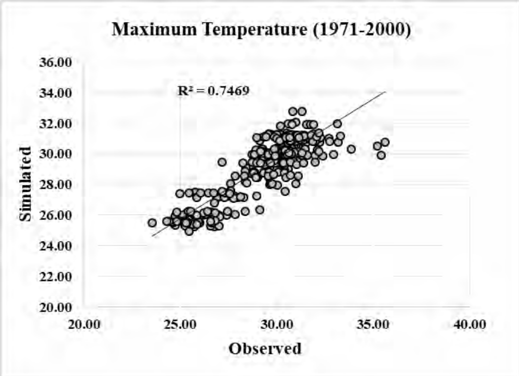
Rajshahi



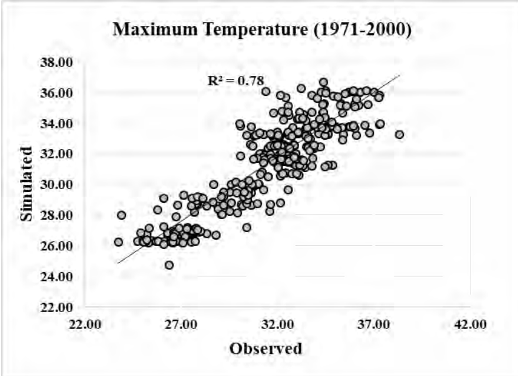
Rangamati



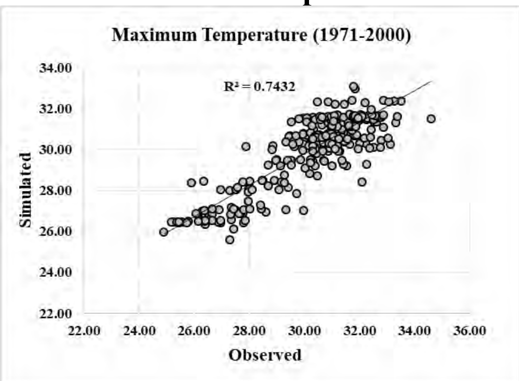
Rangpur



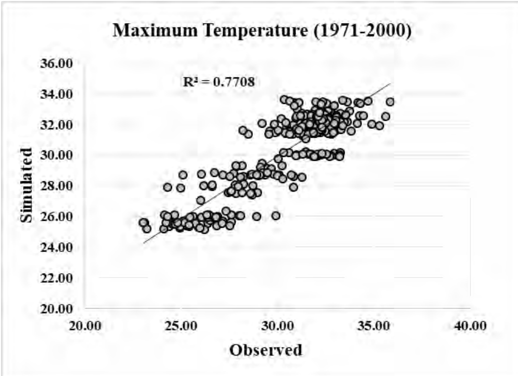
Sandwip



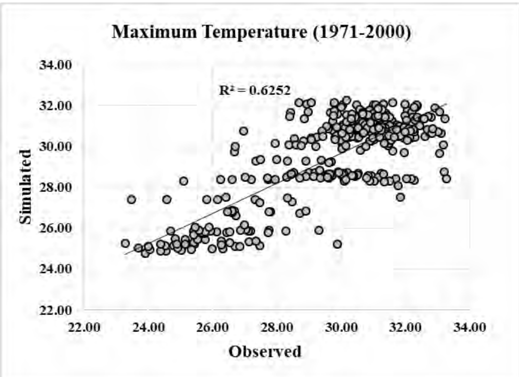
Satkhira



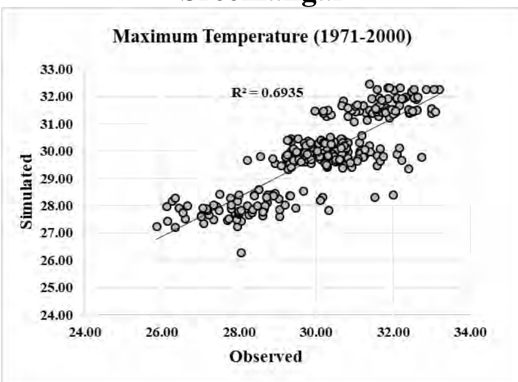
Sitakunda



Sreemangal

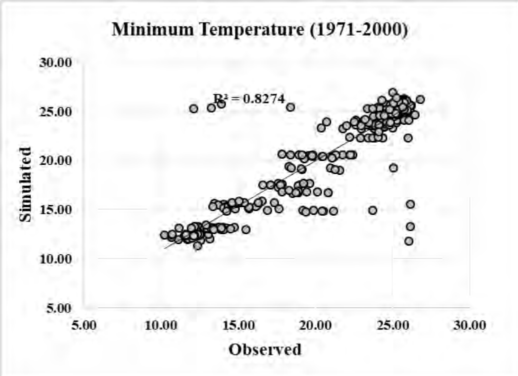


Sylhet

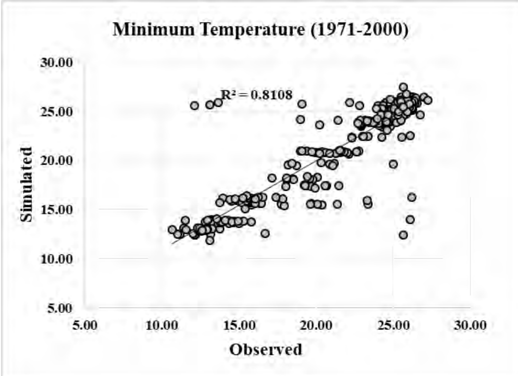


Teknaf

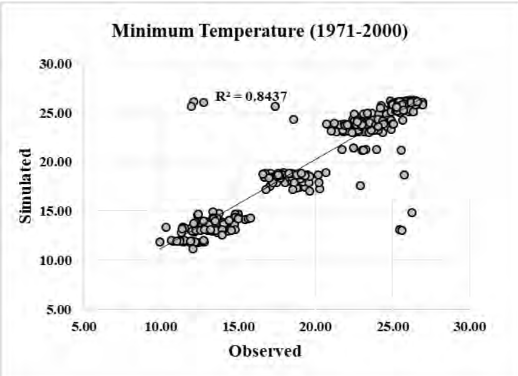
Table A2: Graphs of Performance of SDSM for Minimum Temperature in Calibration and Validation Period (1971-2000) for Full Time Series



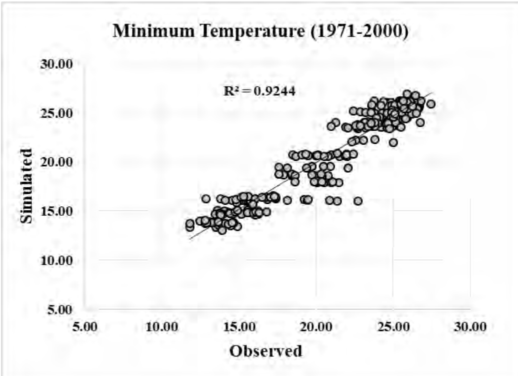
Barisal



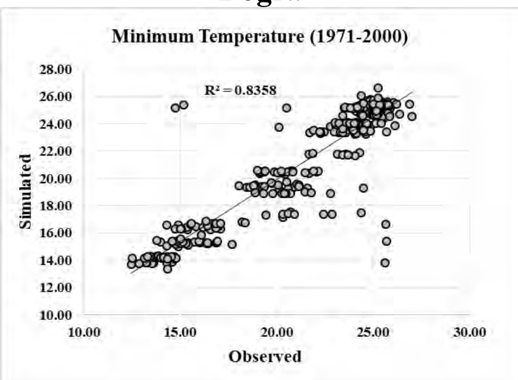
Bhola



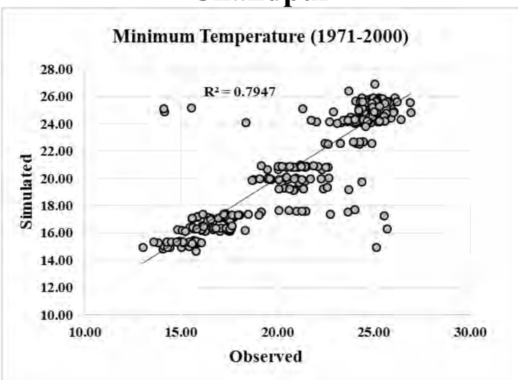
Bogra



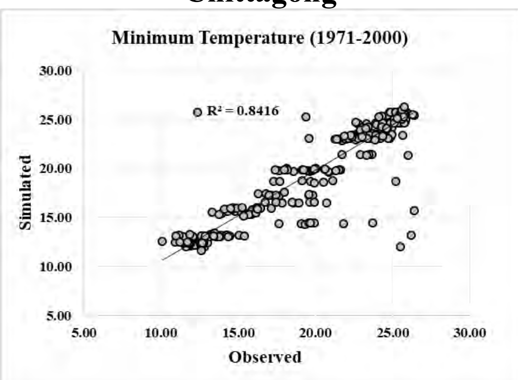
Chandpur



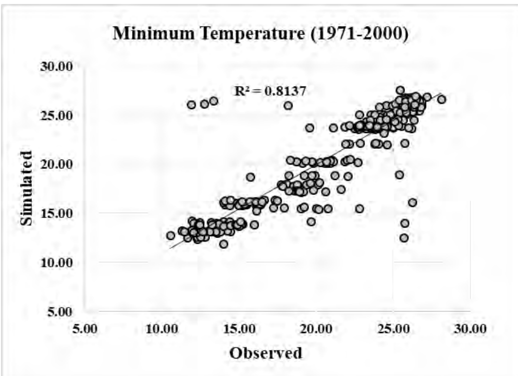
Chittagong



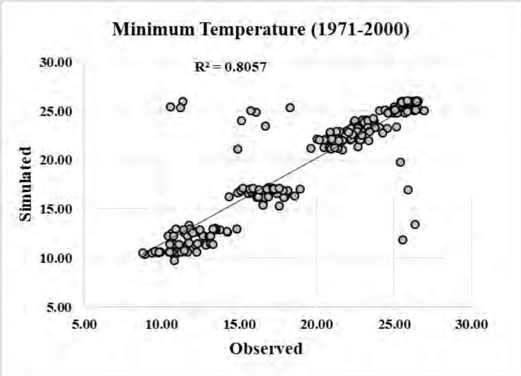
Cox's Bazar



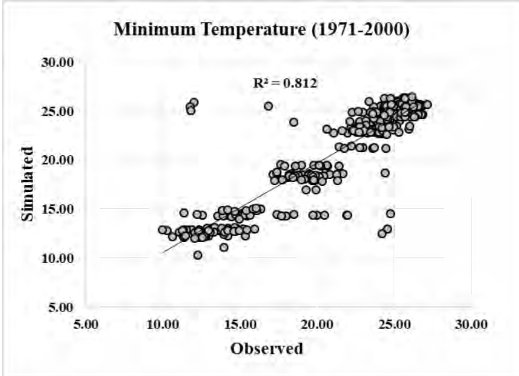
Comilla



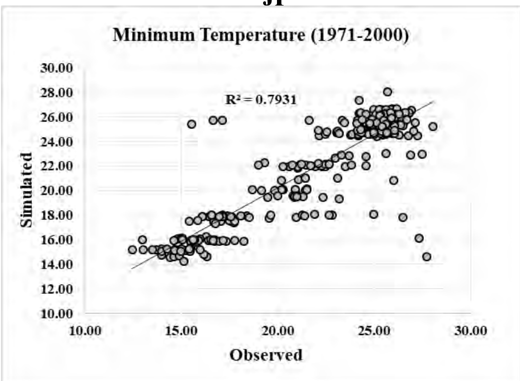
Dhaka



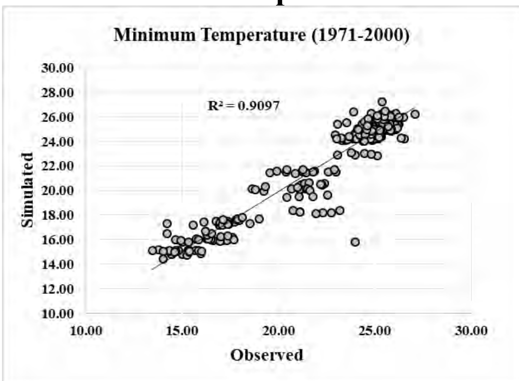
Dinajpur



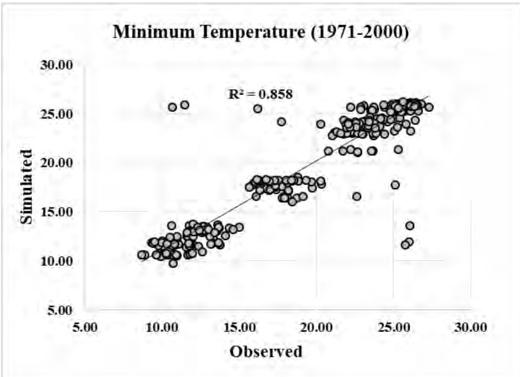
Faridpur



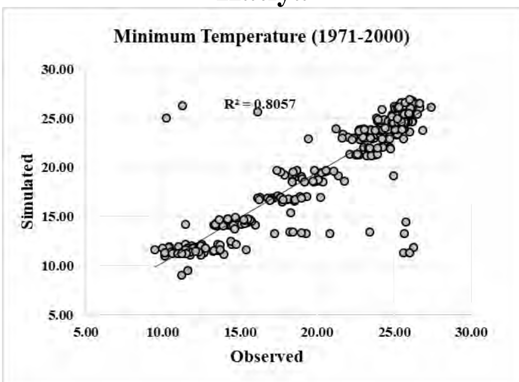
Feni



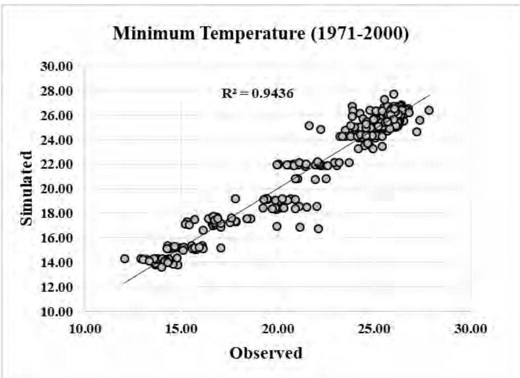
Hatiya



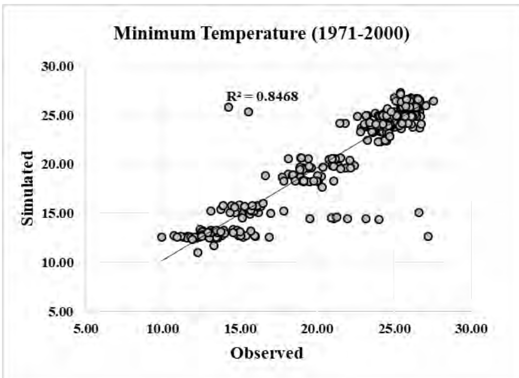
Ishawrdi



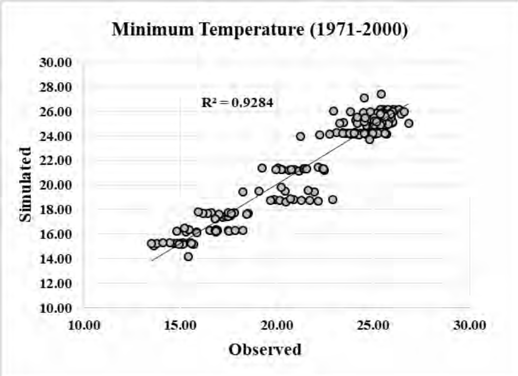
Jessore



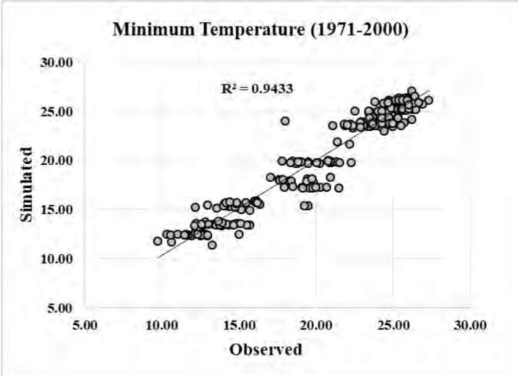
Khepupara



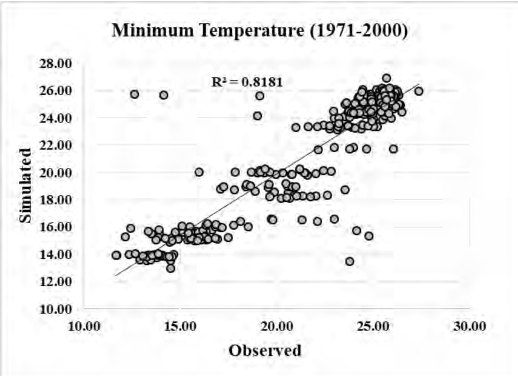
Khulna



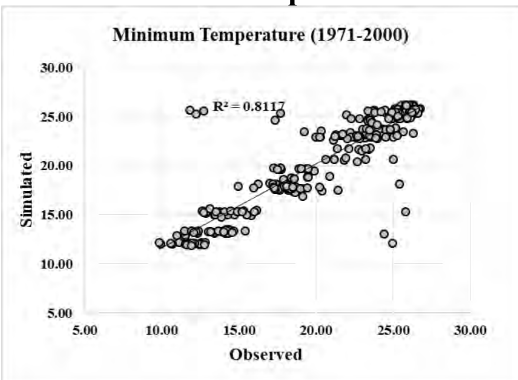
Kutubdia



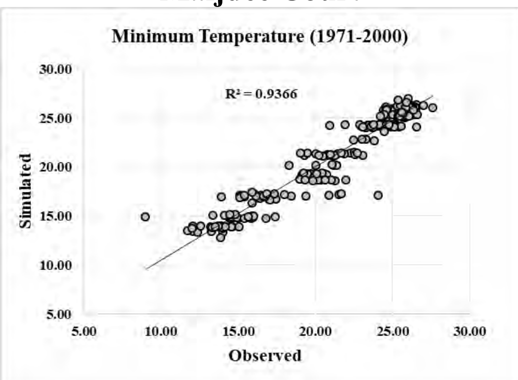
Madaripur



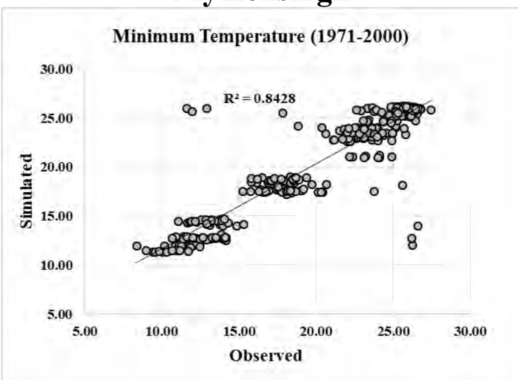
Maijdee Court



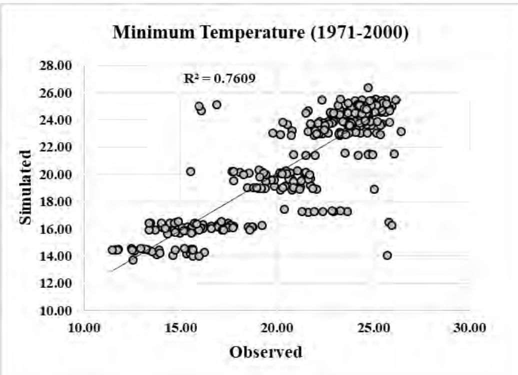
Mymensingh



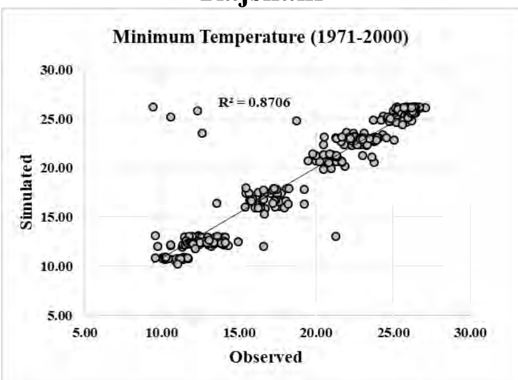
Patuakhali



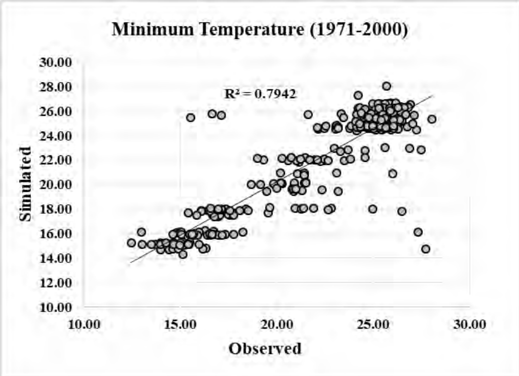
Rajshahi



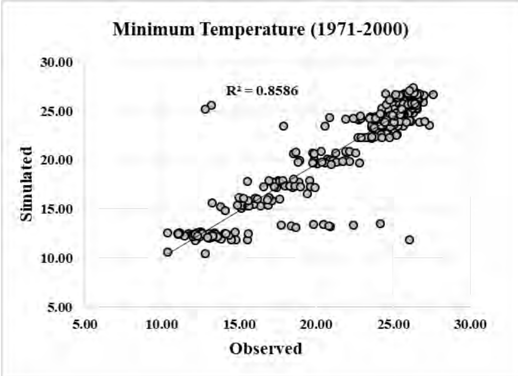
Rangamati



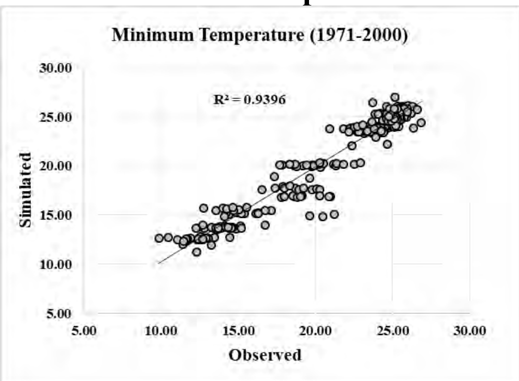
Rangpur



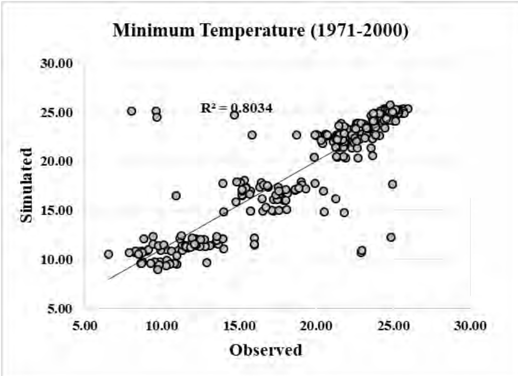
Sandwip



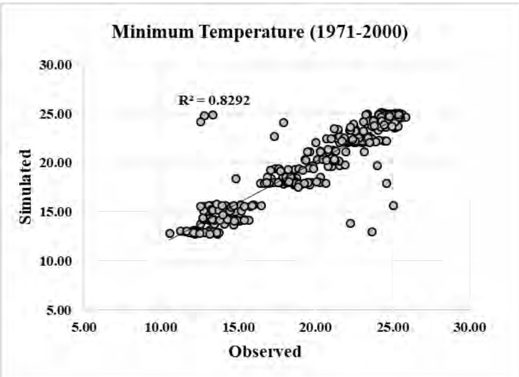
Satkhira



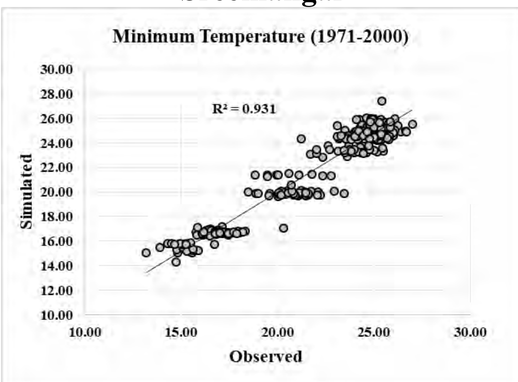
Sitakunda



Sreemangal

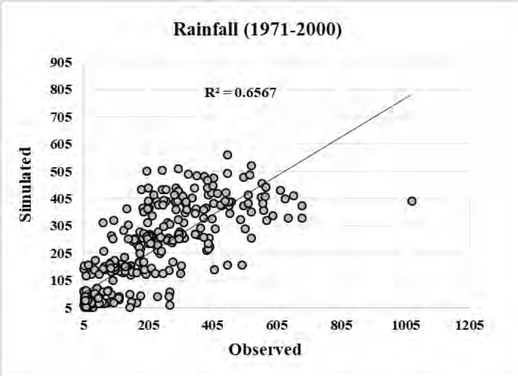


Sylhet

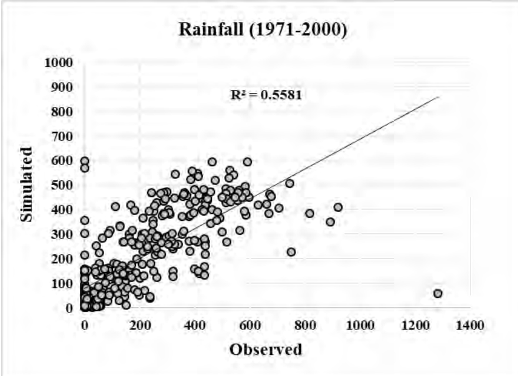


Teknaf

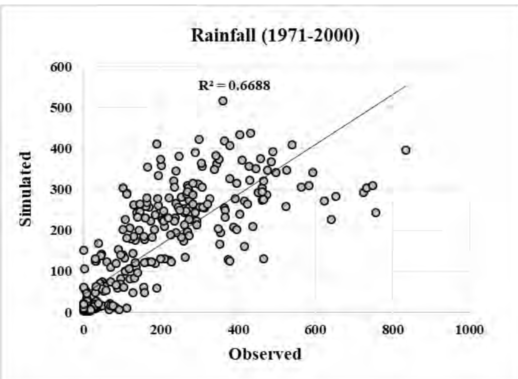
Table A3: Graphs of Performance of SDSM for Rainfall in Calibration and Validation Period (1971-2000) for Full Time Series



