Policy Brief

Development of Four Decade Long Climate Scenario and Trend

Temperature, Rainfall, Sunshine & Humidity

June 2014

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

POLICY BRIEF

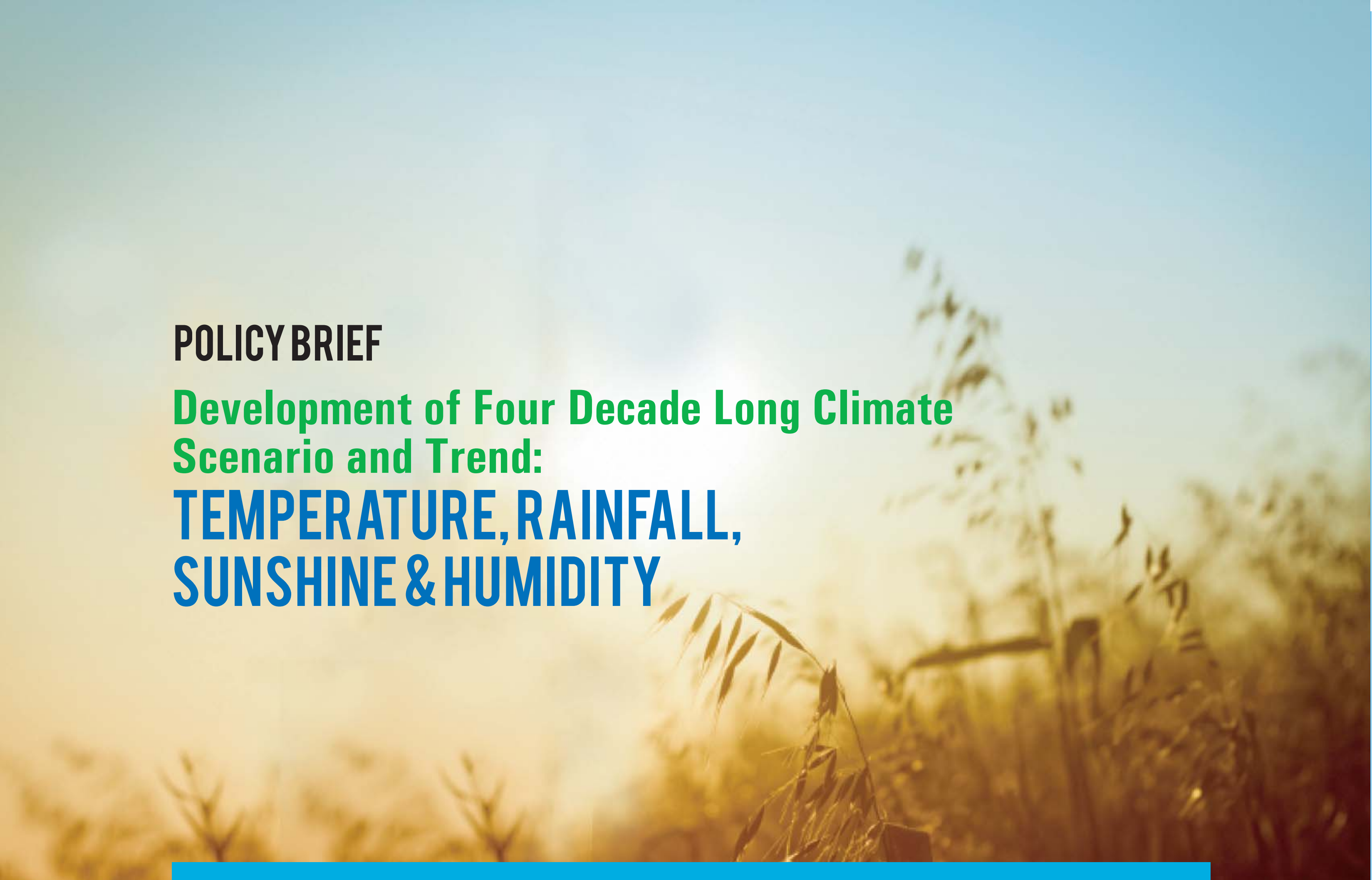
DEVELOPMENT OF FOUR DECADE LONG CLIMATE SCENARIO AND TREND

TEMPERATURE, RAINFALL, SUNSHINE & HUMIDITY

June 2014

Study Conducted by
Institute of Water and Flood Management
Bangladesh University of Engineering and Technology

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



POLICY BRIEF

Development of Four Decade Long Climate Scenario and Trend:
TEMPERATURE, RAINFALL, SUNSHINE & HUMIDITY

First Published in June 2014

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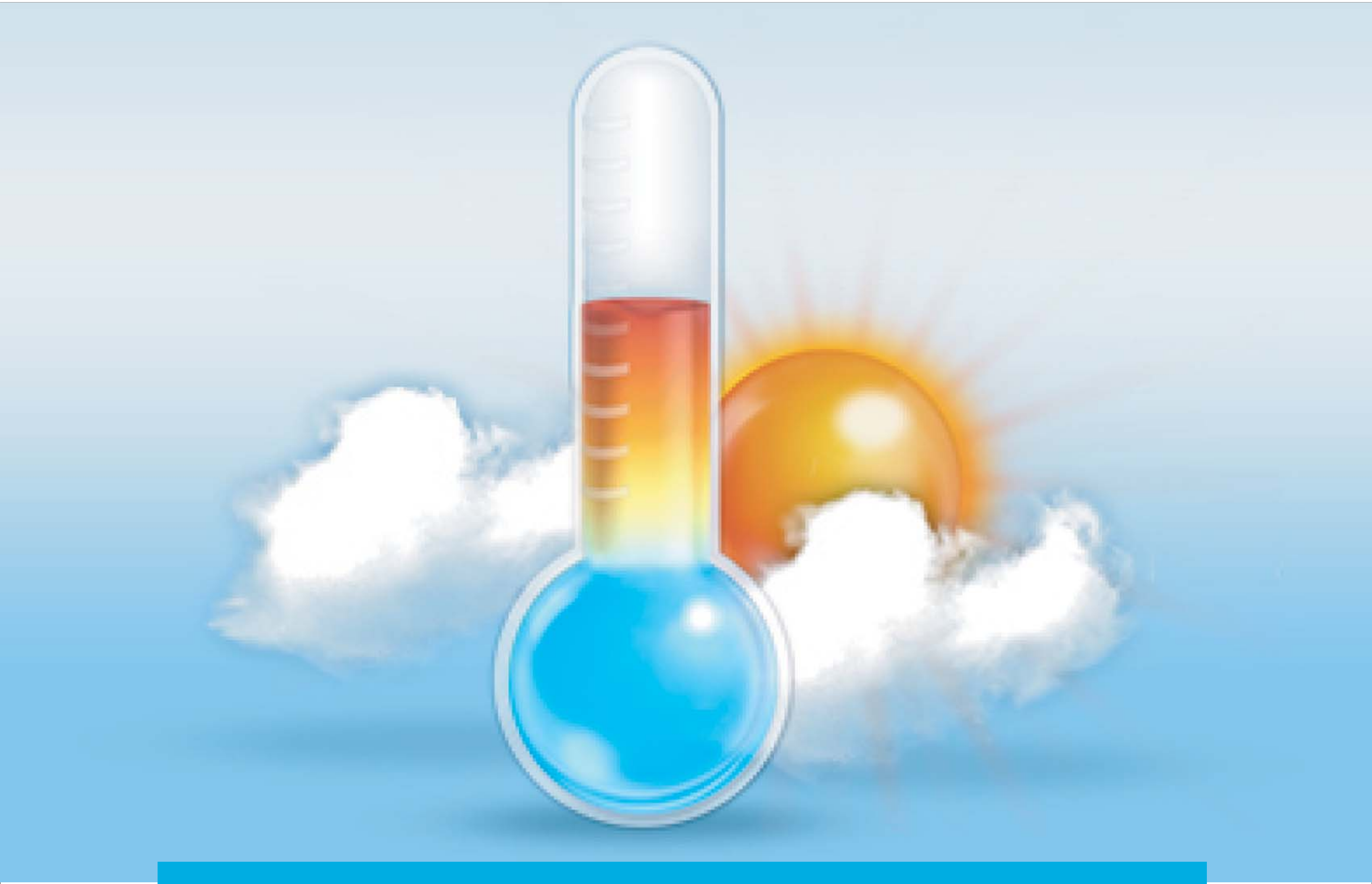

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Secretary
Ministry of Disaster Management and Relief

Message

Historically Bangladesh is a disaster prone country and suffers from innumerable natural calamities. It is predicted, in the changing climate, the country will be even more vulnerable and all the development gains may suffer due to climate change impacts. As a developing country, our response towards climate change impact is to improve the resilience of the local communities through Climate Change Adaptation and Disaster Risk Reduction.

I am pleased to know that Comprehensive Disaster Management Programme (CDMP II) has completed several studies on climate change adaptation to improve the existing knowledge base of the country. The study, "Development of Four decade long climate scenario and trend: Temperature, Rainfall, Sunshine and Humidity" has tried to assess the long-term trends of change of various climatic variables, such as temperature, rainfall, sunshine duration and humidity.

I thank CDMP II for further taking the initiative to develop a Policy Brief, taking excerpts from the main study, which will add value as a handy tool for decision making and planning purposes.

I firmly believe that this Policy Brief will be of great help to the Policy Makers, planners and relevant officials, while taking various decisions at National and Local level as well as during preparation of plans for local level adaptation.

Mesbah ul Alam

National Project Director
Comprehensive Disaster Management Programme (CDMP II)

Foreword

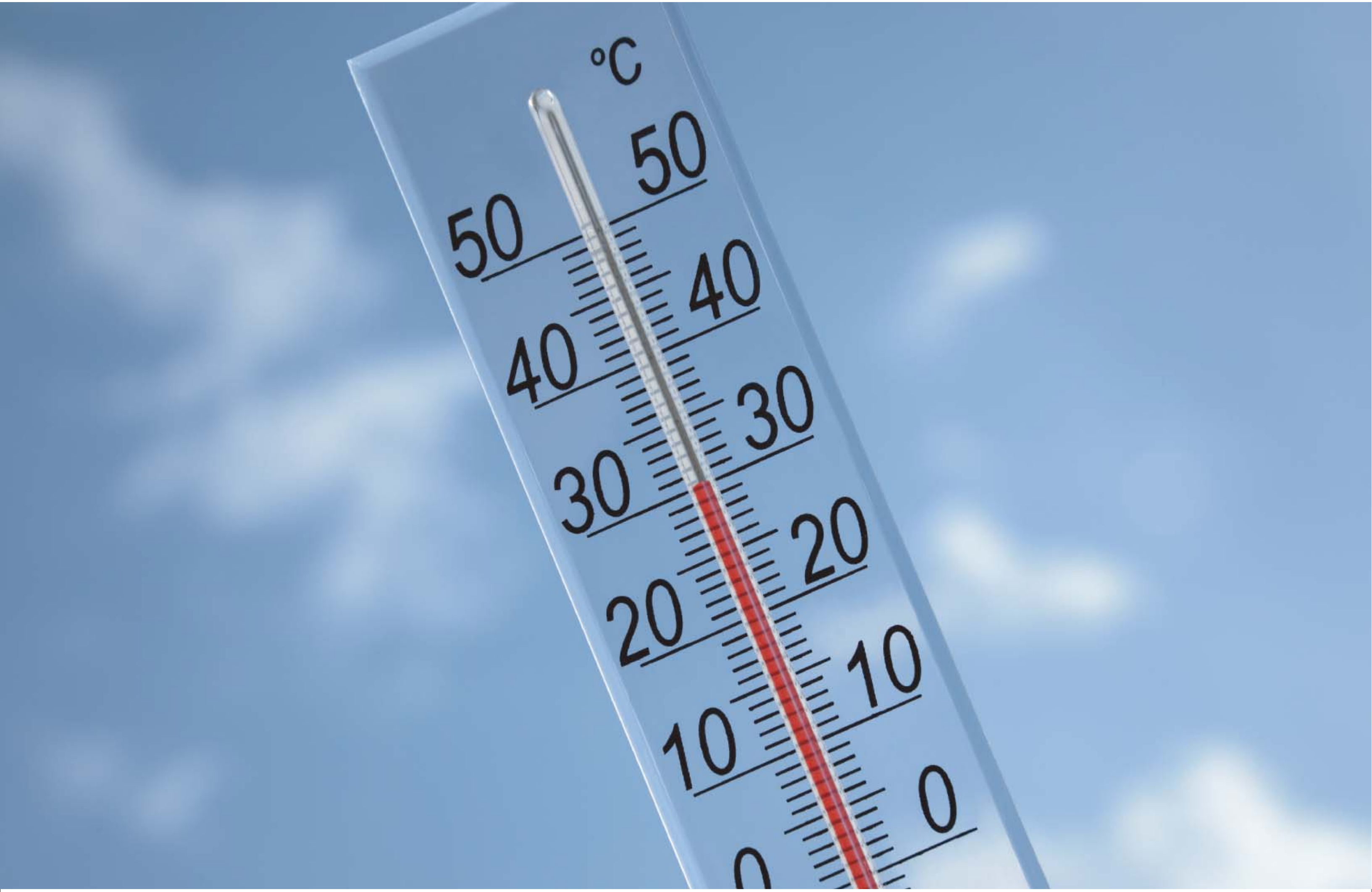
Bangladesh is recognized globally as one of the most vulnerable countries to climate change impacts. Due to its geographical location, the country is prone to natural disasters. Climate change impact is predicted to aggravate the existing vulnerability of the country and affect the much needed development gains that Bangladesh has attained over the years.

