ASSESSMENT OF PRECIS REGIONAL CLIMATIC MODEL FOR SOME SELECTED CLIMATIC PARAMETERS IN BANGLADESH

Aklima Haque

Department of Water Resources Engineering

BANGLADESH UNIVERSITY OF ENGINEERING AND TECHNOLOGY

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ASSESSMENT OF PRECIS REGIONAL CLIMATIC MODEL FOR SOME SELECTED CLIMATIC PARAMETERS IN BANGLADESH

by

Aklima Haque

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Certification of Project

The project work entitled "ASSESSMENT OF PRECIS REGIONAL CLIMATIC MODEL FOR SOME SELECTED CLIMATIC PARAMETERS IN BANGLADESH" submitted by Aklima Haque, Roll No. 0409162006(F), Session: April, 2009 has been accepted as satisfactory in partial fulfillment of requirement for the degree of Master of Engineering in Water Resources Engineering on 24th December, 2014.

Dr. Md. Sabbir Mostafa Khan
Professor — Chairman
Department of WRE, BUET, Dhaka
(Supervisor)

Dr. A. T. M. Hasan Zobeyer
Assistant Professor — Member
Department of WRE, BUET, Dhaka

Dr. Nasreen Jahan
Assistant Professor — Member
Department of WRE, BUET, Dhaka

Declaration

This is to certify that this project work entitled "ASSESSMENT OF PRECIS REGIONAL CLIMATIC MODEL FOR SOME SELECTED CLIMATIC PARAMETERS IN BANGLADESH" has been done by me under the supervision of Dr. Md. Sabbir Mostafa Khan, Professor, Department of Water Resources Engineering, Bangladesh University of Engineering and Technology Dhaka, Bangladesh. I do hereby declare that this project or any part of it has not been submitted elsewhere for the award of any degree or diploma.

Signature of the candidate

Aklima Haque

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Abstract

Bangladesh is considered as one of the most vulnerable zone under climate change where climate change is likely to exacerbate frequently occurring climatic hazards such as flood, cyclone, storm surge, drought and heavy rain. Long term planning is impossible without any idea of change of climate to be anticipated in the future. Rainfall and temperature are the most important climatic parameters and regional climate models are the main tools available for developing projections of climate change.

The assessment of PRECIS regional climate model in Bangladesh is performed with the surface observational data of rainfall and temperature collected by the Bangladesh Meteorological Department at 7 observational sites throughout the country from 1990-2010. PRECIS is overestimating the rainfall at different regions of the country except at a few locations where it is underestimating. Data averages from all seven regions over Bangladesh with yearly variation provide reasonable validation of PRECIS in Bangladesh than regional variation. Monthly biases are calculated +1.15 mm/day in May and – 1.55 mm/day in September respectively. Regional PRECIS data underestimates temperature at different regions of the country as compared to BMD data except for some regions where it is overestimating. PRECIS annual average of maximum and minimum temperature values vary by 0.4 to 2.7 ºC and 0.1 to 0.5 ºC respectively from BMD values. Thus this work revealed satisfactory results for validation of PRECIS in Bangladesh.

In the next step PRECIS model generated rainfall and temperature scenarios are calibrated with ground-based observed data during 1990-2010 in Bangladesh. Through calibration, regression coefficients such as slopes and constants are obtained at seven regions over Bangladesh. The regression coefficients are utilized in obtaining the projected rainfall and temperature for Bangladesh in 2015, 2025, 2035, 2045 and 2050. The future daily average rainfall for Bangladesh is found to increase about 1.7 to 5.8 mm/day from the past in July to August which are the month of monsoon season but falls slightly about 0.2 to 0.7 mm/day at winter and pre-monsoon periods. The maximum and minimum temperature will be increased in future years. Annual average of maximum and minimum temperature values are increasing between 1.70 ºC and 2.0 ºC. This work decisively disclosed that PRECIS may be admissible in future impact studies of climate change in Bangladesh.

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List of Abbreviations

Figure: 4.28	Bangladesh Meteorological Department
Figure: 4.29	Bangladesh University of Engineering and Technology
DFID	Department for International Development
LBC	Lateral Boundary Condition
PRECIS	Providing REgional Climates for Impact Studies
RCM	Regional Climate Model
IPCC	Intergovernmental Panel on Climate Change
SAARC	South Asian Association for Regional Cooperation
GCM	Global Climate Models
SRES	Special Report on Emissions Scenarios
SMRC	SAARC Meteorological Research Center
TRMM	Tropical Rainfall Measuring Mission
AGCM	Global Atmospheric General Circulation Model
GBM	Ganges Brahmaputra Meghna
IWFM	Institute of Water and Flood Management
BD	Bangladesh
DJF	December, January and February
MAM	March, April and May
JJAS	June, July, August and September
ON	October and November
NE	North East
DEFRA	Department for Environment, Food and Rural Affairs
UNDP	United Nations Development Program
SPARRSO	Bangladesh Space Research and Remote Sensing Organization
DoE	Department of Environment
IITM	Indian Institute of Tropical Meteorology

CHAPTER 1
INTRODUCTION

1.1 GENERAL

Climate change has been escalating over recent centuries, causing a great impact on the ecosystem of the earth surface. The historical climate change along with the present rate of change has influenced engineers to project the future climate change to aid policy makers in making decisions. According to the assessment reports of the Intergovernmental Panel on Climate Change (IPCC), South Asia is one of the most vulnerable regions of the world to climate change impacts (McCarthy et al, 2001). Bangladesh is located between 20° to 26°N and 88° to 92°E. The international community also recognizes that Bangladesh, a South-Asian country, ranks high in the list of most climate vulnerable countries on Earth. Since Bangladesh is primarily agrarian; the projection of rainfall and temperature and its effects on water related hazards and subsequent implications for people's lives and livelihoods are very high (Ferdousi et al, 2008). Increase in temperature during the months with less precipitation as a result of climate change will increase evapotranspiration and create situations like water loss from soil and resultant reduced crop yield, lower levels of water both in surface and ground water systems, higher microbial concentration and growth rate in the surface waters and so on. If not checked in time, the exacerbating aridity and accompanying desertification processes as a consequence of increased surface temperature with less precipitation are destined to cause severe environmental degradation in different parts of the country, (Rajib and Rahman, 2012).

1.2 BACKGROUND OF THE STUDY

Bangladesh is amongst the most densely populated areas of the world where proper planning and management of water resources are essential. Model-simulated climate scenarios can play an important role in developing such types of plans. Bangladesh is regarded as one of the most vulnerable countries under climate change. Climate change is likely to exacerbate frequently occurring climatic hazards such as floods, cyclones, storm surges, droughts, and heavy rain (Ahmed et al, 1998 and Ali, 1999).

The World Bank climate change experts' opinion is that the poorest of the poor in South Asia are the most affected by climate change. The impact of higher temperatures, more extreme weather events such as floods, cyclone, severe drought, and sea level rise are already being felt in South Asia, and will continue to intensify (Karim et al, 1998).

Eight South Asian nations- Afghanistan, Bangladesh, Bhutan, India, Maldives, Nepal, Pakistan and Sri Lanka, have an economic and political body, the South Asian Association for Regional Cooperation (SAARC). Climate change is recognized as the greatest long-term threat to the World and particularly to the SAARC region. The economic impact of climate change, rising food prices and assessment of food security are key issues to discuss. It is accounted that in the SAARC countries 21% of world population resides on only 4% of the world's total physical area. In this connection proper planning and judicious management of water resources are essential for this region. Long-term planning is impossible without any idea of the climate change (Rahman et al, 2009 and Islam, 2009).

In a country like Bangladesh, where about 60% of the population finds employment from agriculture, the importance of predicted rainfall and temperature towards planning for the sector and ensuring food security of one forty million people is paramount. Since the country is primarily agrarian, the projection of rainfall and temperature, and their effects on water related hazards and subsequent implications for peoples' lives and livelihoods are very important (Islam, Rafiuddin et al, 2008).

To anticipate future climate change, we need to project how greenhouse gases will change in the future. A range of emission scenarios has been developed in the IPCC Special Report on Emissions Scenarios that reflect a number of different ways in which the world might develop storylines and the consequences for population, economic growth, energy use and technology. To estimate the effect that these emissions have on the global climate, global climate models (GCMs) are employed. Run a climate model means to divide the planet into a three-dimensional grid, apply the basic equations and evaluate the results at individual grid points. General Circulation Models (GCMs) run typically on a horizontal resolution of around 100 km (Rajib and Rahman, 2012).

Global climate models (GCMs) might be adequate for areas where the terrain is reasonably flat, uniform and away from coasts. But in areas like Bangladesh where coasts of the Bay of Bengal and the Himalayan Mountain have significant effects on weather, General Circulation Models (GCMs) might be unable to capture the local level details needed for assessing climate change impacts at national and regional scales. Also, at the coarse resolution of GCMs, meso-scale atmospheric circulations are either not captured or their intensities are unrealistic.

A Regional Climate Model (RCM), therefore, is a good tool for dynamic downscaling of climate features in case of obtaining detailed information for a particular region. A regional model also known as limited area model generally covers a specific area of the globe at a higher resolution (typically around 50 km) for which conditions at its boundary are specified from an GCMs (Jones et al. 2004 and Bader et al, 2008). The RCM is better able to resolve meso-scale forcing associated with coastlines, mountains, lakes, and vegetation characteristics that exert a strong influence on the local climate.

The Hadley Centre of UK has developed a regional climate model named PRECIS (Providing Regional Climates for Impacts Studies) that can be run on a PC and can be applied easily to any area of the globe to generate detailed climate change predictions. Details of PRECIS can be found at their website. PRECIS has a horizontal resolution of 50 km with 19 levels in the atmosphere (from the surface to 30 km in the stratosphere) and four levels in the soil. The present version of PRECIS has the option to downscale to 25 km horizontal resolution. In addition to a comprehensive representation of the physical processes in the atmosphere and land-surface, it also includes the sulphur cycle.

The intention is to make PRECIS freely available for use by developing country scientists involved in vulnerability and adaptation studies conducted by their governments. It is assumed that scientists in a group of neighboring countries can work together so that they can configure the model over their own region and run their own regional climate change predictions. PRECIS developers advised to work based on groups of countries, as in many cases they have similar vulnerabilities and face similar impacts from climate change.

The Institute of Tropical Meteorology (IITM), Pune, India runs PRECIS with 50 km horizontal resolution for present climate (1961-1990) using different base line local boundary condition (LBC) and for future scenarios (2070-2100) using IPCC (Intergovernmental Plan on Climate Change) Special Report on Emissions Scenarios (SRES). PRECIS is installed in Bangladesh and a test run has been done for a short period (one and half a year). The model output is compared with that of IITM runs. Results are the same. Then we take the advantage to use IITM PRECIS output to validate PRECIS in Bangladesh for 1961-1990 to save computing time. Once the obtained validation result give the confidence level of simulated outputs, future scenarios will be generated and climate change will be explained based on the present validation information. Otherwise, downscaling run has to be considered (Islam, Mannan et al, 2005).