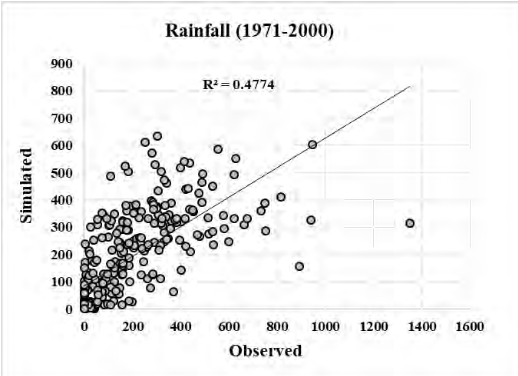
Barisal



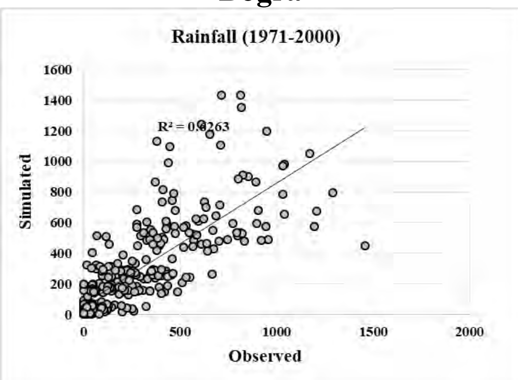
Bhola



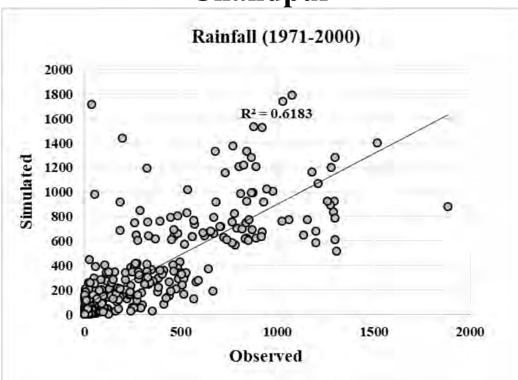
Bogra



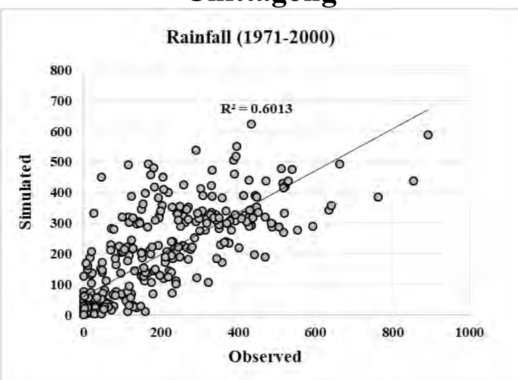
Chandpur



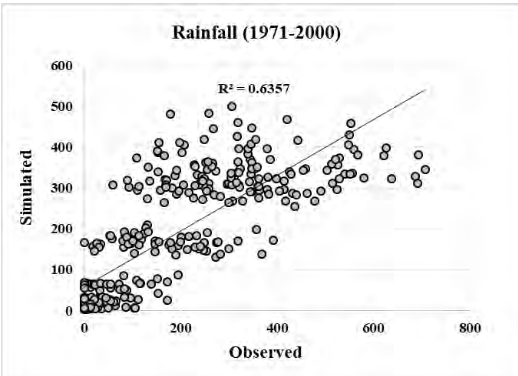
Chittagong



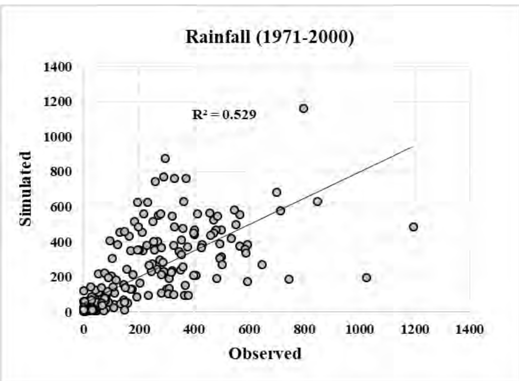
Cox's Bazar



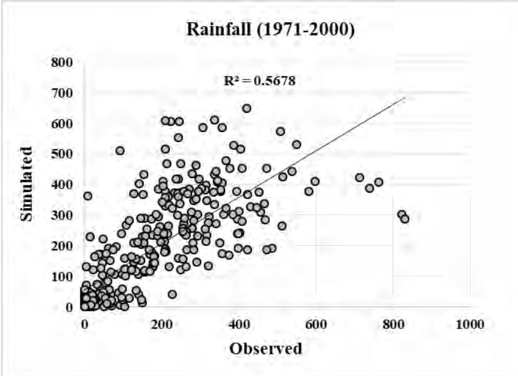
Comilla



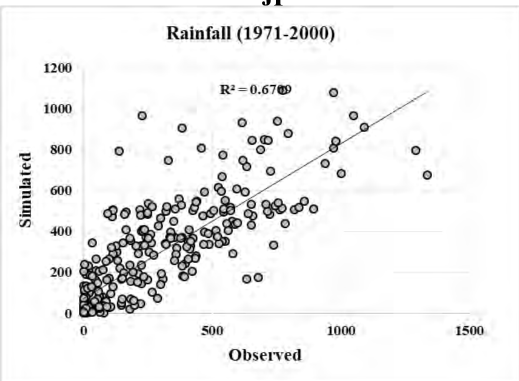
Dhaka



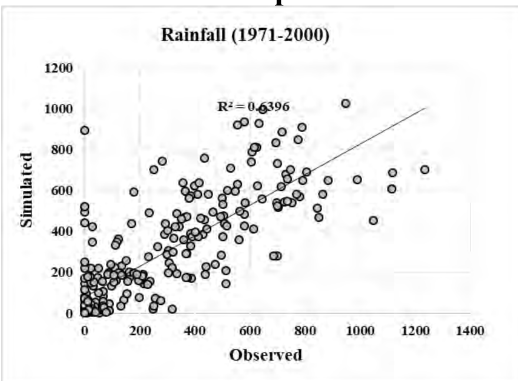
Dinajpur



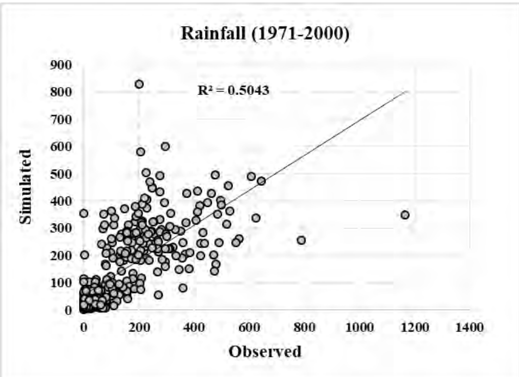
Faridpur



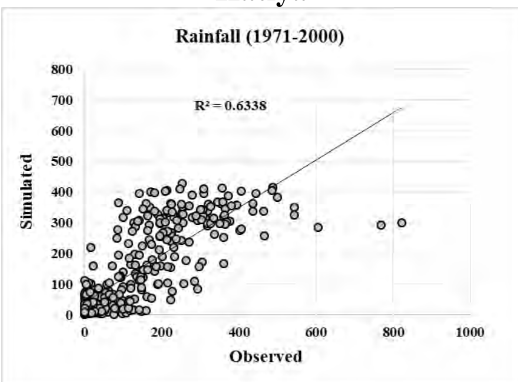
Feni



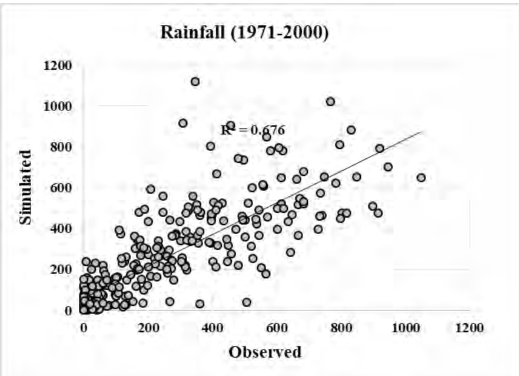
Hatiya



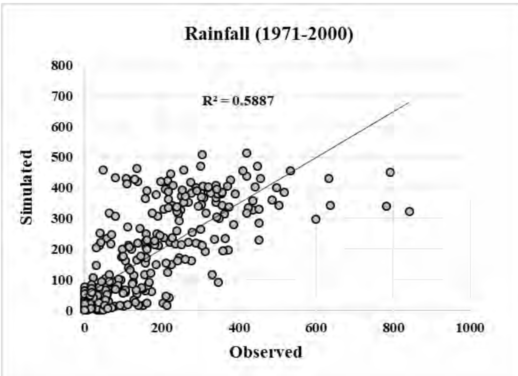
Ishawrdi



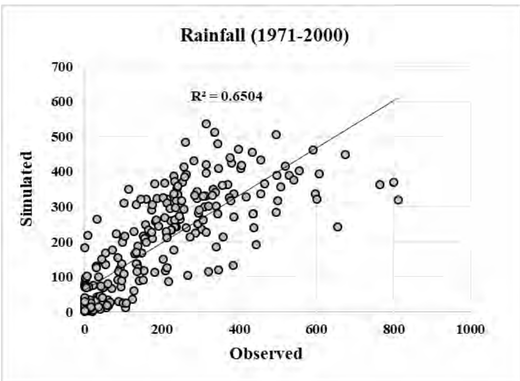
Jessore



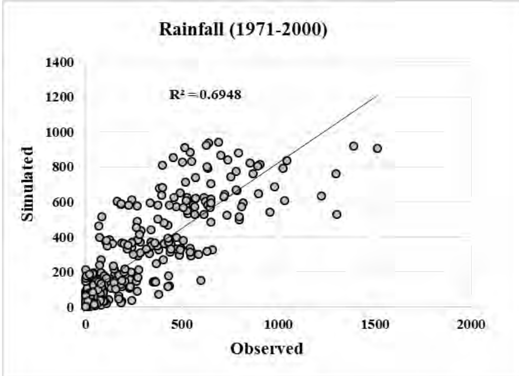
Khepupara



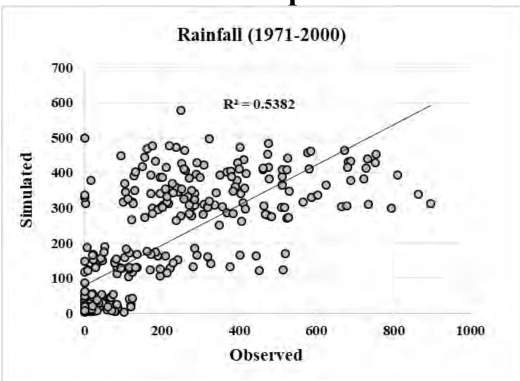
Khulna



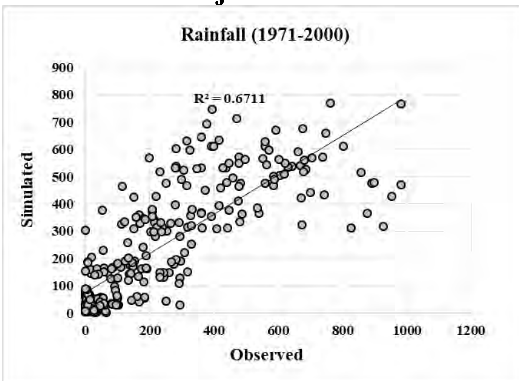
Madaripur



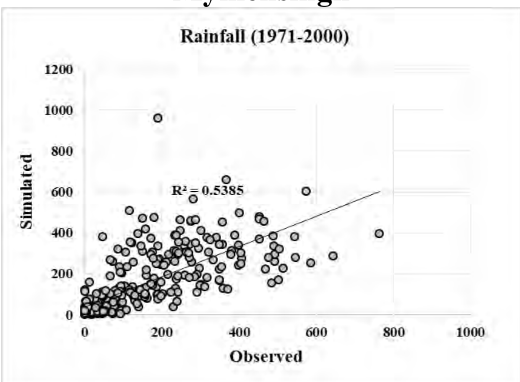
Maijdee Court



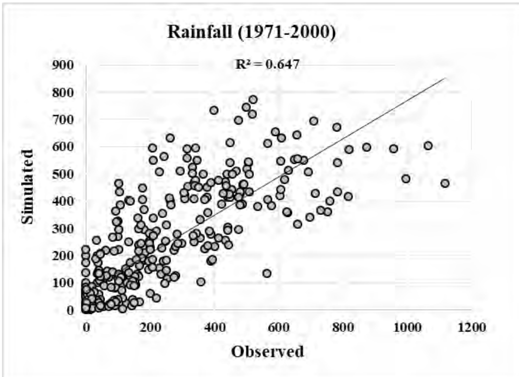
Mymensingh



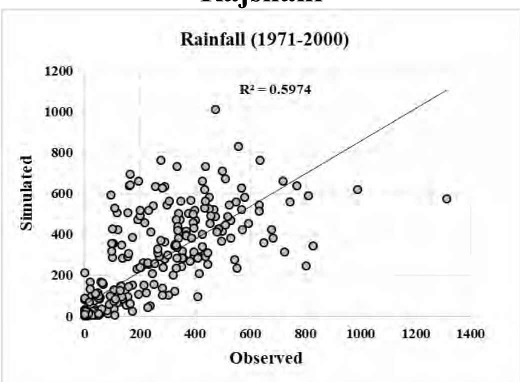
Patuakhali



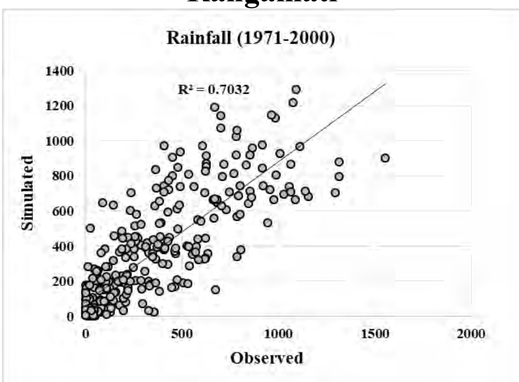
Rajshahi



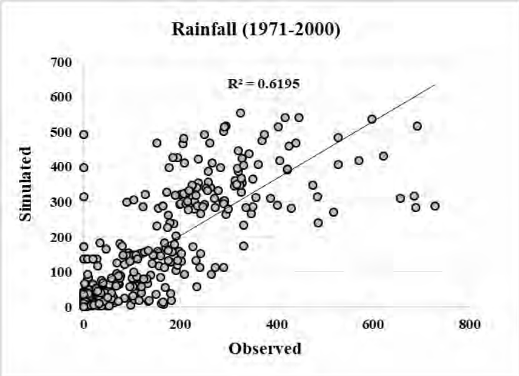
Rangamati



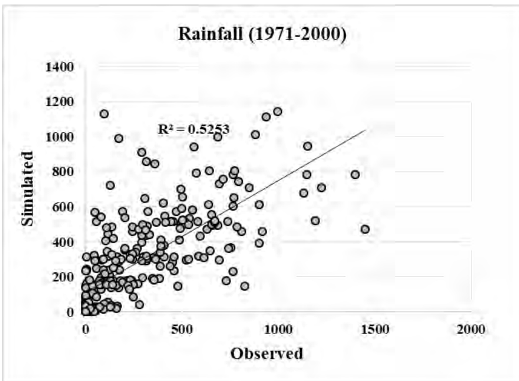
Rangpur



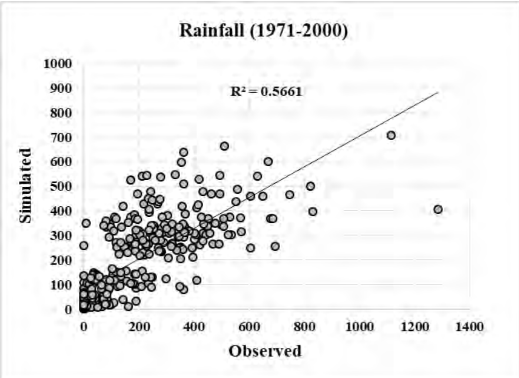
Sandwip



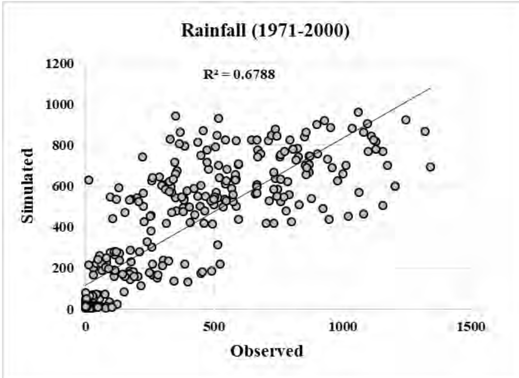
Satkhira



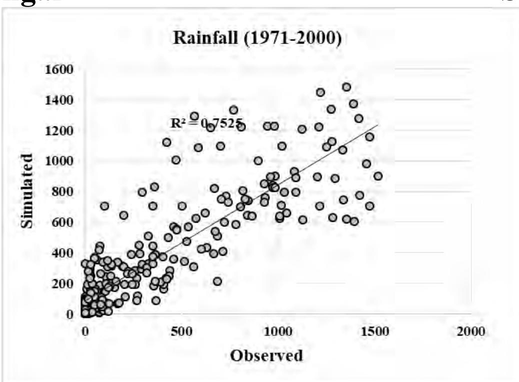
Sitakunda



Sreemangal

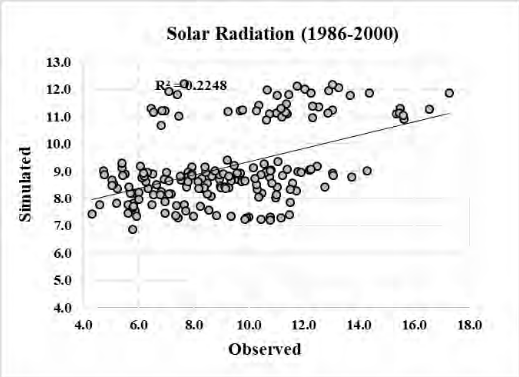


Sylhet

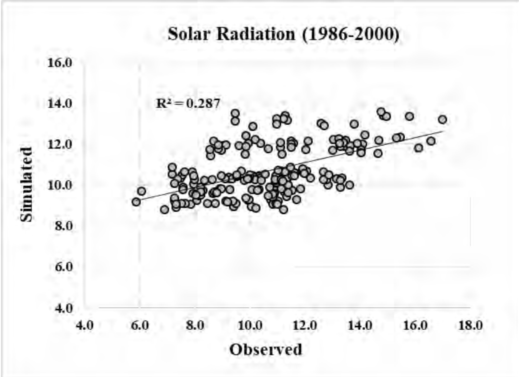


Teknaf

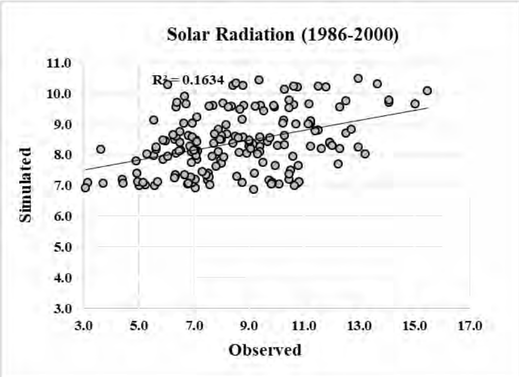
Table A4: Graphs of Performance of SDSM for Solar Radiation in Calibration and Validation Period (1986-2000) for Full Time Series



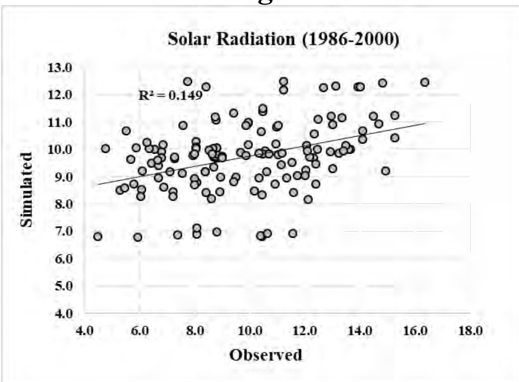
Barisal



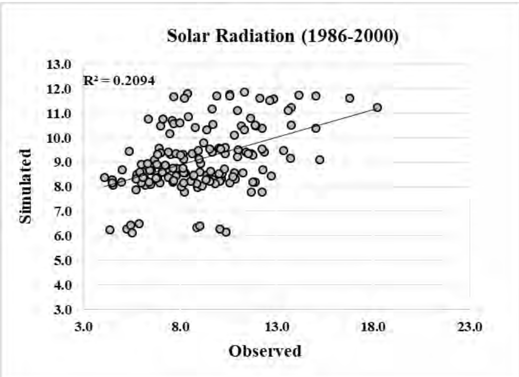
Bogra



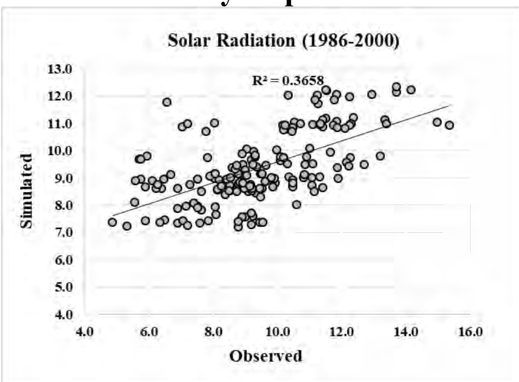
Comilla



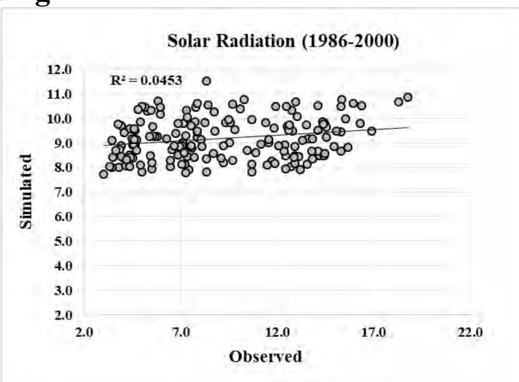
Joydevpur



Mymensingh



Rangpur



Sreemangal

Appendix B: Maximum Temperature Anomaly

Table B1: Annual Average Maximum Temperature Anomaly (^0C)

Hydrologic Region	Station	Base (1971-2000)	RCP2.6			RCP4.5			RCP8.5		
			2030s	2050s	2080s	2030s	2050s	2080s	2030s	2050s	2080s
NC	Dhaka	30.6	0.9	1.2	1.1	0.9	1.1	1.3	1.0	1.5	2.3
	Mymensingh	30.0	0.3	0.4	0.4	0.4	0.5	0.6	0.4	0.6	1.0
NE	Sreemangal	30.4	0.5	0.6	0.6	0.6	0.8	0.9	0.6	0.9	1.5
	Sylhet	29.6	0.5	0.6	0.7	0.6	0.8	1.0	0.6	1.0	1.7
NW	Bogra	30.6	0.7	0.8	0.9	0.7	0.7	0.7	0.7	0.9	1.2
	Dinajpur	30.0	0.7	0.8	0.8	0.7	0.6	0.7	0.7	0.8	1.1
	Ishwardi	30.9	0.8	1.0	1.0	0.8	0.8	0.9	0.9	1.1	1.5
	Rajshahi	31.1	0.8	1.0	1.0	0.9	0.9	1.0	0.9	1.1	1.5
	Rangpur	29.6	0.5	0.6	0.6	0.5	0.5	0.5	0.5	0.6	0.8
SC	Barisal	30.4	0.8	1.1	1.0	0.7	0.9	1.1	0.8	1.3	1.9
	Bhola	30.3	0.9	1.1	1.0	0.8	1.0	1.2	0.9	1.4	2.1
	Faridpur	30.4	0.7	1.0	1.0	0.8	0.9	1.1	0.8	1.4	2.2
	Madaripur	30.9	0.7	1.0	0.9	0.7	0.9	1.1	0.8	1.3	2.0
	Khepupara	30.1	0.6	0.8	0.8	0.6	0.8	1.0	0.7	1.1	1.8
	Patuakhali	30.3	0.7	1.0	0.9	0.7	0.9	1.0	0.8	1.2	1.8
SE	Chandpur	30.2	0.8	1.1	0.9	0.7	0.9	1.1	0.8	1.3	2.0
	Comilla	30.1	0.9	1.2	1.1	0.9	1.2	1.4	1.0	1.6	2.5
	Feni	30.3	0.9	1.2	1.1	0.9	1.1	1.3	1.0	1.5	2.4
	Hatiya	29.5	0.9	1.1	1.1	0.9	1.1	1.4	1.0	1.5	2.4
	Maijdeecourt	29.9	1.0	1.3	1.2	0.9	1.2	1.4	1.0	1.6	2.4
	Sandwip	29.4	0.7	1.0	0.9	0.7	1.0	1.2	0.8	1.3	2.2

Hydrologic Region	Station	Base (1971-2000)	RCP2.6			RCP4.5			RCP8.5		
			2030s	**2050s**	**2080s**	**2030s**	**2050s**	**2080s**	**2030s**	**2050s**	**2080s**
SW	**Jessore**	31.4	0.8	1.2	1.2	0.8	1.1	1.3	1.0	1.6	2.5
	Khulna	31.1	0.8	1.1	1.2	1.2	1.2	1.4	1.0	1.6	2.7
	Satkhira	31.5	0.8	1.1	1.1	0.8	1.0	1.2	0.9	1.4	2.3
EH	**Chittagong**	30.2	0.8	1.0	0.9	0.7	1.0	1.2	0.8	1.3	2.1
	Coxsbazar	30.1	0.9	1.1	1.1	0.9	1.2	1.4	1.0	1.5	2.5
	Kutubdia	29.8	0.7	0.9	0.9	0.7	0.9	1.1	0.7	1.2	2.0
	Rangamati	30.2	0.9	1.2	1.1	0.8	1.1	1.2	0.9	1.4	2.2
	Sitakunda	30.2	0.7	1.0	0.9	0.7	1.0	1.3	0.8	1.4	2.3
	Teknaf	30.1	0.6	0.9	0.8	0.6	0.8	1.1	0.7	1.1	2.0
Nationwide Average		**30.3**	**0.8**	**1.1**	**1.0**	**0.8**	**1.0**	**1.2**	**0.9**	**1.4**	**2.2**

Table B2: Seasonal Average Maximum Temperature Anomaly under RCP2.6 (^{o}C)

Hydrologic Region	Station	Base (1971-2000)				2030s				2050s				2080s			
		DJF	MAM	JJAS	ON	DJF	MAM	JJAS	ON	DJF	MAM	JJAS	ON	DJF	MAM	JJAS	ON
NC	Dhaka	26.6	33.1	31.7	30.6	0.4	0.4	1.5	1.5	0.6	0.4	1.9	2.0	0.6	0.2	1.8	1.7
	Mymensingh	26.0	31.6	31.4	30.5	0.5	0.6	-0.1	0.5	0.6	0.7	-0.2	0.7	0.7	0.7	-0.3	0.7
NE	Sreemangal	26.4	32.2	32.1	30.3	0.5	0.8	0.3	0.7	0.6	0.9	0.2	0.9	0.7	0.8	0.2	0.9
	Sylhet	26.2	30.6	31.1	30.1	0.3	0.8	0.4	0.8	0.5	0.9	0.4	1.0	0.5	0.8	0.3	1.0
NW	Bogra	26.3	33.0	32.0	30.9	1.1	1.4	0.1	0.2	1.3	1.5	0.2	0.3	1.4	1.6	0.2	0.3
	Dinajpur	25.1	32.3	32.0	30.0	1.1	1.6	-0.1	0.1	1.3	1.7	-0.1	0.2	1.4	1.8	0.0	0.3
	Ishwardi	25.9	34.4	32.3	30.4	1.2	1.8	0.1	0.3	1.4	1.9	0.2	0.4	1.6	1.9	0.2	0.5
	Rajshahi	26.0	34.8	32.6	30.5	1.0	1.7	0.3	0.3	1.2	1.9	0.4	0.4	1.4	1.9	0.4	0.5
	Rangpur	24.9	31.5	31.8	29.7	0.9	1.2	-0.1	0.1	1.1	1.2	-0.1	0.2	1.2	1.3	-0.1	0.2
SC	Barisal	26.7	32.8	31.2	30.6	0.4	0.3	1.2	1.4	0.7	0.3	1.5	1.9	0.6	0.1	1.5	1.6
	Bhola	26.9	32.4	31.0	30.7	0.4	0.3	1.4	1.6	0.6	0.3	1.7	2.1	0.5	0.1	1.7	1.8
	Faridpur	25.9	33.3	31.6	30.2	0.7	0.2	0.7	1.4	1.1	0.3	1.1	2.0	1.2	0.2	1.1	2.0
	Madaripur	26.8	33.4	32.1	31.1	0.5	0.4	1.1	0.7	0.7	0.5	1.4	1.1	0.7	0.3	1.4	1.0
	Khepupara	26.9	32.2	30.8	30.3	0.5	0.1	1.2	0.6	0.7	0.2	1.4	0.8	0.6	0.1	1.4	0.8
	Patuakhali	26.9	32.7	31.1	30.5	0.4	0.3	1.2	1.2	0.6	0.3	1.4	1.7	0.6	0.1	1.4	1.4
SE	Chandpur	26.1	32.4	31.6	30.3	0.3	0.3	1.2	1.4	0.5	0.3	1.5	2.0	0.5	0.1	1.5	1.7
	Comilla	26.5	31.8	31.3	30.5	0.5	0.3	1.7	0.9	0.7	0.4	2.1	1.2	0.7	0.2	2.1	1.2
	Feni	27.1	32.0	31.1	30.7	0.6	0.2	1.7	0.8	0.8	0.3	2.1	1.1	0.8	0.1	2.0	1.0
	Hatiya	26.1	31.5	30.2	29.9	0.4	0.4	1.6	0.7	0.6	0.5	2.0	1.1	0.6	0.4	1.9	1.0
	Maijdee Court	26.4	32.0	30.7	30.2	0.4	0.2	1.7	1.6	0.6	0.3	2.1	2.2	0.6	0.1	2.1	1.9
	Sandwip	26.3	30.9	30.3	30.2	0.3	0.3	1.5	0.6	0.5	0.4	1.9	1.0	0.5	0.3	1.8	0.9
SW	Jessore	26.9	34.8	32.5	31.1	0.6	0.3	1.0	1.5	1.0	0.4	1.4	2.1	1.1	0.4	1.4	2.0