Though Bangladesh is highly vulnerable to Natural Disaster and Climate Change impacts, our technical/scientific knowledge base on our vulnerability is quite low; most of our vulnerability information is based on few national and international studies. It is worthwhile to mention, as climate change is a slow on-set event, collecting climate change related information requires longer time frame; often years, even decades. Taking the urgency into consideration, Comprehensive Disaster Management Programme (CDMP II) commissioned a series of research studies on climate change adaptation and disaster risk reduction. Recently four studies have been completed. The Study, "Development of Four Decade Long Climate Scenario and Trend: Temperature, Rainfall, Sunshine and Humidity" was conducted by Institute of Water and Flood Management, BUET. The study has assessed Long-term temporal and spatial changes including trends in climatic variables, such as temperature, rainfall, sunshine duration and humidity through both statistical analyses and climate modelling.

Drawing on the above mentioned study, a 'Policy Brief' has been prepared, with the intention of assisting the policy makers, government officials, planners at various Ministries and Departments to understand the vulnerabilities of the respective sectors and areas of the country, enabling them to take informed decision for design/implementation of development initiatives.

I trust, this study will contribute to the existing national knowledge pool on climate change and related vulnerabilities. I also believe, this Policy Brief will be a handy tool for Policy makers, planners and government officials in guiding their decision making and planning process.

Mohammad Abdul Qayyum



Acknowledgement

CDMP wishes to extend heartfelt thanks to the Study Team of the Institute of Water and Flood Management of Bangladesh University of Engineering and Technology for conducting the main study, "Development of Four Decade Long Climate Scenario and Trend: Temperature, Rainfall, Sunshine & Humidity".

Special thanks are due to the CDMP Professionals for their hard work and sincere efforts to compile the'Policy Brief' from the main report.

Finally, the guidance and support from the Ministry of Disaster Management and Relief and financial support from the development partners and UNDP are gratefully acknowledged.

Key Messages

Crop agriculture is the strength of Bangladesh and will continue to be so in the foreseeable future. About 60% of the area is presently under agriculture and the sector contributes about 20% to the GNP. Any unfavorable change in future climate could have a devastating impact on agriculture and the economy of the country. It is crucial to know the agricultural practices, anticipated changes in climatic parameters and the link between the climatic variables and crop growth and productivity.

The studies that have been done so far on long-term changes in observed climates are not comprehensive enough in spatial coverage, temporal resolution and number of variables. None of these studies provides collective information for the country as a whole at a glance. The only exception could be the study by the Climate Change Cell (2009a) on temperature and sunshine. The current study is an extension of our previous study for Climate Change Cell incorporating more climatic variables, recent climatic data, field data and crop growth simulation. It has generated base maps of local climatic trends and evaluated the impacts of climate change and variability on agricultural crops both from crop growth model and community perception.

This Policy Brief, which is the abridged version of the main report on, "Development of Four Decade Long Climate Scenario and Trend: Temperature, Rainfall, Sunshine and Humidity" deems one of the most significant study undertaken in the country. Long-term temporal and spatial changes including trends in climatic variables have been investigated in this study through both statistical analyses and climate modeling.

- The analysis of measured temperature (1948-2010) at 34 locations indicates that the overall trend in all-Bangladesh annual temperatures is rising at a rate of about 1.2°C per century. This trend has become stronger inrecent years. The trend in recent mean annual temperatures (1980-2010) is almost the double (2.4°C per century) of thelonger-term trend.
- The PRECIS projected future temperature has even a much higher trend (4.6°C) per century. While, the risein mean annual temperatures projected by IPCC (2007) for South Asia is 3.3 °C with a range of 2.0-4.7°C.
- The spatial distribution of the current trends indicates that the temperature in the northern part of the country is increasingat a higher rate compared to the mid-western and eastern hilly regions.
- The analysis of measured rainfalls reveals that the annual rainfall in the countryis free of any significantchanges and trend; The PRECIS outputs also indicate similar results.
- The seasonal rainfalls at country level are also found tobe free of trend except for the pre-monsoon season, when it has significant increasing trend. Rainfall in the post-monsoonseason has also increased though not statistically significant.
- The analysis of sunshine duration data reveals that the winter, pre-monsoon, monsoon and post-monsoon sunshine aredeclining at a rate of 8.1%, 4.1%, 3.4% and 5.3%, respectively, in every 10 years for the entire Bangladesh.
- In Bangladesh annual humidity has increased gradually in Bangladesh since 1980s.

1. Introduction

Development of Four Decade Long Climate Scenario and Trend: Temperature, Rainfall, Sunshine & Humidity

1. Introduction

This study was undertaken by CDMP II to overcome some of national requirements of overcoming the deficiencies in climatic data and variables to understanding the vulnerability of the country in changing climate. Under this study, Long-term temporal and spatial changes including trends in climatic variables, such as temperature, rainfall, sunshine duration and humidity, have been investigated in this study through both statistical analyses and climate modeling. Bangladesh Meteorological Department (BMD) data for temperature, rainfall, sunshine duration and humidity were used under the study. Bangladesh Water Development Board (BWDB) data for rainfall was also used. BWDB rainfall data are used due to its extensive coverage. BMD data were available for 34 stations of Bangladesh. Daily maximum and minimum temperatures (1948-2010), rainfall (1948-2010), Sunshine duration (1961-2010) and Humidity (1948-2010) data available at all these BMD stations were analyzed. BWDB rainfall data (1957-2010) were available for 284 stations.

A regional climate model called PRECIS (Providing Regional Climates for Impact Studies) was run for this study at the Institute of Water and Flood Management (IWFM) to generate future climates (temperature, rainfall and cloud coverage) over the domain of Bangladesh. A crop growth model called DSSAT (Decision Support System for Agro-technology Transfer) was also used for evaluation of potential impact of climate change on selected agricultural crops.

1.1 Objective of the Study

The objective of the study was to characterize the spatial and temporal changes and trends in long-term climate of Bangladesh using the data available with the Bangladesh Meteorological Department (BMD) and Bangladesh Water Development Board (BWDB)

1.2 Scope of the Study

i. To evaluate long-term changes and trends in air temperatures (maximum, minimum, average) at differentstations of the BMD;

ii. To evaluate long-term changes and trends in rainfalls at different stations of the BWDB. Annual, seasonal (monsoon, pre-monsoon, post-monsoon, winter, dry season and critical period) and monthly trends were assessed;

iii. To evaluate long-term changes and trends in sunshine and humidity at different stations of the BMD. Annual,seasonal (monsoon, pre-monsoon, post-monsoon, winter, dry season and critical period) and monthly trends were assessed;

iv. To evaluate vulnerability of crop agriculture (mainly rice and wheat) in each region using a standard crop.

2. Methodology and Data

2. Methodology and Data

2.1 Temporal Trend Analysis

Temporal trend is the gradual change in a variable at a specific location with time. The analyses of trends for temperature, rainfall, sunshine duration and humidity were carried out using the Statistical package for Social Science (SPSS) software. The study made use of the Bangladesh Meteorological Department (BMD) data on temperature, sunshine duration and humidity and Bangladesh Water Development Board (BWDB) data on rainfall. The study incorporated all the available stations of these two organizations.The main purpose of this study was to generate information about the change of climate at local level.

2.2 Prediction of Future Climate

Global climate models are used to predict plausible future climate based on various Special Report on Emission Scenarios (SRES) proposed by IPCC.General circulation models (GCMs) are typically run with horizontal scales of 300 km which is not often adequate toproduce fine scale information.

A Regional Climate Model, PRECIS (Providing Regional Climates for Impact Studies), was run with horizontal scales of 50 km at the IWFM simulationlaboratory from which the primary climate prediction data were collected. The PRECIS model is a physically-based modelwhich helped generate high-resolution climate change information for Bangladesh. It is a mathematical model of theatmosphere and land surface and sometimes the ocean. It contains representations of most of the important physical processes within the climate system including cloud, radiation, rainfall, atmospheric aerosols and soil hydrology. Figure 2.1(a) shows the simulation domain that includes Bangladesh and South Asia and Figure 2.1(b) shows the grid points of the domain over Bangladesh. The domain has 88x88 grid points with a 50 km horizontal resolution.

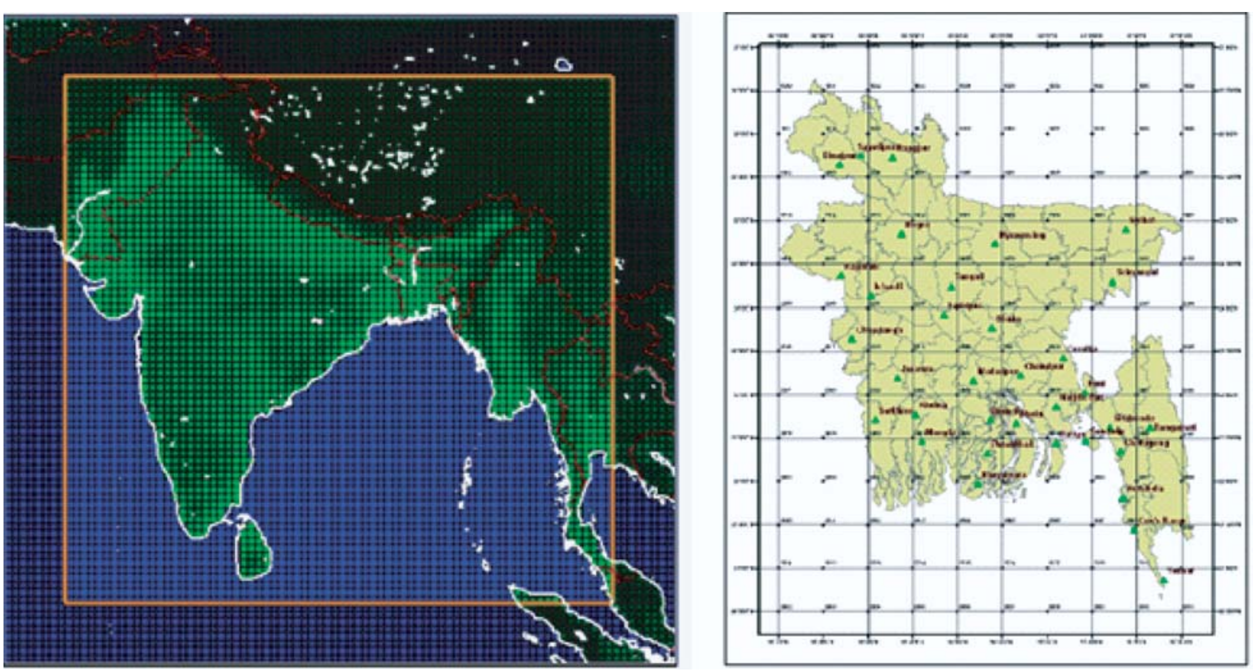
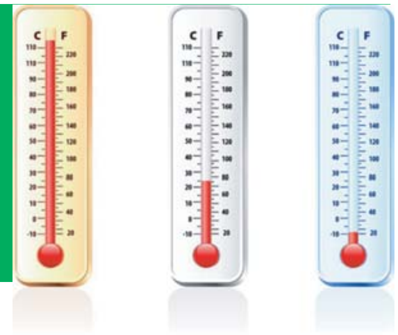


Figure 2.1 (a) and (b)

3. Analysis of Observed Temperature



3.1 Trend in Mean Temperature

Daily maximum and minimum temperatures were available at 34 locations for a period of 63 years (1948-2010). Fromthese two temperatures, mean temperatures were calculated. In this study, the data available at all these stations were analyzed. The estimated trends in mean annual temperatures for some selected stations are given in Table 3.1.