In view of the above now it is essential to assess the performance of PRECIS for recent year of various climatic parameters which is normally available in Bangladesh climatic system such as temperature, rainfall at different directional sites throughout the country. On this goal the present study investigates the validation of PRECIS regional climatic model with A1B scenario for recent twenty one year 1990 to 2010 of climatic parameters of Bangladesh such as temperature, rainfall at seven observational sites throughout the country like as Dhaka (centre), Khulna (southwest), Chittagong (southeast), Rangpur (northwest), Sylhet (northeast), Rajshahi (weste) and Barisal (south). Also PRECIS is employed to generate projections for rainfall and temperature in 2015, 2025, 2035, 2045 and 2050 in Bangladesh using A1B emission scenario as the model input.

1.3 OBJECTIVE OF THE STUDY

The main objective of the study is to determine the validation of PRECIS regional climatic model for climatic parameters rainfall and temperature (maximum and minimum) in Bangladesh for recent year. The specific objectives are as follows:

- To compare PRECIS data with observed climatic data (temperature, rainfall) regarding monthly, seasonal and annual average, maximum and minimum values.
- To determine the biases between observed and PRECIS data.
- To predict global climatic issues such as global warming and shifting of rainfall patterns in wet and dry season from corrected PRECIS data for some selected years.

CHAPTER 2
LITERATURE RIVIEW

2.1 GENERAL

Many researchers have been conducted to assess the performance of PRECIS and acceptability of regional climatic model in impact studies of future climate change in all over the world especially in developing country for climatic parameters. The aim of the study cannot be accomplished without having the proper idea and conception of knowledge about previous researchers and studies. Some of the pioneering works of past studies have been abbreviated here in order to obtain knowledge about the performance of PRECIS and the future predictions of climatic change and its regional effects using regional climatic model for some major influencing climatic parameters such as temperature and rainfall. A gist of some of the study report is described in this chapter.

2.2 HISTORY OF PRECIS IN BANGLADESH

Providing REgional Climates for Impacts Studies (PRECIS) is a regional climate modeling system developed by the Hadley Centre, UK. A training workshop on PRECIS was held on 21- 24 July 2004 in Bhutan. Participants from BUET (Bangladesh University of Engineering & Technology) and SPARRSO (Space Research and Remote Sensing Organization) took part in the said workshop. After that a working group from Bangladesh took part in the informal workshop (24-28 February 2005) on PRECIS at IITM, Pune, India. In the working group participants are from BUET, BMD (Bangladesh Meteorological Department), SPARRSO and SMRC (SAARC Meteorological Research Center). There after PRECIS is installed in PC at BUET. The PC is provided by the Department of Environment (DoE), Ministry of Forest and Environment, the Peoples' Republic of Bangladesh with cooperation of UNDP and DFID. The Department of Physics, BUET updated PRECIS with its latest version 1.5.1 from Hadley Centre and working on it since 2005 besides other modeling activities (Rahman, Mannan and Nessa, 2009)

2.3 REVIEW OF RELATED STUDIES

Islam N. M., Mannan A. M., Devkota P. L., Nessa M. (2005) is showed the validation of PRECIS regional climate model for different lateral boundary conditions (LBCs) data, which are blsula, blsulb, blsulc and era15 in Bangladesh is performed with the surface observational data of rainfall and temperature (maximum and minimum) collected by the Bangladesh Meteorological Department (BMD) at 26 observational sites throughout the country from 1961-1990. It is found that regional analysis provides overestimation of PRECIS values in Bangladesh whereas data extracted at some particular locations provide better performance of PRECIS. Overall, PRECIS can calculate about 92% of surface rainfall in case of blsula. It overestimated rainfall for blsulb and blsulc. Performance of era15 is found much better than other baseline categories. For all baseline categories (bla, blb and blc), the performance of PRECIS is about 90% for rainfall. PRECIS can detect about 96% and 100.3% of maximum and minimum temperature respectively. The merits of PRECIS can be used in predicting rainfall and temperature in Bangladesh using the look-up table proposed in this analysis.

Rahman M. M., Islam N. M., Mannan A. M., Nessa M. (2009) is described Validation and Parameterization of PRECIS scenarios for Bangladesh. The study is employed to generate projections for rainfall and temperature in 2030, 2031, 2050, 2051, 2070 and 2071 in Bangladesh using ECHAM4 SRES A2 emission scenarios as the model input whereas the baseline period (1961-1990). To obtain the projected rainfall and temperature (maximum and minimum), firstly a Look-up table is prepared in reference to the observed data during baseline period 1961-1990. Using the prepared Look-up table PRECIS generated scenarios is validated for 1989, 1990, 2000 and 2001. This work revealed that use of Look-up table facilitates a lot for the validation of PRECIS outputs. The important notice is that in Bangladesh, rainfall during monsoon and post monsoon periods will increase whereas it will remain close to historical amount during dry season. It is found that PRECIS over-performed by only 4.471% in estimating rainfall over Bangladesh. Over the country, rainfall will increase in 2030, 2050 and 2070 respectively in reference to the observed baseline period 1961 to 1990. Maximum temperature will increase during monsoon period and it will decrease in other periods. On the other hand, monthly average minimum temperature will increase in all periods in 2030, 2050 and 2070. Large increase of temperature is the clear indication of global warming. This admirable performance of PRECIS encourages using it for projection of rainfall in Bangladesh. This work decisively disclosed that PRECIS is very much successful for seasonal forecasting of meteorological parameters like rainfall and temperature (maximum and minimum) in Bangladesh.

Islam Nazrul (2009) is conducted the Rainfall and Temperature Scenario for Bangladesh. In this study regional climate model named PRECIS adapted in generating rainfall scenarios for the SAARC (South Asian Association for Regional Cooperation) region. At first, PRECIS generated rainfall scenario is calibrated with ground-based observed rainfall during baseline period (1961-1990) in Bangladesh. The regression coefficients obtained through calibration are utilized for validation of PRECIS simulated rainfall during 2000-2006. The Special Report on Emissions Scenarios (SRES) A2 of ECHAM4 is used as model input. The TRMM (Tropical Rainfall Measuring Mission) version 6 3B42 3-hourly data products are also utilized to understand the distribution of model generated rainfall. It is found that regional analysis provides rainfall overestimation in 2000, 2002, 2003, 2005 and 2006 respectively and underestimation in 2001 and 2004 respectively. On an average, PRECIS overestimated about 4.47% of surface rainfall. Better performance of PRECIS through validation encourages employing it in rainfall forecasting for Bangladesh. In the second step, rainfall and temperature forecast for Bangladesh is experimentally obtained for 2010-2020. This work discloses that the PRECIS simulated rainfall and temperature are not directly useful in application purposes. Without calibration with ground truth data, model outputs are very risky in providing long term rainfall prediction. However, after performing calibration acceptable result is obtained in estimating rainfall in Bangladesh with correlation is 0.90. The monsoon rainfall forecasting approach using downscaling of regional climate model outputs is very new in Bangladesh. This result suggests for extending the work for other SAARC countries in a consecutive research project. Model run with other ensembles and with high horizontal resolution are also under consideration.

Bhaskaran B., Jones R.G., Murphy J.M. and Noguer M. (1996) has made a study for simulations of the Indian summer monsoon using a nested regional climate model, domain size experiments. The purpose of the present study is to establish the impact of domain size on the RCM monsoon simulations. It is described results from simulations of the Indian summer monsoon for 1984, 1985, 1987 and 1988 made with a 50 km regional climate model. The RCM was driven by output from a global atmospheric general circulation model (AGCM) integration for 1979–91 using observed SSTs. RCM simulations were carried out using three alternative domains (RCM1–3). In each case mean precipitation over land points within the monsoon region increases by F20% relative to the AGCM due to stronger vertical motion in the RCMs. This work concludes that the use of a small domain not restricts the ability of the RCM to develop energetic ISOs or mesoscale circulations; hence for most applications it is acceptable to use the RCM3 domain. Accordingly a continuous integration of RCM3 for the period 1979–91 has been run, driven by the AGCM integration used in the present study.

Jones R.G., Noguer M., Hassell D.C. et al (2004) is mention about generating high resolution climate change scenarios using PRÉCIS. The objectives and structure of this study is to introduce the use of Regional Climate Models as a viable tool to generate high-resolution climate change scenarios and to present ways to use PRECIS output for impact assessments. It is showed the application of PRECIS throughout the Southern Africa, over Europe and over the Indian subcontinent. Also explain the Modeling storm surges over the Bay of Bengal and Climate change scenarios and their impact on water resources in southern Africa. In the application on Indian subcontinent and Bangladesh this work is found that the GCM projects a decrease in rainfall whereas the local effect seen in the RCM is actually an increase and the RCM represents the influence of the topography better than GCM.

Islam S.M.K.A, Bhaskaran B. et al (2011) is focused on Domain size experiment using PRECIS regional climate model for Bangladesh. RCM can be one peninsula help to study the regional scale hydrological and eco-system processes. While dealing with RCM simulation, it is essential to determine a suitable domain for that area which can successfully represent the meso-scale processes of that area for any RCM experiment. Larger domain size can cost computation time though they can cover major atmospheric circulation and processes over the area. Therefore, determining optimum domain size for an area of interest is essential and crucial for that region. In this study, experiments were conducted by PRECIS regional climate model on four domains of variable size over a period of 1981 to 1990 using ERA 40 Reanalysis data products. The goal of this study is to identify smallest size of the domain which can substantially reduce computational time and accurately present climate of Bangladesh. It has been found that the smallest domain is able to capture the mean monsoon precipitation pattern over India and Bangladesh. Such information can be helpful to study the future impact of climate change on the magnitude of extreme events such as floods and droughts etc., change of cropping pattern, and impact on livelihood and food security.

Islam N. M., Rafiuddin M., Ahmed A.U., Kolli R.K. (2008) is assessed Calibration of PRECIS in employing future scenarios in Bangladesh. The calibration of rainfall and temperature simulated by PRECIS is performed in Bangladesh with the surface observational data from the Bangladesh Meteorological Department (BMD) for the period 1961–1990. The Climate Research Unit (CRU) data is also used for understanding the performance of the model. The results for the period 1961–1990 are used as a reference to find the variation of PRECIS-projected rainfall and temperature in 2071, in and around Bangladesh, as an example. It is found that grid-to-grid analysis provides overestimation of PRECIS in Bangladesh because of downscaling of observed data when gridded from asymmetric low-density data network of BMD. On the other hand, model data extracted at observational sites provide better performance of PRECIS. The model overestimates rainfall in dry and pre-monsoon periods, whereas it underestimates it in the monsoon period. Overall, PRECIS is found to be able to estimate about 92% of surface rainfall. Model performance in estimating rainfall increases substantially with the increase in the length of time series of datasets. Systematic cold bias is found in simulating the annual scale of the surface temperature. In the annual scale, the model underestimates temperature of about 0.61 °C that varies within a range of +1.45 °C to −3.89 °C in different months. This analysis reveals that rainfall and temperature will be increased in Bangladesh in 2071. The look-up tables proposed in this analysis can be employed in the application of the projected rainfall and temperature in different sectors of the country. These look-up tables are useful only for the calibration of PRECIS simulation results for future climate projection for Bangladesh.