Hydrologic Region	Station	Base (1971-2000)				2030s				2050s				2080s			
		DJF	**MAM**	**JJAS**	**ON**	**DJF**	**MAM**	**JJAS**	**ON**	**DJF**	**MAM**	**JJAS**	**ON**	**DJF**	**MAM**	**JJAS**	**ON**
	Khulna	26.9	34.0	32.2	31.0	0.7	0.4	1.1	0.8	1.1	0.6	1.5	1.2	1.2	0.6	1.6	1.3
	Satkhira	27.2	34.6	32.4	31.3	0.7	0.3	0.8	1.4	1.1	0.3	1.2	2.0	1.1	0.3	1.3	1.9
EH	**Chittagong**	27.0	31.6	31.2	30.7	0.7	0.1	1.3	0.8	0.9	0.2	1.6	1.2	0.8	0.1	1.6	1.1
	Coxs Bazar	27.6	31.8	30.4	30.8	0.3	0.2	1.7	0.9	0.6	0.3	2.1	1.3	0.6	0.2	2.1	1.2
	Kutubdia	26.6	31.2	30.6	30.5	0.5	0.2	1.2	0.8	0.6	0.3	1.5	1.2	0.6	0.1	1.5	1.1
	Rangamati	26.8	32.6	31.1	30.3	0.4	0.2	1.4	1.8	0.6	0.3	1.7	2.5	0.6	0.0	1.7	2.1
	Sitakunda	27.3	31.6	30.9	30.8	0.2	0.2	1.5	0.7	0.5	0.3	1.9	1.1	0.5	0.2	1.8	1.0
	Teknaf	28.0	31.6	30.2	30.8	0.6	0.1	0.7	1.0	1.0	0.3	1.0	1.5	0.9	0.2	1.0	1.4
Nationwide Average		**26.5**	**32.5**	**31.4**	**30.5**	**0.6**	**0.5**	**1.0**	**0.9**	**0.8**	**0.6**	**1.2**	**1.3**	**0.8**	**0.5**	**1.2**	**1.2**

Table B3: Seasonal Average Maximum Temperature Anomaly under RCP4.5 (^oC)

Hydrologic Region	Station	Base (1971-2000)				2030s				2050s				2080s			
		DJF	MAM	JJAS	ON	DJF	MAM	JJAS	ON	DJF	MAM	JJAS	ON	DJF	MAM	JJAS	ON
NC	Dhaka	26.6	33.1	31.7	30.6	0.4	0.1	1.6	1.2	0.6	0.3	2.0	1.4	0.8	0.2	2.2	2.0
	Mymensingh	26.0	31.6	31.4	30.5	0.5	0.7	-0.1	0.6	0.9	0.9	-0.1	0.8	1.0	1.0	-0.3	1.1
NE	Sreemangal	26.4	32.2	32.1	30.3	0.5	0.8	0.3	0.7	0.8	1.1	0.4	1.0	0.9	1.3	0.4	1.3
	Sylhet	26.2	30.6	31.1	30.1	0.3	0.9	0.5	0.8	0.7	1.1	0.6	1.1	0.8	1.3	0.6	1.6
NW	Bogra	26.3	33.0	32.0	30.9	1.0	1.3	0.2	0.3	1.2	1.1	0.2	0.4	1.3	1.2	0.1	0.4
	Dinajpur	25.1	32.3	32.0	30.0	1.0	1.5	0.0	0.3	1.1	1.3	-0.1	0.3	1.3	1.4	-0.1	0.4
	Ishwardi	25.9	34.4	32.3	30.4	1.1	1.7	0.2	0.4	1.3	1.5	0.3	0.4	1.4	1.6	0.2	0.6
	Rajshahi	26.0	34.8	32.6	30.5	1.0	1.6	0.4	0.4	1.2	1.4	0.4	0.5	1.2	1.6	0.4	0.7
	Rangpur	24.9	31.5	31.8	29.7	0.9	1.1	0.0	0.3	1.0	0.8	-0.1	0.3	1.0	0.8	-0.1	0.3
SC	Barisal	26.7	32.8	31.2	30.6	0.4	0.1	1.2	1.1	0.7	0.2	1.5	1.3	0.9	0.2	1.6	1.9
	Bhola	26.9	32.4	31.0	30.7	0.4	0.1	1.4	1.2	0.6	0.2	1.7	1.4	0.8	0.1	1.9	2.0
	Faridpur	25.9	33.3	31.6	30.2	0.6	0.1	0.9	1.5	1.0	0.0	1.1	1.9	1.3	0.0	1.1	2.3
	Madaripur	26.8	33.4	32.1	31.1	0.5	0.2	1.2	0.7	0.6	0.4	1.5	1.0	0.8	0.5	1.8	1.3
	Khepupara	26.9	32.2	30.8	30.3	0.5	0.0	1.2	0.6	0.6	0.1	1.6	0.7	0.8	0.2	1.8	1.0
	Patuakhali	26.9	32.7	31.1	30.5	0.4	0.1	1.2	0.9	0.6	0.2	1.5	1.1	0.8	0.1	1.6	1.6
SE	Chandpur	26.1	32.4	31.6	30.3	0.4	0.1	1.3	1.1	0.5	0.2	1.6	1.4	0.8	0.1	1.7	2.0
	Comilla	26.5	31.8	31.3	30.5	0.5	0.2	1.8	0.8	0.7	0.3	2.3	1.1	0.8	0.4	2.6	1.5
	Feni	27.1	32.0	31.1	30.7	0.6	0.1	1.8	0.7	0.7	0.1	2.3	1.0	0.9	0.2	2.6	1.3
	Hatiya	26.1	31.5	30.2	29.9	0.4	0.3	1.7	0.7	0.6	0.5	2.1	0.9	0.7	0.6	2.4	1.4
	Maijdee Court	26.4	32.0	30.7	30.2	0.4	0.1	1.8	1.3	0.6	0.1	2.2	1.5	0.8	0.1	2.4	2.2
	Sandwip	26.3	30.9	30.3	30.2	0.2	0.2	1.6	0.6	0.4	0.4	2.0	0.8	0.6	0.5	2.3	1.2
SW	Jessore	26.9	34.8	32.5	31.1	0.6	0.2	1.2	1.5	1.0	0.1	1.5	1.9	1.3	0.2	1.5	2.3

Hydrologic Region	Station	Base (1971-2000)				2030s				2050s				2080s			
		DJF	MAM	JJAS	ON	DJF	MAM	JJAS	ON	DJF	MAM	JJAS	ON	DJF	MAM	JJAS	ON
	Khulna	26.9	34.0	32.2	31.0	1.0	0.5	1.7	1.2	1.0	0.5	1.7	1.2	1.3	0.8	1.9	1.6
	Satkhira	27.2	34.6	32.4	31.3	0.6	0.2	1.1	1.5	1.0	0.1	1.3	1.8	1.3	0.2	1.2	2.2
EH	**Chittagong**	27.0	31.6	31.2	30.7	0.6	0.0	1.4	0.8	0.8	0.1	1.7	1.0	1.0	0.1	2.0	1.4
	Coxs Bazar	27.6	31.8	30.4	30.8	0.3	0.2	1.8	0.8	0.5	0.3	2.3	1.1	0.7	0.4	2.6	1.6
	Kutubdia	26.6	31.2	30.6	30.5	0.4	0.1	1.3	0.7	0.6	0.1	1.6	1.0	0.7	0.2	1.9	1.4
	Rangamati	26.8	32.6	31.1	30.3	0.4	0.0	1.5	1.4	0.6	0.1	1.8	1.7	0.8	0.0	1.9	2.5
	Sitakunda	27.3	31.6	30.9	30.8	0.2	0.1	1.6	0.7	0.4	0.3	2.0	0.9	0.6	0.4	2.3	1.4
	Teknaf	28.0	31.6	30.2	30.8	0.6	0.1	0.8	0.9	0.8	0.2	1.0	1.2	1.2	0.3	1.3	1.7
Nationwide Average		**26.5**	**32.5**	**31.4**	**30.5**	**0.5**	**0.4**	**1.1**	**0.9**	**0.8**	**0.5**	**1.3**	**1.1**	**1.0**	**0.5**	**1.5**	**1.5**

Table B4: Seasonal Average Maximum Temperature Anomaly under RCP8.5 (^{0}C)

Hydrologic Region	Station	Base (1971-2000)				2030s				2050s				2080s			
		DJF	MAM	JJAS	ON	DJF	MAM	JJAS	ON	DJF	MAM	JJAS	ON	DJF	MAM	JJAS	ON
NC	Dhaka	26.6	33.1	31.7	30.6	0.4	0.2	1.7	1.4	0.8	0.6	2.5	2.0	1.3	0.7	3.7	3.3
	Mymensingh	26.0	31.6	31.4	30.5	0.6	0.7	-0.1	0.7	1.0	1.0	-0.3	1.0	1.8	1.7	-0.6	1.8
NE	Sreemangal	26.4	32.2	32.1	30.3	0.6	0.9	0.4	0.8	0.9	1.4	0.5	1.3	1.6	2.2	0.6	2.2
	Sylhet	26.2	30.6	31.1	30.1	0.5	0.9	0.6	0.9	0.9	1.4	0.7	1.5	1.7	2.2	1.0	2.6
NW	Bogra	26.3	33.0	32.0	30.9	1.1	1.3	0.2	0.3	1.5	1.4	0.2	0.5	2.2	1.7	0.3	1.0
	Dinajpur	25.1	32.3	32.0	30.0	1.1	1.5	0.1	0.2	1.5	1.6	-0.1	0.5	2.1	1.8	-0.2	1.0
	Ishwardi	25.9	34.4	32.3	30.4	1.2	1.7	0.4	0.4	1.7	1.9	0.3	0.7	2.3	2.4	0.4	1.2
	Rajshahi	26.0	34.8	32.6	30.5	1.1	1.6	0.5	0.4	1.5	1.8	0.5	0.7	2.1	2.3	0.7	1.2
	Rangpur	24.9	31.5	31.8	29.7	1.0	1.0	0.1	0.2	1.3	1.0	-0.1	0.4	1.8	1.1	-0.2	0.9
SC	Barisal	26.7	32.8	31.2	30.6	0.4	0.2	1.4	1.3	0.8	0.5	1.9	1.9	1.4	0.6	2.8	2.9
	Bhola	26.9	32.4	31.0	30.7	0.4	0.1	1.6	1.4	0.7	0.4	2.2	2.0	1.3	0.5	3.2	3.1
	Faridpur	25.9	33.3	31.6	30.2	0.8	0.0	1.0	1.8	1.4	0.4	1.6	2.4	2.4	0.6	2.5	3.7
	Madaripur	26.8	33.4	32.1	31.1	0.5	0.3	1.3	0.9	0.8	0.8	2.0	1.3	1.2	1.3	3.1	2.1
	Khepupara	26.9	32.2	30.8	30.3	0.5	0.1	1.3	0.7	0.8	0.3	2.1	1.0	1.2	0.7	3.2	1.6
	Patuakhali	26.9	32.7	31.1	30.5	0.4	0.2	1.3	1.1	0.8	0.4	1.8	1.6	1.4	0.5	2.7	2.5
SE	Chandpur	26.1	32.4	31.6	30.3	0.3	0.1	1.4	1.4	0.7	0.4	2.0	2.0	1.2	0.5	2.9	3.3
	Comilla	26.5	31.8	31.3	30.5	0.5	0.2	1.9	1.0	0.8	0.6	2.9	1.4	1.3	1.1	4.5	2.4
	Feni	27.1	32.0	31.1	30.7	0.6	0.1	1.9	0.9	0.9	0.4	3.0	1.3	1.4	0.8	4.6	2.0
	Hatiya	26.1	31.5	30.2	29.9	0.4	0.4	1.8	0.8	0.7	0.8	2.7	1.3	1.3	1.2	4.1	2.3
	Maijdee court	26.4	32.0	30.7	30.2	0.4	0.1	1.9	1.5	0.7	0.4	2.7	2.2	1.3	0.4	4.1	3.5
	Sandwip	26.3	30.9	30.3	30.2	0.3	0.3	1.7	0.7	0.6	0.6	2.5	1.2	1.2	1.0	3.9	2.1
SW	Jessore	26.9	34.8	32.5	31.1	0.8	0.1	1.3	1.8	1.4	0.6	2.0	2.4	2.3	0.9	3.3	3.7

Hydrologic Region	Station	Base (1971-2000)				2030s				2050s				2080s			
		DJF	**MAM**	**JJAS**	**ON**	**DJF**	**MAM**	**JJAS**	**ON**	**DJF**	**MAM**	**JJAS**	**ON**	**DJF**	**MAM**	**JJAS**	**ON**
	Khulna	26.9	34.0	32.2	31.0	0.9	0.5	1.5	1.1	1.4	1.0	2.3	1.6	2.4	1.8	3.7	2.6
	Satkhira	27.2	34.6	32.4	31.3	0.8	0.1	1.2	1.8	1.4	0.5	1.8	2.4	2.3	0.9	2.8	3.6
EH	**Chittagong**	27.0	31.6	31.2	30.7	0.7	0.0	1.5	0.9	1.0	0.3	2.3	1.3	1.6	0.6	3.5	2.3
	Coxs bazar	27.6	31.8	30.4	30.8	0.4	0.2	2.0	1.0	0.7	0.6	2.9	1.5	1.4	0.9	4.5	2.7
	Kutubdia	26.6	31.2	30.6	30.5	0.4	0.1	1.4	0.9	0.7	0.4	2.2	1.4	1.2	0.7	3.4	2.3
	Rangamati	26.8	32.6	31.1	30.3	0.4	0.0	1.6	1.8	0.7	0.3	2.2	2.5	1.3	0.3	3.4	3.9
	Sitakunda	27.3	31.6	30.9	30.8	0.3	0.2	1.7	0.8	0.6	0.5	2.6	1.3	1.3	1.0	4.0	2.4
	Teknaf	28.0	31.6	30.2	30.8	0.6	0.1	0.9	1.1	1.2	0.4	1.4	1.7	2.2	0.8	2.3	3.0
Nationwide Average		**26.5**	**32.5**	**31.4**	**30.5**	**0.6**	**0.4**	**1.2**	**1.0**	**1.0**	**0.8**	**1.7**	**1.5**	**1.7**	**1.1**	**2.6**	**2.4**

Appendix C: Minimum Temperature Anomaly

Table C1: Annual Average Minimum Temperature Anomaly (^0C)

Hydrologic Region	Station	Base (1971-2000)	RCP2.6			RCP4.5			RCP8.5		
			2030s	2050s	2080s	2030s	2050s	2080s	2030s	2050s	2080s
NC	Dhaka	21.5	0.9	1.2	1.1	0.8	1.1	1.5	0.9	1.5	2.6
	Mymensingh	20.6	1.0	1.2	1.2	1.0	1.3	1.5	1.1	1.7	2.6
NE	Sreemangal	19.4	0.9	1.0	1.1	0.9	1.1	1.5	1.0	1.4	2.3
	Sylhet	20.2	0.9	1.1	1.1	0.9	1.2	1.4	1.0	1.5	2.4
NW	Bogra	20.7	0.8	0.9	0.9	0.7	0.9	1.1	0.8	1.2	1.9
	Dinajpur	19.6	0.7	0.8	0.9	0.7	0.8	1.1	0.8	1.1	1.8
	Ishwardi	20.2	0.9	1.1	1.1	0.9	1.1	1.3	1.0	1.4	2.2
	Rajshahi	20.5	1.0	1.2	1.2	0.9	1.1	1.3	1.0	1.5	2.3
	Rangpur	19.8	0.6	0.7	0.7	0.5	0.7	0.9	0.6	0.9	1.5
SC	Barisal	21.1	0.9	1.2	1.1	0.8	1.1	1.4	0.9	1.5	2.5
	Bhola	21.4	0.9	1.3	1.2	0.9	1.2	1.6	1.0	1.6	2.7
	Faridpur	21.0	0.8	1.1	1.2	0.9	1.2	1.6	0.9	1.7	3.0
	Madaripur	21.2	0.9	1.2	1.1	0.8	1.1	1.4	0.9	1.5	2.5
	Khepupara	22.2	0.8	1.1	1.0	0.8	1.1	1.4	0.9	1.4	2.4
	Patuakhali	22.0	0.8	1.0	0.9	0.7	1.0	1.3	0.8	1.3	2.2
SE	Chandpur	21.6	0.9	1.2	1.1	0.8	1.1	1.5	0.9	1.5	2.5
	Comilla	22.0	0.7	1.0	0.9	0.7	0.9	1.2	0.8	1.2	2.1
	Feni	22.3	0.8	1.0	0.9	0.7	1.0	1.3	0.8	1.3	2.1
	Hatiya	22.2	0.8	1.1	1.0	0.8	1.1	1.3	0.9	1.4	2.3
	Maijdeecourt	21.6	0.9	1.2	1.1	0.8	1.1	1.4	0.9	1.5	2.5

Hydrologic Region	Station	Base (1971-2000)	RCP2.6			RCP4.5			RCP8.5		
			2030s	2050s	2080s	2030s	2050s	2080s	2030s	2050s	2080s
	Sandwip	22.3	0.8	1.0	0.9	0.7	1.0	1.2	0.8	1.3	2.1
SW	**Jessore**	20.9	0.6	1.0	1.1	0.8	1.2	1.6	0.9	1.6	3.1
	Khulna	21.6	0.8	1.1	1.2	0.9	1.2	1.6	1.0	1.7	3.1
	Satkhira	21.4	0.8	1.2	1.3	1.0	1.4	1.8	1.1	1.9	3.3
EH	**Chittagong**	21.6	0.7	1.0	0.9	0.7	1.0	1.2	0.8	1.3	2.2
	Coxsbazar	20.9	0.8	1.0	0.9	0.7	1.0	1.3	0.8	1.3	2.2
	Kutubdia	22.1	0.8	1.0	1.0	0.7	1.0	1.3	0.8	1.3	2.2
	Rangamati	21.4	0.7	0.9	0.8	0.6	0.9	1.1	0.7	1.1	1.9
	Sitakunda	21.1	0.8	1.1	1.0	0.7	1.0	1.4	0.9	1.4	2.4
	Teknaf	22.0	0.7	1.1	1.0	0.7	1.0	1.3	0.8	1.3	2.3
Nationwide Average		**21.6**	**0.8**	**1.1**	**1.0**	**0.8**	**1.1**	**1.4**	**0.9**	**1.4**	**2.5**

Table C2: Seasonal Average Minimum Temperature Anomaly under RCP2.6 (^oC)

Hydrologic Region	Station	Base (1971-2000)				2030s				2050s				2080s			
		DJF	MAM	JJAS	ON	DJF	MAM	JJAS	ON	DJF	MAM	JJAS	ON	DJF	MAM	JJAS	ON
NC	Dhaka	14.1	22.8	26.1	21.5	0.7	0.6	1.0	1.3	1.0	0.8	1.2	2.1	1.0	0.4	1.2	2.0
	Mymensingh	13.1	21.3	25.7	20.9	0.8	1.6	0.8	1.0	1.0	1.8	1.0	1.2	1.0	1.6	1.0	1.3
NE	Sreemangal	11.0	20.5	24.8	19.3	1.0	1.3	0.6	0.6	1.2	1.4	0.7	0.8	1.2	1.4	0.7	1.0
	Sylhet	13.6	20.6	24.7	20.5	1.0	1.1	0.7	0.9	1.2	1.3	0.9	1.2	1.2	1.2	0.9	1.3
NW	Bogra	13.0	21.6	25.9	20.8	1.1	1.1	0.2	0.8	1.3	1.2	0.3	0.9	1.4	1.2	0.3	1.0
	Dinajpur	11.6	20.2	25.4	19.3	1.1	1.1	0.0	0.9	1.3	1.3	0.0	1.0	1.5	1.2	0.0	1.2
	Ishwardi	11.7	21.5	25.7	20.2	1.2	1.4	0.3	0.9	1.4	1.6	0.4	1.0	1.6	1.5	0.4	1.2
	Rajshahi	12.3	21.6	25.8	20.5	1.1	1.6	0.4	1.2	1.3	1.8	0.5	1.4	1.4	1.7	0.5	1.6
	Rangpur	12.0	20.1	25.5	19.9	0.9	0.7	0.1	0.8	1.1	0.8	0.1	1.0	1.2	0.7	0.1	1.1
SC	Barisal	13.4	22.8	25.5	21.2	0.8	0.7	0.9	1.3	1.1	0.8	1.1	2.0	1.0	0.5	1.1	1.9
	Bhola	14.0	23.1	25.7	21.6	0.7	0.6	1.2	1.3	1.0	0.7	1.5	2.0	1.0	0.5	1.4	1.9
	Faridpur	13.5	22.1	25.7	21.5	1.1	0.6	0.7	0.6	1.7	0.8	0.9	1.2	1.6	0.8	0.9	1.5
	Madaripur	13.5	22.4	25.8	21.6	0.8	0.8	0.7	1.4	1.1	0.9	0.9	2.2	1.1	0.6	0.9	2.1
	Khepupara	15.4	24.0	25.8	22.3	0.6	0.7	1.0	1.1	0.9	0.8	1.3	1.7	0.9	0.6	1.3	1.5
	Patuakhali	15.0	23.4	25.8	22.4	0.6	0.6	0.8	1.0	0.9	0.8	1.0	1.6	0.8	0.5	1.0	1.5
SE	Chandpur	14.7	22.8	25.8	21.9	0.7	0.6	1.1	1.3	0.9	0.7	1.3	2.0	0.9	0.5	1.3	1.9
	Comilla	13.5	22.2	25.3	21.1	0.6	0.6	0.8	1.1	0.9	0.7	1.0	1.8	0.9	0.4	1.0	1.7
	Feni	16.0	23.9	25.6	22.8	0.7	0.8	0.8	0.9	0.9	0.9	1.0	1.4	0.9	0.6	1.0	1.3
	Hatiya	16.1	23.5	25.4	22.8	0.4	0.6	1.2	1.1	0.6	0.7	1.4	1.6	0.6	0.4	1.4	1.5
	Maijdee court	14.8	22.6	25.5	22.4	0.6	0.6	1.1	1.2	0.8	0.7	1.4	1.9	0.8	0.4	1.4	1.7
	Sandwip	16.0	23.9	25.6	22.8	0.7	0.8	0.8	0.9	0.9	0.9	1.0	1.4	0.9	0.6	1.0	1.3
SW	Jessore	12.8	22.6	25.7	20.7	1.1	1.0	0.7	-0.5	1.7	1.2	0.9	-0.1	1.7	1.3	0.9	0.3

Hydrologic Region	Station	Base (1971-2000)				2030s				2050s				2080s			
		DJF	**MAM**	**JJAS**	**ON**	**DJF**	**MAM**	**JJAS**	**ON**	**DJF**	**MAM**	**JJAS**	**ON**	**DJF**	**MAM**	**JJAS**	**ON**
	Khulna	13.9	23.2	26.0	21.8	0.9	0.8	0.7	0.8	1.4	1.0	0.9	1.5	1.4	1.0	0.9	1.7
	Satkhira	13.7	23.4	26.0	21.1	1.0	0.9	0.7	0.7	1.6	1.1	1.0	1.4	1.6	1.2	1.0	1.7
EH	**Chittagong**	15.2	22.8	25.1	22.2	0.5	0.6	0.9	1.0	0.8	0.7	1.1	1.5	0.8	0.4	1.1	1.4
	Coxs bazar	16.2	23.3	25.1	22.7	0.5	0.6	0.9	1.0	0.7	0.7	1.1	1.6	0.7	0.5	1.1	1.5
	Kutubdia	16.2	23.4	25.4	22.5	0.5	0.7	0.9	1.1	0.7	0.8	1.1	1.7	0.7	0.6	1.1	1.6
	Rangamati	15.3	22.3	24.8	22.2	0.6	0.6	0.7	0.8	0.7	0.7	0.9	1.3	0.7	0.5	0.9	1.2
	Sitakunda	13.7	22.7	25.3	21.3	0.6	0.8	0.8	1.2	0.8	0.9	1.0	1.9	0.8	0.6	1.0	1.8
	Teknaf	16.4	23.2	25.0	22.5	0.8	0.2	0.9	1.3	1.1	0.3	1.2	1.9	1.1	0.2	1.2	1.8
Nationwide Average		**14.1**	**22.5**	**25.5**	**21.5**	**0.8**	**0.8**	**0.8**	**1.0**	**1.1**	**1.0**	**0.9**	**1.5**	**1.1**	**0.8**	**0.9**	**1.5**

Table C3: Seasonal Average Minimum Temperature Anomaly under RCP4.5 (^oC)

Hydrologic Region	Station	Base				2030s				2050s				2080s			
		DJF	MAM	JJAS	ON	DJF	MAM	JJAS	ON	DJF	MAM	JJAS	ON	DJF	MAM	JJAS	ON
NC	Dhaka	14.1	22.8	26.1	21.5	0.7	0.4	1.0	1.1	1.0	0.7	1.3	1.7	1.3	0.8	1.5	2.7
	Mymensingh	13.1	21.3	25.7	20.9	0.8	1.5	0.8	0.8	0.9	1.8	1.2	1.2	1.0	2.0	1.4	1.7
NE	Sreemangal	11.0	20.5	24.8	19.3	1.1	1.2	0.7	0.6	1.4	1.5	0.8	1.0	1.8	1.6	1.0	1.6
	Sylhet	13.6	20.6	24.7	20.5	1.0	1.1	0.8	0.8	1.1	1.4	1.0	1.1	1.3	1.5	1.2	1.6
NW	Bogra	13.0	21.6	25.9	20.8	1.1	1.0	0.3	0.6	1.3	1.1	0.4	0.9	1.6	1.3	0.4	1.4
	Dinajpur	11.6	20.2	25.4	19.3	1.1	1.1	0.0	0.8	1.4	1.2	0.0	1.1	1.7	1.3	0.1	1.6
	Ishwardi	11.7	21.5	25.7	20.2	1.2	1.3	0.4	0.7	1.5	1.4	0.5	1.0	1.8	1.6	0.6	1.6
	Rajshahi	12.3	21.6	25.8	20.5	1.0	1.4	0.4	1.2	1.1	1.6	0.5	1.6	1.2	1.8	0.6	2.2
	Rangpur	12.0	20.1	25.5	19.9	0.9	0.6	0.1	0.7	1.1	0.8	0.1	1.0	1.4	0.9	0.2	1.5
SC	Barisal	13.4	22.8	25.5	21.2	0.7	0.5	1.0	1.0	1.0	0.7	1.2	1.6	1.3	0.8	1.4	2.6
	Bhola	14.0	23.1	25.7	21.6	0.7	0.5	1.3	1.1	1.0	0.7	1.6	1.7	1.3	0.8	1.8	2.7
	Faridpur	13.5	22.1	25.7	21.5	1.3	0.6	0.7	1.0	1.7	0.8	1.0	1.5	2.3	1.0	1.2	2.3
	Madaripur	13.5	22.4	25.8	21.6	0.8	0.6	0.8	1.2	1.1	0.8	1.0	1.8	1.4	1.0	1.1	2.9
	Khepupara	15.4	24.0	25.8	22.3	0.6	0.5	1.1	0.9	0.9	0.8	1.4	1.4	1.1	0.9	1.6	2.2
	Patuakhali	15.0	23.4	25.8	22.4	0.6	0.5	0.9	0.9	0.8	0.7	1.1	1.3	1.1	0.8	1.3	2.2
SE	Chandpur	14.7	22.8	25.8	21.9	0.6	0.5	1.1	1.1	0.9	0.7	1.4	1.6	1.1	0.8	1.6	2.6
	Comilla	13.5	22.2	25.3	21.1	0.6	0.4	0.9	0.9	0.8	0.6	1.1	1.5	1.1	0.7	1.3	2.5
	Feni	16.0	23.9	25.6	22.8	0.6	0.6	0.9	0.7	0.9	0.8	1.1	1.1	1.1	1.0	1.3	1.8
	Hatiya	16.1	23.5	25.4	22.8	0.4	0.4	1.3	0.9	0.6	0.6	1.6	1.3	0.8	0.7	1.7	2.1
	Maijdee court	14.8	22.6	25.5	22.4	0.5	0.4	1.2	1.0	0.8	0.6	1.5	1.5	1.1	0.7	1.7	2.5
	Sandwip	16.0	23.9	25.6	22.8	0.6	0.6	0.9	0.7	0.9	0.8	1.1	1.1	1.1	1.0	1.3	1.8
SW	Jessore	12.8	22.6	25.7	20.7	1.3	1.0	0.8	-0.2	1.8	1.3	1.0	0.4	2.5	1.6	1.1	1.2