Table-3.1: Trends in mean annual temperatures at some selected stations of Bangladesh

Station	Available period of data	Number of available years	Trend (°C/century)	Significance
Cox's Bazaar	1948-2010	63	2.7	**
Jessore	1948-2010	62	2.2	**
Chittagong	1949-2010	62	1.5	**
Srimangal	1948-2010	61	1.3	**
Satkhira	1948-2010	61	0.9	**
Faridpur	1948-2010	60	3.0	**
Khulna	1948-2010	60	0.1	NS
Bogra	1948-2010	59	2.7	**
Comilla	1948-2010	59	0.4	NS
Dhaka	1953-2010	58	2.3	**
Barisal	1949-2010	58	-0.1	NS
Maijdee Court	1951-2010	57	2.1	**
Mymensingh	1948-2010	59	0.3	NS
Dinajpur	1948-2010	55	-0.2	NS
Sylhet	1956-2010	54	1.5	NS
Rangamati	1957-2010	54	-0.8	*
Ishwardi	1961-2010	49	0.6	NS
Ranjpur	1957-2010	48	0.3	NS
Rajshahi	1964-2010	46	1.4	*
Bhloa	1966-2010	44	2.3	**

Note: ** Significant at the 95% level of confidence
* Significant at the 90% level of confidence; NS-Not Significant at the 90% level of confidence.

corresponding winter (December-February), pre-monsoon (March-May), monsoon (June-September) and post-monsoon (October-November) trends are 1.2, 0.7, 1.2 and 2.00C per century (Figures 3.2-3.5).

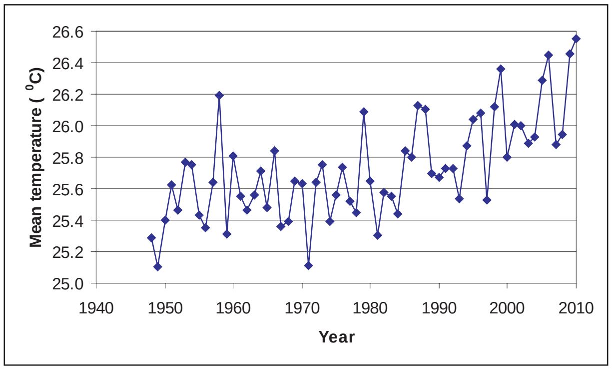


Figure 3.1: Time Series of all-Bangladesh Annual Mean Temperatures (1948-2010)

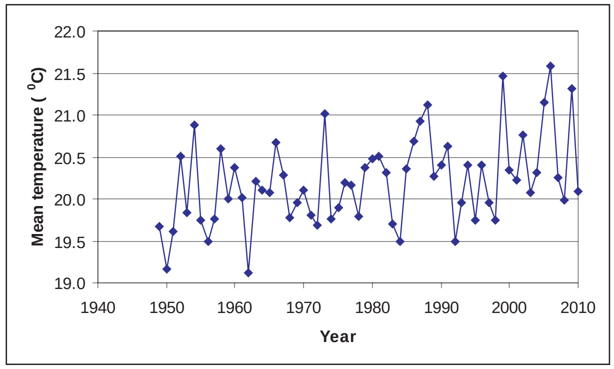


Figure 3.2: Time Series of all-Bangladesh Winter mean temperatures (1948-2010)

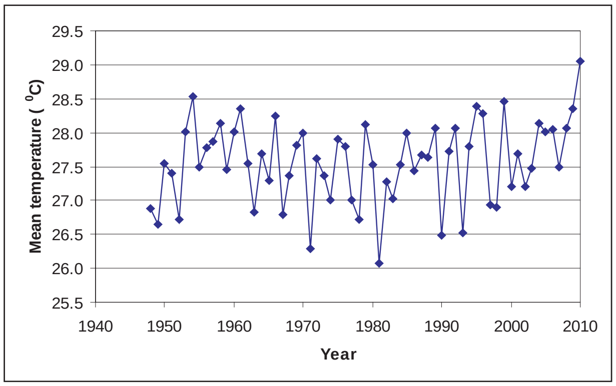


Figure 3.3: Time Series of all-Bangladesh pre-monsoon Mean Temperatures (1948-2010)

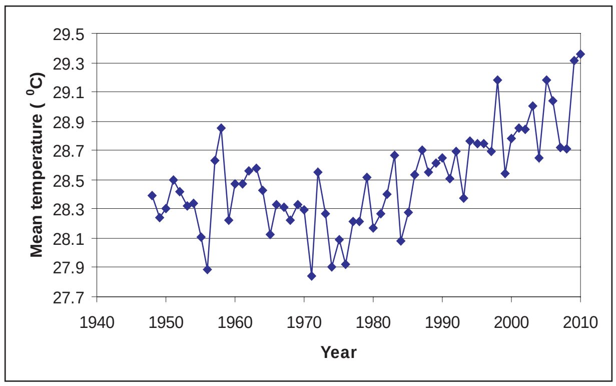


Figure 3.4: Time Series of all-Bangladesh monsoon mean temperatures (1948-2010)

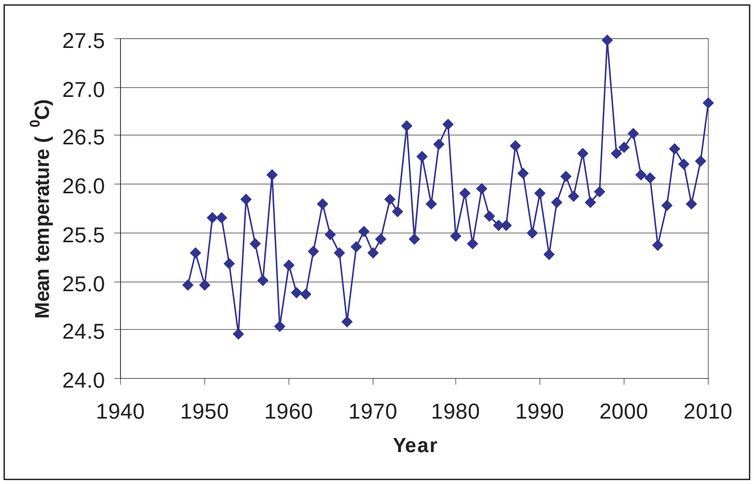


Figure 3.5: Time series of all-Bangladesh post-monsoon mean temperature (1948-2010)

Table 3.2: All-Bangladesh trends in seasonal and annual mean temperatures [data used from 1980 to 2010 for all 34 stations]

Season	**Trend** (°C/Century)
Winter (Dec – Feb)	1.2
Pre-monsoon (Mar – May)	3.2
Monsoon (Jun – Sept)	2.7
Post Monsoon (Oct – Nov)	1.5
Annual (Jan – Dec)	2.4

Table 3.2 shows that the increasing trend in annual mean temperatures during the 1980-2010 period is about 2.4 0C per century. This value is about double the value computed using the data for the entire time period (1948-2010). The pre-monsoon, monsoon and winter trends have become stronger and the post-monsoon trend has become weaker in the recent time period.

The spatial distribution of trends, expressed as % of normal annual temperature, is shown in Figure 3.6. It is seen from the figure that the northern part of the country has a higher rate of increase in mean temperatures compared to the mid-western and eastern hilly regions.

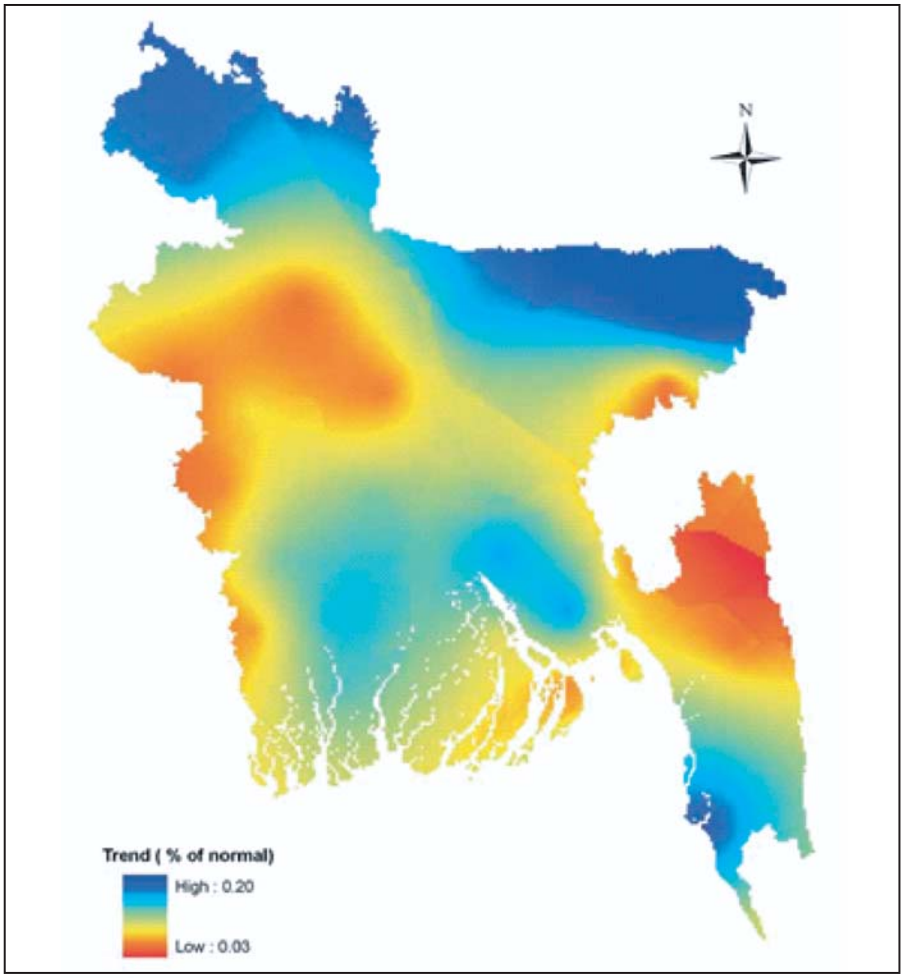


Figure 3.6: Spatial pattern of trends in annual mean temperatures (% of normal) [based on data from 1980 to 2010 for all 34 stations]

Trends in all-Bangladesh mean monthly temperatureis given in Table 3.3. Two values are reported in the table - one using the data since 1948 and the other using the recent data since 1980. If we compare the values reported in Columns 2 and 4, we find that the recent trends are higher for all months except November, December and January.

Peak winter is becoming Cooler
The trend in recent temperatures in the month of January, which is the coldest month, is negative. This indicates that the peak winter is becoming cooler day by day. The recent increasing trend in the month of May is a staggering 4.0 ^{0}C per century.