Ferdousi N., Islam N. M., Rahman A. M., Ahsan N. M., Abdullah A.M.S. (2008) is studied on summer monsoon rainfall using Regional Climate Model PRECIS for the SAARC domain at SMRC to run for SRES A2 and B1 scenarios during 1961-2100. In this work PRECIS rainfall is calibrated with ground-based rainfall measurement at 27 observational sites throughout Bangladesh. The model is again run for 2000-2006 to carryout validation work. It is found that PRECIS over-performed in estimating rainfall over Bangladesh. This excellent performance of PRECIS encourages using it for projection of rainfall in the SAARC region. Ii is important to note that without calibration PRECIS generated rainfall scenarios are unrealistic with observational rainfall pattern. Calibration makes the model outputs more realistic with the historical rainfall blueprint. Through this research, the rainfall forecast for the SAARC domain in 2009 is experimentally prepared. The ultimate goal is post seasonal rainfall forecast for entire SAARC region in the SMRC website Homepage. The forecasted rainfall will be benefited to the planners of the SAARC member states to utilize in their application in different sectors.

Rajib A. M. and Rahman M. M.(2012) is deal with a Comprehensive Modeling Study on Regional Climate Model Application for Regional Warming Projections in Monthly Resolutions under IPCC A1B Scenario. This paper features the development of future surface temperature projections for Bangladesh on monthly resolution for each year from 2011 to 2100 applying PRECIS) and it explains in detail the modeling processes including the model features, domain size selection, bias identification as well as construction of change field for the concerned climatic variable, in this case, surface temperature. it was found to perform reasonably well in simulating future surface temperature of Bangladesh. The linear regression between observed and model simulated results of monthly average temperatures, within the 30-year period from 1971 to 2000, gives a high correlation of 0.93. The applied change field in average annual temperature shows only 0.5°C – 1°C deviation from the observed values over the period from 2005 to 2008. Eventually, from the projected average temperature change during the years 1971–2000, it is apparent that warming in Bangladesh prevails invariably every month, which might eventually result in an average annual increase of 4 °C by the year 2100. Calculated anomalies in country-average annual temperature mostly remain on the positive side throughout the period of 2071–2100 indicating an overall up-shift. Apart from these quantitative analyses of temporal changes of temperature, this paper also illustrates their spatial distribution with a view to identify the most vulnerable zones under consequent warming through future times.

CHAPTER 3
METHODOLOGY

3.1 GENERAL

Intensity of rainfalls and temperature in Bangladesh depends on period and location. About 2%, 20%, 62% and 16% of the annual rainfall (2200 mm) in Bangladesh occurs during winter (DJF), pre-monsoon (MAM), monsoon (JJAS) and post-monsoon (ON) periods respectively (Islam and Uyeda, 2005). North-eastern and south-eastern parts of the country are heavy rainfall regions compared to western parts of the country (Rahman, Mannan and Nessa, 2009). On the other hand some of the major dimensions of climate change include increase in surface temperature, longer spells of droughts in significant portions of Bangladesh, associated higher evapo-transpiration rates, and so on. It is therefore essential to comprehend the future possible scenario of climate change in terms of global warming (Rajib and Rahman, 2012). Comparison of PRECIS data with observed climatic data (temperature, rainfall) regarding monthly, seasonal and annual average, maximum and minimum values and determination of the biases between observed and PRECIS data are the objectives of this study. Also the prediction of global warming and shifting of rainfall patterns in wet and dry season is observed.

3.2 STUDY AREA

This study focuses on climatic parameter rainfall and temperature (maximum and minimum) in generating climatic information for seven divisions of Bangladesh.

Bangladesh is situated in the north-east of South Asia. The Padma, the Meghna and the Jamuna flowing from the west, north and southeast respectively have together formed the huge delta. Much of the country's land area has been built up from the major rivers. It is guarded by the Himalayas in the north, the Bay of Bengal in the south, the gangetic plains of Indian West Bengal, and the almost impassable forest of Myanmar and India to the east.

In Bangladesh Summer monsoon depressions are coming from south east parts of India towards the north east of Bangladesh. This depression causes major rainfall during the monsoon season (June to September) on the country and over the Ganges-Brahmaputra-Meghna (GBM) basins. Major floods of Bangladesh are mainly caused by heavy precipitations over the GBM basins during monsoon season. Monsoon rainfall generates runoff and finally conveys as flood water towards Bay of Bengal through Bangladesh by the three major river systems: the Ganges, Brahmaputra and Meghna.

Tropical thunder storms occurred during the pre-monsoon season (March-May) in the central parts of Bangladesh. Every year many sudden devastations occur which takes lives and damages houses, roads etc. due to pre monsoon thunderstorms. Post monsoon (October to November) tropical thunder storms which is commonly known as Tropical Cyclones or Cyclones are formed in the Bay of Bengal, the largest bay in the world, forms the northeastern part of the Indian Ocean. Cyclones are usually characterized by inward spiraling winds that rotate counter clockwise in the Northern Hemisphere and clockwise in the Southern Hemisphere of the Earth. Coastal districts of Bangladesh faced heavy rainfall as an early impact of the major cyclone (above category 3). When cyclone hit on the coastal areas of Bangladesh, the damage in Bangladesh becomes extensive, including tin shacks flattened, houses and schools blown away and enormous tree damage.

Winter (November-February) western disturbance causes drought in the north-west part of Bangladesh and North part of India. Also, pre-monsoon (March-May) disturbance causes heavy rainfall and Flash floods in the north-east part of Bangladesh. Drought occurs in the north-west region receives consistently below average precipitation. It effects substantially on the ecosystem and agriculture of the affected region. Flash flood causes by heavy rain associated with a storm, hurricane, or tropical storm. What makes flash floods most dangerous is their sudden nature with no protection against being swept away causes human fatality.

Bangladesh is one of the largest deltas of the world experienced a subtropical monsoon climate characterized by wide seasonal variations in rainfall and moderately warm temperature. So the most important climatic parameter rainfall and temperature (maximum and minimum) has been chosen for this work and seven metrological stations are selected from the divisions of Bangladesh which nearly cover all part of the country as follows. Figure 1 is showed the study area of this project.

- Dhaka (Central zone)
- Khulna (South-Western zone)
- Chittagong (South-Eastern zone)
- Rangpur (North-Western zone)
- Sylhet (North-Eastern zone)
- Rajshahi (Western zone) and
- Barisal (Southern zone) .

Figure 1 Position of seven observational sites throughout Bangladesh (Bangladesh Division)

3.3 DATA COLLECTION

3.3.1 BMD DATA COLLECTION

The required observed climatic data such as rainfall and temperature (maximum and minimum) for the purpose of the study have been collected from Bangladesh Meteorological Department (BMD) at seven observational locations throughout the country for recent twenty one year 1990 to 2010. All the data are received in soft format. The summary of available observed monthly climatic data is given in Appendix A, Appendix B and Appendix C. Bangladesh is divided into seven major administrative regions called divisions. Each division is named after the major city within its jurisdiction that serves as the administrative capital of that division. The necessary data have been collected from Bangladesh Meteorological Department at these seven divisions as stations throughout the country. The station information is showed in Table 1.

Table 1: Station Information

Serial No	**Station Name**	**Station No (from BMD)**	**Direction**	**Station No (from PRECIS)**
1	Dhaka	923	Centre (C)	2064
2	Khulna	947	Southwest (S-W)	2278
3	Chittagong	977	Southeast (S-E)	2355
4	Rangpur	859	Northwest (N-W)	1773
5	Sylhet	891	Northeast (N-E)	1923
6	Rajshahi	895	West (W)	1988
7	Barisal	950	South (S)	2279

3.3.2 BANGLADESH METEOROLOGICAL DEPARTMENT

Bangladesh Meteorological Department (BMD) also known as Abohawa Office (Weather Office) is the national meteorological organization of Bangladesh, working under Ministry of Defense of the Government of Bangladesh. It is responsible for maintaining the network of surface and upper air observatories, radar and satellite stations, agro meteorological observatories, geomagnetic and seismological observatories and meteorological telecommunication system of Bangladesh.

The functions of BMD include to observe and collect meteorological information for the entire country, to issue early warnings on weather, to provide weather forecasts and climate services and warnings to the general public and to Government and private sector users including Agriculture, Shipping, Environment, Civil aviation authority, Water resources and disaster management agencies. Daily weather forecast, marine forecasts, divisional weather forecast, one month forecast, rainfall forecast, special weather bulletin, inland river port warming etc. can be found at BMD official website. The headquarter of BMD located in Dhaka with two regional centers, Storm Warning Centre Dhaka and Meteorological & Geo-Physical Centre Chittagong.

Rainfall

Rainfall data is measured by Manual Rain gauge and Self Recoding Rain gauge by BMD. The manual rain gauge consists of a funnel attached to a graduated cylinder that fit into larger container. If the water overflows from the graduated cylinder the outside container will catch it. So when it is measured, the cylinder will be measured and then the excess will be put in another cylinder and measured.

Figure: 2.1 Rain gauges used to measure the amount of rainfall manually

Figure: 2.2 Rain gauges used to measure the amount of rainfall automatically

A metal pipe is attached to the container and can be adjusted to ensure the rain gauge is level. This pipe then fits over a metal rod that has been in the ground. The self recording or tipping bucket rain gauge consists of a large copper cylinder set into the ground. At the top of the cylinder is a funnel that collects and channels the precipitation. Self recording rain gauge measures rainfall by means of electromagnetic signal. Rainfall data is available for seven stations of Bangladesh for the time period of 1990 to 2010. Rainfall is measured on daily basis and unit is millimeter. The summery of rainfall data is shown in appendix A.

Temperature

BMD is used three types of thermometer for temperature measurement. These are i) dry bulb thermometer ii) wet bulb thermometer iii) maximum thermometer and iv) minimum thermometer for the measurement of maximum and minimum temperature of the day, to determine the daily average temperature dry bulb thermometer is used. Maximum and minimum thermometers are used for determining daily maximum and minimum temperature. Wet bulb thermometer is required for determining relative humidity.