Hydrologic Region	Station	Base				2030s				2050s				2080s			
		DJF	**MAM**	**JJAS**	**ON**	**DJF**	**MAM**	**JJAS**	**ON**	**DJF**	**MAM**	**JJAS**	**ON**	**DJF**	**MAM**	**JJAS**	**ON**
	Khulna	13.9	23.2	26.0	21.8	0.9	0.8	0.8	1.1	1.4	1.0	1.0	1.8	1.9	1.3	1.2	2.6
	Satkhira	13.7	23.4	26.0	21.1	1.1	0.9	0.8	1.0	1.6	1.1	1.1	1.8	2.2	1.5	1.3	2.7
EH	**Chittagong**	15.2	22.8	25.1	22.2	0.5	0.4	1.0	0.8	0.8	0.6	1.3	1.2	1.0	0.8	1.4	2.0
	Coxs bazar	16.2	23.3	25.1	22.7	0.4	0.4	0.9	0.8	0.7	0.6	1.2	1.3	0.9	0.7	1.3	2.1
	Kutubdia	16.2	23.4	25.4	22.5	0.5	0.6	0.9	0.9	0.7	0.8	1.2	1.4	0.9	0.9	1.4	2.3
	Rangamati	15.3	22.3	24.8	22.2	0.5	0.5	0.8	0.6	0.7	0.7	1.0	1.0	0.9	0.8	1.1	1.7
	Sitakunda	13.7	22.7	25.3	21.3	0.5	0.6	0.9	1.0	0.8	0.8	1.1	1.5	1.1	1.0	1.2	2.5
	Teknaf	16.4	23.2	25.0	22.5	0.7	0.1	0.9	1.0	1.0	0.3	1.2	1.5	1.4	0.5	1.5	2.2
Nationwide Average		**14.1**	**22.5**	**25.5**	**21.5**	**0.8**	**0.7**	**0.8**	**0.9**	**1.1**	**0.9**	**1.0**	**1.3**	**1.4**	**1.1**	**1.2**	**2.1**

Table C4: Seasonal Average Minimum Temperature Anomaly under RCP8.5 (^oC)

Hydrologic Region	Station	Base (1971-2000)				2030s				2050s				2080s			
		DJF	MAM	JJAS	ON	DJF	MAM	JJAS	ON	DJF	MAM	JJAS	ON	DJF	MAM	JJAS	ON
NC	Dhaka	14.1	22.8	26.1	21.5	0.73	0.52	1.14	1.45	1.22	1.02	1.68	2.46	2.13	1.62	2.60	4.73
	Mymensingh	13.1	21.3	25.7	20.9	0.85	1.64	0.96	1.02	1.14	2.33	1.46	1.88	1.60	3.41	2.36	3.18
NE	Sreemangal	11.0	20.5	24.8	19.3	1.08	1.32	0.73	0.70	1.62	1.71	1.03	1.40	2.56	2.55	1.60	2.81
	Sylhet	13.6	20.6	24.7	20.5	1.05	1.20	0.87	1.00	1.37	1.79	1.31	1.79	1.99	2.71	2.10	3.02
NW	Bogra	13.0	21.6	25.9	20.8	1.18	1.15	0.30	0.77	1.72	1.53	0.46	1.39	2.64	2.20	0.73	2.48
	Dinajpur	11.6	20.2	25.4	19.3	1.21	1.19	0.03	0.86	1.75	1.59	0.10	1.52	2.71	2.30	0.22	2.69
	Ishwardi	11.7	21.5	25.7	20.2	1.29	1.42	0.41	0.89	1.85	1.89	0.60	1.58	2.78	2.76	0.94	2.78
	Rajshahi	12.3	21.6	25.8	20.5	1.08	1.60	0.46	1.31	1.43	2.16	0.69	2.17	2.02	3.08	1.10	3.66
	Rangpur	12.0	20.1	25.5	19.9	0.98	0.74	0.06	0.85	1.44	1.14	0.17	1.46	2.27	1.76	0.32	2.58
SC	Barisal	13.4	22.8	25.5	21.2	0.76	0.61	1.05	1.38	1.27	1.05	1.55	2.35	2.16	1.55	2.39	4.57
	Bhola	14.0	23.1	25.7	21.6	0.74	0.52	1.37	1.44	1.23	0.98	1.99	2.40	2.15	1.50	3.05	4.61
	Faridpur	13.5	22.1	25.7	21.5	1.35	0.65	0.77	1.10	2.22	1.18	1.39	2.23	3.78	2.09	2.37	4.61
	Madaripur	13.5	22.4	25.8	21.6	0.82	0.69	0.87	1.58	1.34	1.19	1.28	2.63	2.26	1.70	1.92	5.02
	Khepupara	15.4	24.0	25.8	22.3	0.62	0.62	1.20	1.16	1.07	1.07	1.73	1.98	1.84	1.57	2.67	3.85
	Patuakhali	15.0	23.4	25.8	22.4	0.64	0.58	0.95	1.15	1.09	0.97	1.41	1.95	1.84	1.43	2.18	3.76
SE	Chandpur	14.7	22.8	25.8	21.9	0.67	0.54	1.23	1.38	1.10	0.98	1.82	2.35	1.92	1.46	2.79	4.55
	Comilla	13.5	22.2	25.3	21.1	0.66	0.51	0.94	1.24	1.05	0.91	1.42	2.14	1.80	1.36	2.20	4.30
	Feni	16.0	23.9	25.6	22.8	0.66	0.68	1.00	0.97	1.09	1.18	1.41	1.64	1.81	1.75	2.13	3.21
	Hatiya	16.1	23.5	25.4	22.8	0.47	0.51	1.34	1.16	0.82	0.90	1.95	1.91	1.41	1.34	2.96	3.62
	Maijdee court	14.8	22.6	25.5	22.4	0.59	0.49	1.29	1.29	1.02	0.94	1.91	2.21	1.84	1.49	2.95	4.28
	Sandwip	16.0	23.9	25.6	22.8	0.67	0.70	1.00	0.97	1.07	1.17	1.40	1.65	1.82	1.74	2.11	3.20
SW	Jessore	12.8	22.6	25.7	20.7	1.39	1.11	0.79	-0.15	2.35	1.79	1.34	0.95	4.01	3.09	2.26	3.27

Hydrologic Region	Station	Base (1971-2000)				2030s				2050s				2080s			
		DJF	**MAM**	**JJAS**	**ON**	**DJF**	**MAM**	**JJAS**	**ON**	**DJF**	**MAM**	**JJAS**	**ON**	**DJF**	**MAM**	**JJAS**	**ON**
	Khulna	13.9	23.2	26.0	21.8	1.15	0.86	0.84	1.38	1.87	1.49	1.37	2.52	3.28	2.61	2.29	4.99
	Satkhira	13.7	23.4	26.0	21.1	1.29	0.96	0.92	1.29	2.09	1.67	1.50	2.51	3.64	2.96	2.48	5.18
EH	**Chittagong**	15.2	22.8	25.1	22.2	0.57	0.49	1.07	1.09	0.98	0.94	1.56	1.79	1.76	1.45	2.37	3.46
	Coxs bazar	16.2	23.3	25.1	22.7	0.46	0.49	1.02	1.12	0.84	0.89	1.47	1.88	1.57	1.33	2.24	3.66
	Kutubdia	16.2	23.4	25.4	22.5	0.50	0.65	1.06	1.18	0.87	1.08	1.53	2.04	1.55	1.59	2.34	4.02
	Rangamati	15.3	22.3	24.8	22.2	0.53	0.55	0.87	0.84	0.88	0.98	1.24	1.45	1.51	1.50	1.90	2.94
	Sitakunda	13.7	22.7	25.3	21.3	0.59	0.70	0.95	1.33	1.06	1.21	1.38	2.25	1.89	1.78	2.15	4.44
	Teknaf	16.4	23.2	25.0	22.5	0.69	0.24	1.05	1.33	1.28	0.50	1.55	2.03	2.26	1.05	2.48	3.72
Nationwide Average		**14.1**	**22.5**	**25.5**	**21.5**	**0.8**	**0.8**	**0.9**	**1.1**	**1.3**	**1.3**	**1.3**	**2.0**	**2.2**	**2.0**	**2.1**	**3.8**

Appendix D: Rainfall Anomaly

Table D1: Annual Average Rainfall Anomaly (% Change)

Hydrologic Region	Station	Base (mm) (1971-2000)	RCP2.6			RCP4.5			RCP8.5		
			2030s	2050s	2080s	2030s	2050s	2080s	2030s	2050s	2080s
NC	Dhaka	2139	1	2	2	2	5	6	3	2	6
	Mymensingh	2195	2	1	4	2	5	6	3	3	6
NE	Sreemangal	2339	6	6	9	7	9	10	7	7	9
	Sylhet	4161	7	7	10	9	10	13	9	9	14
NW	Bogra	1837	10	10	6	6	3	7	9	9	11
	Dinajpur	2004	17	17	10	9	7	13	13	16	19
	Ishwardi	1650	9	9	5	5	2	6	6	7	8
	Rajshahi	1536	10	11	5	6	1	5	8	8	11
	Rangpur	2232	15	16	12	12	9	14	13	16	20
SC	Barisal	2116	3	3	3	3	6	6	3	3	6
	Bhola	2328	2	3	2	4	7	6	3	3	7
	Faridpur	1935	9	11	12	11	12	10	9	10	13
	Madaripur	2090	3	3	3	3	6	8	4	4	8
	Khepupara	2725	5	8	7	8	12	13	7	8	15
	Patuakhali	2687	5	6	6	6	11	10	7	6	10
SE	Chandpur	2119	4	6	5	6	8	9	5	6	10
	Comilla	3474	8	13	12	11	17	16	12	13	23
	Feni	3057	6	7	7	8	12	12	7	9	13
	Hatiya	2967	7	8	9	9	14	13	10	10	14
	Maijdeecourt	3092	5	6	5	6	8	10	7	6	10

Hydrologic Region	Station	Base (mm) (1971-2000)	RCP2.6			RCP4.5			RCP8.5		
			2030s	2050s	2080s	2030s	2050s	2080s	2030s	2050s	2080s
	Sandwip	3468	6	7	9	8	13	13	8	9	15
SW	**Jessore**	1607	8	8	10	10	10	7	7	8	12
	Khulna	1759	9	10	12	12	13	11	10	10	14
	Satkhira	1695	11	10	12	13	13	12	10	11	15
EH	**Chittagong**	2897	5	8	9	7	13	12	8	8	17
	Coxsbazar	2046	3	3	5	6	9	9	4	5	10
	Rangamati	2541	3	4	4	5	9	9	6	6	10
	Sitakunda	3052	7	9	10	10	15	17	10	10	18
	Teknaf	3943	7	11	15	10	13	12	9	14	31
Nationwide Average		**2580**	**6**	**7**	**8**	**8**	**11**	**11**	**7**	**8**	**14**

Table D2: Seasonal Average Rainfall Anomaly under RCP2.6 (% Change)

Hydrologic Region	Station	Base (mm) (1971-2000)				2030s				2050s				2080s			
		DJF	MAM	JJAS	ON	DJF	MAM	JJAS	ON	DJF	MAM	JJAS	ON	DJF	MAM	JJAS	ON
NC	Dhaka	46	552	1331	210	-20	8	0	-9	-14	10	1	-9	-15	8	2	-10
	Mymensingh	38	501	1455	202	3	7	2	-12	-1	6	1	-12	-5	9	5	-13
NE	Sreemangal	48	732	1363	195	14	23	-1	-18	13	24	-1	-17	13	31	1	-19
	Sylhet	52	1057	2792	261	12	30	0	-17	9	29	0	-18	2	37	3	-22
NW	Bogra	35	317	1339	146	13	-18	21	-25	5	-15	21	-32	7	-23	16	-29
	Dinajpur	32	306	1530	136	4	-24	29	-34	-12	-25	31	-44	-1	-32	24	-43
	Ishwardi	40	326	1166	118	6	-1	15	-20	4	-1	16	-31	7	-3	10	-29
	Rajshahi	39	218	1149	130	4	-8	18	-23	-7	-8	20	-29	4	-17	13	-29
	Rangpur	30	403	1650	149	0	-12	25	-23	-4	-10	27	-33	1	-16	23	-30
SC	Barisal	49	410	1444	214	-10	14	2	-14	-8	13	3	-16	-11	13	3	-16
	Bhola	50	451	1574	254	-3	19	1	-23	-7	19	4	-26	-12	15	3	-25
	Faridpur	46	455	1240	194	-35	-8	17	9	-29	-4	18	11	-33	-4	20	9
	Madaripur	42	478	1384	185	3	13	1	-10	4	14	2	-11	-1	11	3	-12
	Khepupara	38	410	1978	299	-5	24	4	-15	-3	25	8	-15	-6	20	8	-16
	Patuakhali	43	429	1974	241	-9	26	3	-13	-6	26	4	-13	-5	25	5	-12
SE	Chandpur	34	516	1402	167	-15	15	3	-13	-8	15	5	-14	-13	13	5	-18
	Comilla	41	526	1286	194	-15	16	2	-20	-16	17	2	-21	-13	17	4	-21
	Feni	50	636	2108	263	-14	24	5	-23	-19	24	7	-23	-14	22	7	-25
	Hatiya	39	493	2159	276	-7	19	8	-19	-5	19	10	-20	-10	19	11	-21
	Maijdee court	47	533	2278	233	0	14	5	-19	-1	17	6	-21	-5	13	6	-20
	Sandwip	44	556	2574	294	-13	19	6	-16	-12	22	7	-17	-7	20	9	-17
SW	Jessore	56	287	1123	140	-41	-4	15	-4	-35	-3	14	-1	-35	0	16	-2

Hydrologic Region	Station	Base (mm) (1971-2000)				2030s				2050s				2080s			
		DJF	**MAM**	**JJAS**	**ON**	**DJF**	**MAM**	**JJAS**	**ON**	**DJF**	**MAM**	**JJAS**	**ON**	**DJF**	**MAM**	**JJAS**	**ON**
	Khulna	56	324	1211	168	-44	-2	15	0	-37	-1	16	6	-32	0	19	3
	Satkhira	61	272	1210	152	-37	-6	18	0	-33	-4	17	1	-36	-1	19	4
EH	**Chittagong**	41	471	2122	262	-8	18	6	-23	-10	20	10	-24	-12	15	11	-20
	Coxs bazar	37	430	2679	328	-19	20	10	-26	-23	27	16	-29	-19	19	17	-27
	Rangamati	39	522	1766	214	-5	19	1	-19	-8	21	2	-22	-10	16	3	-25
	Sitakunda	33	588	2135	296	-13	31	5	-21	-14	30	9	-24	-12	26	10	-20
	Teknaf	27	338	3292	286	46	40	2	17	48	38	6	24	48	48	12	8
Nationwide Average		**43**	**467**	**1749**	**214**	**-7**	**11**	**8**	**-15**	**-8**	**12**	**10**	**-17**	**-8**	**10**	**10**	**-17**

Table D3: Seasonal Average Rainfall Anomaly under RCP4.5 (% Change)

Hydrologic Region	Station	Base (mm) (1971-2000)				2030s				2050s				2080s			
		DJF	MAM	JJAS	ON	DJF	MAM	JJAS	ON	DJF	MAM	JJAS	ON	DJF	MAM	JJAS	ON
NC	Dhaka	46	552	1331	210	-13	9	2	-8	-13	14	4	-9	-13	19	3	-11
	Mymensingh	38	501	1455	202	2	8	2	-10	6	12	5	-15	4	9	7	-11
NE	Sreemangal	48	732	1363	195	21	27	0	-16	17	29	2	-18	22	29	4	-16
	Sylhet	52	1057	2792	261	4	35	1	-14	13	35	3	-15	12	36	7	-18
NW	Bogra	35	317	1339	146	20	-23	16	-25	3	-12	10	-25	8	-14	15	-26
	Dinajpur	32	306	1530	136	-4	-28	21	-39	-14	-21	17	-39	-11	-21	25	-36
	Ishwardi	40	326	1166	118	5	2	9	-29	-4	6	5	-30	-5	1	10	-23
	Rajshahi	39	218	1149	130	6	-12	13	-27	-8	-4	6	-30	-11	-7	12	-29
	Rangpur	30	403	1650	149	3	-14	22	-24	-6	-8	16	-25	-4	-7	23	-30
SC	Barisal	49	410	1444	214	-6	13	3	-16	-9	23	5	-18	-14	28	5	-20
	Bhola	50	451	1574	254	-10	20	4	-22	-15	29	6	-25	-9	34	4	-28
	Faridpur	46	455	1240	194	-24	-3	17	7	-26	-5	19	11	-27	-5	17	14
	Madaripur	42	478	1384	185	-2	13	1	-10	-3	21	4	-12	-1	24	5	-10
	Khepupara	38	410	1978	299	-3	25	8	-17	-9	37	12	-18	-7	47	10	-15
	Patuakhali	43	429	1974	241	-12	28	4	-13	-14	39	8	-14	-14	44	5	-13
SE	Chandpur	34	516	1402	167	-8	14	5	-12	-14	21	7	-18	-16	27	6	-16
	Comilla	41	526	1286	194	-15	21	4	-19	-12	30	6	-21	-15	31	5	-24
	Feni	50	636	2108	263	-13	22	7	-23	-11	34	10	-24	-8	40	8	-22
	Hatiya	39	493	2159	276	-8	22	10	-21	-7	32	14	-22	-6	40	12	-23
	Maijdee court	47	533	2278	233	-4	13	7	-21	0	21	9	-23	-1	30	8	-21
	Sandwip	44	556	2574	294	-11	19	8	-16	-11	31	13	-18	-16	42	11	-21
SW	Jessore	56	287	1123	140	-42	-2	17	2	-37	-7	18	0	-34	-7	14	-2

Hydrologic Region	Station	Base (mm) (1971-2000)				2030s				2050s				2080s			
		DJF	MAM	JJAS	ON	DJF	MAM	JJAS	ON	DJF	MAM	JJAS	ON	DJF	MAM	JJAS	ON
	Khulna	56	324	1211	168	-43	-1	19	0	-35	-3	20	5	-31	-3	17	1
	Satkhira	61	272	1210	152	-38	-1	19	3	-35	-4	21	3	-31	-4	19	3
EH	**Chittagong**	41	471	2122	262	-10	17	9	-25	-13	26	16	-25	-8	33	12	-27
	Coxs bazar	37	430	2679	328	-19	19	14	-28	-19	34	21	-30	-14	41	18	-30
	Rangamati	39	522	1766	214	-7	20	4	-22	-8	34	6	-25	-1	40	5	-24
	Sitakunda	33	588	2135	296	-13	32	9	-21	-17	49	12	-23	-14	57	12	-21
	Teknaf	27	338	3292	286	48	41	5	21	66	44	10	11	55	48	7	21
Nationwide Average		**43**	**467**	**1749**	**214**	**-7**	**12**	**9**	**-15**	**-8**	**19**	**11**	**-17**	**-7**	**22**	**11**	**-17**

Table D4: Seasonal Average Rainfall Anomaly under RCP8.5 (% Change)

Hydrologic Region	Station	Base (mm) (1971-2000)				2030s				2050s				2080s			
		DJF	MAM	JJAS	ON	DJF	MAM	JJAS	ON	DJF	MAM	JJAS	ON	DJF	MAM	JJAS	ON
NC	Dhaka	46	552	1331	210	-11	12	1	-9	-4	13	0	-12	-17	13	6	-8
	Mymensingh	38	501	1455	202	-4	10	2	-10	0	9	3	-12	4	7	9	-13
NE	Sreemangal	48	732	1363	195	13	28	0	-16	18	27	-1	-17	17	26	4	-24
	Sylhet	52	1057	2792	261	7	36	2	-16	4	33	3	-20	14	35	9	-23
NW	Bogra	35	317	1339	146	9	-18	20	-28	-1	-17	19	-23	-6	-16	21	-13
	Dinajpur	32	306	1530	136	-9	-26	25	-38	-9	-25	29	-35	-16	-24	33	-29
	Ishwardi	40	326	1166	118	0	-1	12	-28	-4	-1	13	-23	-11	2	12	-14
	Rajshahi	39	218	1149	130	-7	-10	16	-27	-13	-12	16	-23	-14	-9	19	-18
	Rangpur	30	403	1650	149	-11	-12	24	-27	-4	-9	27	-25	-10	-8	31	-20
SC	Barisal	49	410	1444	214	-10	19	2	-17	-11	20	2	-19	-12	19	6	-17
	Bhola	50	451	1574	254	-6	24	1	-26	-8	23	2	-31	-10	25	8	-27
	Faridpur	46	455	1240	194	-28	-8	17	9	-22	-5	16	13	-27	-4	21	14
	Madaripur	42	478	1384	185	-2	18	2	-11	-2	17	2	-9	-3	19	6	-9
	Khepupara	38	410	1978	299	-6	29	7	-16	-1	30	8	-19	-6	35	16	-17
	Patuakhali	43	429	1974	241	-7	31	4	-13	-10	31	4	-12	-10	34	8	-15
SE	Chandpur	34	516	1402	167	-11	17	4	-16	-10	17	5	-19	-7	20	9	-17
	Comilla	41	526	1286	194	-16	21	2	-23	-16	22	3	-24	-11	25	9	-22
	Feni	50	636	2108	263	-9	28	6	-28	-9	28	8	-27	-10	31	13	-26
	Hatiya	39	493	2159	276	-5	26	11	-20	-4	26	11	-22	-2	31	16	-22
	Maijdee court	47	533	2278	233	-1	19	7	-21	1	19	6	-18	-1	20	11	-20
	Sandwip	44	556	2574	294	-9	26	8	-20	-11	28	9	-19	-9	31	16	-18
SW	Jessore	56	287	1123	140	-36	-9	15	-2	-27	-4	14	-5	-31	1	19	-2

Hydrologic Region	Station	Base (mm) (1971-2000)				2030s				2050s				2080s			
		DJF	**MAM**	**JJAS**	**ON**	**DJF**	**MAM**	**JJAS**	**ON**	**DJF**	**MAM**	**JJAS**	**ON**	**DJF**	**MAM**	**JJAS**	**ON**
	Khulna	56	324	1211	168	-33	-8	17	2	-28	-4	17	2	-31	1	21	5
	Satkhira	61	272	1210	152	-35	-8	18	2	-33	-2	17	3	-26	0	22	3
EH	**Chittagong**	41	471	2122	262	-13	21	9	-25	-11	21	10	-26	-16	23	22	-27
	Coxs bazar	37	430	2679	328	-15	24	16	-31	-17	26	16	-32	-18	29	29	-32
	Rangamati	39	522	1766	214	-5	27	4	-27	-4	27	4	-28	-5	29	9	-23
	Sitakunda	33	588	2135	296	-8	38	7	-22	-7	37	8	-26	-13	44	16	-21
	Teknaf	27	338	3292	286	40	45	5	16	51	49	10	23	63	47	30	26
Nationwide Average		**43**	**467**	**1749**	**214**	**-8**	**14**	**9**	**-17**	**-7**	**15**	**10**	**-17**	**-8**	**17**	**16**	**-15**

Appendix E: Solar Radiation Anomaly

Table E1: Annual Average Solar Radiation Anomaly (% Change)

Station	Base (MJ/Sq.m/day) (1986-2000)	RCP2.6			RCP4.5			RCP8.5		
		2030s	2050s	2080s	2030s	2050s	2080s	2030s	2050s	2080s
Barisal	9.3	-1.5	-1.3	-1.6	-1.3	-1.7	-1.6	-1.3	-1.6	-2.0
Bogra	10.7	0.3	0.3	0.2	0.3	0.4	0.3	0.1	0.2	0.7
Comilla	8.5	-0.2	-0.3	-0.2	0.2	0.0	0.1	-0.4	0.0	-0.2
Joydevpur	9.9	1.3	0.6	0.4	1.4	1.3	0.9	1.5	1.1	-0.3
Mymensingh	9.1	1.2	0.7	0.4	1.5	1.5	0.8	1.3	1.2	-0.2
Rangpur	9.5	0.3	0.5	0.1	0.2	0.3	0.4	0.5	0.7	1.2
Sreemangal	9.3	0.1	-0.3	-0.4	0.3	0.2	-0.4	0.2	-0.5	-1.3
Nationwide Average	**9.3**	**0.5**	**0.3**	**0.0**	**0.7**	**0.6**	**0.3**	**0.7**	**0.5**	**-0.1**

Table E2: Seasonal Average Solar Radiation Anomaly under RCP2.6 (% Change)

Station	Base (MJ/Sq.m/Day) (1986-2000)				2030s				2050s				2080s			
	DJF	MAM	JJAS	ON	DJF	MAM	JJAS	ON	DJF	MAM	JJAS	ON	DJF	MAM	JJAS	ON
Barisal	8.2	11.4	9.0	8.5	-4.3	-0.1	-1.4	-0.4	-3.2	0.0	-1.8	-0.2	-3.9	-0.2	-1.9	-0.2
Bogra	9.5	12.2	10.6	10.2	0.1	0.9	0.1	0.3	0.1	0.8	0.2	0.0	0.1	0.6	0.0	0.1
Comilla	7.5	9.8	8.5	8.0	0.9	-0.3	-0.5	-1.1	1.0	0.0	-1.1	-0.7	0.7	-0.1	-1.0	-0.2
Joydevpur	9.0	11.5	9.5	9.5	1.4	0.4	2.7	0.1	1.3	0.3	0.7	0.1	1.8	0.3	-0.2	0.0
Mymensingh	8.6	11.0	8.3	8.8	0.9	0.9	1.8	0.9	0.7	1.2	-0.2	1.5	1.2	0.9	-1.2	1.4
Rangpur	8.1	11.3	9.4	8.9	-0.2	0.3	0.2	1.0	0.5	0.8	-0.2	1.2	-0.1	0.2	-0.3	0.6
Sreemangal	8.7	10.1	9.1	9.1	-4.2	1.6	1.4	0.9	-3.7	1.1	0.0	1.5	-4.2	1.6	-0.3	1.3
Nationwide Average	**8.5**	**11.1**	**9.2**	**9.0**	**-0.8**	**0.5**	**0.6**	**0.2**	**-0.5**	**0.6**	**-0.3**	**0.5**	**-0.6**	**0.5**	**-0.7**	**0.4**

Table E2: Seasonal Average Solar Radiation Anomaly under RCP4.5 (% Change)

Station	Base (MJ/Sq.m/Day) (1986-2000)				2030s				2050s				2080s			
	DJF	MAM	JJAS	ON	DJF	MAM	JJAS	ON	DJF	MAM	JJAS	ON	DJF	MAM	JJAS	ON
Barisal	8.2	11.4	9.0	8.5	-2.7	0.3	-2.2	-0.2	-4.1	-0.1	-2.2	-0.5	-4.3	0.0	-1.6	-0.8
Bogra	9.5	12.2	10.6	10.2	0.4	1.1	-0.2	-0.3	0.1	1.1	0.0	0.1	0.3	0.5	0.2	0.0
Comilla	7.5	9.8	8.5	8.0	1.1	0.0	0.1	-0.4	0.8	-0.5	0.4	-0.7	0.6	-0.5	0.5	-0.5
Joydevpur	9.0	11.5	9.5	9.5	1.0	0.9	2.9	0.0	1.1	0.2	3.1	-0.2	1.4	0.1	1.8	0.0
Mymensingh	8.6	11.0	8.3	8.8	1.1	1.8	1.4	1.5	1.1	1.0	2.1	2.0	0.9	0.7	0.3	1.7
Rangpur	8.1	11.3	9.4	8.9	0.8	0.3	-0.5	0.9	0.4	0.1	0.1	0.6	0.9	0.6	-0.2	0.8
Sreemangal	8.7	10.1	9.1	9.1	-4.5	1.7	1.8	1.6	-3.9	0.6	1.8	1.9	-3.9	0.7	0.3	1.4
Nationwide Average	**8.5**	**11.1**	**9.2**	**9.0**	**-0.4**	**0.9**	**0.5**	**0.4**	**-0.6**	**0.4**	**0.8**	**0.5**	**-0.6**	**0.3**	**0.2**	**0.4**