Table 3.3: All-Bangladesh trends in seasonal and annual mean temperatures
[data used from 1980 to 2010 for all 34 stations]

Month	Trend[1]	Significance[1]	Trend[2]	Significance[2]
Jan	-0.1	NS	-1.5	NS
Feb	1.5	**	3.2	*
Mar	0.9	NS	2.8	NS
Apr	0.5	NS	2.9	*
May	0.6	NS	4.0	**
Jun	1.4	**	2.6	*
Jul	1.1	**	3.0	**
Aug	1.4	**	2.9	**
Sep	0.7	**	2.3	**
Oct	1.2	**	1.9	*
Nov	2.7	**	2.6	**
Dec	2.0	**	1.8	NS

Note: [1]using data of all stations from 1948 to 2010; [2]using data of all stations from 1980 to 2010

3.2 Trend in Maximum Temperature

The time series of annual mean maximum temperatures for all-Bangladesh is shown in Figure 3.7. It is seen from the figure that the maximum temperature has started rising since 1970s or 1980s. The rising trend is 0.82 ^{0}C per century since 1948 and 2.84 ^{0}C per century since 1980. So, the recent trend since 1980 is much higher than the historical trend since 1948. The seasonal trends are 0, -0.3, 1.5 and 2.3 ^{0}C per century for winter, pre-monsoon, monsoon and post-monsoon seasons, respectively, since 1948. The corresponding trends from 1980 are 1.6, 3.6, 3.7 and 2.2 ^{0}C per century.

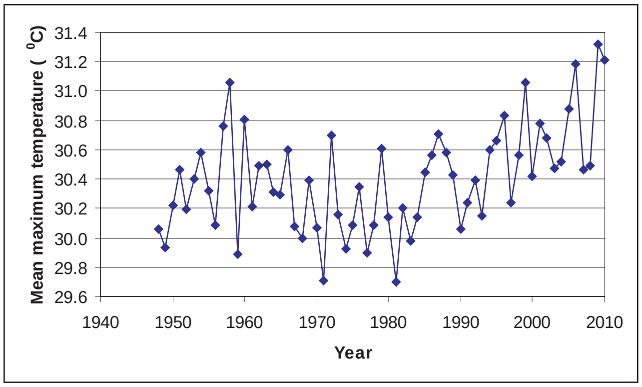


Figure 3.7: Time series of all-Bangladesh mean maximum temperatures[1948-2010 data]

The monthly trends in mean maximum temperatures are given in Table 3.4. The table shows that the trends have become steeper since 1980 for all months except November. During June-October, the trends are statistically significant for both periods (1948-2010 and 1980-2010).

Table 3.4: All-Bangladesh trends (0C/century) in mean monthly maximum temperatures

Month	Trend[1]	Significance[1]	Trend[2]	Significance[2]
Jan	-1.3	**	-0.1	NS
Feb	0.1	NS	4.0	*
Mar	-0.7	NS	3.1	*
Apr	-0.7	NS	2.8	NS
May	0.6	NS	4.9	NS
Jun	1.7	**	3.6	**
Jul	1.3	**	3.7	**
Aug	2.0	**	4.0	**
Sep	1.0	*	3.4	**
Oct	1.9	**	2.1	*
Nov	2.8	**	2.3	**
Dec	1.3	**	1.8	NS

Note: [1]using data of all stations from 1948 to 2010; [2]using data of all stations from 1980 to 2010

3.3 Trend in Minimum Temperature

The time series of mean annual minimum temperatures for all-Bangladesh is shown in Figure 3.8. It is seen from the figure that unlike the mean maximum temperatures, the minimum temperatures show an increasing trend from the very beginning. The trend is 1.50 ^{0}C per century since 1948 and 1.91 ^{0}C per century since 1980. The trends in winter, pre-monsoon, monsoon and post-monsoon temperatures are 2.3, 1.6, 0.8 and 1.6 ^{0}C per century, respectively, since 1948 and 0.8, 2.9, 1.7 and 2.3 ^{0}C per century since 1980. It is noted from the values that the winter trend has substantially decreased and the monsoon trend has substantially increased in recent years.

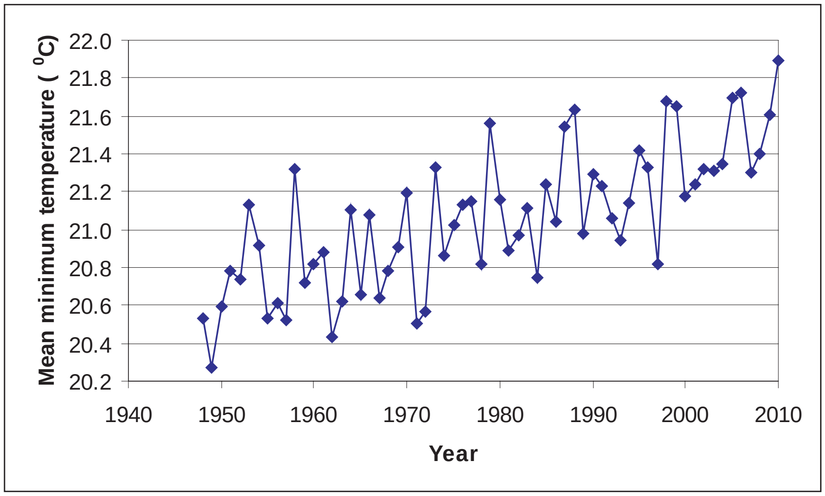


Figure 3.8: Time series of all-Bangladesh annual mean minimum temperature[1948-2010 data]

Trends in monthly mean minimum temperatures for all-Bangladesh are given in Table 3.5. It is seen from the table that the trends have increased for April-November and decreased for December-March in recent times.

Table 3.5: All-Bangladesh trends (^{0}C/century) in monthly mean minimum temperatures

Month	Trend[1]	Significance[1]	Trend[2]	Significance[2]
Jan	1.1	**	-1.4	NS
Feb	2.9	**	2.5	NS
Mar	2.6	**	2.5	NS
Apr	1.7	**	3.0	NS
May	0.7	NS	3.2	**
Jun	1.1	**	1.5	*
Jul	0.9	**	2.3	**
Aug	0.9	**	1.8	**
Sep	0.4	*	1.1	*
Oct	0.6	NS	1.8	NS
Nov	2.7	**	2.8	NS
Dec	2.6	**	1.8	NS

Note: [1]using data of all stations from 1948 to 2010; [2]using data of all stations from 1980 to 2010

4. Analysis of Observed Rainfall

4.1 Introduction

Daily rainfall data for 284 stations were collected from Bangladesh Water Development Board (BWDB) for this study. Data scrutiny and consistency and continuity checking suggested that the data of 50 stations could not be used in trend analysis and they were dropped. A list of the stations along with the length of available records that were used in this study is available in Appendix A of the main report. A map showing the locations of the BWDB stations is given in Figure 4.1. The study also prepared all-Bangladesh rainfall series from 17 selected Bangladesh Meteorological Department (BMD) stations for which a relatively longer data set is available to further verify the averaging process.

Figure 4.1: Locations of the BWDB rainfall stations used in the study

4.2 Annual Rainfall

All-Bangladesh annual normal rainfall for a period of 30 years (1980-2009) is found to be 2306 mm. Such rainfalls were 2298 and 2314 mm during 1960-1989 and 1970-1999, respectively. It thus appears that the annual normal rainfalls have not changed much in Bangladesh.

All-Bangladesh decadal (10 years) rainfalls are shown in Figure 4.2.The figure shows, rainfall increased gradually over the first three decades and then decreased. The highest rainfall was observed during the 1980s. There is no overall trend in decadal annual rainfalls.

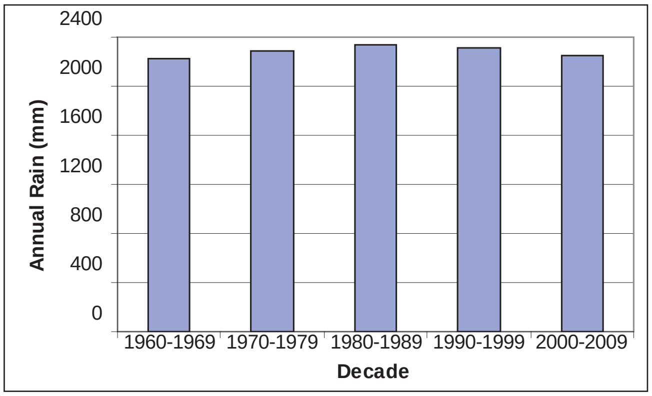


Figure 4.2: All-Bangladesh annual rainfalls during different decades

A time series plot of all-Bangladesh annual rainfalls is given in Figure 4.3. The annual rainfall series created from the 17 selected BMD stations revealed that the series is trend free. It is to be noted that the same 17 stations were used by Shahid (2010). He found an increasing trend of 5.5 mm/year for an analysis period of 1958-2007 at a confidence level of 90%. This study analysis with the same data set and for the same period but with parametric technique indicated an increasing trend of 4.9 mm/year and significant at 90% confidence level. It appears that the use of two methods provides comparable results.

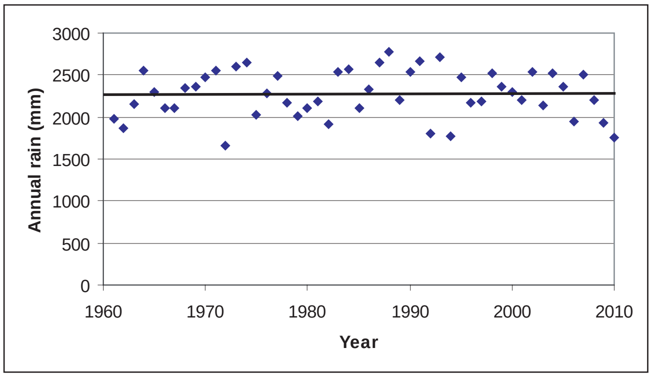


Figure 4.3: All-Bangladesh annual rainfall time series (1961-2010)

4.3 Seasonal Rainfall

All-Bangladesh normal rainfalls in different seasons are given in Table 4.1. It is seen from the table that the pre-monsoon (March-May) and post-monsoonal (October-November) normal rainfalls have increased and the monsoonal (June-September) normal rainfall has decreased over the three time periods. The critical period (11 March-10 May) normal rainfalls have increased. The winter (December-February) normal rainfall has increased in the last two periods compared to the first period. However, these changes in rainfall in different seasons are not statistically significant except for the pre-monsoon season.

Table 4.1:All-Bangladesh normal rainfalls in different seasons

Season	Normal rainfall (mm)		
	1960-1989	1970-1999	1980-2009
Pre-monsoon	428	449	452
Monsoon	1657	1639	1617
Post-monsoon	181	186	197
Winter	32	41	40
Critical period (11 Mar – 10 May)	233	241	244

The decadal rainfalls in different seasons are given in Figure 4.4. It is seen from the figure that the rainfalls in the pre-monsoon and post-monsoon seasons have increased and that in the monsoon season have decreased.