Figure 2.3 Dry**,** Wet and Maximum, Minimum Thermometer

The dry bulb temperature is the temperature of air measured by thermometer. The wet bulb temperature is a type of temperature measurement usually air and water vapor. The maximum thermometer is measure maximum temperature of the day. The minimum thermometer is measure minimum temperature of the day. Temperature (maximum and minimum) data have been collected for seven stations of Bangladesh for the time period of 1990 to 2010. Temperature is measured on daily basis and unit is degree centigrade. The summery of monthly Temperature (maximum and minimum) data is shown in Appendix B, Appendix C**.**

3.3.3 PRECIS DATA COLLECTION

Again data is gathered for climatic parameters rainfall and temperature (maximum and minimum) from PRECIS outputs from Institute of Water and Flood Management, Bangladesh University of Engineering & Technology. All the data are received in soft format at seven observational locations throughout the country for the year 1990 to 2050. PRECIS is installed in PC at BUET. BUET updated PRECIS with its latest version 1.5.1 from Hadley Centre and working on it since 2005 besides other modeling activities. PRECIS was run on a 50 km horizontal grid-spacing under the Intergovernmental Panel on Climate Change (IPCC) A1B scenario resembling a future world of very rapid economic growth, balanced across energy sources with clean and resource-efficient technology warming (Rajib and Rahman, 2012 and Nakicenovic et al, 2000).

3.3.4 EMISSIONS SCENARIOS

We will never know exactly how anthropogenic emissions will change in the future. The Special Report on Emissions Scenarios (SRES) was a report prepared by the Intergovernmental Panel on Climate Change (IPCC) for the Third Assessment Report (TAR) in 2001, on future emission scenarios to be used for driving global circulation models to develop climate change scenarios. Emission scenarios are plausible representations of future emissions of substances that are radioactively active (i.e. greenhouse gases) or which can affect constituents which are radioactively active (e.g. sulphur dioxide which forms sulphate aerosols). These are based on a coherent and internally consistent set of assumptions about driving forces (such as demographic and socio-economic development and technological change) and their key relationships.

The SRES scenario set comprises four scenario families: A1, A2, B1 and B2. The scenarios within each family follow the same picture of world development which is showed in Figure 2. The SRES four scenarios are explained here.

(i) **A1** – the A1 scenarios are of a more integrated world. The A1 family of scenarios is characterized by: a) Rapid economic growth, b) A global population that reaches 9 billion in 2050 and then gradually declines, c) The quick spread of new and efficient technologies, d) A convergent world - income and way of life converge between regions and extensive social and cultural interactions worldwide. There are subsets to the A1 family based on their technological emphasis: 1) A1FI - An emphasis on fossil-fuels, 2) A1B - A balanced emphasis on all energy sources, 3) A1T - Emphasis on non-fossil energy sources.

(ii) **A2**- the A2 scenarios are of a more divided world. The A2 family of scenarios is characterized by a) A world of independently operating, self-reliant nations, b) Continuously increasing population c) Regionally oriented economic development, d) Slower and more fragmented technological changes and improvements to per capita income.

(iii) **B1-** The B1 scenarios are of a world more integrated, and more ecologically friendly. The B1 scenarios are characterized by a) Rapid economic growth as in A1, but with rapid changes towards a service and information economy, b) Population rising to 9 billion in 2050 and then declining as in A1, c) Reductions in material intensity and the introduction of clean and resource efficient technologies, d) An emphasis on global solutions to economic, social and environmental stability.

(iv) **B2-** The B2 scenarios are of a world more divided, but more ecologically friendly. The B2 scenarios are characterized by a) Continuously increasing population, but at a slower rate than in A2, b) Emphasis on local rather than global solutions to economic, social and environmental stability, c) Intermediate levels of economic development, d) Less rapid and more fragmented technological change than in A1 and B1 (Jones et al, 2004).

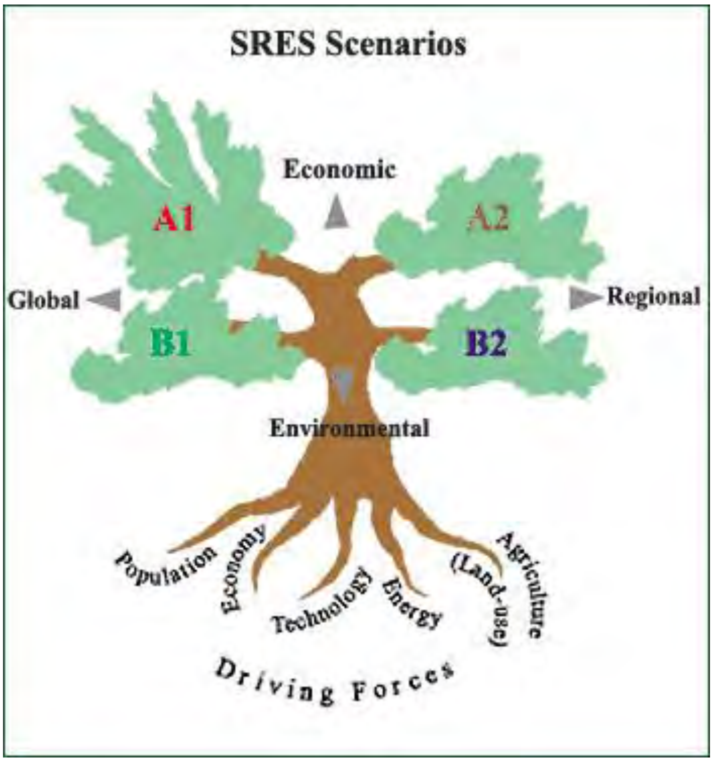

Figure 3: SRES scenario

3.3.5 PRECIS MODEL DESCRIPTION

Timely access to detailed climate change scenarios is particularly vital in developing countries, where economic stresses are likely to increase vulnerability to potentially damaging impacts of climate change. In order to help address this need the Hadley Centre of United Kingdom has developed PRECIS (Providing REgional Climates for Impacts Studies), a regional climate modeling system which can be run on a cheap, easily available personal computer.

The aim of PRECIS is to allow developing countries, or groups of developing countries, to generate their own national scenarios of climate change for use in impacts studies. This will allow transfers of technology and ownership resulting in much more timely and effective dissemination of expertise and awareness than if results are simply handed out from models run in developed countries. In addition, countries using PRECIS are in a better position to validate the model using their own observations. An important aspect of PRECIS is the availability of training and training materials explaining its role and how to make the best use of it. One of the main materials is the technical manual which discusses the steps needed to install, configure and use of PRECIS. It is designed both to guide users of PRECIS and as resource for the PRECIS training course.

PRECIS is a hydrostatic, primitive equation grid point model containing 19 levels described by a hybrid vertical coordinate. The Hadley Centre, under contract from the United Kingdom government departments DEFRA and DFID and from the UNDP, has developed PC-based PRECIS to provide non-Annex I Parties with a practical tool to make their own predictions of national patterns of climate change and hence assess their vulnerability. PRECIS only works on 32-bit Intel (x86) compatible Linux based systems, and not under Microsoft Windows, and not on other Unix systems. PRECIS only run on a single processor, and cannot be configured for multi-processor running. It may be possible however, to run concurrent jobs on a multi-processor system. To run PRECIS at least 512MB of memory is needed, 768MB is recommended. Higher RAM gives a small increase in performance. At least 100GB of disk space is required. PRECIS works under a single or dual disk system. On a dual disk system, one disk should be a dedicated data disk. Some form of off-line storage is needed both to supply the input data that drives PRECIS and to archive its output data. Either DLT or DAT tapes are recommended; hard disks can also be used, but are less robust and more difficult to duplicate.

The PRECIS RCM is able to adhere to one of two types of calendar, the standard Gregorian calendar or an artificial calendar consisting of 360 days per year. The choice of calendar is determined by the calendar implicit in the driving data, which in turn is determined by the choice of scenario. The choice of calendar is made automatically by PRECIS and is displayed in the GUI. The RCM's clock is always based on Universal Time (UTC), denoted Z e.g. 0300Z. The 360-day calendar divides a year up into 12 months, each of 30 days in length. It is used in long climate simulations for internal organizational convenience. The introduced distortions of the seasonal cycle are minimized by altering the average date of perihelion, shifting it from 2.5 days after the beginning of the year (0Z 1st January) to 3.2 days after the beginning of the year. This ensures that monthly and seasonal mean values diagnosed from the RCM are comparable with their equivalent observed quantities.

The PRECIS RCM is able to run at two different horizontal resolutions: 0.44°×0.44° and 0.22°×0.22°, giving grid boxes of approximately 50km×50km and 25km×25km respectively. Whilst more realistic land-sea mask topography is expected at 25km resolution, the time taken to complete a simulation is approximately six times longer than for a 50km resolution run covering the same area. Two-thirds of this increase comes from the fourfold increase in the number of grid points and the rest from a halving of the time step used in solving the dynamical equations. In this case, the time step associated with the physical parameterizations in the model remains the same (five minutes) for both resolutions. This both reduces the cost of the high resolution version of the PRECIS RCM and also ensures that the influence of possible time step dependencies in these parameterizations is removed. PRECIS is made freely available for use by scientists of developing countries involved in vulnerability and adaptation studies (Ferdousi, Islam et al, 2008).

3.4 PROCEDURE OF DATA ANALYSIS

3.4.1 MONTHLY, SEASONAL AND ANNUAL DATA ANALYSIS PROCEDURE

The collected data are not continuous for all years and all locations. There are many data missing in a month or sometimes many months in a year. Also the observation network density is not well enough, somewhere observation sites are located at about 25 km apart whereas somewhere these are at about 145 km. When the coverage of Bangladesh is gridded say 0.5° by 0.5° as shown, there are many grids which do not contain any observation site. For proper analysis procedure it is important to find out the exact validation of PRECIS in Bangladesh. Taking this in mind, analysis has been done on grid-to-grid basis and point-to-point basis, which are explained below. For this reason data will be checked and processed to convert it into daily average time series data by using spreadsheet.

Comparison of rainfall and temperature analyzed by both observation and model are performed month-to-month, season-to-season, year-to-year by using different chart and bar diagram as MS Excel and MS Access. For monthly variation of climatic parameters such as rainfall and temperature (maximum and minimum) has been computed from daily time series data which is averaged for all seven stations and all twenty one year of 1990 to 2010 for observed and model data using statistical technique.

For seasonal variation the whole year is divided into four season based on the rainfall and temperature variation of Bangladesh and also based on agricultural products. The season is named by winter as December, January and February (DJF), pre-monsoon as March, April and May (MAM) periods, monsoon as June, July, August and September (JJAS) and post-monsoon as October and November (ON). For winter, pre-monsoon, monsoon and post-monsoon variation of climatic parameters such as rainfall and temperature (maximum and minimum) has been determined from monthly time series data for each station and is averaged for all twenty one year of 1990 to 2010 for observed and model data using statistical technique as different chart and bar diagram in MS Excel and MS Access.

For comparison of each twenty one year PRECIS data with observed data of climatic parameters such as rainfall and temperature (maximum and minimum) has been computed from monthly time series data averaged for country which is obtained by taking average from all seven sites data using statistical technique with chart and graph in suitable format. Climatic parameter biases are defined for seven station as

Bias = PRECIS model value – observational value.