Table E4: Seasonal Average Solar Radiation Anomaly under RCP8.5 (% Change)

Station	Base (MJ/Sq.m/Day) (1986-2000)				2030s				2050s				2080s			
	DJF	MAM	JJAS	ON	DJF	MAM	JJAS	ON	DJF	MAM	JJAS	ON	DJF	MAM	JJAS	ON
Barisal	8.2	11.4	9.0	8.5	-3.2	-0.1	-1.7	-0.2	-2.8	-0.4	-2.4	-0.7	-4.1	-0.5	-2.4	-1.1
Bogra	9.5	12.2	10.6	10.2	0.2	0.5	0.0	-0.4	0.5	0.7	-0.4	0.1	1.0	0.4	0.7	0.9
Comilla	7.5	9.8	8.5	8.0	0.6	0.1	-1.2	-1.2	0.8	0.3	-0.2	-1.3	0.8	-0.5	-0.2	-1.3
Joydevpur	9.0	11.5	9.5	9.5	1.3	0.4	3.4	0.1	1.1	0.2	2.6	-0.1	1.4	-0.4	-1.5	-0.2
Mymensingh	8.6	11.0	8.3	8.8	0.9	1.0	1.8	1.5	1.1	1.0	1.4	1.5	0.7	0.6	-2.6	1.5
Rangpur	8.1	11.3	9.4	8.9	0.6	0.4	0.1	1.5	1.2	0.5	0.2	1.3	2.2	0.7	0.9	1.6
Sreemangal	8.7	10.1	9.1	9.1	-3.5	0.8	1.8	1.4	-4.2	0.5	0.7	0.8	-4.5	1.1	-2.1	0.7
Nationwide average	**8.5**	**11.1**	**9.2**	**9.0**	**-0.4**	**0.5**	**0.6**	**0.4**	**-0.3**	**0.4**	**0.3**	**0.2**	**-0.3**	**0.2**	**-1.0**	**0.3**

Appendix F: Drought Severity

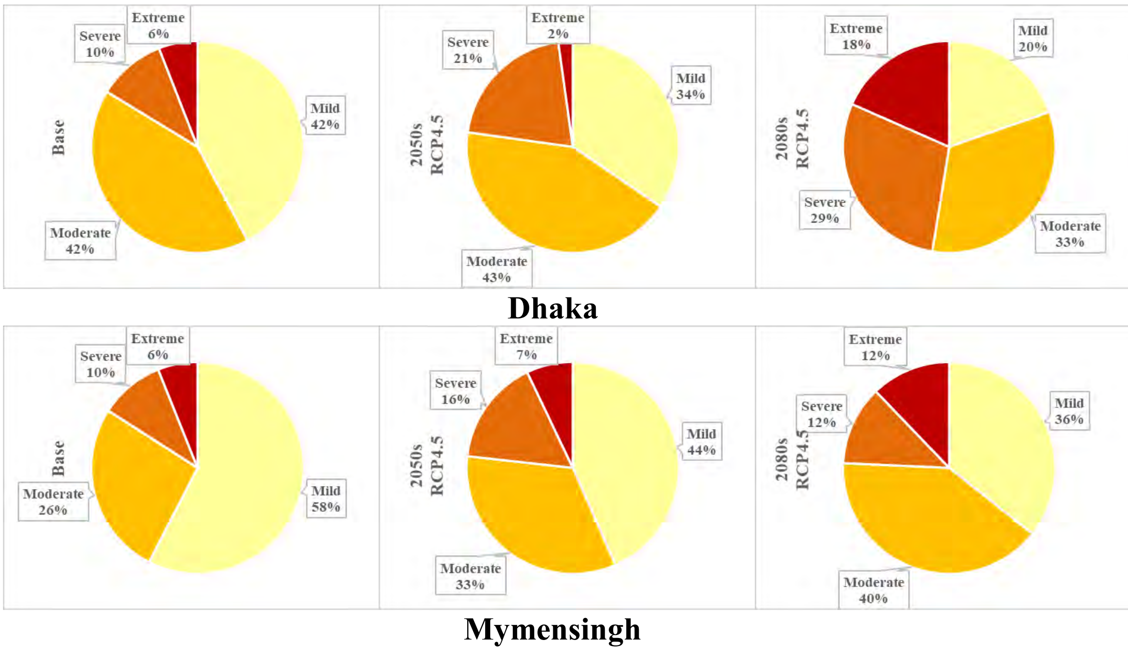


Figure F1: Distribution of future occurrence of drought in north-central region for RCP4.5

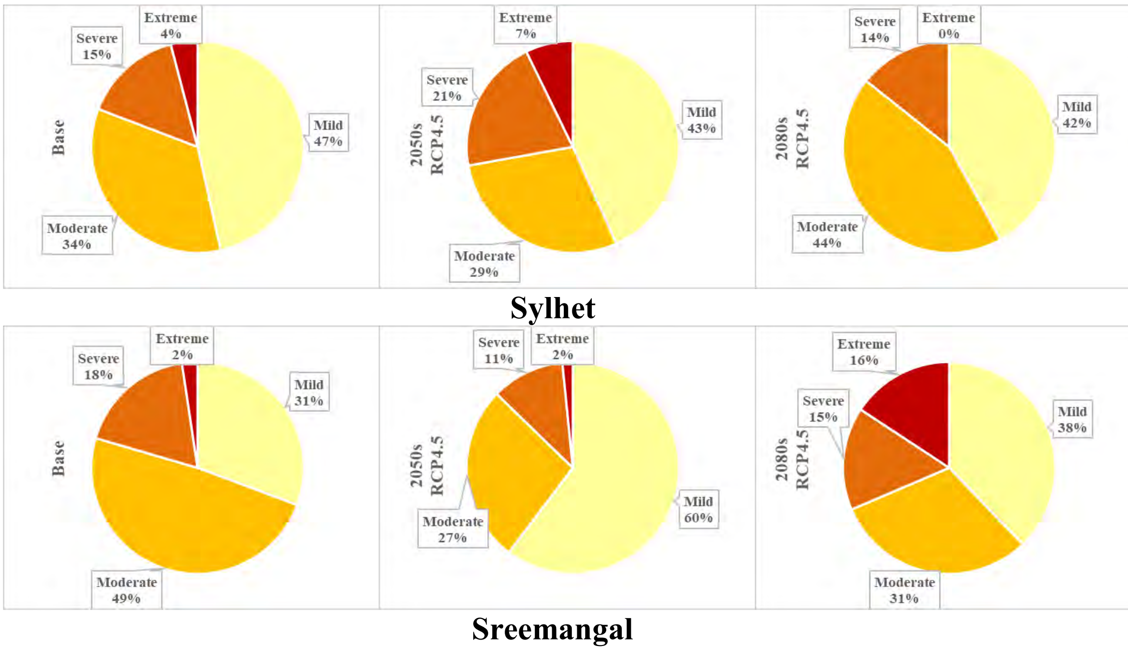


Figure F2: Distribution of future occurrence of drought in north-east region for RCP4.5

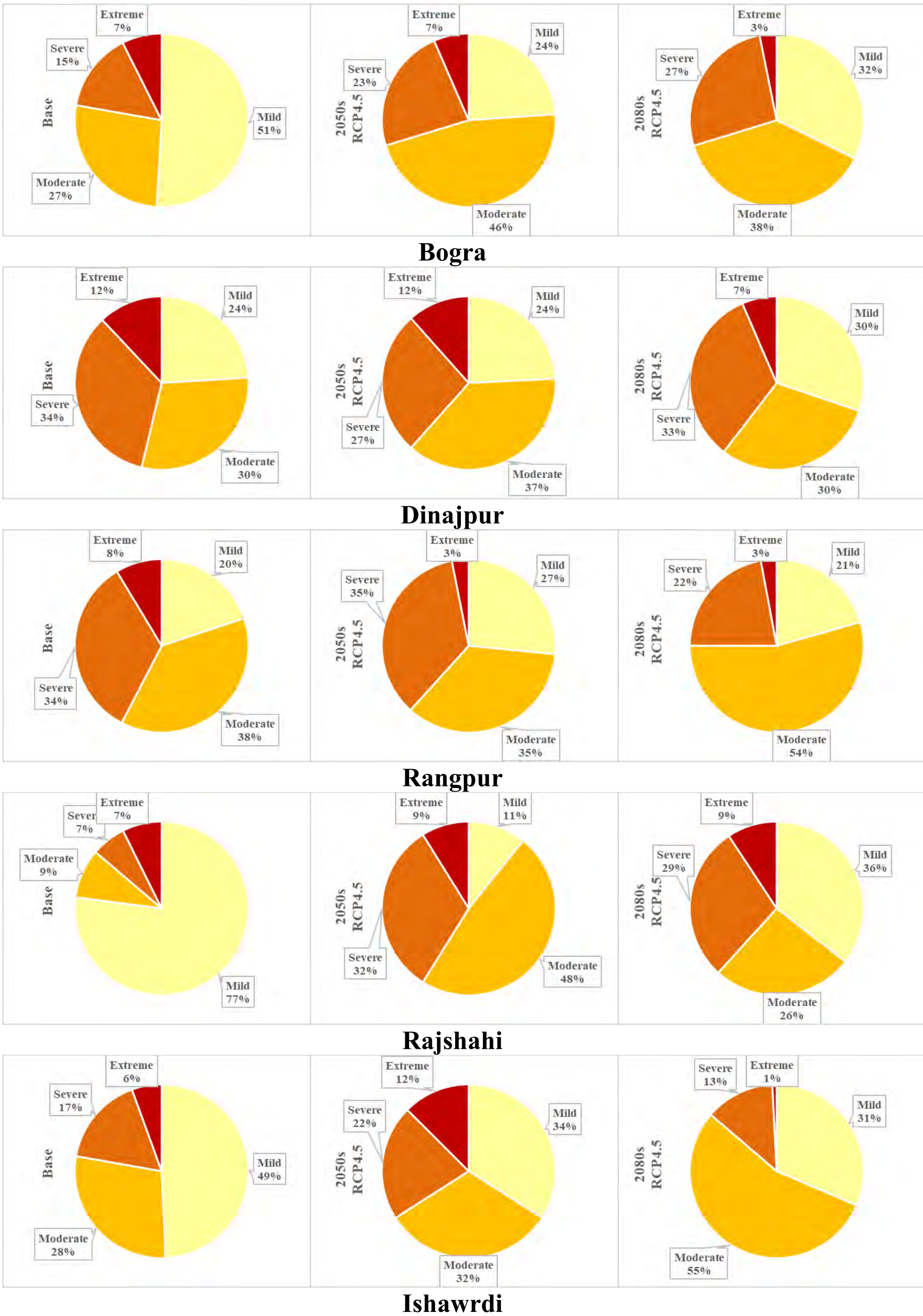
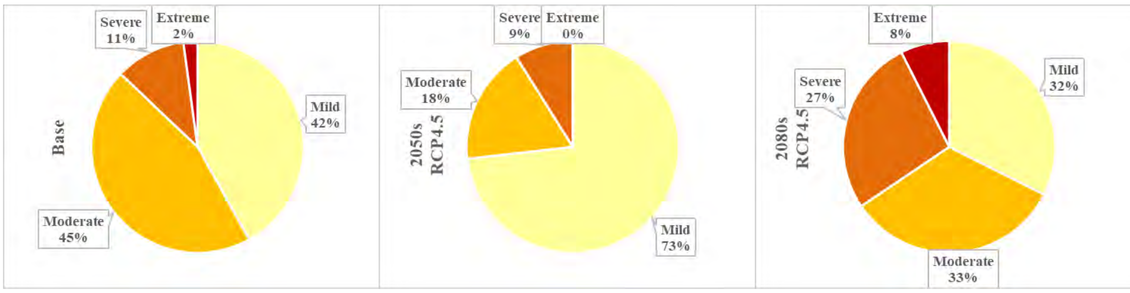
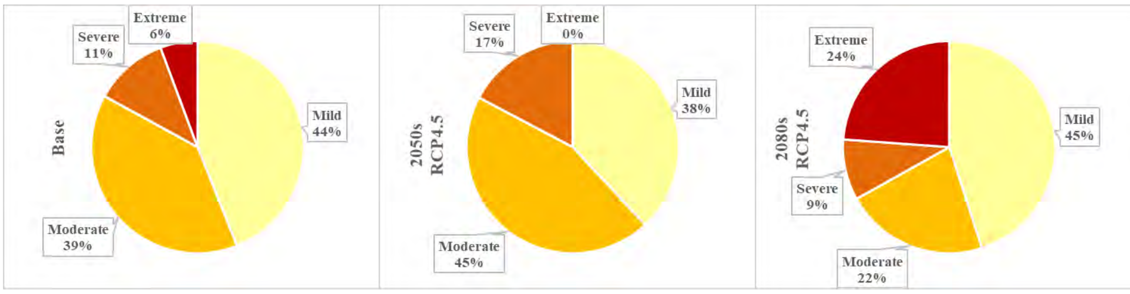


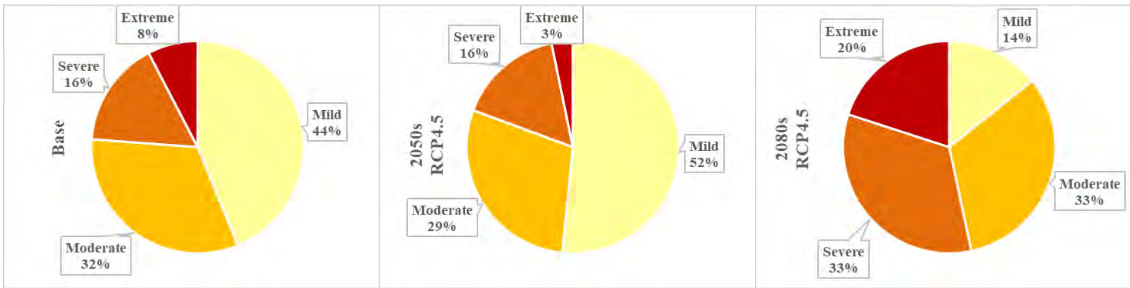
Figure F3: Distribution of future occurrence of drought in north-west region for RCP4.5



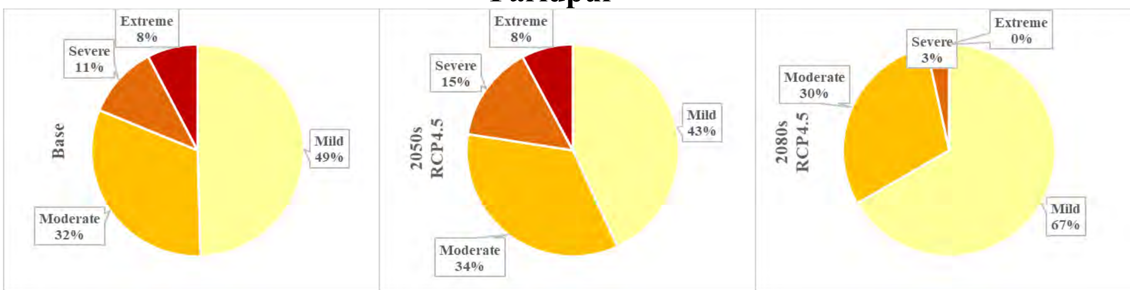
Barisal



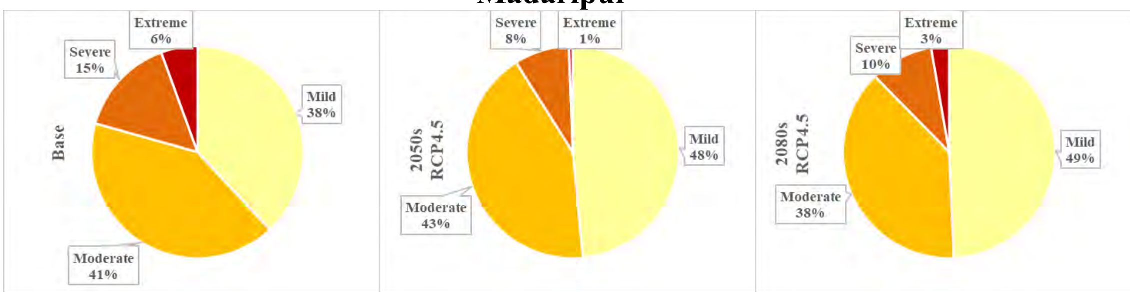
Bhola



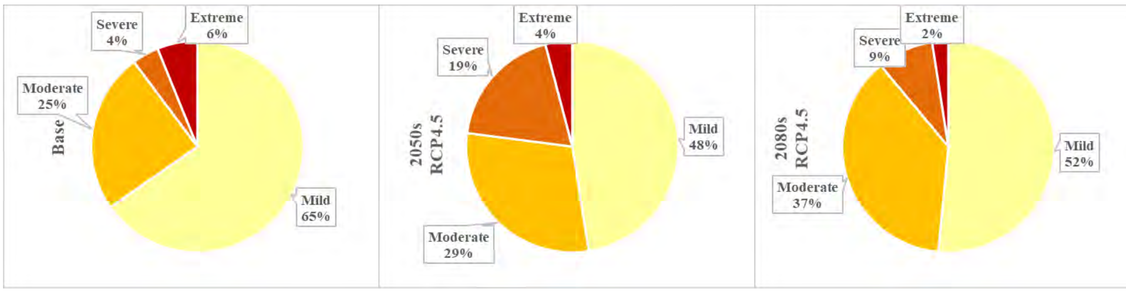
Faridpur



Madaripur

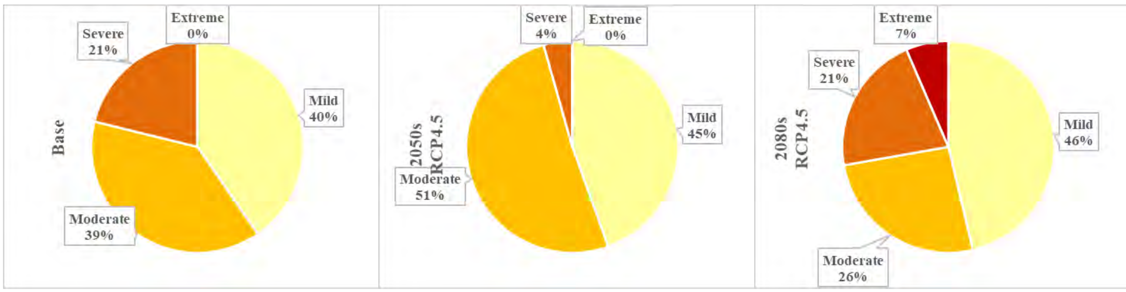


Khepupara

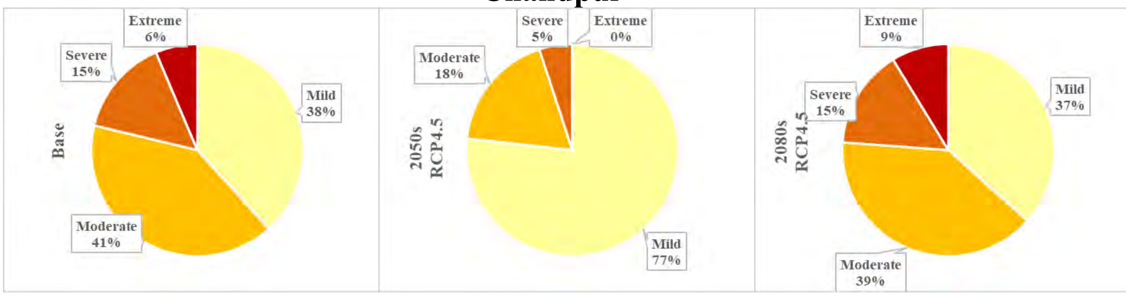


Patuakhali

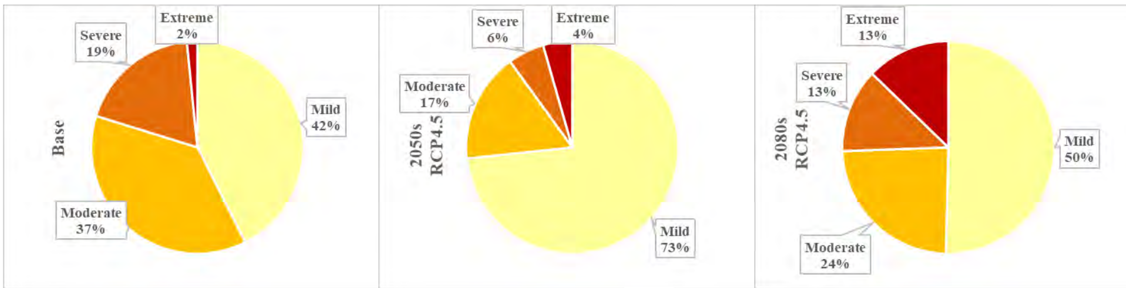
Figure F4: Distribution of future occurrence of drought in south-central region for RCP4.5



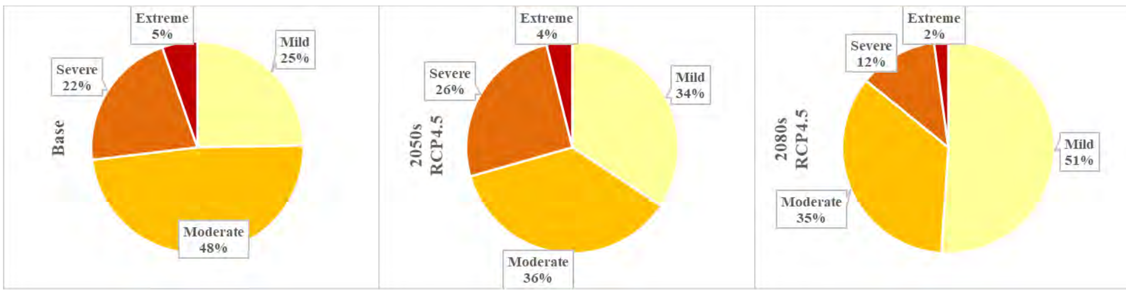
Chandpur



Comilla

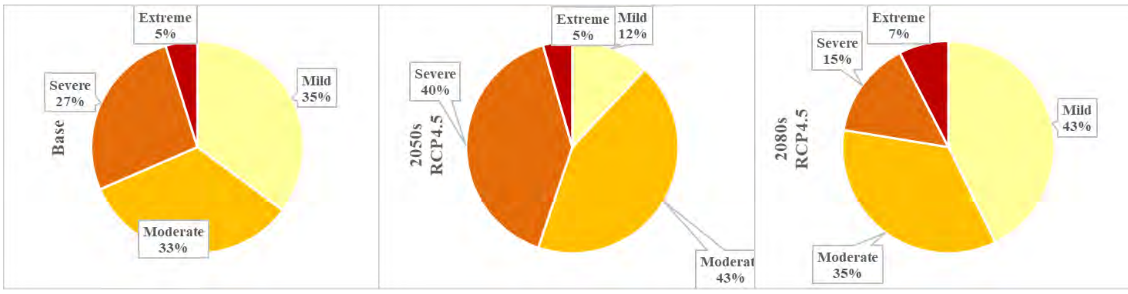


Feni

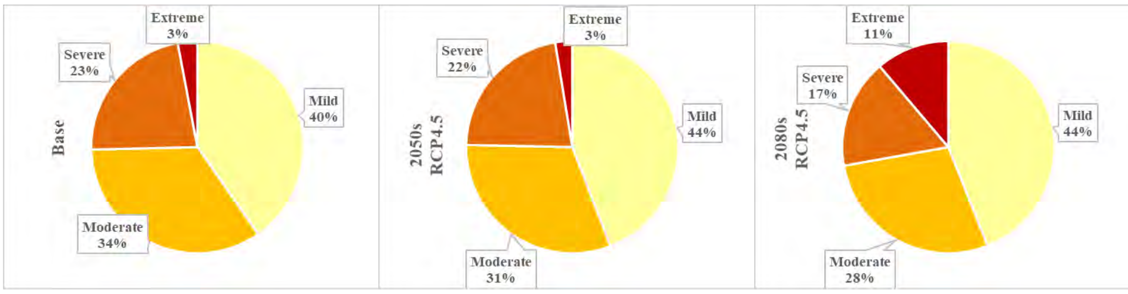


Maijdeecourt

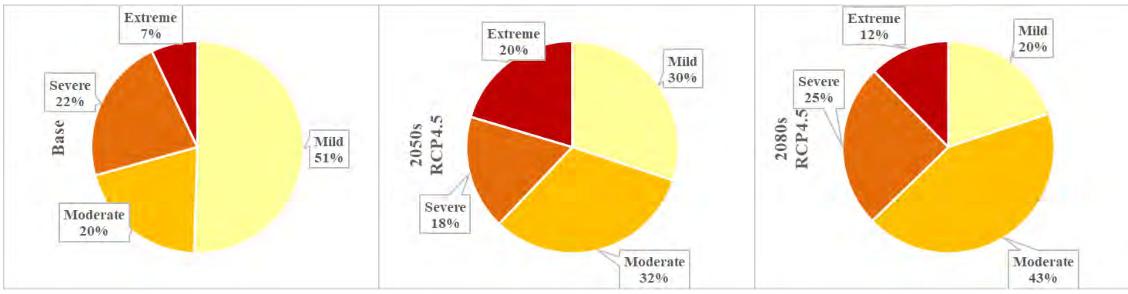
Figure F5: Distribution of future occurrence of drought in south-east region for RCP4.5



Jessore

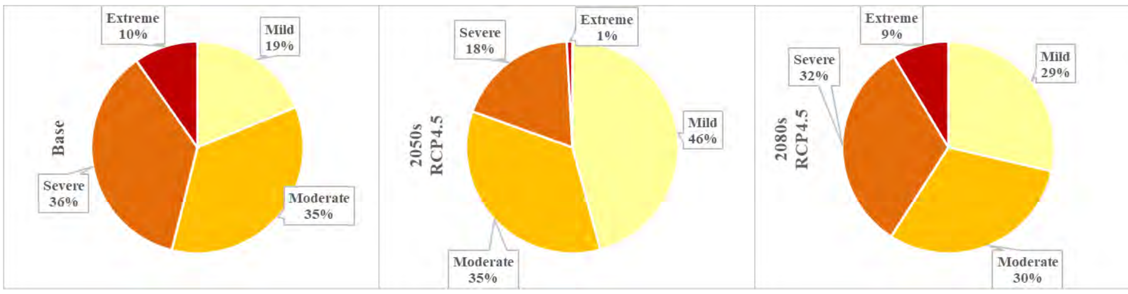


Khulna

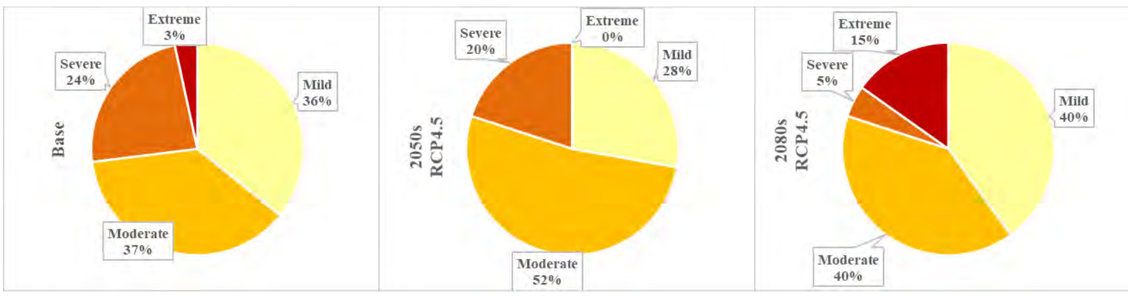


Satkhira

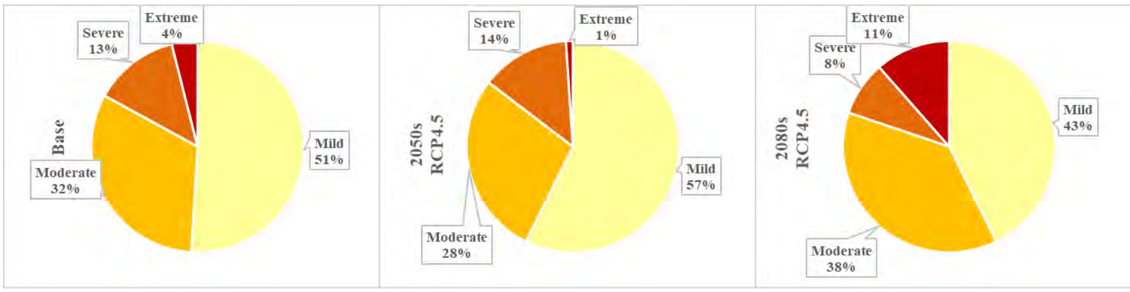
Figure F6: Distribution of future occurrence of drought in south-west region for RCP4.5