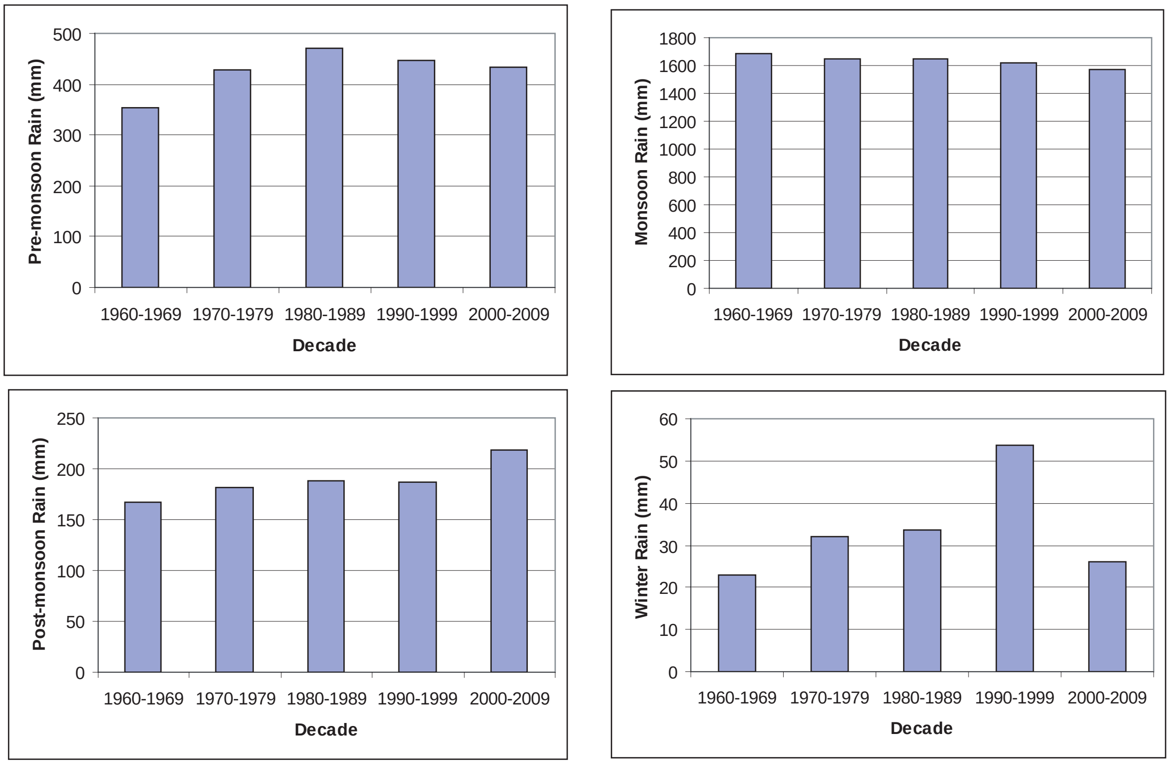


Figure 4.4: All-Bangladesh decadal rainfall variation in different seasons.

4.4 Monthly Rainfall

All-Bangladesh monthly normal rainfall variations are given in Table 4.2. It is seen from the figure and table that, the normal rainfalls in the months of March and May of the pre-monsoon season and September of the monsoon season have increased, while the normal rainfalls in the months of June and August of the monsoon season have decreased.

Table 4.2:All-Bangladesh normal rainfalls in different months

Month	Normal rainfall (mm)		
	1960-1989	1970-1999	1980-2009
Jan	7.1	7.5	8.1
Feb	15.4	22.9	21.8
Mar	36.1	44.1	49.2
Apr	126.3	127.2	124.3
May	258.8	275.8	277.5
Jun	439.3	418.8	413.2
Jul	500.6	506.2	493.3
Aug	391.3	385.7	377.1
Sep	309.3	331.2	336.6
Oct	155.6	153.4	169.9
Nov	26.7	32.2	27.3
Dec	8.6	10.8	8.2

A summary of spatial pattern of rainfall trends for May-October is given in Table 4.3. Further details are available in the main report.

Table 4.3: Summary of monthly rainfall trends for some selected months

Month	Trend per decade (%)	Chance of increase (%)	Areas of increase	Areas of decrease
May	2.2	65.5	Eastern hilly andSouth-West coast	Kurigram-Lalmonirhat-Bogra
Jun	-2.9	34.5	North-West	South-East and Eastern Hilly
Jul	-0.7	44.5	South-West and far North-West	Rajshahi, Eastern Hilly and S-E
Aug	-3.8	29.4	North-West and Eastern Hilly	South-East and upper S-W
Sep	3.2	73.1	South-West and Eastern Hilly	South-East and Bogra-Jamalpur
Oct	4.2	71.4	Far North-West	South-East and Eastern Hilly

The variability, measured in terms of standard deviation, in all-Bangladesh monthly rainfalls is given in Figure 4.5. It is seen from the figure that the variability in rainfalls in the months of September, March, February, January, October, July and June have increased, while that in the months of August has decreased. It thus appears that the inter-annual variability in rainfalls in most months has increased. This indicates that the rainfall is becoming increasingly more uncertain and unpredictable.

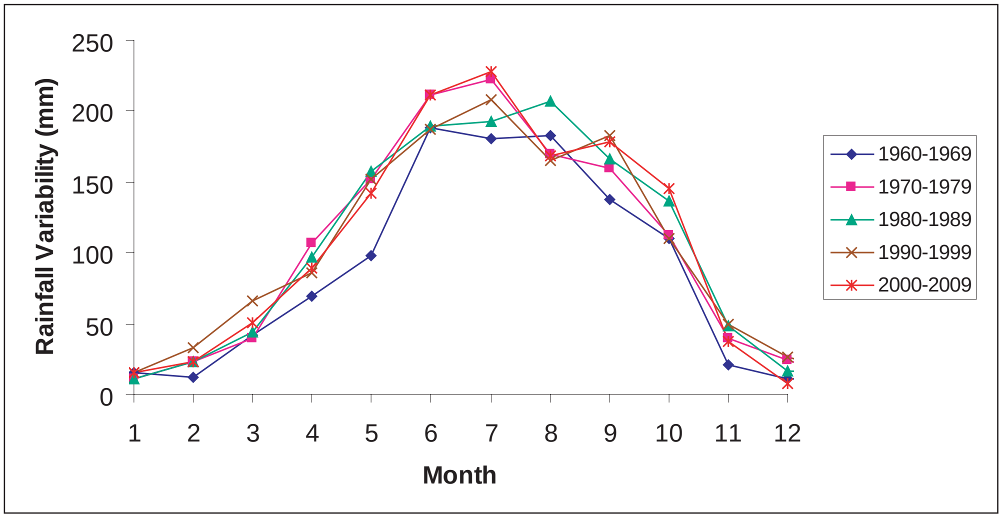


Figure 4.5: All-Bangladesh variability in monthly rainfalls

5. Analysis of Observed Sunshine Duration

5.1 Introduction

Daily data on bright sunshine duration available at different stations of BMD were collected. The data were available for 34 stations. A list of the stations along with the length of available records is given in Appendix B. The data were available for a period of 50 years (1961-2010). A map showing the locations of the stations is given in Figure 5.1.

Figure 5.1: Location of the BMD Weather Stations

All-Bangladesh decadal (10 years) sunshine durations are shown in 5.2 It is seen from the figure that the sunshine durations started falling since 1970s. The highest sunshine duration was observed during the 1970s and the lowest during the 1990s. There is an overall decreasing trend in decadal sunshine durations.

1 Available records for Mongla station was not adequate to carry out analysis and hence it was dropped.

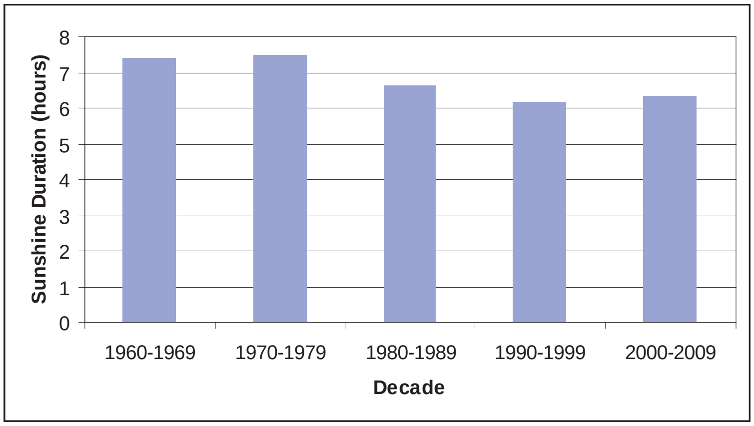


Figure 5.2: All-Bangladesh annual rainfalls during different decades

5.2 Seasonal Sunshine Duration

Time series plots of all-Bangladesh sunshine durations for different seasons are shown in Figure 5.4. It is seen from the figure that the sunshine durations in all the seasons have decreasing trends. The trends are found to be 4.1%, 3.4%, 5.3% and 8.1% per decade during the pre-monsoon, monsoon, post-monsoon and winter seasons, respectively (Table 5.1). The winter sunshine duration is decreasing at a staggering rate of 8.1% per decade. Moreover, the trends in the four seasons were found to be statistically significant at a confidence level of 99%.

Table 5.1: Trends in sunshine durations in different seasons

Season	Normal sunshine hours (1980-2009)	Trend[1] (% per decade)	Significance[2]
Pre-monsoon(Mar-May)	7.49	4.1	***
Monsoon(Jun-Sep)	4.39	3.4	***
Post-monsoon(Oct-Nov)	7.18	5.3	***
Winter(Dec-Feb)	7.40	8.1	***

Note: [1]based on data of all 34 stations (1961-2010); [2]***indicates that the trend is significant at a confidence level of 99%.

5.3 Monthly Sunshine Duration

All-Bangladesh monthly normal sunshine duration variations are given in Figure 5.3. It is seen from the figure that the normal sunshine durations in all the months have decreased. The decrease is higher during November-February and lower during June-August.

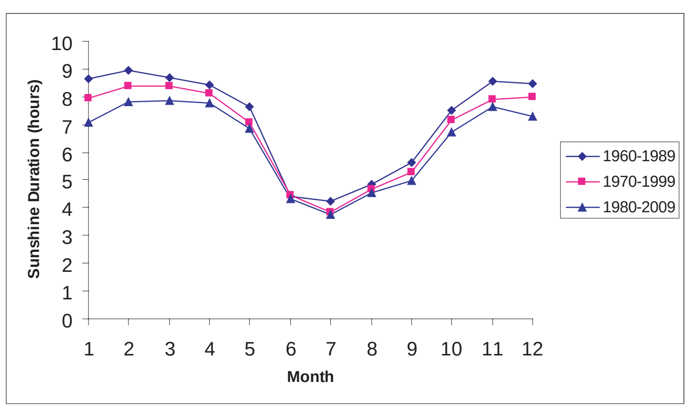


Figure 5.3: All-Bangladesh normal rainfall variation in different months

6. Analysis of Observed Humidity

6. Analysis of Observed Humidity

Daily data on relative humidity available for different stations of BMD were collected. The data were available for 34 stations. Initial scrutiny suggested that the length of available records for Mongla station was not adequate to carry out any analysis and it was dropped.

6.1 Annual Humidity

All-Bangladesh annual normal relative humidity for a period of 30 years (1980-2009) is found to be 78.4%. Such humidity was 77.1%, 75.9% and 76.9% during 1970-1999, 1960-1989 and 1950-1979, respectively (Figure 6.1). It thus appears that the annual normal humidity has increased gradually in Bangladesh since 1960s.

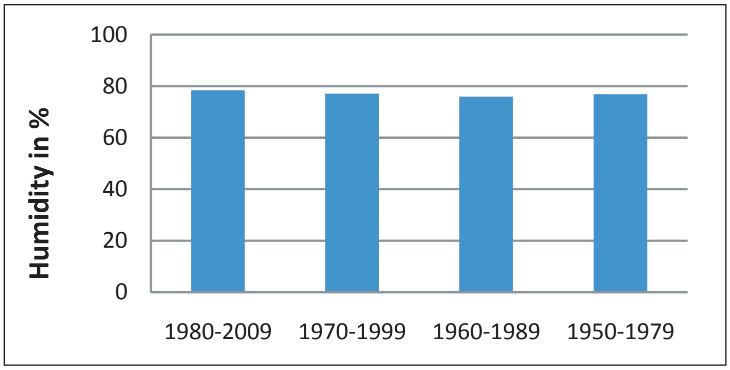


Figure 6.1: All-Bangladesh Annual Humidity for a period of 30 years.

6.2 Seasonal Humidity

The normal relative humidity for different seasons is given in Figure 6.2. It is seen from the figure that the humidity has changed more in recent years compared to the distant past during the winter and post-monsoon seasons. The humidity has increased by about 3.2% and 3.0% during the winter and post-monsoon seasons, respectively, during 1980-2009 compared to 1950-1979. In contrast, the humidity has decreased by about 0.5% during the monsoon season. The pre-monsoon humidity has increased by only about 0.7% during 1980-2009 compared to 1950-1979.