By this equation regional positive and negative value is found. Similarly seasonal and annual biases are calculated by this equation and presented with graph for this study.

Statistical analysis is a component of data analysis, refers to a collection of methods used to process large amounts of data (particularly useful when dealing with noisy data) and scrutinizing every single data sample in a set of items. Processing of data has been done for calculating monthly, seasonal and annual mean rainfall and maximum and minimum temperature for this study. For finding monthly, seasonal and annual data to compare model value and observational value the equation of statistical analysis is used.

3.4.2 FUTURE MODEL DATA ANALYSIS PROCEDURE

Taking the aim of bias determination of observed and PRECIS data, a Look-up Table has been prepared. The reason is that model generated parameters are not free from uncertainties. Even uncertainties are there, till to date, there are no alternatives to predict meteorological variables in advance without any help from model. It is to be remembering that meteorological parameters are so complex and completely natural. There is no way to control the meteorological parameters. Therefore, climate models are used as one of the prediction tools with considering the limitations. There is a substantial difference between rainfall or temperature amounts obtained from both PRECIS and observed data sources in different months. It does not mean that we cannot use model outputs because two different tools never can measure the same (Rahman, Islam et al, 2009). From this point of view, we have to find the suitable way of utilizing model simulated outputs and preparation of Look-up table is one of the techniques to make useful the model generated scenarios in application purposes which are satisfactorily disclose throughout this research. Therefore, preparation of Look-up table for rainfall and temperature are very essential, which are obtained through this project. The equation of Look-up table for rainfall is obtained averages from 1990 to 2010 and all stations for observed and corrected model data.

Regression equation

A regression equation is used in statistics to find out what relationship, if any, exists between a set of variables. Regression equations are the equations of relationship among a set of data. This is extremely useful to make predictions from the data, either future predictions or indications of past behavior. There are several types of regression equations. Some of the more common include exponential and linear regression.

Linear regression

Linear regression attempts to model the relationship between two variables by fitting a linear equation to observational data. One variable is considered to be an explanatory variable, and the others are considered to be dependent variable. The general linear regression equation has an equation of the form as

$$y = mx + c$$

Where x is the explanatory variables and y is the dependent variable. The gradient/slope of the line is m and c is the intercept/constant (the value of y when x = 0). Statistically, regression procedure is utilized to calibrate one unknown parameter in reference to the known one.

Linear regression equation for rainfall projection

For the estimation of projected rainfall from PRECIS model generated future scenarios, the regression equation for rainfall is proposed below:

$$RFprojection = m_{RF}\ RFmodel + C_{RF}$$

Where RFprojection is the rainfall to project, m_{RF} is the slope for rainfall, RFmodel is the rainfall model generated values for year 2015, 2025, 2035, 2045 and 2050 and C_{RF} is a constant value for rainfall. m_{RF} and C_{RF} values for individual month at different locations in Bangladesh for 1990-2010 are shown in Look-up table 4.

Linear regression equation for temperature projection

For the estimation of projected maximum temperature from PRECIS model generated future scenarios, the regression equation for maximum temperature is proposed below:

$$TXprojection = m_{TX}\ TXmodel + C_{TX}$$

Where TXprojection is the maximum temperature to project, m_{TX} is the slope for maximum temperature, TXmodel is the maximum temperature model generated values for year 2015, 2025, 2035, 2045 and 2050 and C_{TX} is a constant value for maximum temperature. m_{TX} and C_{TX} values for individual month at different locations in Bangladesh for 1990-2010 are shown in Look-up table 7 .

For the estimation of projected minimum temperature from PRECIS model generated future scenarios, the regression equation for minimum temperature is proposed below:

$$TNprojection = m_{TN}\ TNmodel + C_{TN}$$

Where TNprojection is the minimum temperature to project, m_{TN} is the slope for minimum temperature, TNmodel is the minimum temperature model generated values for year 2015, 2025, 2035, 2045 and 2050 and C_{TN} is a constant value for minimum temperature. m_{TN} and C_{TN} values for individual month at different locations in Bangladesh for 1990-2010 are shown in Look-up table 8 .

CHAPTER 4
RESULTS AND DISCUSSION

4.1 GENERAL

The required data has been collected from Bangladesh Meteorological Department (BMD) and PRECIS output at seven observational sites throughout the country as shown in Figure 4.1. The coverage of Bangladesh is gridded say 0.5º by 0.5º as shown in Figure 4.2; there are many grids which do not contain any observation site.

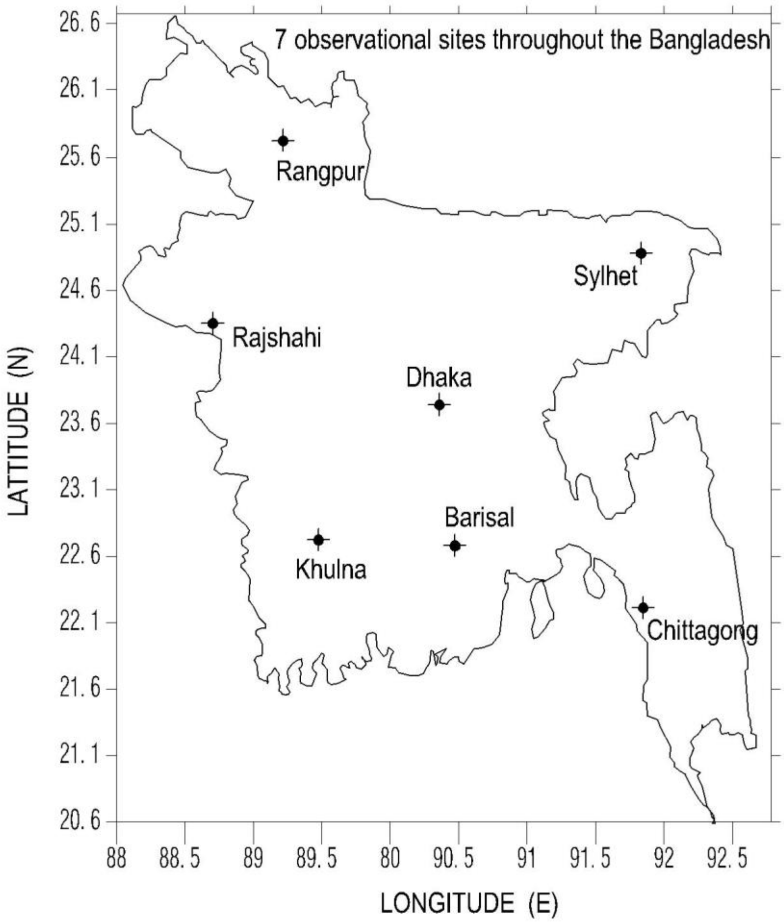

Figure 4.1: Seven observational sites throughout the country with location point

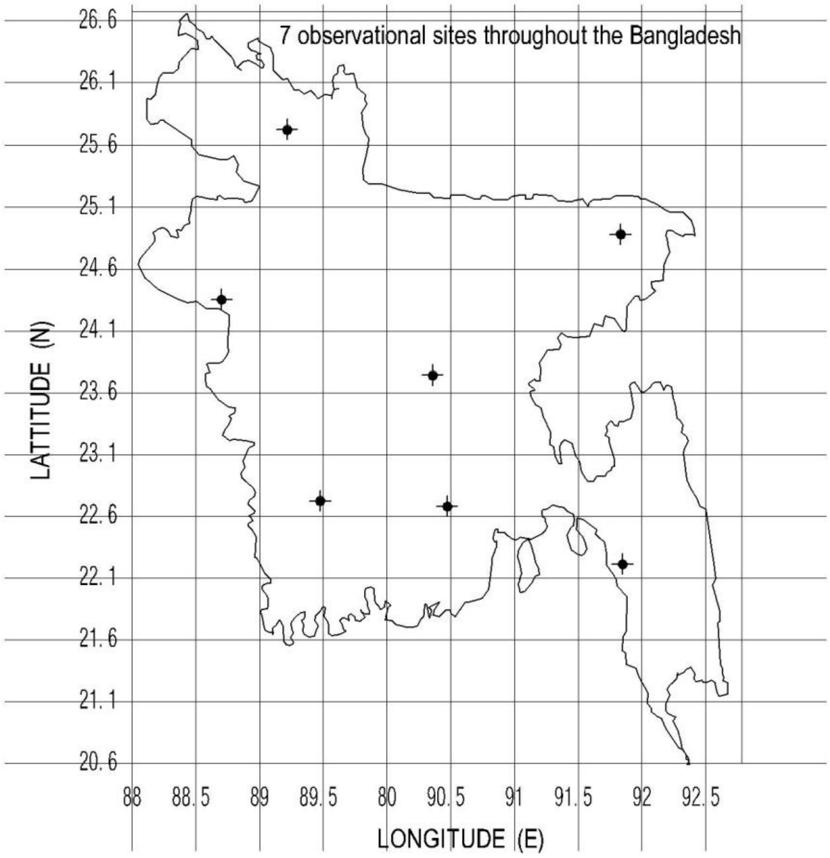

Figure 4.2: Seven observational sites throughout the country with 0.5º by 0.5º grid

4.2 ASSESSMENT OF RAINFALL

Rainfall is one of the most important climate parameters; especially summer monsoon rainfall, which controls the socio-economy of Bangladesh. The rainfall obtained from PRECIS model data for A1B scenario and observed data are presented and discussed in this section.

4.2.1 MONTHLY RAINFALL

Rainfall in Bangladesh is a much localized phenomena and point-to-point analysis gives opportunity to obtain the exact amount which is to be added or subtracted to the model simulated value to obtain the predicted amount at a particular location. Daily rainfall data of

March, 2002 at Chittagong region are tabulated in Table 2. The daily average observed rainfall at 28th March is found 36 mm but the 30 days monthly average value is 2.3 mm, on the other hand the daily average PRECIS rainfall at 11th March is found 1.3 mm but the 30 days monthly average value is 0.2 mm. All observed and PRECIS daily data are calculated by this procedure and monthly average values are found.

Table 2: Daily rainfall data of March, 2002 at Chittagong region

Date	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	25	26	27	28	29	30	**Avg**
Observed Data	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	7	25	1.0	0	**36**	1.0	0	**2.3**
PRECIS Data	0.06	0	0	0	0.1	0.2	0.5	0.9	0.4	0.5	**1.3**	0	0.1	0	0.1	0.1	0.5	0.4	0.3	0.4	0.1	0	0	0	0	0	0	0	0	0	**0.2**

To obtain the overall monthly validation, comparison of monthly rainfall obtained from PRECIS and observations are shown in Figure 4.3 considering values from 7 selected regions over Bangladesh and averaged for the period 1990–2010 in mm/day. The PRECIS model overestimates rainfall during February to June. During July to October, it underestimates rainfall. After that it overestimates rainfall again during November. In the months January and December, the PRECIS model estimates are almost closer to the observed rainfall. The peak value of rainfall is 14.9 mm/day in June obtained from PRECIS and 15.6 mm/day in July obtained from observed data.