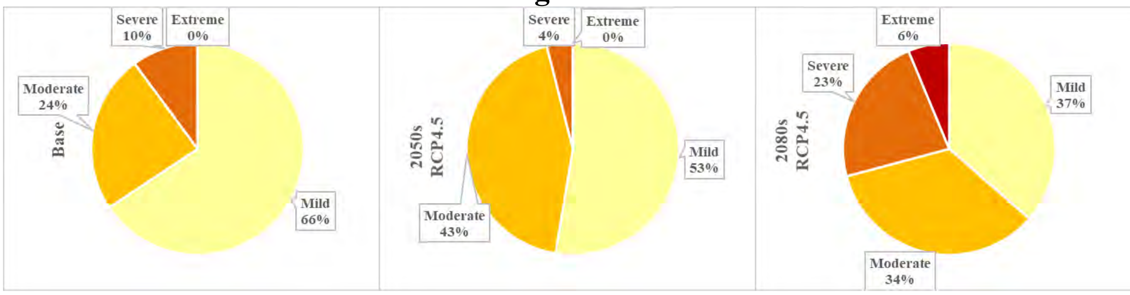
Cox's Bazar



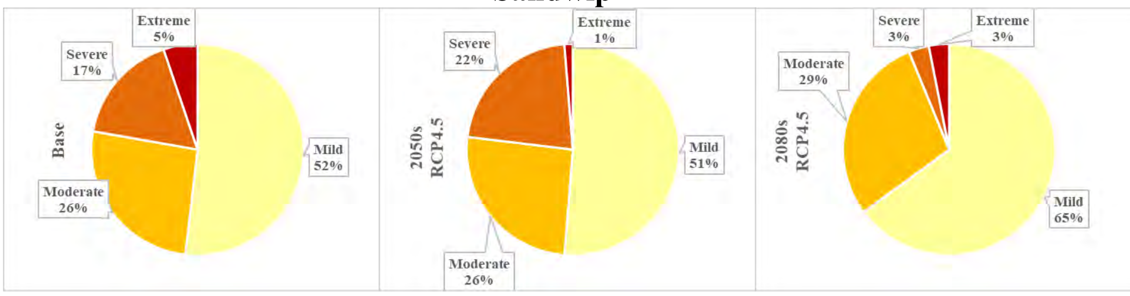
Chittagong



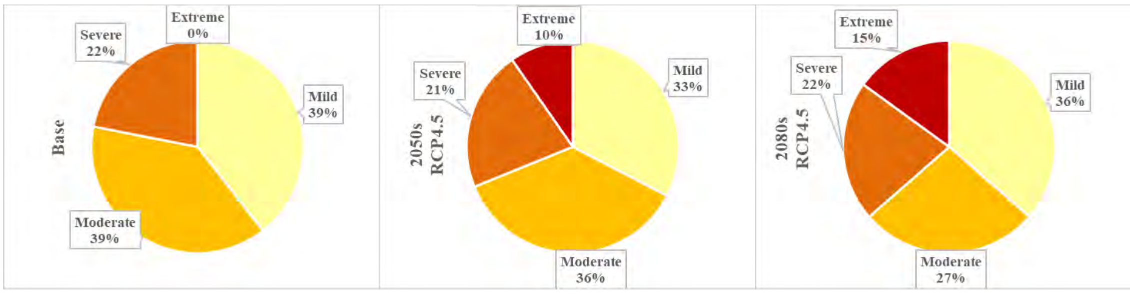
Rangamati



Sandwip



Sitakunda



Teknaf

Figure F7: Distribution of future occurrence of drought in eastern hill region for RCP4.5

Table F1: Drought Occurrence over Bangladesh under RCP4.5 Scenario

Region	Station	Base (1981-2010)					2050s					2080s				
		Mild Drought	Moderate Drought	Severe Drought	Extreme Drought	Total	Mild Drought	Moderate Drought	Severe Drought	Extreme Drought	Total	Mild Drought	Moderate Drought	Severe Drought	Extreme Drought	Total
NC	Dhaka	57	56	14	8	**135**	47	58	28	3	**136**	46	77	68	43	**234**
	Mymensingh	76	35	13	8	**132**	43	33	16	7	**99**	50	56	17	17	**140**
NE	Sreemangal	39	62	23	3	**127**	38	17	7	1	**63**	53	43	22	22	**140**
	Sylhet	80	59	26	7	**172**	42	28	20	7	**97**	47	49	16	0	**112**
NW	Bogra	55	29	16	8	**108**	33	64	32	9	**138**	51	60	42	5	**158**
	Dinajpur	42	52	60	21	**175**	46	71	51	22	**190**	42	42	46	9	**139**
	Ishwardi	71	41	24	8	**144**	49	46	31	18	**144**	39	68	16	1	**124**
	Rajshahi	84	10	7	8	**109**	17	76	51	14	**158**	65	48	53	17	**183**
	Rangpur	30	57	51	13	**151**	34	45	45	4	**128**	28	74	30	4	**136**
SC	Barisal	39	42	10	2	**93**	41	10	5	0	**56**	48	49	40	11	**148**
	Bhola	62	55	16	8	**141**	53	62	24	0	**139**	68	33	14	36	**151**
	Faridpur	46	34	17	8	**105**	48	27	15	3	**93**	15	34	35	21	**105**
	Madaripur	58	37	13	9	**117**	44	35	15	8	**102**	58	26	3	0	**87**
	Khepupara	48	52	19	7	**126**	81	71	14	1	**167**	36	28	7	2	**73**
	Patuakhali	32	12	2	3	**49**	58	36	23	5	**122**	84	61	14	4	**163**
SE	Chandpur	42	40	22	0	**104**	61	70	6	0	**137**	50	28	23	7	**108**
	Comilla	36	38	14	6	**94**	76	18	5	0	**99**	63	68	26	15	**172**
	Feni	80	70	35	3	**188**	66	15	5	4	**90**	67	32	17	17	**133**
	Maijdeecourt	23	45	20	5	**93**	35	37	26	4	**102**	47	32	11	2	**92**
	Sandwip	65	24	10	0	**99**	40	33	3	0	**76**	35	33	22	6	**96**
SW	Jessore	58	55	44	8	**165**	8	29	27	3	**67**	141	115	49	25	**330**
	Khulna	27	23	15	2	**67**	34	24	17	2	**77**	106	68	40	27	**241**

Region	Station	Base (1981-2010)					2050s					2080s				
		Mild Drought	Moderate Drought	Severe Drought	Extreme Drought	Total	Mild Drought	Moderate Drought	Severe Drought	Extreme Drought	Total	Mild Drought	Moderate Drought	Severe Drought	Extreme Drought	Total
	Satkhira	50	20	22	7	**99**	31	33	18	21	**103**	71	153	89	44	**357**
EH	**Chittagong**	73	76	48	7	**204**	25	47	18	0	**90**	50	50	6	19	**125**
	Coxsbazar	29	54	56	15	**154**	54	41	22	1	**118**	63	67	71	19	**220**
	Rangamati	78	49	20	6	**153**	55	27	13	1	**96**	41	36	8	11	**96**
	Sitakunda	70	35	23	7	**135**	40	20	17	1	**78**	63	28	3	3	**97**
	Teknaf	45	44	25	0	**114**	64	71	42	19	**196**	51	38	30	21	**140**

Table F2: Drought Occurrence over Bangladesh under RCP8.5 Scenario

Region	Station	Base (1981-2010)					2050s					2080s				
		Mild Drought	Moderate Drought	Severe Drought	Extreme Drought	Total	Mild Drought	Moderate Drought	Severe Drought	Extreme Drought	Total	Mild Drought	Moderate Drought	Severe Drought	Extreme Drought	Total
NC	**Dhaka**	57	56	14	8	**135**	27	34	3	0	**64**	47	49	22	18	**136**
	Mymensingh	76	35	13	8	**132**	37	42	0	0	**79**	104	48	67	20	**239**
NE	**Sreemangal**	39	62	23	3	**127**	39	17	4	0	**60**	68	80	62	23	**233**
	Sylhet	80	59	26	7	**172**	37	111	62	7	**217**	19	52	48	25	**144**
NW	**Bogra**	55	29	16	8	**108**	62	18	23	8	**111**	45	31	33	12	**121**
	Dinajpur	42	52	60	21	**175**	61	67	22	8	**158**	40	40	10	14	**104**
	Ishwardi	71	41	24	8	**144**	35	6	2	0	**43**	50	11	22	11	**94**
	Rajshahi	84	10	7	8	**109**	56	17	7	4	**84**	4	17	19	7	**47**
	Rangpur	30	57	51	13	**151**	60	61	30	12	**163**	45	63	13	12	**133**
SC	**Barisal**	39	42	10	2	**93**	76	43	11	0	**130**	64	79	58	13	**214**
	Bhola	62	55	16	8	**141**	83	72	10	0	**165**	43	50	15	17	**125**
	Faridpur	46	34	17	8	**105**	61	24	12	3	**100**	44	94	54	0	**192**
	Madaripur	58	37	13	9	**117**	102	20	6	0	**128**	141	78	3	0	**222**
	Khepupara	48	52	19	7	**126**	46	45	33	0	**124**	71	68	36	7	**182**
	Patuakhali	32	12	2	3	**49**	10	30	7	0	**47**	65	37	39	0	**141**
SE	**Chandpur**	42	40	22	0	**104**	18	31	12	0	**61**	61	47	31	11	**150**
	Comilla	36	38	14	6	**94**	50	25	1	0	**76**	70	53	7	0	**130**
	Feni	80	70	35	3	**188**	92	47	23	0	**162**	83	37	42	2	**164**
	Maijdeecourt	23	45	20	5	**93**	47	7	17	2	**73**	88	41	26	19	**174**
	Sandwip	65	24	10	0	**99**	122	63	19	5	**209**	52	35	33	9	**129**
SW	**Jessore**	58	55	44	8	**165**	59	38	17	1	**115**	91	117	20	0	**228**
	Khulna	27	23	15	2	**67**	50	44	14	6	**114**	127	124	30	1	**282**
	Satkhira	50	20	22	7	**99**	71	50	8	4	**133**	58	65	26	0	**149**

Region	Station	Base (1981-2010)					2050s					2080s				
		Mild Drought	Moderate Drought	Severe Drought	Extreme Drought	Total	Mild Drought	Moderate Drought	Severe Drought	Extreme Drought	Total	Mild Drought	Moderate Drought	Severe Drought	Extreme Drought	Total
EH	**Chittagong**	73	76	48	7	**204**	56	55	2	0	**113**	33	76	52	14	**175**
	Coxsbazar	29	54	56	15	**154**	35	20	20	2	**77**	46	80	46	17	**189**
	Rangamati	78	49	20	6	**153**	68	58	41	15	**182**	71	21	37	15	**144**
	Sitakunda	70	35	23	7	**135**	74	65	58	17	**214**	76	119	38	8	**241**
	Teknaf	45	44	25	0	**114**	57	39	0	0	**96**	65	96	44	19	**224**

Table F3: Station wise Drought Severity for Base Period (1981-2010)

Station	Starting of Drought Spell	Ending of Drought Spell	Maximum Severity	Number of Months				
				Mild Drought	Moderate Drought	Severe Drought	Extreme Drought	Total
Barisal	Feb-85	Aug-86	-3.31	6	11	2	-	19
	Sep-94	May-95	-2.62	6	3	-	-	9
	Sep-00	Apr-01	-2.39	7	1	-	-	8
	Feb-04	Jul-04	-2.81	4	2	-	-	6
	May-05	May-07	-2.86	10	15	-	-	25
	Nov-08	Dec-10	-4.5	6	10	8	2	26
Number of Months				**39**	**42**	**10**	**2**	**93**
Percent of Total Time				**11**	**12**	**3**	**1**	**26**
Bhola	Oct-82	Mar-83	-1.67	6				6
	Oct-85	Mar-86	-2.11	5	1			6
	May-89	Jan-90	-1.56	9				9
	Jun-92	Jan-93	-2.37	2	6			8
	Jul-94	Jan-97	-3.78	3	15	13		31
	May-03	Jul-04	-2.43	7	8			15
	May-05	Dec-07	-2.84	20	12			32
	Mar-08	Dec-10	-5.53	10	13	3	8	34
Number of Months				**62**	**55**	**16**	**8**	**141**
Percent of Total Time				**17**	**15**	**4**	**2**	**39**
Bogra	Sep-82	Aug-83	-1.97	12				12
	Aug-89	Apr-90	-1.87	9				9

Station	Starting of Drought Spell	Ending of Drought Spell	Maximum Severity	Number of Months				
				Mild Drought	Moderate Drought	Severe Drought	Extreme Drought	Total
	May-94	May-95	-2.35	12	1			13
	Sep-97	May-98	-1.56	9				9
	Apr-01	Mar-02	-2.12	10	2			12
	Aug-06	Dec-10	-4.88	3	26	16	8	53
Number of Months				**55**	**29**	**16**	**8**	**108**
Percent of Total Time				**15**	**8**	**4**	**2**	**30**
Chandpur	Dec-85	Aug-86	-2.68	5	4			9
	Apr-89	Sep-89	-2.46	4	2			6
	May-92	Jan-93	-2.8	4	5			9
	Oct-94	Oct-95	-2.88	5	8			13
	Sep-00	Apr-01	-2.45	6	2			8
	Aug-03	Aug-04	-2.44	8	5			13
	Jun-05	May-07	-3.71	7	4	13		24
	Mar-09	Dec-10	-3.78	3	10	9		22
Number of Months				**42**	**40**	**22**	**0**	**104**
Percent of Total Time				**12**	**11**	**6**	**0**	**29**
Chittagong	Oct-81	Mar-87	-3.98	18	33	15		66
	May-87	Oct-88	-2.97	9	9			18
	Dec-88	Jul-89	-2.71	5	3			8
	Oct-94	Oct-95	-4.67	2	3	6	2	13
	Jul-98	Sep-00	-4.37	9	9	7	2	27

Station	Starting of Drought Spell	Ending of Drought Spell	Maximum Severity	Number of Months				
				Mild Drought	Moderate Drought	Severe Drought	Extreme Drought	Total
	Nov-00	Oct-02	-2.77	16	8			24
	Feb-05	Apr-06	-3.99	6	7	2		15
	Apr-08	Dec-10	-4.39	8	4	18	3	33
Number of Months				**73**	**76**	**48**	**7**	**204**
Percent of Total Time				**20**	**21**	**13**	**2**	**57**
Comilla	Oct-81	Mar-82	-2.55	3	3			6
	Oct-85	Aug-86	-3.49	2	6	3		11
	May-89	Feb-90	-2.61	3	7			10
	Sep-94	Oct-95	-3.47	1	7	6		14
	Nov-00	Dec-01	-2.52	11	3			14
	Sep-03	May-04	-2.58	5	4			9
	Oct-06	May-07	-2.08	7	1			8
	Mar-09	Dec-10	-4.76	4	7	5	6	22
Number of Months				**36**	**38**	**14**	**6**	**94**
Percent of Total Time				**10**	**11**	**4**	**2**	**26**
CoxsBazar	Nov-81	Dec-82	-3.34	6	4	4		14
	Sep-84	Mar-88	-3.92	6	21	16		43
	Oct-94	Oct-95	-3.93	1	5	7		13
	Nov-03	Dec-07	-4.54	15	16	17	2	50
	Mar-08	Dec-10	-5.21	1	8	12	13	34
Number of Months				**29**	**54**	**56**	**15**	**154**

Station	Starting of Drought Spell	Ending of Drought Spell	Maximum Severity	Number of Months				
				Mild Drought	**Moderate Drought**	**Severe Drought**	**Extreme Drought**	**Total**
Percent of Total Time				**8**	**15**	**16**	**4**	**43**
Dhaka	Apr-82	Oct-82	-1.5	7				7
	May-92	Jan-93	-3.94	1	3	5		9
	Sep-94	Nov-97	-3.3	16	19	4		39
	Feb-01	Aug-04	-2.81	24	19			43
	Mar-06	May-07	-2.71	7	8			15
	Mar-09	Dec-10	-5.1	2	7	5	8	22
Number of Months				**57**	**56**	**14**	**8**	**135**
Percent of Total Time				**16**	**16**	**4**	**2**	**38**
Dinajpur	May-82	May-84	-2.55	11	14			25
	Jan-85	Sep-86	-2.41	16	5			21
	May-92	Dec-92	-2.23	1	7			8
	Jun-94	Apr-99	-5.36	2	15	32	10	59
	Oct-00	May-01	-2.68	5	3			8
	Jul-06	Dec-10	-4.51	7	8	28	11	54
Number of Months				**42**	**52**	**60**	**21**	**175**
Percent of Total Time				**12**	**14**	**17**	**6**	**49**
Faridpur	Nov-85	Aug-86	-1.71	10				10
	Oct-94	Apr-95	-2.23	6	1			7
	Aug-03	Feb-05	-1.93	19				19
	Apr-05	Dec-10	-4.59	11	33	17	8	69

Station	Starting of Drought Spell	Ending of Drought Spell	Maximum Severity	Number of Months				
				Mild Drought	**Moderate Drought**	**Severe Drought**	**Extreme Drought**	**Total**
Number of Months				**46**	**34**	**17**	**8**	**105**
Percent of Total Time				**13**	**9**	**5**	**2**	**29**
Feni	Oct-81	Aug-82	-2.67	9	2			11
	Oct-82	Jul-85	-2.54	28	6			34
	Sep-85	Jun-86	-3.69	2	4	4		10
	Jan-88	Jun-88	-1.71	6				6
	Oct-94	Oct-95	-2.38	7	6			13
	Apr-01	Dec-07	-4.19	18	37	23	3	81
	Apr-08	Dec-10	-3.3	10	15	8		33
Number of Months				**80**	**70**	**35**	**3**	**188**
Percent of Total Time				**22**	**19**	**10**	**1**	**52**
Ishawrdi	Jul-85	Jun-87	-3.21	7	14	3		24
	Jul-92	Dec-93	-1.92	18				18
	Jul-94	Jul-96	-4.04	2	7	15	1	25
	Aug-03	Sep-05	-2.47	15	11			26
	Oct-06	Dec-10	-6.17	29	9	6	7	51
Number of Months				**71**	**41**	**24**	**8**	**144**
Percent of Total Time				**20**	**11**	**7**	**2**	**40**
Jessore	Apr-85	Aug-86	-1.99	17				17
	Jun-89	Oct-90	-3.11	2	14	1		17
	Apr-94	Mar-02	-4.61	12	33	43	8	96

Station	Starting of Drought Spell	Ending of Drought Spell	Maximum Severity	Number of Months				
				Mild Drought	Moderate Drought	Severe Drought	Extreme Drought	Total
	Mar-06	Sep-06	-1.42	6				6
	Oct-06	May-07	-2.02	7	1			8
	Apr-09	Dec-10	-2.9	14	7			21
Number of Months				**58**	**55**	**44**	**8**	**165**
Percent of Total Time				**16**	**15**	**12**	**2**	**46**
Khepupara	Oct-81	Dec-83	-3.48	14	10	3		27
	Feb-84	Jul-84	-1.57	6				6
	Sep-84	Aug-86	-3.8	2	14	8		24
	May-89	Jan-90	-2.7	7	2			9
	Sep-93	Feb-94	-1.77	6				6
	Sep-94	Apr-95	-3.26	6	1	1		8
	Aug-03	Jul-04	-6.02	1	1	3	7	12
	Nov-06	Aug-07	-2.83	4	6			10
	Jan-09	Dec-10	-3.49	2	18	4		24
Number of Months				**48**	**52**	**19**	**7**	**126**
Percent of Total Time				**13**	**14**	**5**	**2**	**35**
Khulna	Mar-85	Mar-86	-3.09	4	8	1		13
	Jul-92	May-93	-2.76	6	5			11
	Dec-93	Jul-95	-4.07	7	3	8	2	20
	Feb-09	Dec-10	-3.99	10	7	6		23
Number of Months				**27**	**23**	**15**	**2**	**67**

Station	Starting of Drought Spell	Ending of Drought Spell	Maximum Severity	Number of Months				
				Mild Drought	Moderate Drought	Severe Drought	Extreme Drought	Total
Percent of Total Time				**8**	**6**	**4**	**1**	**19**
Madaripur	May-89	Jan-90	-2.76	4	5			9
	Jun-92	Jan-93	-1.94	8				8
	Oct-94	May-95	-2.19	6	2			8
	May-03	Dec-10	-5.39	40	30	13	9	92
Number of Months				**58**	**37**	**13**	**9**	**117**
Percent of Total Time				**16**	**10**	**4**	**3**	**33**
MaijdeeCourt	Nov-83	Oct-86	-4.256	7	12	14	3	36
	Oct-94	Oct-95	-2.25	7	5		1	13
	Feb-06	Aug-07	-2.61	6	13			19
	Dec-08	Dec-10	-4.03	3	15	6	1	25
Number of Months				**23**	**45**	**20**	**5**	**93**
Percent of Total Time				**6**	**13**	**6**	**1**	**26**
Mymensingh	Nov-82	Apr-83	-1.43	6				6
	Oct-85	Mar-86	-2.12	5	1			6
	Aug-94	Jul-95	-1.96	12				12
	Apr-96	Sep-99	-3.42	12	24	6		42
	Mar-01	Mar-02	-1.69	13				13
	Aug-03	Sep-04	-2.03	13	1			14
	Jul-06	May-07	-2.13	8	3			11
	Sep-08	Dec-10	-4.19	7	6	7	8	28

Station	Starting of Drought Spell	Ending of Drought Spell	Maximum Severity	Number of Months				
				Mild Drought	Moderate Drought	Severe Drought	Extreme Drought	Total
Number of Months				**76**	**35**	**13**	**8**	**132**
Percent of Total Time				**21**	**10**	**4**	**2**	**37**
Patuakhali	Dec-81	Jun-82	-2.07	6	1			7
	Nov-84	Aug-86	-2.8	15	7			22
	Aug-03	May-04	-4.63	2	3	2	3	10
	Mar-10	Dec-10	-2.1	9	1			10
Number of Months				**32**	**12**	**2**	**3**	**49**
Percent of Total Time				**9**	**3**	**1**	**1**	**14**
Rajshahi	Dec-82	Jun-83	-2.14	6	1			7
	Sep-92	Dec-93	-2.18	14	2			16
	Aug-94	Jun-97	-1.66	35				35
	Oct-06	Dec-10	-5.26	29	7	7	8	51
Number of Months				**84**	**10**	**7**	**8**	**109**
Percent of Total Time				**23**	**3**	**2**	**2**	**30**
Rangamati	Nov-81	Jan-83	-3.68	6	6	3		15
	Oct-84	Oct-86	-4.64	2	5	12	6	25
	Aug-94	Oct-95	-3.2	3	9	3		15
	Dec-98	Nov-99	-3.19	3	7	2		12
	Apr-01	Aug-02	-1.94	17				17
	Feb-03	Aug-04	-2.32	14	5			19
	Nov-04	Jul-05	-1.62	9				9

Station	Starting of Drought Spell	Ending of Drought Spell	Maximum Severity	Number of Months				
				Mild Drought	Moderate Drought	Severe Drought	Extreme Drought	Total
	Nov-05	Jan-07	-2.63	6	9			15
	Apr-08	May-10	-2.91	18	8			26
Number of Months				**78**	**49**	**20**	**6**	**153**
Percent of Total Time				**22**	**14**	**6**	**2**	**43**
Rangpur	Jan-82	Sep-83	-3.04	4	15	2		21
	Apr-89	Jan-90	-2.76	4	6			10
	Jul-94	Mar-99	-5.2	2	7	35	13	57
	Sep-00	Aug-01	-3.35	4	4	4		12
	Aug-06	Jan-07	-1.56	6				6
	Apr-07	Dec-10	-3.43	10	25	10		45
Number of Months				**30**	**57**	**51**	**13**	**151**
Percent of Total Time				**8**	**16**	**14**	**4**	**42**
Sandwip	May-92	Dec-82	-1.87	8				8
	Oct-84	May-86	-2.33	16	4			20
	Mar-99	Nov-99	-1.79	9				9
	Jun-01	May-04	-3.02	28	7	1		36
	Nov-08	Dec-10	-3.79	4	13	9		26
Number of Months				**65**	**24**	**10**	**0**	**99**
Percent of Total Time				**18**	**7**	**3**	**0**	**28**
Satkhira	Jul-82	Jul-83	-2.34	7	6			13
	Dec-84	Aug-86	-3.65	7	8	6		21

Station	Starting of Drought Spell	Ending of Drought Spell	Maximum Severity	Number of Months				
				Mild Drought	Moderate Drought	Severe Drought	Extreme Drought	Total
	Feb-89	Jan-90	-3.52	6	1	5		12
	Jun-92	Aug-93	-1.81	15				15
	Nov-94	Oct-95	-2.23	10	2			12
	Nov-08	Dec-10	-5.88	5	3	11	7	26
Number of Months				**50**	**20**	**22**	**7**	**99**
Percent of Total Time				**14**	**6**	**6**	**2**	**28**
Sitakunda	Nov-81	Feb-83	-2.32	11	5			16
	Feb-85	Oct-86	-1.91	21				21
	Dec-94	Oct-95	-2.42	8	4			12
	Apr-99	Nov-99	-2	7	1			8
	Mar-04	Aug-04	-1.74	6				6
	Nov-04	Dec-07	-3.55	15	16	7		38
	Mar-08	Dec-10	-4.72	2	9	16	7	34
Number of Months				**70**	**35**	**23**	**7**	**135**
Percent of Total Time				**19**	**10**	**6**	**2**	**38**
Sreemangal	Aug-85	Mar-86	-3.85	2	4	2		8
	Jun-92	Jan-93	-2.22	4	4			8
	Jun-94	Jun-99	-4.96	19	36	3	3	61
	Aug-05	Jan-07	-3.54	6	4	8		18
	May-08	Dec-10	-3.77	8	14	10		32
Number of Months				**39**	**62**	**23**	**3**	127

Station	Starting of Drought Spell	Ending of Drought Spell	Maximum Severity	Number of Months				
				Mild Drought	Moderate Drought	Severe Drought	Extreme Drought	Total
Percent of Total Time				**11**	**17**	**6**	**1**	**35**
Sylhet	Nov-85	Aug-86	-2.23	6	4			10
	Mar-95	Oct-95	-1.92	8				8
	Apr-97	Jan-01	-4.57	12	21	6	7	46
	Mar-01	Oct-01	-1.85	8				8
	Dec-01	Feb-05	-2.85	27	12			39
	Dec-05	Dec-10	-3.98	19	22	20		61
Number of Months				**80**	**59**	**26**	**7**	**172**
Percent of Total Time				**22**	**16**	**7**	**2**	**48**
Teknaf	Jun-82	May-83	-2.64	5	7			12
	Jun-84	Sep-86	-3.07	11	15	2		28
	Sep-90	Sep-91	-2.55	9	4			13
	Apr-01	Apr-06	-3.8	20	18	23		61
Number of Months				45	44	25	0	114
Percent of Total Time				13	12	7	0	32