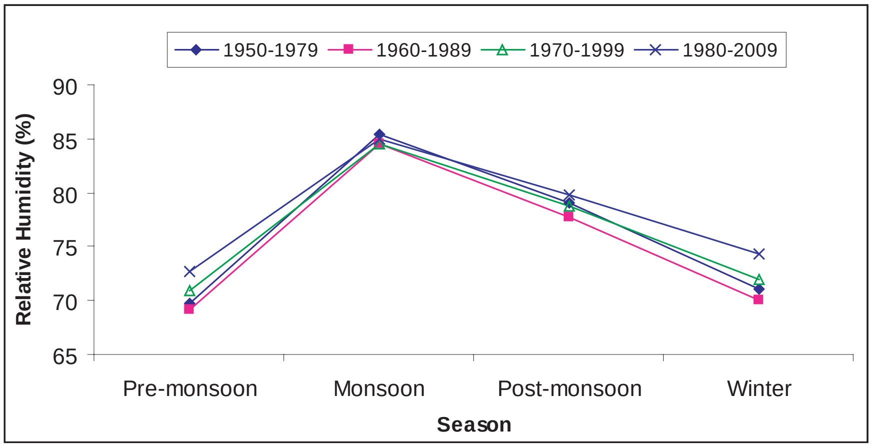


Figure 6.2: All-Bangladesh normal humidity during different seasons

Time series plots of all-Bangladesh humidity for different seasons are shown in Figure 6.3. It is seen from the figure that the humidity has an increasing trend in the pre-monsoon, post-monsoon and winter seasons and a decreasing trend in the monsoon season. The overall trends in humidity over a period of 63 years (1948-2010) are found to be 1.0%, -0.2%, 0.3% and 1.1% during the pre-monsoon, monsoon, post-monsoon and winter seasons, respectively (Table 6.1). The winter and pre-monsoon trends are found to be statistically significant at a confidence level of 99% and the monsoon trend is found to be statistically significant at a confidence level of 95%. The post-monsoon trend is significant only at a confidence level of 80%.

Table 6.1: Trends in all-Bangladesh relative humidity in different seasons

Season	Normal (1980-2009) humidity (%)	Trend[1] (% per decade)	Significance[2]
Pre-monsoon(Mar-May)	72.7	1.0	***
Monsoon(Jun-Sep)	84.9	-0.2	**
Post-monsoon(Oct-Nov)	79.8	0.4	*
Winter(Dec-Feb)	74.3	1.1	***

Note: [1]based on data of all 34 stations from 1948-2010; [2]***indicates that the trend is significant at a confidence level of 99%; **indicates that the trend is significant at a confidence level of 95%; * indicates that the trend is significant at a confidence level of 80%.

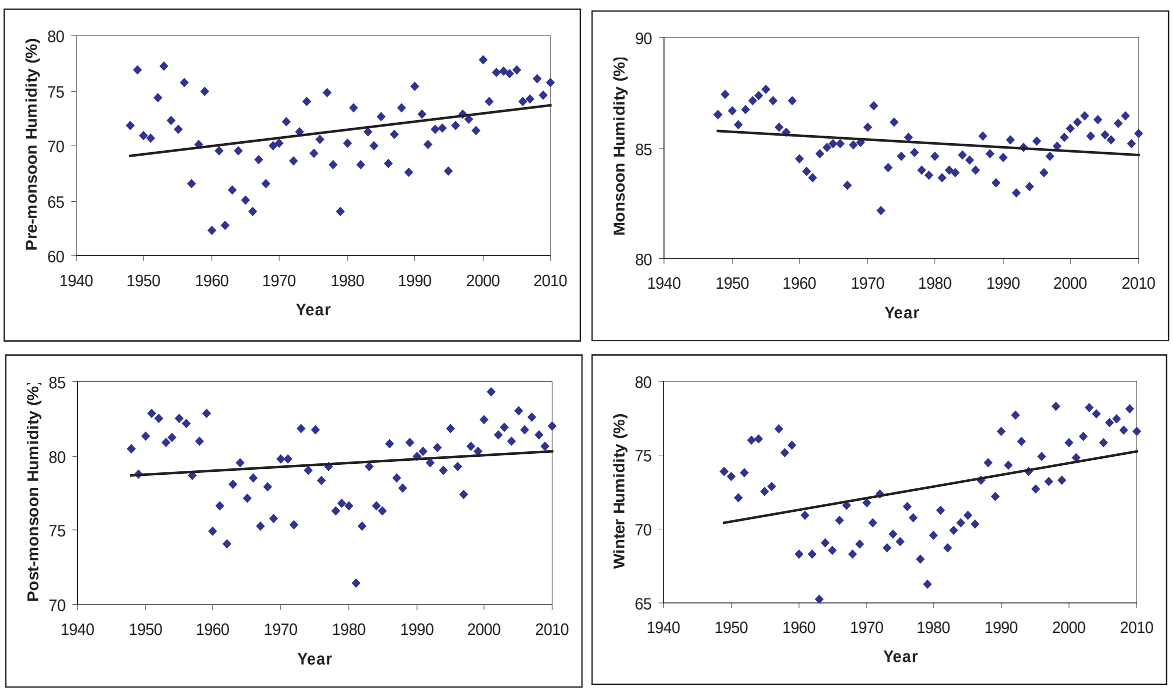
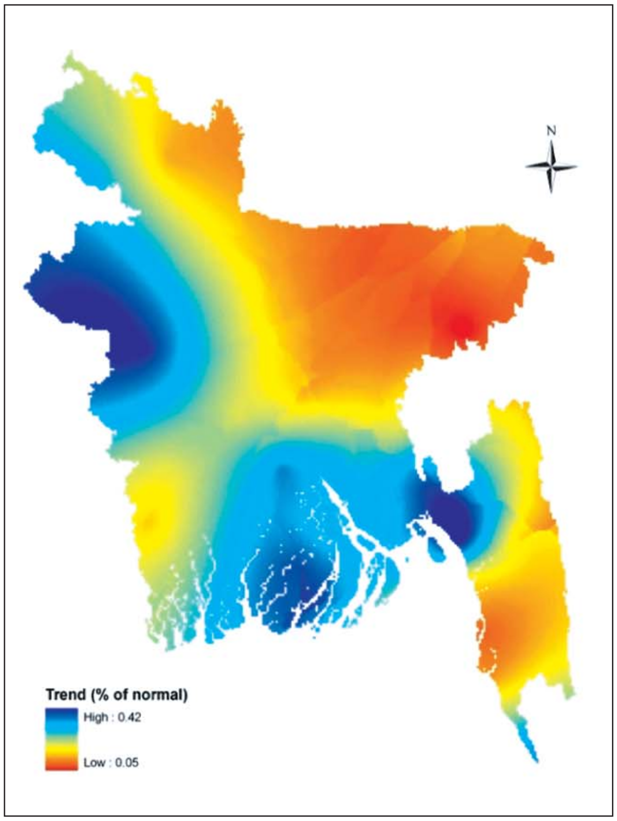


Figure 6.3: Trends in all-Bangladesh seasonal (pre-monsoon, monsoon, post-monsoon and winter) humidity time series

The spatial distribution of trends in seasonal humidity was also investigated and is shown in Figures 6.4-6.7 for the seasons of winter, pre-monsoon, monsoon and post-monsoon seasons, respectively. It appears that the country has in general increasing trend in humidity except at Chittagong for all seasons, at Dhaka for pre-monsoon, monsoon and post-monsoon seasons, at Srimangal for monsoon, post-monsoon and winter seasons, at Sylhet for monsoon and post-monsoon seasons, and at Cox's Bazar for pre-monsoon and monsoon seasons. The monsoon season has mixed trends in humidity.



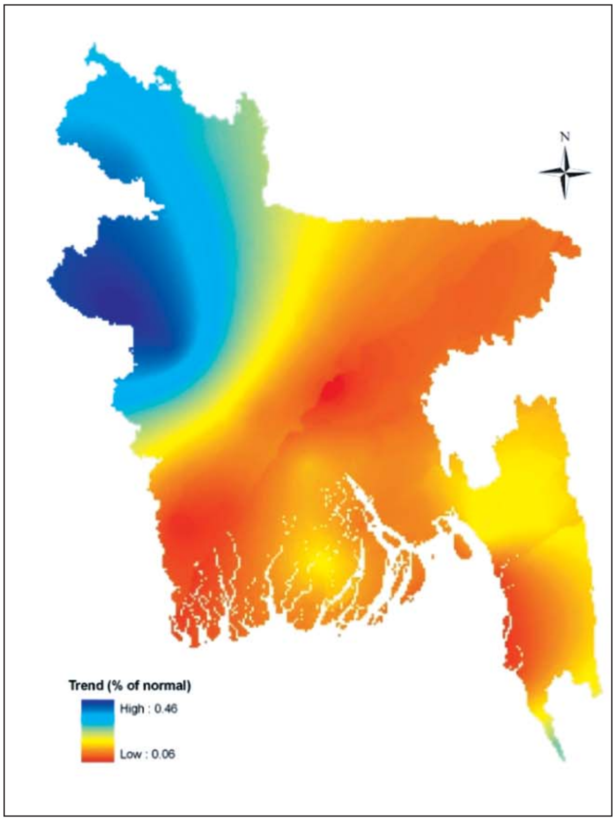
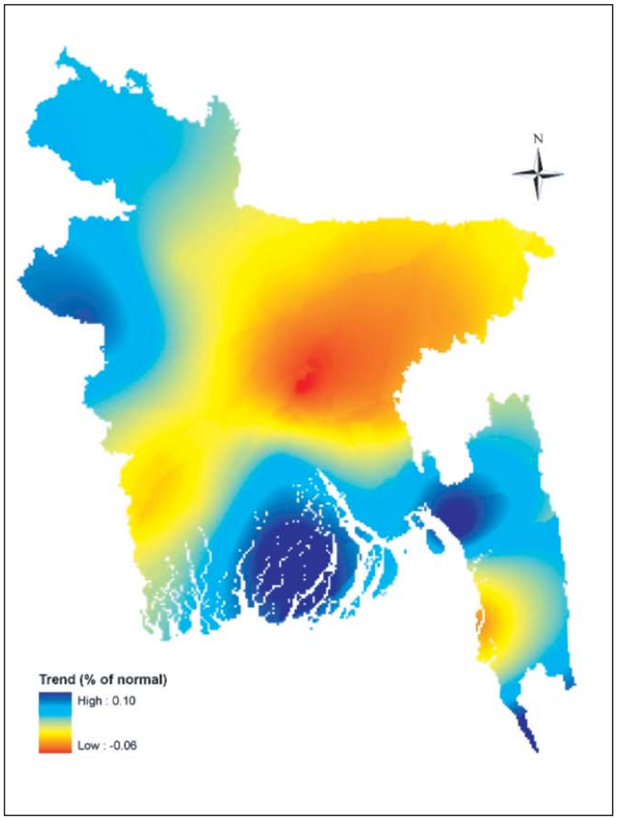
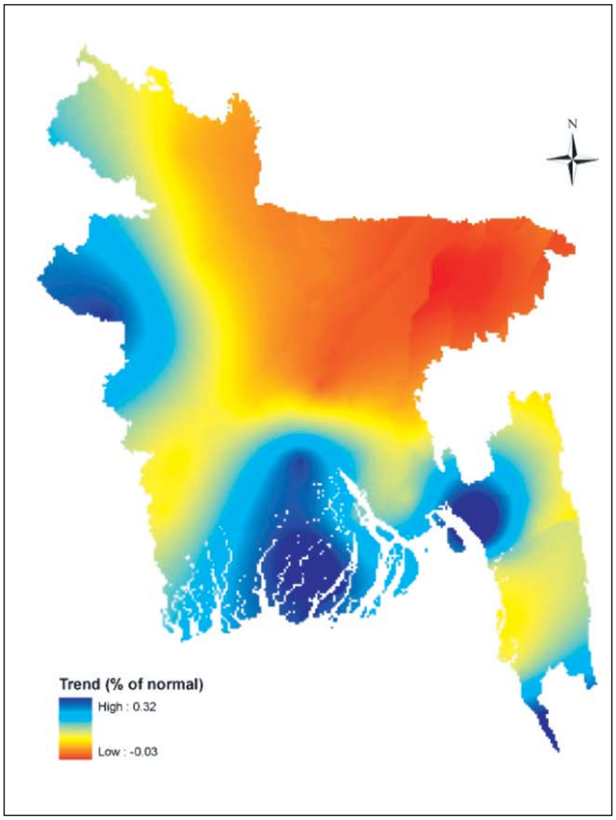


Figure 6.4-6.7: Spatial distribution of the trends in relative humidity (% per year) during the winter Dec.-Feb.), pre-monsoon season (March-May), monsoon (June-Sept.) and post monsoon (Oct.-Nov.)