Again Comparison of monthly rainfall obtained from PRECIS and observations at Dhaka region are shown in Figure 4.4. The PRECIS model overestimates rainfall during April to June. In the months March and December, the PRECIS model underestimates rainfall slightly.

To obtain the exact validation at a particular region, comparison of regional rainfall in March, May, July and November obtained from PRECIS and observations for the years between

1990-2010 are shown in Figure 4.5.1 to Figure 4.5.4. In Figure 4.5.3 it is found that the observed values are almost the double of the PRECIS model simulated values at the northeastern part (Sylhet) and southeastern part (Chittagong). The rainfall patterns of observed data are nearly similar to the PRECIS model simulated rainfall at the centre part (Dhaka) whereas patterns are different in the northwestern part (Rangpur) and southwestern part (Khulna).

From Figure 4.3 and 4.4, it is seen that the PRECIS model considerably overestimates and underestimates rainfall in June and September respectively at Dhaka region (Figure 4.4) than the country average values (Figure 4.3). The PRECIS model slightly overestimates rainfall in March at all over the country as shown in Figure 4.3 but the PRECIS model underestimates rainfall in March at Dhaka region as shown in Figure 4.4.

On the other hand, from the Figure 4.3 and Figure 4.5.3 it is found that the peak value of rainfall obtained from PRECIS is 17.7 mm/day in July at Barishal region whereas 14.2 mm/day in July averages for all regions. PRECIS monthly rainfall average for all regions are more close to observed values than the PRECIS monthly rainfall for a specific region.

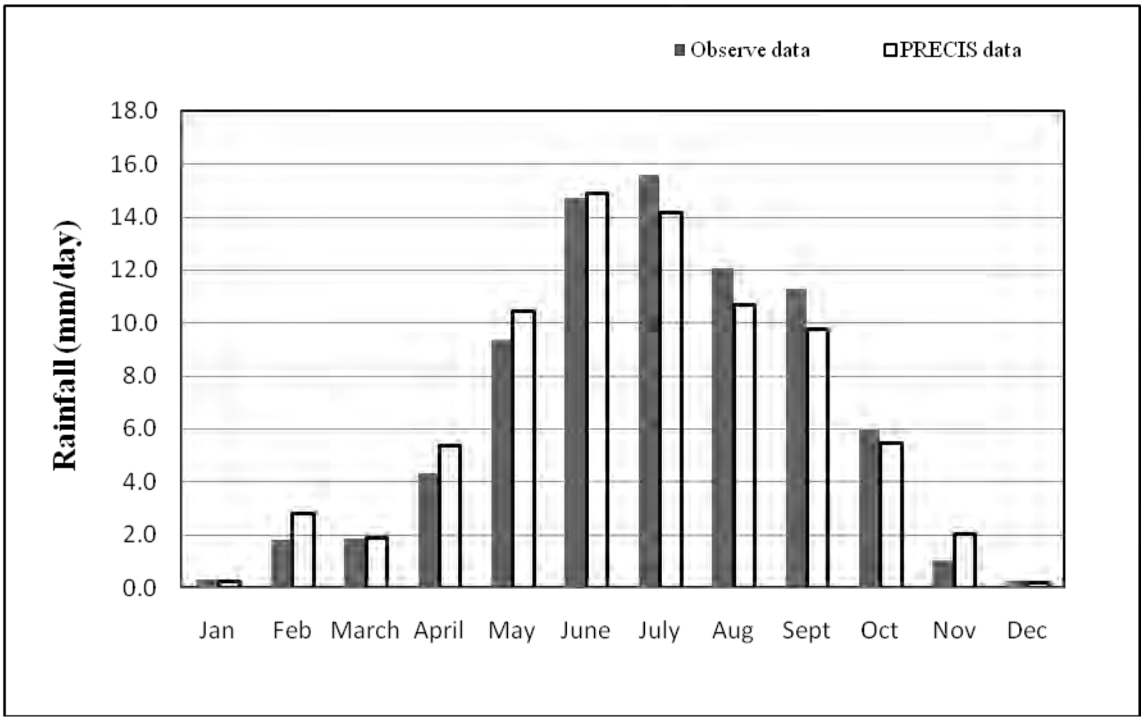

Figure 4.3 Comparison of monthly rainfall obtained from PRECIS and observations

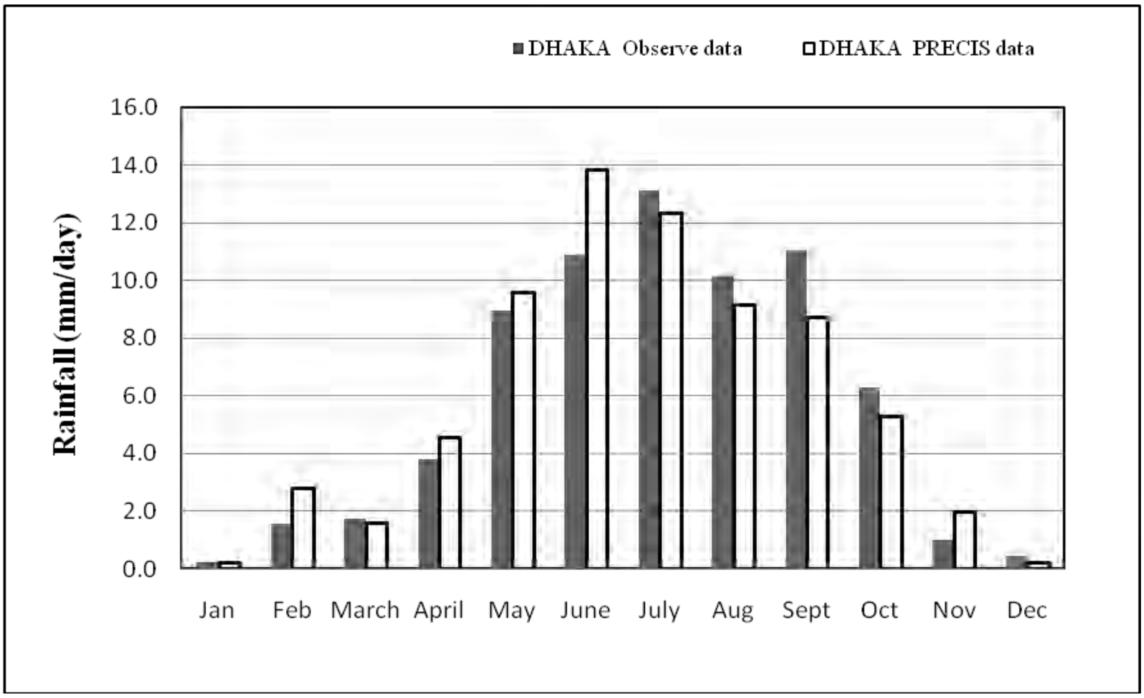

Figure 4.4 Comparison of monthly rainfall obtained from PRECIS and observations at Dhaka region

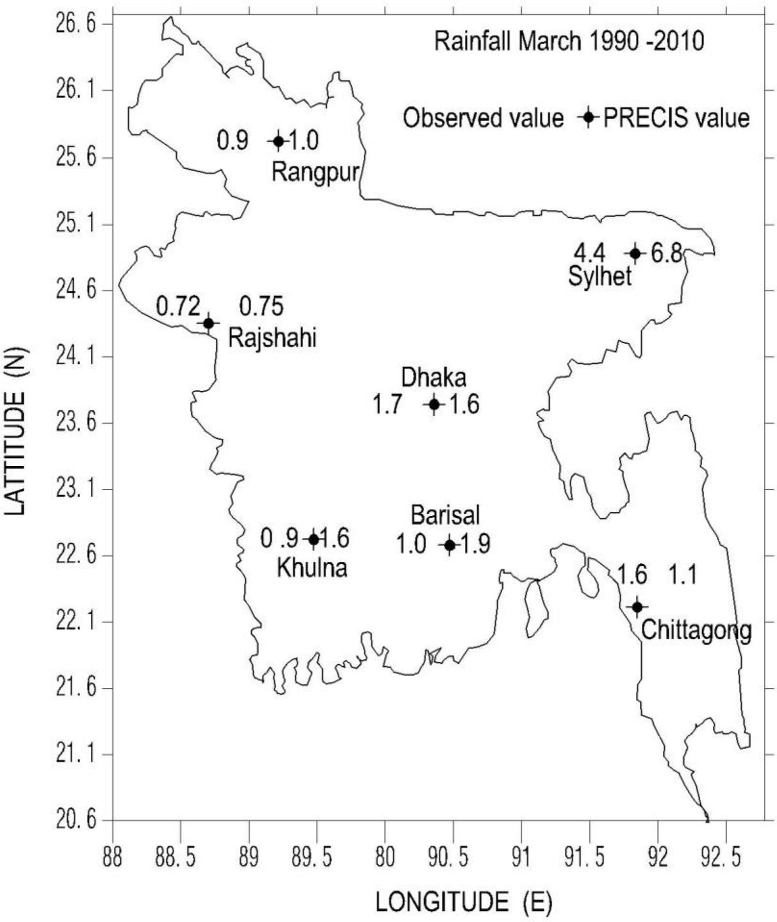

Figure 4.5.1 Comparison of regional rainfall in March obtained from PRECIS and observations

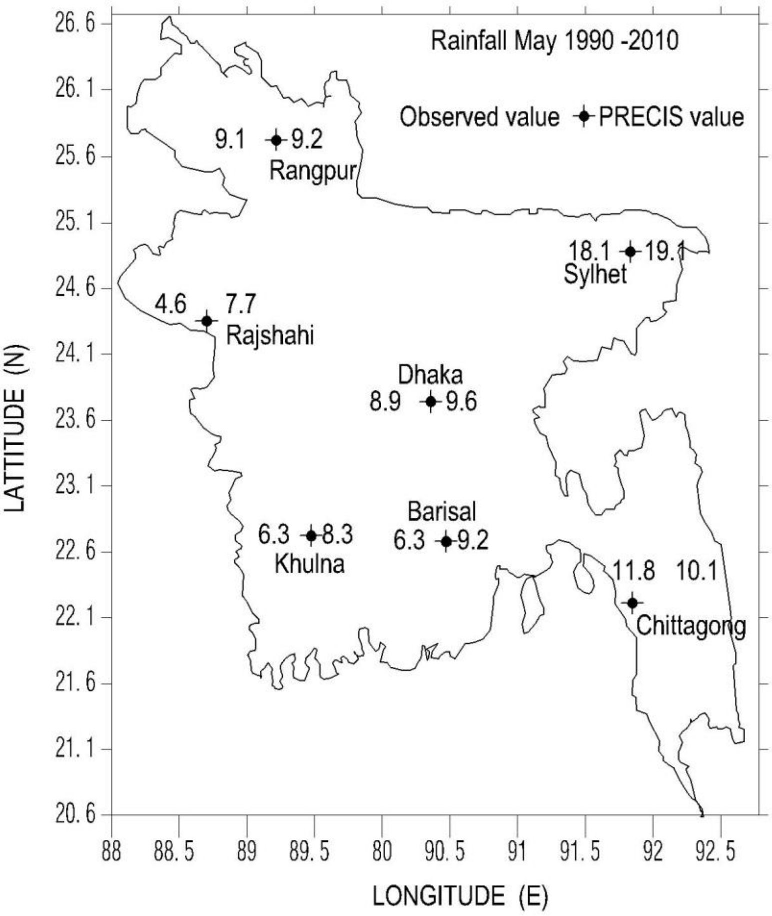

Figure 4.5.2 Comparison of regional rainfall in May obtained from PRECIS and observations