Table F4: Station wise Drought Severity for 2050s under RCP4.5

Station	Starting of Drought Spell	Ending of Drought Spell	Maximum Severity	Number of Months				
				Mild Drought	Moderate Drought	Severe Drought	Extreme Drought	Total
Barisal	Jan-36	Jan-37	-1.75	13				13
	Apr-39	Oct-39	-2.86	2	5			7
	Apr-57	May-58	-2.19	12	2			14
	Apr-61	Jan-62	-3.17	2	3	5		10
	Aug-62	Jul-63	-1.66	12				12
Number of Months				**41**	**10**	**5**	**0**	**56**
Percent of Total Time				**11**	**3**	**1**	**0**	**16**
Bhola	Jun-43	Sep-45	-3.08	22	5	1		28
	May-47	Jan-50	-3.82	3	18	12		33
	Nov-54	Jun-55	-1.33	8				8
	Oct-55	May-60	-3.89	15	30	11		56
	Jan-61	Feb-62	-2.77	5	9			14
Number of Months				**53**	**62**	**24**	**0**	**139**
Percent of Total Time				**15**	**17**	**7**	**0**	**39**
Bogra	Aug-36	Jul-37	-3.77	2	9	1		12
	Apr-42	Jun-43	-4.00	4	3	7	1	15
	Jul-46	Jul-52	-3.59	16	41	16		73
	Aug-55	Apr-56	-1.73	9				9
	May-59	Sep-61	-4.67	2	11	8	8	29
Number of Months				**33**	**64**	**32**	**9**	**138**
Percent of Total Time				**9**	**18**	**9**	**3**	**38**

Station	Starting of Drought Spell	Ending of Drought Spell	Maximum Severity	Number of Months				
				Mild Drought	Moderate Drought	Severe Drought	Extreme Drought	Total
Chandpur	Mar-43	Aug-45	-3.51	12	14	4		30
	Sep-47	Feb-48	-1.15	6				6
	Apr-48	May-49	-2.56	3	11			14
	May-54	Jun-59	-3.09	25	35	2		62
	Aug-59	Mar-60	-1.49	8				8
	Oct-60	Feb-62	-2.84	7	10			17
Number of Months				**61**	**70**	**6**	**0**	**137**
Percent of Total Time				**17**	**19**	**2**	**0**	**38**
Chittagong	Apr-39	Oct-39	-2.33	1	6			7
	Dec-42	Oct-45	-3.57	8	17	10		35
	Sep-55	May-57	-3.71	1	12	8		21
	Oct-60	Mar-62	-2.86	7	11			18
	Aug-62	Apr-63	-2.09	8	1			9
Number of Months				**25**	**47**	**18**	**0**	**90**
Percent of Total Time				**7**	**13**	**5**	**0**	**25**
Coxs Bazar	Jan-36	Jul-36	-3.81		1	6		7
	Sep-37	Mar-38	-1.78	7				7
	May-38	Oct-39	-3.77	3	8	7		18
	May-42	Nov-45	-4.00	19	17	6	1	43
	Nov-55	Oct-57	-3.19	16	5	3		24
	Aug-59	Mar-60	-2.19	4	4			8
	Apr-61	Feb-62	-2.29	5	6			11
Number of Months				**54**	**41**	**22**	**1**	**118**

Station	Starting of Drought Spell	Ending of Drought Spell	Maximum Severity	Number of Months				
				Mild Drought	Moderate Drought	Severe Drought	Extreme Drought	Total
Percent of Total Time				**15**	**11**	**6**	**0**	**33**
Comilla	Jun-43	Sep-45	-3.83	14	9	5		28
	May-48	May-49	-1.76	13				13
	Jul-49	Apr-50	-1.57	10				10
	Apr-56	Mar-60	-2.44	39	9			48
Number of Months				**76**	**18**	**5**	**0**	**99**
Percent of Total Time				**21**	**5**	**1**	**0**	**28**
Dhaka	Jan-36	Jul-36	-3.79		3	4		7
	Sep-37	Oct-39	-3.84	11	8	7		26
	Sep-42	Nov-45	-4.30	9	13	14	3	39
	Aug-49	Mar-50	-2.26	4	4			8
	Oct-55	Oct-57	-3.83	6	16	3		25
	Aug-59	Apr-60	-2.23	7	2			9
	Nov-60	Feb-62	-2.79	6	10			16
	Jul-65	Dec-65	-2.25	4	2			6
Number of Months				**47**	**58**	**28**	**3**	**136**
Percent of Total Time				**13**	**16**	**8**	**1**	**38**
Dinajpur	Jan-36	Aug-37	-5.02	5	3	10	2	20
	Jun-42	Mar-44	-3.98	2	1	19		22
	Oct-45	May-52	-3.84	15	46	19		80
	Aug-55	Mar-61	-6.23	24	21	3	20	68
Number of Months				**46**	**71**	**51**	**22**	**190**
Percent of Total Time				**13**	**20**	**14**	**6**	**53**

Station	Starting of Drought Spell	Ending of Drought Spell	Maximum Severity	Number of Months				
				Mild Drought	Moderate Drought	Severe Drought	Extreme Drought	Total
Faridpur	Mar-43	Aug-43	-2.29	3	3			6
	Oct-44	Nov-45	-3.15	6	5	3		14
	Apr-48	Sep-48	-2.39	2	4			6
	Jan-50	Jun-52	-3.34	17	9	4		30
	Mar-54	Aug-56	-4.50	13	6	8	3	30
	Oct-60	Apr-61	-1.34	7				7
Number of Months				**48**	**27**	**15**	**3**	**93**
Percent of Total Time				**13**	**8**	**4**	**1**	**26**
Feni	Oct-38	Aug-41	-3.14	20	13	2		35
	May-43	Nov-45	-4.19	22	2	3	4	31
	Jul-48	May-49	-1.52	11				11
	Jul-49	Dec-49	-1.42	6				6
	Jul-61	Jan-62	-1.71	7				7
Number of Months				**66**	**15**	**5**	**4**	**90**
Percent of Total Time				**18**	**4**	**1**	**1**	**25**
Ishwardi	Aug-42	Jun-43	-2.23	7	4			11
	Aug-46	Aug-47	-2.18	9	4			13
	May-48	Aug-53	-5.31	23	17	11	13	64
	May-56	Mar-57	-2.36	5	6			11
	Jul-59	Mar-63	-4.59	5	15	20	5	45
Number of Months				**49**	**46**	**31**	**18**	**144**
Percent of Total Time				**14**	**13**	**9**	**5**	**40**
Jessore	Mar-39	Mar-41	-4.19	3	8	11	3	25

Station	Starting of Drought Spell	Ending of Drought Spell	Maximum Severity	Number of Months				
				Mild Drought	Moderate Drought	Severe Drought	Extreme Drought	Total
	Feb-50	Aug-51	-3.33	4	11	4		19
	Jun-56	Apr-58	-3.76	1	10	12		23
Number of Months				**8**	**29**	**27**	**3**	**67**
Percent of Total Time				**2**	**8**	**8**	**1**	**19**
Khepupara	Oct-37	Jun-40	-4.02	14	11	7	1	33
	Apr-43	Jan-45	-3.33	8	11	3		22
	Mar-45	Oct-45	-3.88	1	5	2		8
	Apr-48	Feb-50	-3.04	3	19	1		23
	Apr-54	Jul-58	-3.79	26	25	1		52
	Sep-58	Mar-60	-1.89	19				19
	Sep-62	Jun-63	-1.54	10				10
Number of Months				**81**	**71**	**14**	**1**	**167**
Percent of Total Time				**23**	**20**	**4**	**0**	**46**
Khulna	Oct-37	Sep-39	-2.22	15	9			24
	Apr-40	Oct-40	-3.32	3	1	3		7
	Jun-50	Aug-51	-4.08	12	1	1	1	15
	Feb-56	Aug-58	-4.21	4	13	13	1	31
Number of Months				**34**	**24**	**17**	**2**	**77**
Percent of Total Time				**9**	**7**	**5**	**1**	**21**
Madaripur	Apr-43	Dec-45	-5.45	2	16	8	7	33
	Jul-48	May-50	-2.05	22	1			23
	Apr-54	Jan-58	-4.02	20	18	7	1	46
Number of Months				**44**	**35**	**15**	**8**	**102**

Station	Starting of Drought Spell	Ending of Drought Spell	Maximum Severity	Number of Months				
				Mild Drought	Moderate Drought	Severe Drought	Extreme Drought	Total
Percent of Total Time				**12**	**10**	**4**	**2**	**28**
Maijdeecourt	Sep-37	Feb-38	-1.41	6				6
	Mar-39	Oct-39	-2.61	6	2			8
	Mar-43	Sep-45	-3.93	2	12	17		31
	May-47	Jul-48	-2.89	6	9			15
	Apr-55	Aug-57	-4.92	6	12	7	4	29
	Aug-60	Jan-61	-1.41	6				6
	Mar-61	Sep-61	-3.21	3	2	2		7
Number of Months				**35**	**37**	**26**	**4**	**102**
Percent of Total Time				**10**	**10**	**7**	**1**	**28**
Mymensingh	Jan-36	Sep-37	-2.70	2	19			21
	Oct-42	Jun-43	-2.75	7	2			9
	Mar-48	Jun-50	-4.30	2	3	16	7	28
	Sep-55	May-57	-1.85	21				21
	Jul-57	May-58	-2.35	2	9			11
	Sep-64	May-65	-1.51	9				9
Number of Months				**43**	**33**	**16**	**7**	**99**
Percent of Total Time				**12**	**9**	**4**	**2**	**28**
Patuakhali	Jan-36	Sep-36	-4.21		4	3	2	9
	Apr-39	Jul-41	-2.61	18	10			28
	May-43	Feb-46	-4.11	7	5	19	3	34
	Apr-48	May-49	-2.56	3	11			14
	May-54	Oct-54	-1.44	6				6

Station	Starting of Drought Spell	Ending of Drought Spell	Maximum Severity	Number of Months				
				Mild Drought	Moderate Drought	Severe Drought	Extreme Drought	Total
	Aug-55	Aug-56	-2.07	12	1			13
	Mar-57	Oct-57	-2.17	6	2			8
	Nov-60	Aug-61	-3.19	6	3	1		10
Number of Months				**58**	**36**	**23**	**5**	**122**
Percent of Total Time				**16**	**10**	**6**	**1**	**34**
Rajshahi	Oct-36	Jan-38	-2.77	9	7			16
	Aug-42	Jun-43	-3.63	1	4	6		11
	Aug-46	Sep-53	-4.17	6	48	28	4	86
	Jul-59	Mar-63	-4.46	1	17	17	10	45
Number of Months				**17**	**76**	**51**	**14**	**158**
Percent of Total Time				**5**	**21**	**14**	**4**	**44**
Rangamati	Mar-39	Sep-39	-3.54	1	3	3		7
	Mar-43	Sep-45	-4.05	9	11	10	1	31
	Jul-54	Sep-56	-2.71	24	3			27
	Nov-56	May-57	-2.16	6	1			7
	Jul-57	May-58	-2.40	5	6			11
	Aug-60	Aug-61	-2.94	10	3			13
Number of Months				**55**	**27**	**13**	**1**	**96**
Percent of Total Time				**15**	**8**	**4**	**0**	**27**
Rangpur	May-36	Jul-37	-4.07	1	3	10	1	15
	Jun-42	Jun-43	-3.86	2	1	10		13
	Aug-46	Jul-48	-2.36	14	10			24
	Jun-59	Jun-65	-4.04	17	31	25	3	76

Station	Starting of Drought Spell	Ending of Drought Spell	Maximum Severity	Number of Months				
				Mild Drought	Moderate Drought	Severe Drought	Extreme Drought	Total
Number of Months				**34**	**45**	**45**	**4**	**128**
Percent of Total Time				**9**	**13**	**13**	**1**	**36**
Sandwip	Jan-36	Jun-36	-3.01		5	1		6
	Apr-39	Oct-39	-1.73	7				7
	May-43	Jul-44	-2.93	4	11			15
	Oct-44	Sep-45	-3.75	6	4	2		12
	Nov-55	May-57	-2.59	14	5			19
	Sep-60	Jan-62	-2.44	9	8			17
Number of Months				**40**	**33**	**3**	**0**	**76**
Percent of Total Time				**11**	**9**	**1**	**0**	**21**
Satkhira	Oct-37	Oct-40	-5.68	5	19	8	5	37
	Apr-45	Dec-45	-1.60	9				9
	Feb-50	Mar-52	-5.62	4	1	5	16	26
	Nov-55	Sep-57	-3.67	6	12	5		23
	Feb-61	Sep-61	-2.01	7	1			8
Number of Months				**31**	**33**	**18**	**21**	**103**
Percent of Total Time				**9**	**9**	**5**	**6**	**29**
Sitakunda	Mar-45	Nov-45	-2.74	2	7			9
	May-48	Feb-50	-2.23	18	4			22
	Mar-55	May-57	-4.28	6	3	17	1	27
	Sep-60	Sep-61	-2.84	7	6			13
	Aug-62	Feb-63	-1.80	7				7
Number of Months				**40**	**20**	**17**	**1**	**78**

Station	Starting of Drought Spell	Ending of Drought Spell	Maximum Severity	Number of Months				
				Mild Drought	Moderate Drought	Severe Drought	Extreme Drought	Total
Percent of Total Time				**11**	**6**	**5**	**0**	**22**
Sreemangal	Apr-41	Oct-41	-1.86	7				7
	Jun-48	Jun-50	-4.03	3	14	7	1	25
	May-55	Feb-56	-3.43	10				10
	Apr-58	Feb-59	-1.98	9	2			11
	Jul-64	Apr-65	-2.43	9	1			10
Number of Months				**38**	**17**	**7**	**1**	**63**
Percent of Total Time				**11**	**5**	**2**	**0**	**18**
Sylhet	Jan-36	Jun-38	-4.74		7	16	7	30
	Mar-41	Sep-41	-2.39	3	4			7
	Mar-44	Jun-45	-3.16	5	9	2		16
	Aug-45	Oct-46	-3.77	8	5	2		15
	Aug-55	May-57	-2.33	20	2			22
	Oct-64	Apr-65	-2.47	6	1			7
Number of Months				**42**	**28**	**20**	**7**	**97**
Percent of Total Time				**12**	**8**	**6**	**2**	**27**
Teknaf	Sep-37	Apr-38	-2.34	4	4			8
	Jun-38	Sep-39	-2.45	12	4			16
	Sep-40	Jun-43	-2.91	23	11			34
	Apr-48	Jun-49	-1.80	15				15
	Sep-49	May-58	-4.56	2	44	40	19	105
	Jul-64	Dec-65	-3.32	8	8	2		18
Number of Months				**64**	**71**	**42**	**19**	**196**

Station	Starting of Drought Spell	Ending of Drought Spell	Maximum Severity	Number of Months				
				Mild Drought	Moderate Drought	Severe Drought	Extreme Drought	Total
Percent of Total Time				**18**	**20**	**12**	**5**	**54**

Table F5: Station wise Drought Severity for 2080s under RCP4.5

Station	Starting of Drought Spell	Ending of Drought Spell	Maximum Severity	Number of Months				
				Mild Drought	Moderate Drought	Severe Drought	Extreme Drought	Total
Barisal	Nov-73	May-74	-1.49	7				7
	May-75	Nov-76	-3.06	14	2	3		19
	Apr-82	Feb-83	-2.10	10	1			11
	May-83	Jul-92	-5.07	17	46	37	11	111
Number of Months				**48**	**49**	**40**	**11**	**148**
Percent of Total Time				**13**	**14**	**11**	**3**	**41**
Bhola	Apr-68	Feb-69	-2.88	5	6			11
	May-70	Feb-71	-1.45	10				10
	Jul-72	Jul-73	-1.79	13				13
	Nov-77	May-78	-1.43	7				7
	Oct-82	Jun-84	-2.30	13	8			21
	Nov-84	Mar-92	-5.62	20	19	14	36	89
Number of Months				**68**	**33**	**14**	**36**	**151**
Percent of Total Time				**19**	**9**	**4**	**10**	**42**
Bogra	Jan-66	Jun-66	-2.52	4	2			6
	Sep-68	Sep-70	-4.20	6	4	14	1	25
	Jun-74	Nov-75	-2.74	10	8			18
	Jun-76	Jun-81	-4.60	19	20	18	4	61
	Jun-85	May-89	-3.78	12	26	10		48
Number of Months				**51**	**60**	**42**	**5**	**158**
Percent of Total Time				**14**	**17**	**12**	**1**	**44**
Chandpur	Jan-66	Oct-66	-2.91	4	6			10

Station	Starting of Drought Spell	Ending of Drought Spell	Maximum Severity	Number of Months				
				Mild Drought	**Moderate Drought**	**Severe Drought**	**Extreme Drought**	**Total**
	Apr-68	Jan-69	-1.65	10				10
	Jun-73	May-74	-2.06	11	1			12
	Aug-76	Feb-77	-1.94	7				7
	May-82	Jul-83	-2.80	11	4			15
	Mar-86	Mar-88	-4.51	4	5	12	4	25
	Mar-90	Jul-92	-4.85	3	12	11	3	29
Number of Months				**50**	**28**	**23**	**7**	**108**
Percent of Total Time				**14**	**8**	**6**	**2**	**30**
Chittagong	Jan-66	Oct-66	-1.61	10				10
	Sep-68	Mar-69	-1.76	7				7
	Nov-77	Apr-78	-1.49	6				6
	Apr-82	Sep-82	-1.80	6				6
	Aug-84	Mar-88	-6.40	1	19	5	19	44
	Nov-89	Feb-94	-3.05	20	31	1		52
	Sep-95	Dec-95	-1.7					0
Number of Months				**50**	**50**	**6**	**19**	**125**
Percent of Total Time				**14**	**14**	**2**	**5**	**35**
Comilla	Mar-73	Feb-77	-2.88	17	31			48
	Apr-82	Jul-92	-5.31	46	37	26	15	124
Number of Months				**63**	**68**	**26**	**15**	**172**
Percent of Total Time				**18**	**19**	**7**	**4**	**48**
Coxs Bazar	Jan-66	Sep-66	-2.94		9			9
	Jul-69	Dec-70	-4.32	4	9	1	4	18

Station	Starting of Drought Spell	Ending of Drought Spell	Maximum Severity	Number of Months				
				Mild Drought	Moderate Drought	Severe Drought	Extreme Drought	Total
	Dec-75	Apr-77	-2.46	10	7			17
	Aug-77	Jul-78	-3.80	4	3	5		12
	Oct-81	Apr-81	-1.71	7				7
	Apr-82	Apr-86	-3.59	19	19	11		49
	Jun-86	May-95	-5.27	19	20	54	15	108
Number of Months				**63**	**67**	**71**	**19**	**220**
Percent of Total Time				**18**	**19**	**20**	**5**	**61**
Dhaka	Jan-66	Sep-66	-2.73		9			9
	Jul-69	Jan-71	-4.84	2	9	2	6	19
	Oct-75	Jul-78	-4.85	12	15	5	2	34
	Oct-80	Mar-81	-1.67	6				6
	Feb-82	Apr-86	-3.68	18	22	11		51
	Jun-86	Dec-95	-5.58	8	22	50	35	115
Number of Months				**46**	**77**	**68**	**43**	**234**
Percent of Total Time				**13**	**21**	**19**	**12**	**65**
Dinajpur	Jul-68	Sep-70	-4.84	12	1	11	3	27
	Jan-74	Aug-80	-4.90	21	27	26	6	80
	Nov-83	Jun-84	-2.20	7	1			8
	Jun-85	May-87	-3.77	2	13	9		24
Number of Months				**42**	**42**	**46**	**9**	**139**
Percent of Total Time				**12**	**12**	**13**	**3**	**39**
Faridpur	Nov-71	Sep-72	-3.56	3	7	1		11
	Oct-78	Apr-78	-2.35	3	4			7

Station	Starting of Drought Spell	Ending of Drought Spell	Maximum Severity	Number of Months				
				Mild Drought	Moderate Drought	Severe Drought	Extreme Drought	Total
	Mar-87	Jul-88	-4.30	3	7	6	1	17
	Mar-90	Dec-95	-5.06	6	16	28	20	70
Number of Months				**15**	**34**	**35**	**21**	**105**
Percent of Total Time				**4**	**9**	**10**	**6**	**29**
Feni	Jun-76	Dec-76	-2.08	6	1			7
	Dec-77	May-78	-1.72	6				6
	Jun-82	Jun-84	-2.79	11	14			25
	Aug-84	Apr-85	-1.72	9				9
	Jul-85	May-89	-4.98	20	6	14	7	47
	Jan-90	Mar-93	-4.67	15	11	3	10	39
Number of Months				**67**	**32**	**17**	**17**	**133**
Percent of Total Time				**19**	**9**	**5**	**5**	**37**
Ishawrdi	Feb-69	Sep-70	-4.15	6	8	5	1	20
	Jun-74	Jul-79	-3.43	23	35	4		62
	Apr-80	Jun-81	-3.05	6	8	1		15
	Jun-85	Aug-87	-3.59	4	17	6		27
Number of Months				**39**	**68**	**16**	**1**	**124**
Percent of Total Time				**11**	**19**	**4**	**0**	**34**
Jessore	Feb-66	Mar-77	-4.20	54	60	18	2	134
	Oct-77	Jul-80	-2.99	25	9			34
	Sep-80	Mar-84	-2.68	36	7			43
	May-84	Jul-88	-3.17	24	23	4		51
	May-90	Dec-95	-6.77	2	16	27	23	68

Station	Starting of Drought Spell	Ending of Drought Spell	Maximum Severity	Number of Months				
				Mild Drought	Moderate Drought	Severe Drought	Extreme Drought	Total
Number of Months				**141**	**115**	**49**	**25**	**330**
Percent of Total Time				**39**	**32**	**14**	**7**	**92**
Khepupara	Apr-66	Sep-66	-3.57	3	4	1		8
	May-83	Feb-85	-2.85	15	7			22
	Jul-86	Aug-87	-4.33	5	5	2	2	14
	Mar-91	Oct-92	-3.30	4	12	4		20
	Oct-93	Jun-94	-1.56	9				9
Number of Months				**36**	**28**	**7**	**2**	**73**
Percent of Total Time				**10**	**8**	**2**	**1**	**20**
Khulna	Jan-66	May-67	-2.96	7	10			17
	Oct-71	Sep-76	-3.72	23	24	13		60
	Jun-79	Jun-81	-2.55	17	8			25
	Sep-81	Feb-83	-2.11	16	2			18
	May-83	Apr-85	-2.06	23	1			24
	Jun-85	Dec-85	-1.89	7				7
	Nov-87	May-89	-3.30	9	9	1		19
	Feb-90	Dec-95	-6.59	4	14	26	27	71
Number of Months				**106**	**68**	**40**	**27**	**241**
Percent of Total Time				**29**	**19**	**11**	**8**	**67**
Madaripur	Oct-75	Aug-76	-2.08	10	1			11
	May-82	Aug-83	-1.92	16				16
	Jul-86	Jul-87	-3.87	9	1	3		13
	Aug-90	Jun-94	-2.78	23	24			47

Station	Starting of Drought Spell	Ending of Drought Spell	Maximum Severity	Number of Months				
				Mild Drought	Moderate Drought	Severe Drought	Extreme Drought	Total
Number of Months				**58**	**26**	**3**	**0**	**87**
Percent of Total Time				**16**	**7**	**1**	**0**	**24**
Maijdeecourt	Jul-76	Feb-77	-2.10	6	2			8
	Sep-77	May-78	-2.08	8	1			9
	Mar-82	Nov-82	-1.88	9				9
	Jul-85	Mar-88	-4.60	8	14	9	2	33
	Nov-89	Jul-92	-3.01	16	15	2		33
Number of Months				**47**	**32**	**11**	**2**	**92**
Percent of Total Time				**13**	**9**	**3**	**1**	**26**
Mymensingh	Mar-72	Jun-78	-4.74	5	44	14	13	76
	Aug-78	Nov-79	-4.36	5	4	3	4	16
	Apr-84	Jan-86	-1.97	22				22
	Oct-86	May-87	-1.59	8				8
	Feb-92	Jul-93	-2.45	10	8			18
Number of Months				**50**	**56**	**17**	**17**	**140**
Percent of Total Time				**14**	**16**	**5**	**5**	**39**
Patuakhali	Apr-68	Dec-68	-1.49	9				9
	Jun-75	Aug-76	-2.74	6	9			15
	Sep-78	Jul-79	-2.45	8	3			11
	Apr-82	Oct-87	-4.17	39	16	8	4	67
	May-90	May-95	-3.64	22	33	6		61
Number of Months				**84**	**61**	**14**	**4**	**163**
Percent of Total Time				**23**	**17**	**4**	**1**	**45**

Station	Starting of Drought Spell	Ending of Drought Spell	Maximum Severity	Number of Months				
				Mild Drought	Moderate Drought	Severe Drought	Extreme Drought	Total
Rajshahi	Aug-68	Sep-70	-4.98	10	3	6	7	26
	Jun-74	Apr-81	-4.49	11	16	46	10	83
	Jul-85	Aug-91	-3.02	44	29	1		74
Number of Months				**65**	**48**	**53**	**17**	**183**
Percent of Total Time				**18**	**13**	**15**	**5**	**51**
Rangamati	Apr-75	Aug-76	-3.98	10	4	3		17
	Dec-77	May-78	-1.59	6				6
	Apr-82	Aug-83	-4.03	2	12	2	1	17
	Aug-85	Jan-86	-1.68	6				6
	Jun-86	Mar-88	-4.98		9	3	10	22
	May-90	Jan-91	-2.16	7	2			9
	Mar-91	Sep-92	-2.74	10	9			19
Number of Months				**41**	**36**	**8**	**11**	**96**
Percent of Total Time				**11**	**10**	**2**	**3**	**27**
Rangpur	Sep-68	Sep-70	-3.22	8	15	2		25
	Jun-76	Jun-81	-4.42	17	29	12	3	61
	Jun-85	Jul-89	-4.23	3	30	16	1	50
Number of Months				**28**	**74**	**30**	**4**	**136**
Percent of Total Time				**8**	**21**	**8**	**1**	**38**
Sanswip	Apr-75	Apr-77	-2.81	14	11			25
	Jun-77	May-78	-2.66	7	5			12
	Aug-85	Apr-86	-1.42	9				9
	Jun-86	Mar-88	-4.62	3	8	5	6	22

Station	Starting of Drought Spell	Ending of Drought Spell	Maximum Severity	Number of Months				
				Mild Drought	Moderate Drought	Severe Drought	Extreme Drought	Total
	Apr-90	Jul-92	-3.71	2	9	17		28
Number of Months				**35**	**33**	**22**	**6**	**96**
Percent of Total Time				**10**	**9**	**6**	**2**	**27**
Satkhira	Feb-66	Jun-81	-4.35	49	79	56	1	185
	Sep-81	Dec-95	-7.55	22	74	33	43	172
Number of Months				**71**	**153**	**89**	**44**	**357**
Percent of Total Time				**20**	**43**	**25**	**12**	**99**
Sitakunda	Apr-76	Feb-76	-2.59	4	7			11
	Apr-82	May-83	-2.39	11	3			14
	Sep-84	Aug-87	-4.55	19	13	1	3	36
	May-90	Aug-92	-3.41	21	5	2		28
	Jun-94	Jan-95	-1.54	8				8
Number of Months				**63**	**28**	**3**	**3**	**97**
Percent of Total Time				**18**	**8**	**1**	**1**	**27**
Sreemangal	Nov-66	Aug-67	-3.63	6	1	3		10
	Jun-71	Mar-72	-3.26	8	1	1		10
	Oct-74	Sep-77	-3.92	14	18	4		36
	Dec-78	Mar-80	-2.86	7	9			16
	Apr-84	Aug-85	-2.61	11	6			17
	Apr-90	Jun-94	-5.80	7	8	14	22	51
Number of Months				**53**	**43**	**22**	**22**	**140**
Percent of Total Time				**15**	**12**	**6**	**6**	**39**
Sylhet	Mar-67	Mar-68	-2.60	3	10			13