A comparison of trends in recent humidity with the trends in long-term humidity is made in Figure 6.8. It is seen from the figure that the recent trend (1980-2010) is much higher than the long-term trend (1948-2010).

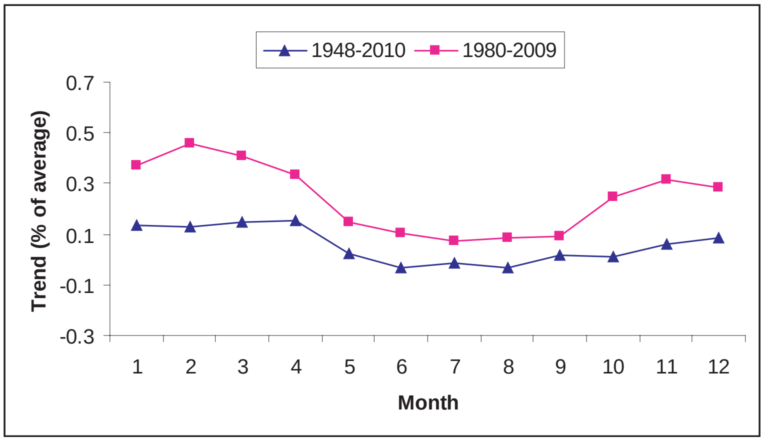


Figure 6.3: Comparison of recent (1980-2010) trend with long-term (1948-2010) trend of all-Bangladesh monthly relative humidity

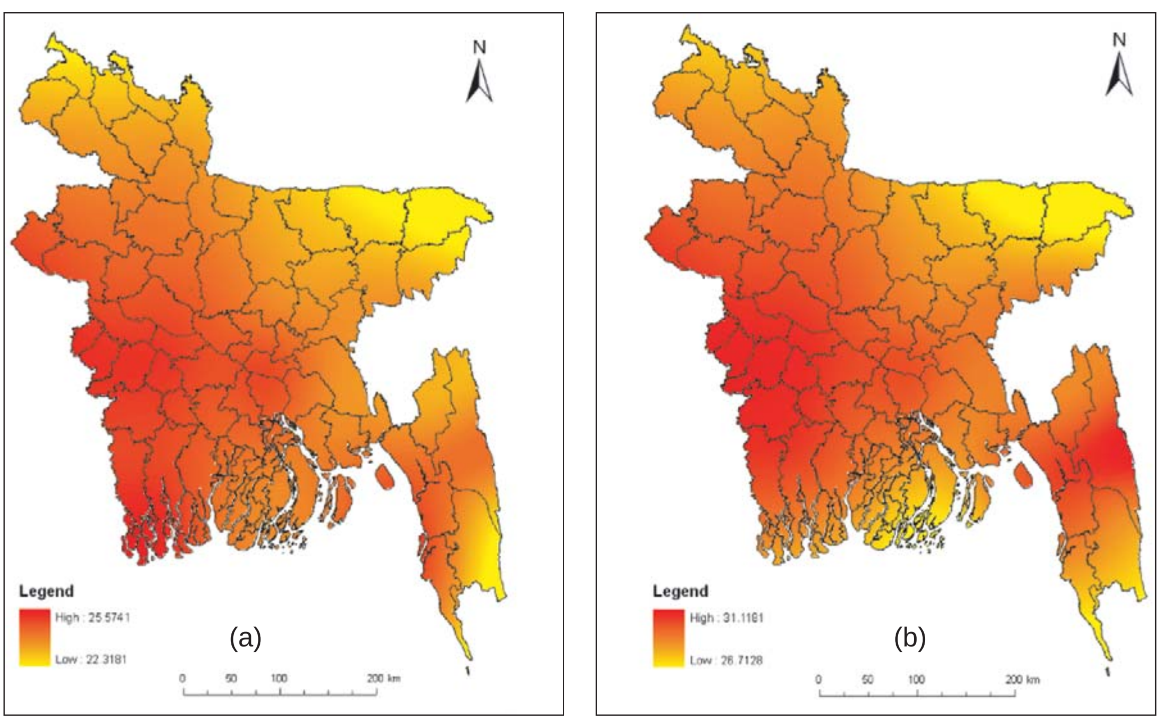
7. Spatial Pattern of Changes in Future Climate

7.1 Simulation of Baseline (1961-1990) Climate

The regional climate has been simulated over Bangladesh domain using Special Report on Emission Scenario (SRES) balanced scenario A1B. Simulation was conducted from 1961 to 2100. However, the period from 1961 to 1990 has been taken as baseline period as suggested by the fourth assessment report of IPCC. Figure 7.1 shows the average spatial distribution maps of the mean, maximum and minimum temperatures, and precipitation based on the model data during 1961-1990. It is seen from the figure that the northern and north-eastern parts of Bangladesh are cooler than the southern and south-western parts. The main reason for this temperature variation is the circulation of the wind. Maximum precipitation is observed in Srimongal, which is located in the north-eastern part of the country. A summary of mean values of baseline climate during 1961-1990 obtained from the high resolution regional climate model (PRECIS) is presented in Table 7.1.

Table 7.1: Baseline climate of Bangladesh obtained from the PRECIS model during 1961-1990

Variable	Annual	Monsoon (Jun-Sep)	Winter (Dec-Feb)
Mean Temperature (^{0}C)	24.6	31.83	16.2
Precipitation (mm/day)	3.5	7.24	0.59



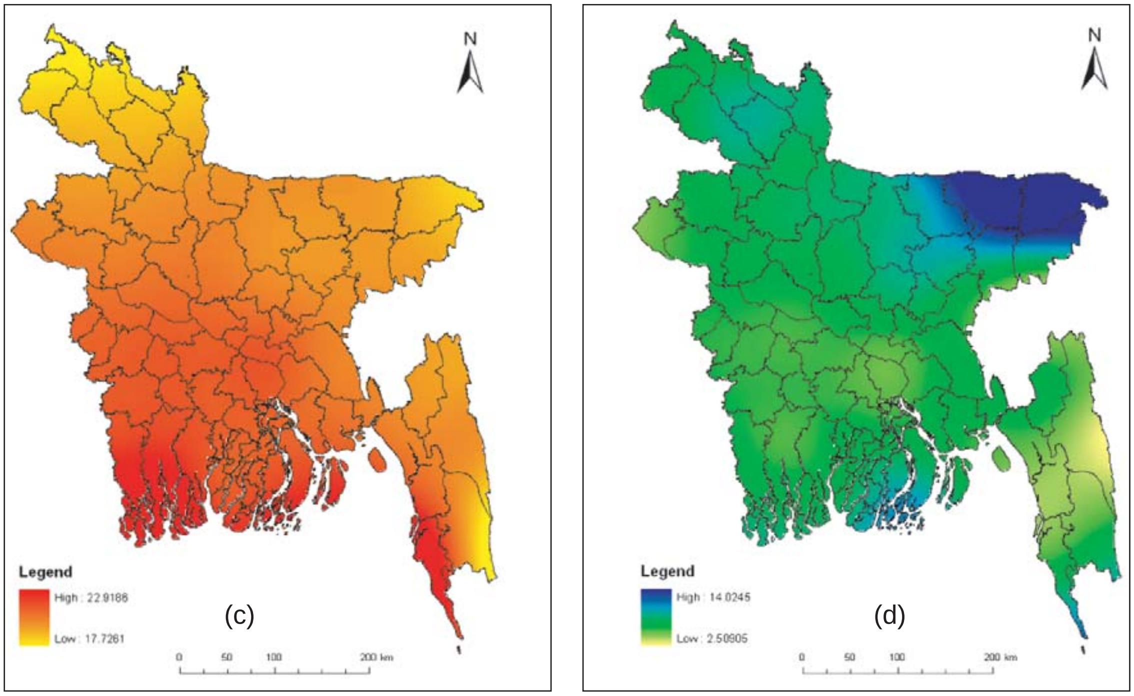
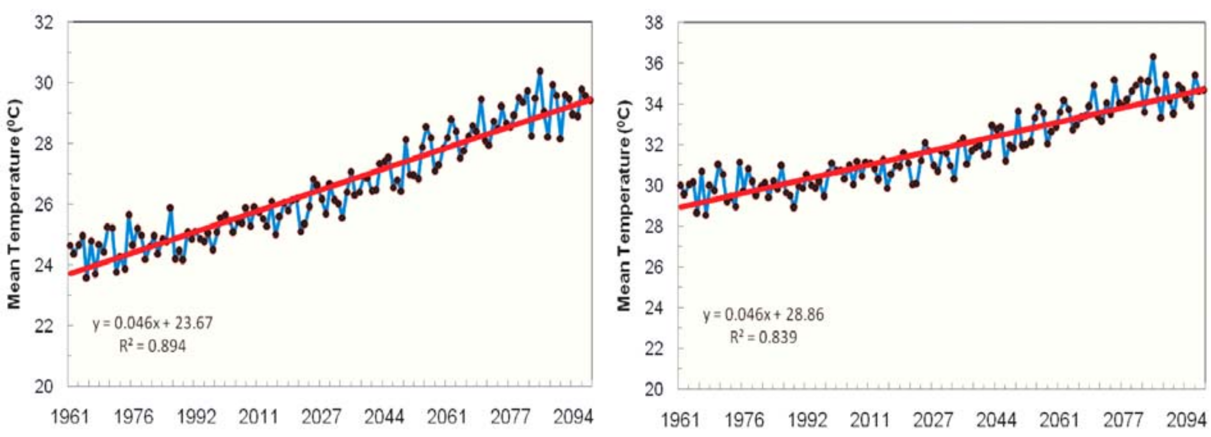


Figure 7.1: Simulated average annual (a) mean, (b) maximum, (c) minimum temperature in 0C and (d) precipitation in mm per day during 1961-1990

7.2 Trends in Future Climate

Figure 7.2 shows the trends in mean, maximum and minimum temperatures, and precipitation over Bangladesh using time series data from 1961 to 2100. It is found from the figure that the annual mean, maximum and minimum temperatures exhibit trends of about 4.6 ^{0}C per century. The trend in annual mean precipitation is about 180 mm per century (0.5 mm/day per century).