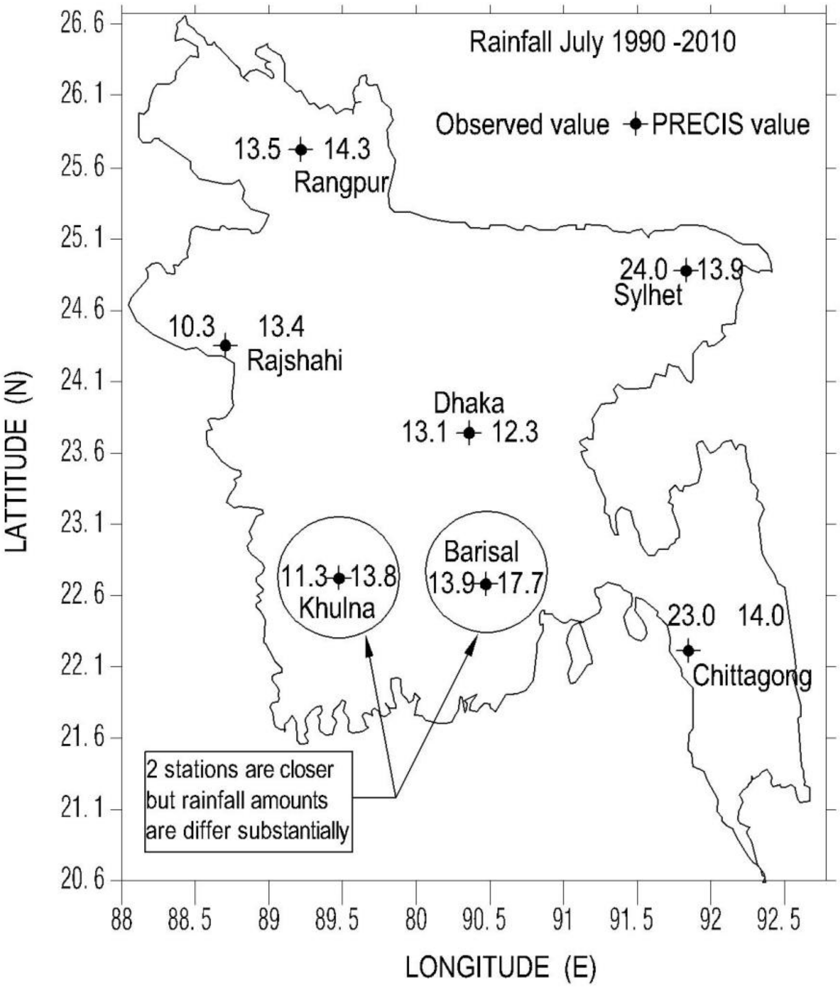

Figure 4.5.3 Comparison of regional rainfall in July obtained from PRECIS and observations

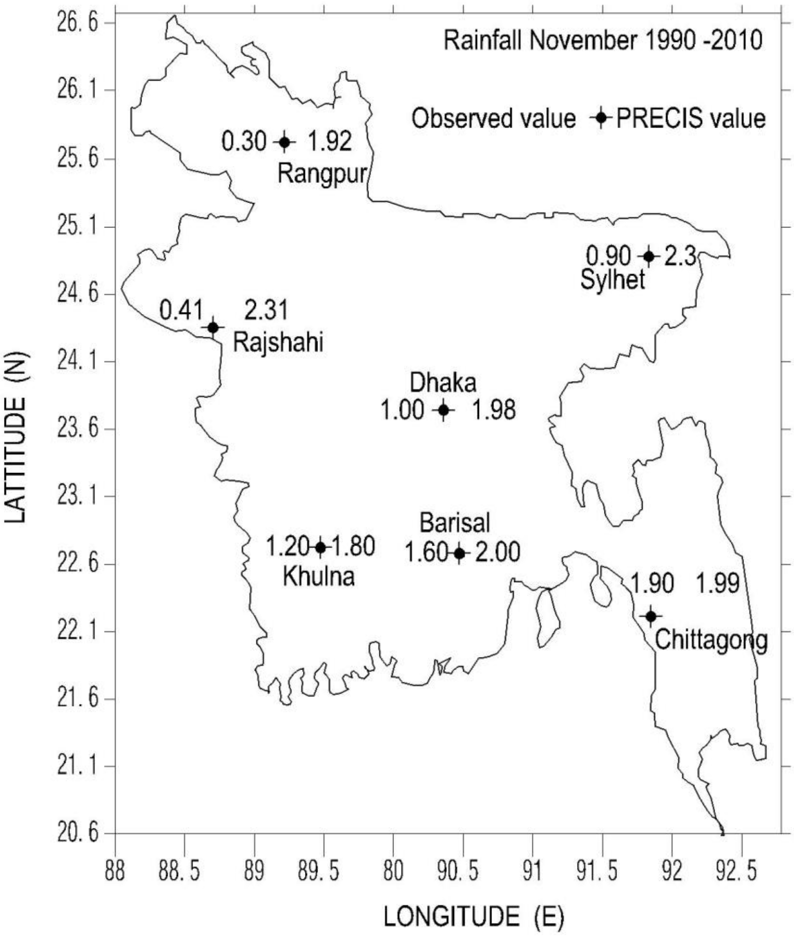

Figure 4.5.4 Comparison of regional rainfall in November obtained from PRECIS and observations

4.2.2 SEASONAL RAINFALL

The characteristics of precipitation systems in Bangladesh (BD) are different in different seasons whereas the model uses the same cloud parameterization for the entire year. The rainfall in different seasons at different regions over Bangladesh is tabulated in Table 3. It can be seen that the rainfall observed values are more close to PRECIS model values in Winter (DJF) periods then the monsoon (JJAS) and pre-monsoon (MAM) period and the value is close in post-monsoon (ON) periods. During post-monsoon period, rainfall is underestimated by PRECIS in the southern and southeastern regions of the country whereas overestimated in all other regions of the country; but overall for BD, it is overestimated by PRECIS in post-monsoon period. One can find large differences at a particular region during monsoon period such as at southeastern zone the PRECIS model underestimates as 4.84 mm/day whereas the model overestimates as 2.47 mm/day at southern zone.

Table 3: Rainfall in different seasons at different regions over Bangladesh

		Rainfall (mm/day) averages from 1990-2010								
		Dhaka (C)	Khulna (S-W)	Chittag (S-E)	Rangpur (N-W)	Sylhet (N-E)	Rajshahi (W)	Barishal (S)	BD	BD seasonal bias
DJF (winter)	observed	0.73	1.09	0.84	0.41	1.10	0.45	0.79	0.775	
	PRECIS	1.09	1.08	1.13	1.01	1.22	0.99	1.08	1.086	0.31
MAM (pre Monsoon)	observed	4.81	3.31	5.69	4.76	11.54	2.26	3.76	5.16	
	PRECIS	5.26	4.51	5.39	4.88	12.11	4.23	4.93	5.90	0.74
JJAS (monsoon)	observed	11.31	10.26	17.00	13.04	21.56	9.05	11.72	13.42	
	PRECIS	11.02	11.39	12.15	12.82	13.06	11.52	14.70	12.38	-1.04
ON (post monsoon)	observed	3.62	3.09	4.57	3.60	3.37	2.21	4.03	3.50	
	PRECIS	3.63	3.36	3.66	3.77	4.54	3.47	3.87	3.76	0.26

Comparison of seasonal rainfall obtained from PRECIS and observations are shown in Figure 4.6 considering values from seven selected regions over Bangladesh and averaged for the period 1990–2010 in mm/day. The PRECIS model underestimates rainfall during monsoon period whereas during pre-monsoon and winter periods it overestimates the observed rainfall. During the post-monsoon period, PRECIS model simulated values are slightly overestimates rainfall from the observations. There are some variation to the values found from Figure 4.6 and Table 3 which indicates that averages for a large area can not represent the exact amount of rainfall at a particular region.

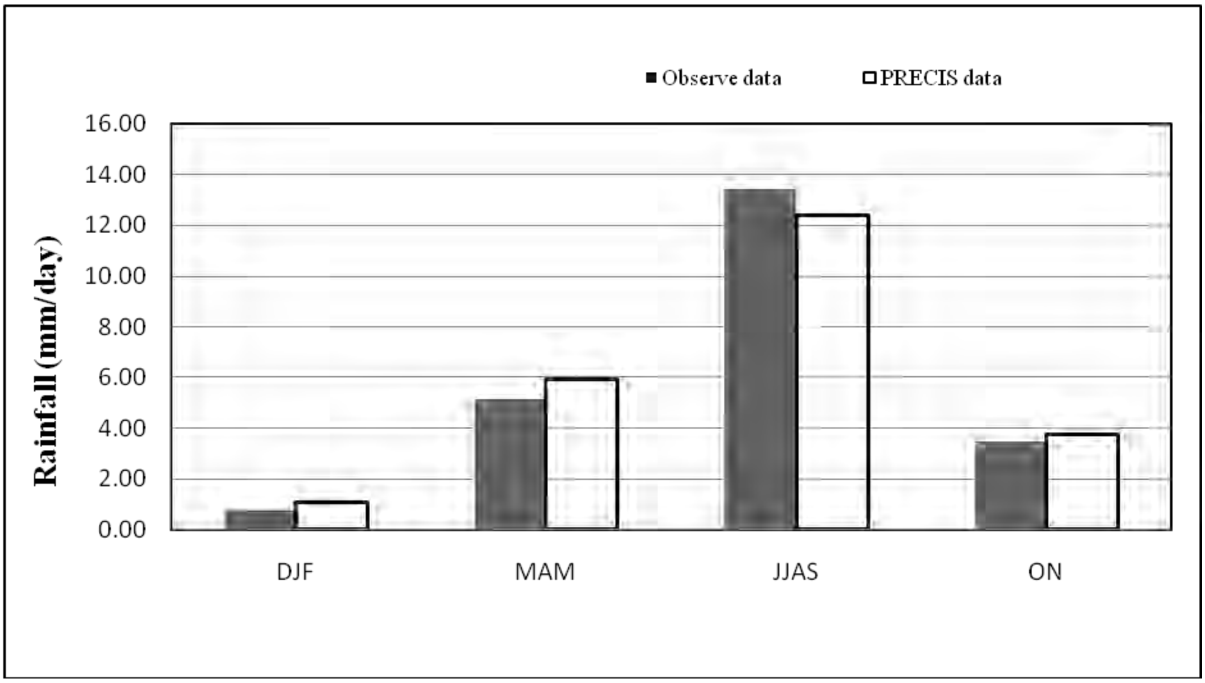

Figure: 4.6 Comparison of seasonal rainfall obtained from PRECIS and observations