Station	Starting of Drought Spell	Ending of Drought Spell	Maximum Severity	Number of Months				
				Mild Drought	Moderate Drought	Severe Drought	Extreme Drought	Total
	May-71	Nov-71	-2.03	6	1			7
	Mar-72	Mar-73	-2.67	7	6			13
	Sep-74	Aug-77	-3.59	15	15	6		36
	Mar-79	Mar-80	-3.51	4	2	7		13
	Oct-84	Apr-85	-1.21	7				7
	Nov-90	Sep-92	-3.37	5	15	3		23
Number of Months				**47**	**49**	**16**	**0**	**112**
Percent of Total Time				**13**	**14**	**4**	**0**	**31**
Teknaf	Jan-66	Apr-68	-4.40		5	15	8	28
	Jul-69	Nov-70	-3.37	9	3	5		17
	Sep-75	Jun-77	-2.77	8	14			22
	Sep-77	Aug-78	-2.77	9	3			12
	May-83	Mar-84	-1.41	11				11
	Feb-88	Aug-89	-2.43	10	9			19
	Dec-89	Jun-92	-5.39	4	4	10	13	31
Number of Months				**51**	**38**	**30**	**21**	**140**
Percent of Total Time				**14**	**11**	**8**	**6**	**39**

Table F6: Station wise Drought Severity for 2050s under RCP8.5

Station	Starting of Drought Spell	Ending of Drought Spell	Maximum Severity	Number of Months				
				Mild Drought	Moderate Drought	Severe Drought	Extreme Drought	Total
Barisal	Jul-50	May-55	-3.8	14	34	11		59
	Sep-55	May-58	-2.1	30	3			33
	Aug-59	Mar-60	-1.5	8				8
	Aug-60	Jun-61	-1.4	11				11
	Jun-64	Dec-65	-2.2	13	6			19
Number of Months				**76**	**43**	**11**	**0**	**130**
Percent of Total Time				**21**	**12**	**3**	**0**	**36**
Bhola	Jun-39	May-40	-2.3	5	7			12
	Aug-40	Nov-41	-2.4	12	4			16
	Jun-44	Apr-46	-1.9	23				23
	Jul-46	Nov-48	-3.1	12	14	3		29
	May-50	Dec-54	-3.8	5	44	7		56
	Oct-56	Mar-58	-1.9	18				18
	Feb-65	Dec-65	-2.3	8	3			11
Number of Months				**83**	**72**	**10**	**0**	**165**
Percent of Total Time				**23**	**20**	**3**	**0**	**46**
Bogra	Nov-36	Nov-37	-1.9	13				13
	Aug-41	Mar-44	-4.7	20	3	1	8	32
	Jul-46	Mar-51	-3.6	20	15	22		57

Station	Starting of Drought Spell	Ending of Drought Spell	Maximum Severity	Number of Months				
				Mild Drought	Moderate Drought	Severe Drought	Extreme Drought	Total
	Sep-53	May-54	-1.8	9				9
Number of Months				**62**	**18**	**23**	**8**	**111**
Percent of Total Time				**17**	**5**	**6**	**2**	**31**
Chandpur	Jun-39	Dec-39	-1.7	7				7
	Jul-50	Dec-54	-3.3	11	31	12		54
Number of Months				**18**	**31**	**12**	**0**	**61**
Percent of Total Time				**5**	**9**	**3**	**0**	**17**
Chittagong	Oct-39	Mar-40	-1.6	6				6
	May-40	Aug--41	-2.7	7	9			16
	Aug-46	Apr-48	-2.6	14	7			21
	Aug-50	May-54	-3.1	9	35	2		46
	Sep-60	Aug-62	-2.5	20	4			24
Number of Months				**56**	**55**	**2**	**0**	**113**
Percent of Total Time				**16**	**15**	**1**	**0**	**31**
Comilla	Oct-39	Nov-40	-2.2	12	2			14
	Jun-44	Aug-45	-1.9	15				15
	Mar-51	May-54	-3.0	15	23	1		39
	May-65	Dec-65	-1.7	8				8
Number of Months				**50**	**25**	**1**	**0**	**76**
Percent of Total Time				**14**	**7**	**0**	**0**	**21**

Station	Starting of Drought Spell	Ending of Drought Spell	Maximum Severity	Number of Months				
				Mild Drought	Moderate Drought	Severe Drought	Extreme Drought	Total
Coxs Bazar	Nov-38	Aug-41	-4.4	10	5	17	2	34
	Nov-55	Oct-57	-3.2	16	5	3		24
	Aug-59	Mar-60	-2.2	4	4			8
	Apr-61	Feb-62	-2.3	5	6			11
Number of Months				**35**	**20**	**20**	**2**	**77**
Percent of Total Time				**10**	**6**	**6**	**1**	**21**
Dhaka	Aug-49	Mar-50	-2.3	4	4			8
	Oct-55	Oct-57	-3.8	6	16	3		25
	Aug-59	Apr-60	-2.2	7	2			9
	Nov-60	Feb-62	-2.8	6	10			16
	Jul-65	Dec-65	-2.3	4	2			6
Number of Months				**27**	**34**	**3**	**0**	**64**
Percent of Total Time				**8**	**9**	**1**	**0**	**18**
Dinajpur	Jan-36	Oct-37	-2.6	7	15			22
	Jul-41	Mar-44	-4.5	4	18	6	5	33
	Jun-46	Oct-50	-4.1	13	21	16	3	53
	Sep-53	May-54	-1.9	9				9
	Sep-54	Apr-57	-2.5	22	10			32
	Dec-57	Aug-58	-2.6	6	3			9
Number of Months				**61**	**67**	**22**	**8**	**158**

Station	Starting of Drought Spell	Ending of Drought Spell	Maximum Severity	Number of Months				
				Mild Drought	Moderate Drought	Severe Drought	Extreme Drought	Total
Percent of Total Time				**17**	**19**	**6**	**2**	**44**
Faridpur	Oct-39	Oct-40	-2.3	11	2			13
	Aug-43	Sep-44	-2.3	11	3			14
	Apr-48	Sep-48	-2.4	2	4			6
	Jan-50	Jun-52	-3.3	17	9	4		30
	Mar-54	Aug-56	-4.5	13	6	8	3	30
	Oct-60	Apr-61	-1.3	7				7
Number of Months				**61**	**24**	**12**	**3**	**100**
Percent of Total Time				**17**	**7**	**3**	**1**	**28**
Feni	Jan-36	Dec-37	-2.0	23	1			24
	Oct-38	Mar-41	-3.0	16	14			30
	Mar-45	Jan-46	-2.0	11				11
	May-46	Jun-49	-3.2	20	16	2		38
	Apr-50	May-54	-3.9	13	16	21		50
	Apr-65	Dec-65	-1.6	9				9
Number of Months				**92**	**47**	**23**	**0**	**162**
Percent of Total Time				**26**	**13**	**6**	**0**	**45**
Ishawrdi	Jun-41	Dec-42	-2.2	16	3			19
	Apr-43	Dec-43	-3.0	4	3	2		9
	Jul-47	Sep-48	-1.6	15				15

Station	Starting of Drought Spell	Ending of Drought Spell	Maximum Severity	Number of Months				
				Mild Drought	Moderate Drought	Severe Drought	Extreme Drought	Total
Number of Months				**35**	**6**	**2**	**0**	**43**
Percent of Total Time				**10**	**2**	**1**	**0**	**12**
Jessore	Mar-44	Sep-44	-2.2	6	1			7
	Oct-50	Aug-54	-2.7	36	11			47
	Mar-56	Oct-59	-4.1	10	16	17	1	44
	Aug-64	Dec-65	-2.9	7	10			17
Number of Months				**59**	**38**	**17**	**1**	**115**
Percent of Total Time				**16**	**11**	**5**	**0**	**32**
Khepupara	May-39	Aug-41	-2.9	8	20			28
	Jun-46	Dec-46	-1.4	7				7
	Mar-47	Apr-48	-2.5	4	10			14
	Jun-50	May-54	-4.0	10	5	33		48
	Jan-61	Mar-63	-2.7	17	10			27
Number of Months				**46**	**45**	**33**	**0**	**124**
Percent of Total Time				**13**	**13**	**9**	**0**	**34**
Khulna	Nov-39	Apr-40	-1.5	6				6
	Sep-43	Sep-44	-3.2	9	3	1		13
	Oct-47	Jul-48	-2.5	7	3			10
	Feb-54	Jul-60	-4.3	21	38	13	6	78
	Jun-65	Dec-65	-1.6	7				7

Station	Starting of Drought Spell	Ending of Drought Spell	Maximum Severity	Number of Months				
				Mild Drought	Moderate Drought	Severe Drought	Extreme Drought	Total
Number of Months				**50**	**44**	**14**	**6**	**114**
Percent of Total Time				**14**	**12**	**4**	**2**	**32**
Madaripur	Aug-40	Jan-41	-1.2	6				6
	Apr-51	May-58	-3.3	60	20	6		86
	Jul-58	Aug-60	-2.0	26				26
	Jun-62	Mar-63	-1.8	10				10
Number of Months				**102**	**20**	**6**	**0**	**128**
Percent of Total Time				**28**	**6**	**2**	**0**	**36**
Maijdeecourt	May-39	Feb-40	-1.9	10				10
	May-47	Dec-48	-2.6	11				11
	Jun-50	Sep-50	-1.5	9				9
	Mar-51	May-54	-4.3	17	7	17	2	43
Number of Months				**47**	**7**	**17**	**2**	**73**
Percent of Total Time				**13**	**2**	**5**	**1**	**20**
Mymensingh	Oct-43	Jun-44	-2.9	7	2			9
	Jun-53	Apr-58	-2.8	22	37			59
	Jul-58	May-59	-2.3	8	3			11
Number of Months				**37**	**42**	**0**	**0**	**79**
Percent of Total Time				**10**	**12**	**0**	**0**	**22**
Patuakhali	Jul-50	May-54	-3.5	10	30	7		47

Station	Starting of Drought Spell	Ending of Drought Spell	Maximum Severity	Number of Months				
				Mild Drought	Moderate Drought	Severe Drought	Extreme Drought	Total
Number of Months				**10**	**30**	**7**	**0**	**47**
Percent of Total Time				**3**	**8**	**2**	**0**	**13**
Rajshahi	Jul-41	Jul-44	-4.1	15	11	7	4	37
	Jul-47	Oct-50	-2.4	34	6			40
	Oct-53	Apr-54	-1.4	7				7
Number of Months				**56**	**17**	**7**	**4**	**84**
Percent of Total Time				**16**	**5**	**2**	**1**	**23**
Rangamati	May-39	Jun-43	-2.9	33	17			50
	Apr-44	May-54	-4.8	25	41	41	15	122
	Jun-62	Mar-63	-1.6	10				10
Number of Months				**68**	**58**	**41**	**15**	**182**
Percent of Total Time				**19**	**16**	**11**	**4**	**51**
Rangpur	Jan-36	Sep-37	-3.1	8	12	1		21
	May-41	May-45	-5.1	3	18	18	10	49
	Oct-46	Mar-51	-4.3	17	24	11	2	54
	Sep-63	Dec-55	-2.2	24	4			28
	Nov-60	Sep-61	-2.2	8	3			11
Number of Months				**60**	**61**	**30**	**12**	**163**
Percent of Total Time				**17**	**17**	**8**	**3**	**45**
Sandwip	Aug-40	Mar-41	-1.5	8				8

Station	Starting of Drought Spell	Ending of Drought Spell	Maximum Severity	Number of Months				
				Mild Drought	Moderate Drought	Severe Drought	Extreme Drought	Total
	Aug-46	Sep-49	-3.2	18	19	1		38
	Mar-50	Jun-56	-4.2	18	34	18	5	75
	Jul-56	Feb-59	-2.4	22	10			32
	Apr-59	Mar-60	-1.7	12				12
	Jun-60	Feb-61	-1.7	9				9
	Aug-61	Mar-62	-1.6	8				8
	May-62	Mar-63	-2.0	11				11
	Sep-64	Dec-65	-1.9	16				16
Number of Months				**122**	**63**	**19**	**5**	**209**
Percent of Total Time				**34**	**18**	**5**	**1**	**58**
Satkhira	Jul-39	May-40	-3.0	2	9			11
	Aug-43	Sep-44	-3.0	10	4			14
	Oct-47	May-48	-2.0	7	1			8
	Jun-51	Jan-52	-1.4	8				8
	Apr-53	Mar-54	-2.4	7	5			12
	Aug-55	Sep-60	-4.4	23	27	8	4	62
	Jul-64	Dec-65	-2.6	14	4			18
Number of Months				**71**	**50**	**8**	**4**	**133**
Percent of Total Time				**20**	**14**	**2**	**1**	**37**
Sitakunda	Jan-36	Nov-36	-1.8	11				11

Station	Starting of Drought Spell	Ending of Drought Spell	Maximum Severity	Number of Months				
				Mild Drought	Moderate Drought	Severe Drought	Extreme Drought	Total
	Jun-38	Aug-41	-3.5	22	12	5		39
	Jun-44	Mar-46	-2.8	14	8			22
	Jun-46	May-54	-5.0	3	26	50	17	96
	Sep-57	Mar-58	-1.4	7				7
	Sep-61	Mar-63	-3.1	8	8	3		19
	May-64	Dec-65	-2.7	9	11			20
Number of Months				**74**	**65**	**58**	**17**	**214**
Percent of Total Time				**21**	**18**	**16**	**5**	**59**
Sreemangal	May-44	Nov-44	-2.5	1	6			7
	Jul-49	Jul-50	-2.6	11	2			13
	Jun-52	Nov-52	-1.7	6				6
	May-59	May-60	-2.3	8	3			11
	Jun-62	Jul-62	-1.2					0
	Feb-65	Mar-65	-2.9	7	4			11
Number of Months				**39**	**17**	**4**	**0**	**60**
Percent of Total Time				**11**	**5**	**1**	**0**	**17**
Sylhet	Jan-36	Aug-36	-3.3	1	6	1		8
	Jul-48	May-56	-4.0	32	40	23		95
	Jul-56	Dec-65	-4.2	4	65	38	7	114
Number of Months				**37**	**111**	**62**	**7**	**217**

Station	Starting of Drought Spell	Ending of Drought Spell	Maximum Severity	Number of Months				
				Mild Drought	Moderate Drought	Severe Drought	Extreme Drought	Total
Percent of Total Time				**10**	**31**	**17**	**2**	**60**
Teknaf	Apr-38	Apr-39	-2.9	2	11			13
	Oct-39	May-40	-2.3	3	5			8
	Jul-43	Jun-44	-2.7	1	11			12
	Aug-44	Aug-45	-2.7	11	2			13
	Jul-47	Sep-48	-1.9	15				15
	Feb-50	May-51	-2.9	6	10			16
	Jul-56	Jun-57	-1.9	12				12
	Jul-59	Jan-60	-1.5	7				7
Number of Months				**57**	**39**	**0**	**0**	**96**
Percent of Total Time				**16**	**11**	**0**	**0**	**27**

Table F7: Station wise Drought Severity for 2080s under RCP8.5

Station	Starting of Drought Spell	Ending of Drought Spell	Maximum Severity	Number of Months				
				Mild Drought	Moderate Drought	Severe Drought	Extreme Drought	Total
Barisal	Jan-66	Oct-66	-2.29	1	9			10
	May-73	Sep-75	-2.32	19	10			29
	Mar-76	Jun-77	-2.63	14	2			16
	Oct-82	Dec-95	-4.58	30	58	58	13	159
Number of Months				**64**	**79**	**58**	**13**	**214**
Percent of Total Time				**18**	**22**	**16**	**4**	**59**
Bhola	May-66	Oct-66	-1.83	6				6
	Jan-74	Jun-74	-2.05	5	1			6
	May-77	Feb-78	-2.77	4	6			10
	Feb-83	Jun-86	-4.50	9	14	9	9	41
	Jul-87	Feb-92	-4.83	13	29	6	8	56
	Sep-93	Feb-94	-1.40	6				6
Number of Months				**43**	**50**	**15**	**17**	**125**
Percent of Total Time				**12**	**14**	**4**	**5**	**35**
Bogra	Apr-71	May-72	-2.37	12	2			14
	Jun-83	Aug-90	-5.71	19	24	32	12	87
	Oct-90	Aug-91	-2.65	7	4			11
	Nov-91	Jul-92	-3.05	7	1	1		9
Number of Months				**45**	**31**	**33**	**12**	**121**
Percent of Total Time				**13**	**9**	**9**	**3**	**34**
Chandpur	Jul-66	Sep-67	-1.98	15				15

Station	Starting of Drought Spell	Ending of Drought Spell	Maximum Severity	Number of Months				
				Mild Drought	Moderate Drought	Severe Drought	Extreme Drought	Total
	Oct-73	Sep-76	-3.06	8	26	2		36
	Feb-84	Sep-84	-3.11	3	4	1		8
	May-88	Apr-89	-2.12	6	6			12
	Jun-89	Dec-95	-4.52	29	11	28	11	79
Number of Months				**61**	**47**	**31**	**11**	**150**
Percent of Total Time				**17**	**13**	**9**	**3**	**42**
Chittagog	Sep-68	Aug-69	-2.02	11	1			12
	Mar-70	Jan-71	-2.45	6	5			11
	Oct-78	Mar-79	-2.09	4	2			6
	Mar-82	Apr-94	-5.32	12	68	52	14	146
Number of Months				**33**	**76**	**52**	**14**	**175**
Percent of Total Time				**9**	**21**	**14**	**4**	**49**
Comilla	Jan-66	Aug-66	-2.32	3	5			8
	May-74	Jul-75	-1.96	15				15
	Jan-76	Jun-77	-2.38	14	4			18
	Nov-78	May-79	-1.46	7				7
	Jul-79	May-80	-1.73	11				11
	Apr-83	May-86	-3.61	3	28	7		38
	Mar-91	Jun-92	-2.58	8	8			16
	Jan-93	May-94	-2.36	9	8			17
Number of Months				**70**	**53**	**7**	**0**	**130**
Percent of Total Time				**19**	**15**	**2**	**0**	**36**
Coxs bazar	Nov-73	Jul-74	-2.49	6	3			9

Station	Starting of Drought Spell	Ending of Drought Spell	Maximum Severity	Number of Months				
				Mild Drought	Moderate Drought	Severe Drought	Extreme Drought	Total
	Aug-76	Apr-79	-3.36	10	13	10		33
	Apr-82	Jul-90	-4.62	25	53	17	5	100
	Oct-90	Aug-94	-4.64	5	11	19	12	47
Number of Months				**46**	**80**	**46**	**17**	**189**
Percent of Total Time				**13**	**22**	**13**	**5**	**53**
Dhaka	Jan-66	Sep-66	-1.63	9				9
	Dec-76	Mar-78	-1.96	16				16
	Oct-83	Jun-95	-4.60	22	49	22	18	111
Number of Months				**47**	**49**	**22**	**18**	**136**
Percent of Total Time				**13**	**14**	**6**	**5**	**38**
Dinajpur	May-71	Jun-72	-2.37	10	4			14
	Jul-83	Apr-87	-5.68	1	24	9	12	46
	Nov-90	Sep-91	-2.06	10	1			11
	Jan-91	Sep-94	-4.22	19	11	1	2	33
Number of Months				**40**	**40**	**10**	**14**	**104**
Percent of Total Time				**11**	**11**	**3**	**4**	**29**
Faridpur	Jan-66	Jan-67	-2.79	3	10			13
	Mar-70	Sep-70	-2.76	2	4			6
	Sep-75	Jun-78	-3.69	13	8	13		34
	Jun-82	Jul-89	-3.76	4	41	41		86
	Aug-91	Dec-95	-2.66	22	31			53
Number of Months				**44**	**94**	**54**	**0**	**192**
Percent of Total Time				**12**	**26**	**15**	**0**	**53**

Station	Starting of Drought Spell	Ending of Drought Spell	Maximum Severity	Number of Months				
				Mild Drought	**Moderate Drought**	**Severe Drought**	**Extreme Drought**	**Total**
Feni	Jan-66	Oct-66	-1.94	9				9
	Jul-73	Jun-74	-3.01	10	1	1		12
	May-77	Jul-77	-1.50					0
	Sep-77	Jun-78	-1.61	10				10
	Aug-78	Apr-80	-1.70	21				21
	Sep-82	Oct-85	-4.29	7	10	19	2	38
	Jun-88	Nov-88	-1.44	6				6
	Jun-89	Sep-90	-2.46	14	2			16
	Feb-91	May-95	-3.88	6	24	22		52
Number of Months				**83**	**37**	**42**	**2**	**164**
Percent of Total Time				**23**	**10**	**12**	**1**	**46**
Ishwadi	Jul-82	Aug-86	-4.51	12	5	22	11	50
	Feb-91	Sep-94	-2.73	38	6			44
Number of Months				**50**	**11**	**22**	**11**	**94**
Percent of Total Time				**14**	**3**	**6**	**3**	**26**
Jessore	Jan-66	Aug-70	-3.57	26	27	3		56
	Nov-72	Apr-73	-1.85	6				6
	Jun-75	Feb-80	-3.66	9	36	12		57
	Apr-82	May-85	-2.38	25	13			38
	Jul-86	Jun-88	-3.82	1	18	5		24
	Feb-92	Dec-95	-2.95	24	23			47
Number of Months				**91**	**117**	**20**	**0**	**228**
Percent of Total Time				**25**	**33**	**6**	**0**	**63**

Station	Starting of Drought Spell	Ending of Drought Spell	Maximum Severity	Number of Months				
				Mild Drought	Moderate Drought	Severe Drought	Extreme Drought	Total
Khepupara	Apr-66	May-70	-2.80	34	16			50
	Dec-82	Mar-87	-2.57	30	22			52
	Sep-87	Apr-94	-4.59	7	30	36	7	80
Number of Months				**71**	**68**	**36**	**7**	**182**
Percent of Total Time				**20**	**19**	**10**	**2**	**51**
Khulna	Jan-66	May-73	-4.05	35	38	15	1	89
	Oct-75	Sep-88	-3.82	61	80	15		156
	Nov-92	Jun-94	-2.36	16	4			20
	Aug-94	Dec-95	-2.30	15	2			17
Number of Months				**127**	**124**	**30**	**1**	**282**
Percent of Total Time				**35**	**34**	**8**	**0**	**78**
Madaripur	Jan-74	May-79	-2.90	37	28			65
	Aug-79	Aug-83	-2.12	46	3			49
	Oct-83	Jul-85	-3.01	6	14	2		22
	May-88	Jul-95	-3.01	52	33	1		86
Number of Months				**141**	**78**	**3**	**0**	**222**
Percent of Total Time				**39**	**22**	**1**	**0**	**62**
Majdeecourt	Oct-69	May-70	-2.09	7	1			8
	Aug-71	Jul-72	-2.02	11	1			12
	Jun-73	Nov-74	-2.63	13	5			18
	Nov-77	Jun-78	-1.45	8				8
	Sep-82	May-87	-4.64	17	13	18	9	57
	Oct-87	Jul-88	-1.54	10				10

Station	Starting of Drought Spell	Ending of Drought Spell	Maximum Severity	Number of Months				
				Mild Drought	Moderate Drought	Severe Drought	Extreme Drought	Total
	Sep-88	Sep-93	-4.43	22	21	8	10	61
Number of Months				**88**	**41**	**26**	**19**	**174**
Percent of Total Time				**24**	**11**	**7**	**5**	**48**
Mymensingh	May-66	Apr-67	-1.65	12				12
	Apr-68	Jun-69	-2.03	14	1			15
	Sep-70	Jun-71	-1.72	10				10
	May-76	Jun-77	-1.87	14				14
	Oct-77	Jun-78	-2.31	8	1			9
	Aug-78	Apr-79	-2.59	3	6			9
	May-81	Jun-95	-5.95	43	40	67	20	170
Number of Months				**104**	**48**	**67**	**20**	**239**
Percent of Total Time				**29**	**13**	**19**	**6**	**66**
Patuakhali	Nov-68	Jun-69	-1.64	8				8
	Jul-73	Jun-74	-1.90	12				12
	Sep-83	Jun-85	-3.01	7	14	1		22
	Oct-87	Dec-95	-3.82	38	23	38		99
Number of Months				**65**	**37**	**39**	**0**	**141**
Percent of Total Time				**18**	**10**	**11**	**0**	**39**
Rajshahi	Apr-83	Feb-87	-4.69	4	17	19	7	47
Number of Months				**4**	**17**	**19**	**7**	**47**
Percent of Total Time				**1**	**5**	**5**	**2**	**13**
Rangamati	Sep-66	Mar-67	-1.22	7				7
	Apr-70	Jan-71	-1.55	10				10

Station	Starting of Drought Spell	Ending of Drought Spell	Maximum Severity	Number of Months				
				Mild Drought	Moderate Drought	Severe Drought	Extreme Drought	Total
	Mar-84	Feb-87	-2.19	33	3			36
	Mar-88	Apr-89	-2.05	13	1			14
	Aug-89	Dec-95	-4.85	8	17	37	15	77
Number of Months				**71**	**21**	**37**	**15**	**144**
Percent of Total Time				**20**	**6**	**10**	**4**	**40**
Rangpur	Feb-67	Aug-67	-2.66	5	2			7
	May-71	May-72	-2.87	8	5			13
	Aug-78	May-79	-2.99	7	3			10
	Jun-83	Jul-89	-4.96	13	38	11	12	74
	Apr-92	Aug-94	-3.34	12	15	2		29
Number of Months				**45**	**63**	**13**	**12**	**133**
Percent of Total Time				**13**	**18**	**4**	**3**	**37**
Sandwip	Jan-66	Aug-67	-2.08	18	2			20
	Sep-69	May-70	-1.83	9				9
	Nov-71	Jul-72	-2.22	6	3			9
	Aug-82	Sep-85	-4.24	7	6	23	2	38
	Oct-87	Feb-92	-4.91	12	24	10	7	53
Number of Months				**52**	**35**	**33**	**9**	**129**
Percent of Total Time				**14**	**10**	**9**	**3**	**36**
Satkhira	Jan-66	Jul-66	-2.68		7			7
	Jul-68	Sep-70	-3.70	2	10	15		27
	Sep-72	Mar-73	-1.73	7				7
	Jun-75	Jul-78	-3.60	10	20	8		38

Station	Starting of Drought Spell	Ending of Drought Spell	Maximum Severity	Number of Months				
				Mild Drought	Moderate Drought	Severe Drought	Extreme Drought	Total
	Jun-82	Jul-83	-2.54	8	6			14
	Sep-86	Apr-87	-2.27	5	3			8
	Jan-92	Dec-95	-3.27	26	19	3		48
Number of Months				**58**	**65**	**26**	**0**	**149**
Percent of Total Time				**16**	**18**	**7**	**0**	**41**
Sitakunda	Jan-66	Sep-66	-2.84	7	2			9
	Mar-69	Apr-71	-2.35	19	7			26
	Aug-71	Aug-72	-2.76	3	10			13
	Nov-72	Jun-74	-2.93	10	10			20
	Nov-76	May-77	-3.09	5	1	1		7
	Mar-82	Dec-95	-4.82	32	89	37	8	166
Number of Months				**76**	**119**	**38**	**8**	**241**
Percent of Total Time				**21**	**33**	**11**	**2**	**67**
Sreemangal	Apr-69	May-70	-3.74	10	3	1		14
	Nov-72	Apr-73	-1.97	6				6
	May-74	Apr-75	-2.45	11	1			12
	Apr-76	May-78	-5.15	10	6	8	2	26
	Apr-81	May-83	-3.08	14	11	1		26
	Jul-83	Aug-86	-3.71	7	20	11		38
	Oct-86	Dec-95	-4.80	10	39	41	21	111
Number of Months				**68**	**80**	**62**	**23**	**233**
Percent of Total Time				**19**	**22**	**17**	**6**	**65**
Sylhet	Mar-66	May-70	-5.83		14	23	16	53

Station	Starting of Drought Spell	Ending of Drought Spell	Maximum Severity	Number of Months				
				Mild Drought	**Moderate Drought**	**Severe Drought**	**Extreme Drought**	**Total**
	Mar-84	Mar-85	-3.49	2	8	3		13
	Apr-87	Jul-92	-4.45	7	26	22	9	64
	Mar-94	Apr-95	-2.64	10	4			14
Number of Months				**19**	**52**	**48**	**25**	**144**
Percent of Total Time				**5**	**14**	**13**	**7**	**40**
Teknaf	Sep-74	Jan-79	-4.60	15	7	14	17	53
	Jul-80	Jun-91	-4.20	30	75	24	2	131
	Sep-91	Jun-94	-3.35	17	11	6		34
	Jul-95	Dec-95	-2.49	3	3			6
Number of Months				**65**	**96**	**44**	**19**	**224**
Percent of Total Time				**18**	**27**	**12**	**5**	**62**