(a) (b)

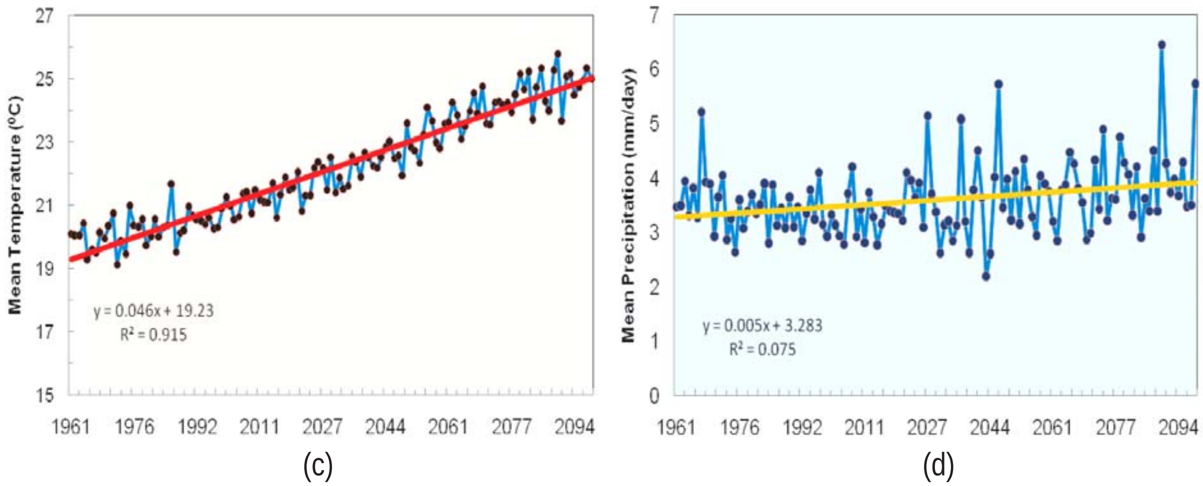


Figure 7.1: Trends in annual (a) mean, (b) maximum, (c) minimum temperatures in 0C and (d) precipitation in mm per day

7.3 Spatial Patterns of Future Climate

Future climate change has been projected as a difference from the baseline period. The differences of mean annual temperature and precipitation during 1911-1941 and 1971-2100 from the baseline period of 1961-1990 have been calculated. A summary of the average difference of mean annual, monsoon and winter temperatures from the baseline period of 1961-1990 to the two future periods (as mentioned above) are provided in Table 7.2. It is found from the table that the winter temperature would rise much higher in future than the temperatures of annual and monsoon periods.

The mean annual and monsoon precipitation would increase by 0.64 and 1.40 mm per day, respectively, during 2011-2041 from the baseline period. However, mean winter precipitation would decrease by 0.05 mm per day during 2011-2041 from the baseline period. The mean annual, monsoon and winter precipitation would increase by about 0.90, 1.43 and 0.03 mm per day, respectively, during 2071-2100 from baseline period.

Table 7.2: Difference of mean annual, monsoon and winter temperature and precipitation from baseline period 1961-1990 to 2011-2040 and 2071-2100

Variable	From 1961-1990	Annual	Monsoon (Jun-Sep)	Winter (Dec-Feb)
Temperature (^{0}C)	2071-2100	4.34	3.43	5.37
	2011-2041	1.49	1.50	1.80
Precipitation (mm/day)	2071-2100	0.90	1.43	0.03
	2011-2041	0.64	1.40	-0.05

8. Crop Vulnerability

Agricultural crops are always vulnerable to unfavorable weather events and climatic conditions. Climatic factors, such as temperature, rainfall, solar radiation, atmospheric carbon dioxide, etc., are closely linked with crop production. Despite technological advances, such as improved crop varieties and irrigation systems, weather and climate play significant roles to crop productivity.

As mentioned earlier, the effect of climate change on agriculture has been assessed in this study through a model simulation. The simulations were made for assessing the potential impacts of climate change on boro rice, *T. aman* and wheat using the crop growth model named Decision Support System for Agro-technology Transfer (DSSAT). The simulation study was conducted for the years of 1975, 2025, 2055 and 2085. In this study, boro rice variety of BR 14, *aman* rice variety of BR 22 and wheat variety of Kanchan were selected to assess the potential impacts of climate change on crop yield.

8.1 Wheat Yield will suffer in Changing Climate

Predicted yield of wheat for different locations in Bangladesh is shown in Table 8.1. Simulated yield of wheat ranges from 2063 kg/ha at Chapai Nawabganj to 2866 kg/ha at Sunamganj in 1975, from 1862 kg/ha at Chapai Nawabganj to 2718 kg/ha at Sunamganj in 2025, from 1790 kg/ha at Satkhira to 2226 kg/ha at Rajbari in 2055, and from 1286 kg/ha at Chapai Nawabganj to 2144 kg/ha at Sunamganj in 2085.

Reduction in Wheat Yield

It is seen from the table that wheat yield would reduce in future at all the locations. The maximum reduction, which is about 49.69%, could occur in Satkhira in 2085.

Table 8.1:Predicted yield (kg/ha) of wheat (Kanchan) at some selected locations of Bangladesh for some selected years

Location	Simulated yield (kg/ha) in the yrs.				Change in yield (%) in the yrs.		
	1975	2025	2055	2085	2025	2055	2085
Rajbari	2245	2207	2226	1936	-1.69	-0.85	-13.76
Nawabganj	2063	1862	1802	1734	-9.74	-12.65	-15.95
Satkhira	2556	2374	1790	1286	-7.12	-29.97	-49.69
Sunamganj	2866	2718	1827	2144	-17.17	-36.25	-25.19

Wheat is very sensitive to temperature. The optimum temperature for wheat in vegetative, reproductive and ripening stages are 20-25, 25-28 and 28-32 ^{0}C, respectively. A high temperature during the reproductive and grain filling stages is one of the main causes of yield loss of wheat in Bangladesh (Rahman et al., 2009).

8.2 Yield Loss of BoroRice in changing climate

Table 8.2 shows the predicted boro rice yield for the four locations. It shows a reduction in yield of bororice in future years compared to the base year of 1975 across all the locations except at Chapai Nawabganj for the year of 2025. Simulated yield of *boro* rice ranges from 5123 kg/ha at Chapai Nawabganj to 5612 kg/ha at Rajbari in 1975, from 5186 kg/ha at Chapai Nawabganj to 5462 kg/ha at Rajbari in 2025, from 5025 kg/ha at Chapai Nawabganj to 5322 kg/ha at Rajbari in 2055 and from 4054 kg/ha at Satkhira to 5049 kg/ha at Sunamganj in 2085.

Boro Yield Loss is predicted
Compared to the yield of 1975, the higher reduction which is about 26.08% could occur in Satkhira for the year 2085 and minimum reduction (1.30%) in Sunamganj for the year of 2025. The table also reveals that the reduction in *boro* yield could be more in the coastal part followed by the central, haor and upland areas.

Table 8.2: Predicted yield (kg/ha) of BR 14 variety of boro rice at some selected locations of Bangladesh for some selected years

Location	Simulated yield (kg/ha) in the yrs				Change in yield (%)in the yrs		
	1975	2025	2055	2085	2025	2055	2085
Rajbari	5612	5462	5322	4990	-2.67	-5.17	-11.08
Chapai Nawabganj	5123	5186	5025	4966	1.23	-1.91	-3.06
Satkhira	5484	5307	5043	4054	-3.23	-8.04	-26.08
Sunamganj	5524	5452	5211	5049	-1.30	-5.67	-8.60

Both the maximum and minimum temperatures are predicted to be increased in the years of 2025, 2055 and 2085 compared to the base year of 1975. Higher temperature accelerates the physiological development, resulting in hastened maturation and reduced yield. Predicted temperatures for the above years exceed the optimum temperature for ripening stage, which is about 21-22 ^{0}C (Amin *et al*., 2004).Thus, the increasing temperature can be attributed to be a reason for the reduction of yield of boro rice in future years.

8.3 Impact on Aman Rice

The model simulated yield of BR 22 variety of T. Aman at the four selected locations of Bangladesh for some selected years is given in Table 8.3. It is seen from the table that the simulated yield of aman rice ranges from 4343 kg/ha at ChapaiNawabganj to 4941 kg/ha at Rajbari in 1975; from 4417 kg/ha at ChapaiNawabganj to 4840 kg/ha at Satkhira in 2025; from 4329 kg/ha at ChapaiNawabganj to 4883 kg/ha at Satkhira in 2055; and from 4382 kg/ha at ChapaiNawabganj to 5022 kg/ha at Satkhira in 2085.

No Significant Change in Aman Yield
Compared to the base condition yield of 1975 (average of 1960-1990), the predicted yield of aman rice shows different degrees of change. In some cases, the predicted yield is found to be decreased, whereas in other cases the predicted yield is found to be increased.

Table 8.3: Predicted yield (kg/ha) of BR 22 variety of aman rice at some selected locations of Bangladesh for some selected years

Location	Simulated yield (kg/ha) in the yrs				Change in yield (%)in the yrs		
	1975	2025	2055	2085	2025	2055	2085
Rajbari	4941	4840	4883	5022	-2.04	-1.17	1.64
Nawabganj	4343	4417	4329	4382	1.70	-0.32	0.90
Satkhira	4432	4429	4525	4580	-0.07	2.10	3.34
Sunamganj	4586	4576	4578	4683	-0.22	-0.17	2.12

The yield of T. aman rice was found to be increased in some other cases. The maximum increase, which could be about 3.34%, might occur in Satkhira in the year of 2055. T. *aman* is one of the important rain-fed crops in Bangladesh. Rainfall plays a significant role in T. *aman* production. In the years of increased yield, predicted precipitation in T. Aman season was found to have exceeded the water requirement for T. *aman* rice (1000-1100 mm). More importantly, solar radiation was predicted to be increased in those years. These in combined could be the reasons for the T. aman rice yield increases for those cases.

9. Conclusions

Temperature

The trend in all-Bangladesh mean annual temperatures using the historical data (1948-2010) from 34 stations was found to be increasing at a rate of about 1.2 ^{0}C per century. This trend has become stronger in recent years. The trend in recent mean temperatures (1980-2010) was found to be the double (2.4 ^{0}C per century) of the historical trend. The spatial distribution of recent trends indicates that the mean annual temperature in the northern part of the country is increasing at a higher rate compared to the mid-western and eastern hilly regions. The winter (Dec-Feb), pre-monsoon (Mar-May), monsoon (Jun-Sep) and post-monsoon (Oct-Nov) trends in last 31 years of data were found to be 1.2, 3.2, 2.7 and 1.5 ^{0}C per century, respectively. The pre-monsoon, monsoon and winter trends were found to be becoming stronger and the post-monsoon trend was becoming weaker in recent times.

Temperature may increase 4.6 ^{0}C per century

The PRECIS model indicates that the annual mean temperature may increase gradually at a rate of 4.6 ^{0}C per century. The increase could be more in the winter season compared to that of the monsoon season.

Rainfall

The all-Bangladesh annual normal rainfall was estimated for the period of 1980-2009 from 236 BWDB stations and was found to be 2306 mm. The annual rainfall at country level was found to be free of trend. However, there are some significant changes in regional scales. The seasonal rainfalls at country level have also remained unchanged except for the pre-monsoon season, when it has significant increasing trend. The post-monsoonal normal rainfalls have increased (but not statistically significant) and the monsoonal normal rainfall has remained almost the same. The number of rainy days in a year was found to be increasing andthe longest duration of consecutive non-rainy days is found to be decreasing.

No Significant Annual precipitation increase in the future
The normal rainfalls in the months of June and August of the monsoon season have decreased and the rainfall of September has increased.

Sunshine

The sunshine duration has a decreasing trend at both annual and seasonal scales. The annual trend is 5.3% per decade; pre-monsoon, monsoon, post-monsoon and winter trends are 4.1%, 3.4%, 5.3% and 8.1%, respectively. All these trends were found to be statistically significant.

Humidity

The humidity has increasing trends of 1.0%, 0.4% and 1.1% per decade in the pre-monsoon, post-monsoon and winter seasons, respectively, and decreasing trend of 0.2% in the monsoon season. The winter and pre-monsoon trends are statistically significant. The humidity in all the months has increasing trends except for June-August. The trend is the highest in April, which is the warmest month of the year.

Wheat and Boro Rice will suffer in changing climate
The results of the simulation studies indicate that the winter crop **wheat** will be highly vulnerable to climate change, followed by *boro rice*. The wheat and *boro* yields might decrease by about 26% and 12%, respectively, by the end of this century.

Effect of Climate Change on Aman Rice will be mixed and insignificant
The effect of climate change on *aman* yield would be less and mixed depending on the years and locations. The south-western coastal region and the north-eastern *haor* basin would be more vulnerable than the central plain and high *Barind* area to predicated climatic changes.

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