4.2.3 ANNUAL RAINFALL

Comparison of rainfall in 2005 obtained from PRECIS and observations at seven different regions over Bangladesh are shown in Figure 4.7. In this Figure PRECIS model simulated amounts show that less rainfall strip is passed along western (Rajshahi) and southwestern (Khulna) regions of the country while northern (Rangpur) and southeastern (Chittagong) regions show higher amounts. Very strong rainfall is localized in the northeastern (Sylhet) area of the country. It is clear that the rainfall distribution patterns are changed and overestimated by PRECIS at western and southern region and similar at south western regions. Rainfall is underestimated by PRECIS at the northwestern, southeastern and centre regions of the country, especially rainfall distribution pattern are changed greatly at northeastern side of the country. Hence it is clear that some high rainfall pockets of observational values are not caught by PRECIS model simulations. It may be due to the 50km horizontal resolution of the model simulation. High horizontal resolution, as in a 25km PRECIS run, may provide the better result for spatial distribution of rainfall in this heavy rainfall region.

Comparison of annual rainfall obtained from PRECIS and observations are shown in Figure 4.8 considering values from 7 selected regions over Bangladesh in mm/day. The PRECIS model overestimates rainfall in all years except it underestimates for 5 years (1990, 1993, 1998, 2002 and 2007) out of twenty one years. The PRECIS model overestimates substantially for five years (1992, 1994, 1996, 2003 and 2008) out of twenty one years whereas PRECIS model simulated values are almost the same as the observed values in1995, 1997 and 2001.

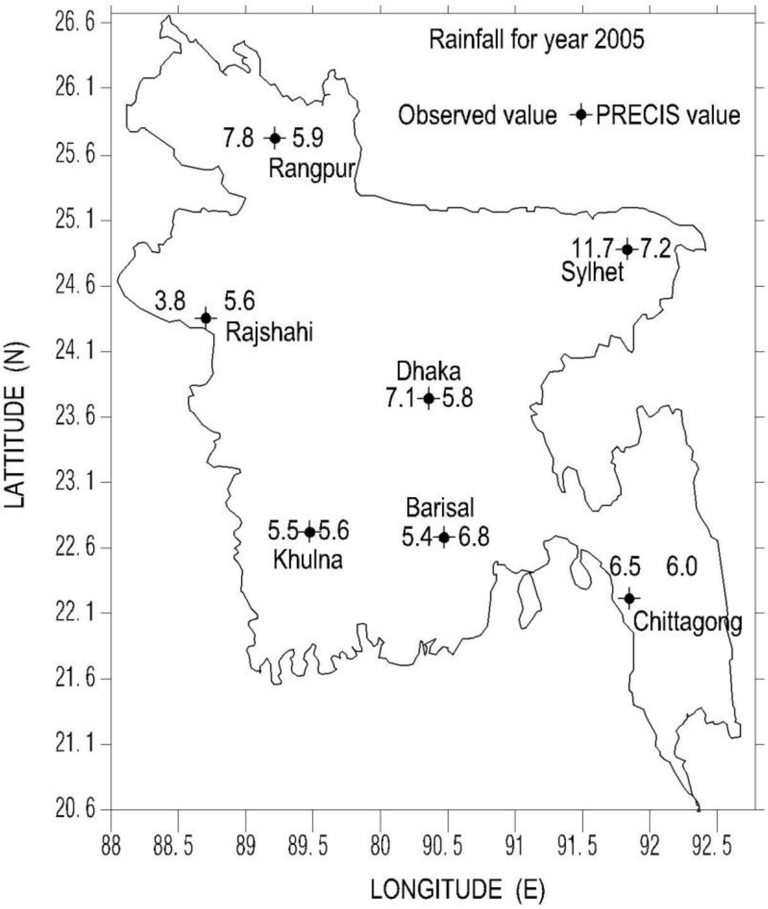

Figure: 4.7 Comparison of rainfall in 2005 obtained from PRECIS and observations

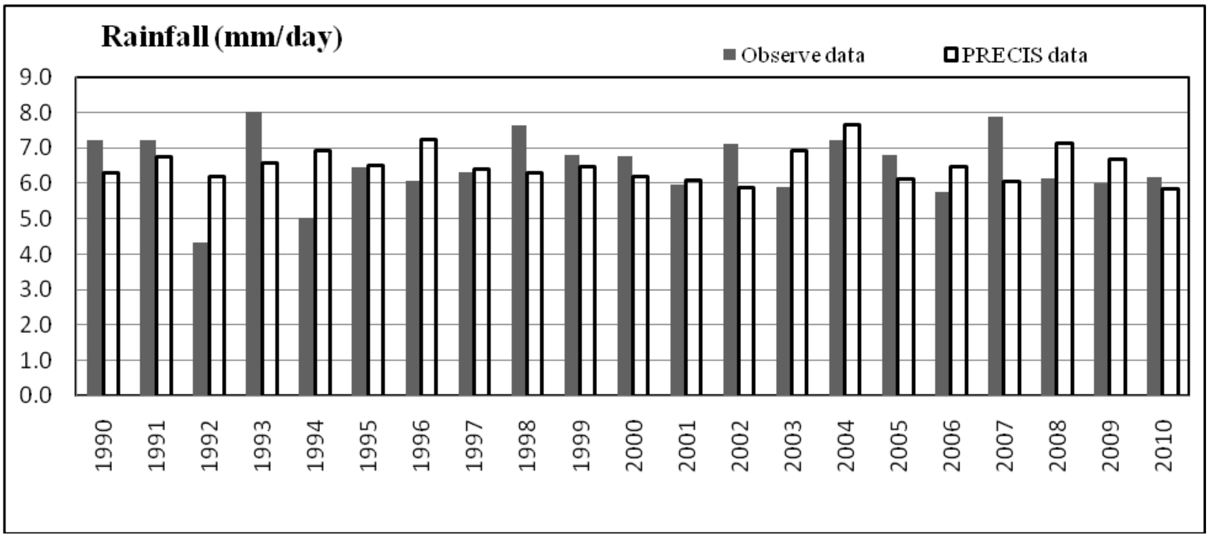

Figure 4.8 Comparison of annual rainfall obtained from PRECIS and observations

4.2.4 RAINFALL BIAS

Rainfall biases are defined as the difference between rainfall measured by PRECIS model values and observational BMD values. Monthly and seasonal rainfall biases are shown in Figure 4.9 and Figure 4.10 respectively considering values from 7 selected regions over Bangladesh and averaged for the period 1990–2010 in mm/day. Monthly rainfall biases (Figure 4.9) are found +1.15 mm/day in May and – 1.55 mm/day in September whereas seasonal rainfall biases (Figure 4.10) are found +0.74 mm/day in pre-monsoon period and -1.04 mm/day in monsoon period. From the Figure 4.9 and Figure 4.10 it is seen that seasonal rainfall biases are lower than monthly rainfall biases. Therefore, it may be concluded that the PRECIS model provides better results for seasonal rainfall than monthly rainfall.

Regional and annual rainfall biases are shown in Figure 4.11 and Figure 4.12 respectively considering values from 7 selected regions over Bangladesh and the years between 1990–2010 in mm/day. Regional rainfall biases (Figure 4.11) are found +1.7 mm/day at western region and – 2.5 mm/day at northeastern region whereas annual rainfall biases (Figure 4.12) are found +1.9 mm/day in year 1994 and – 1.8 mm/day in year 2007. From the Figure 4.11 to 4.12 it is seen that regional rainfall biases are higher than annual rainfall biases. Therefore, it may be concluded that annual rainfall provides reasonable validation of PRECIS in Bangladesh than regional variation.

Here it is clear that the PRECIS model simulation is not always in the same nature i.e., the bias is not systematic. So, average for long-term data may provide the reasonable validation. Therefore, PRECIS can be used to generate future climate scenarios and those scenarios can be used in rainfall forecasting with some tolerance of biases at different locations of Bangladesh.

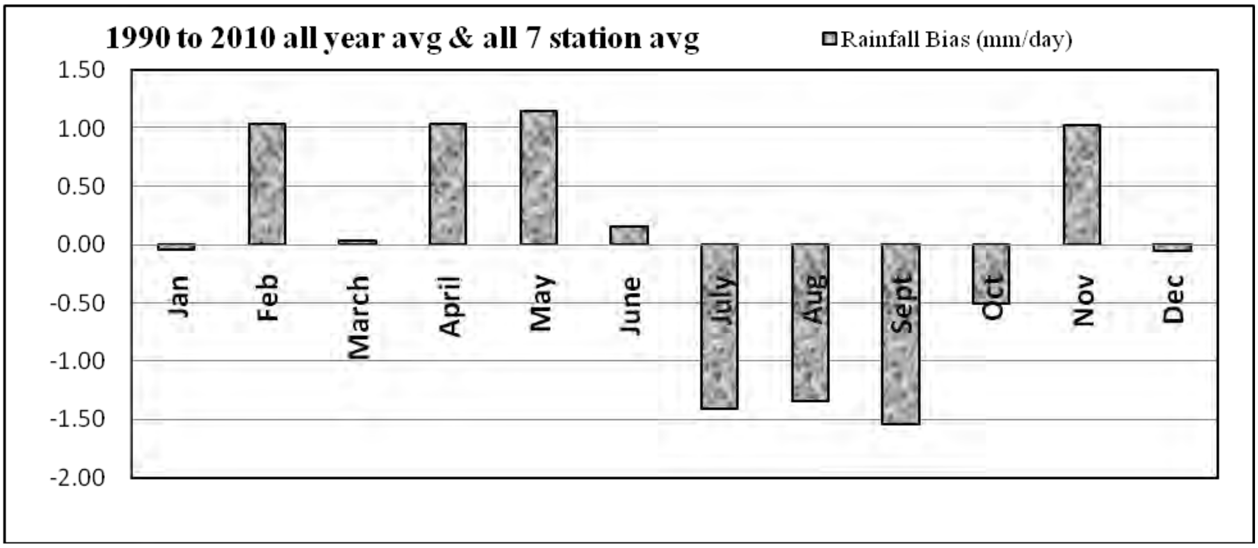

Figure 4.9 Monthly rainfall biases

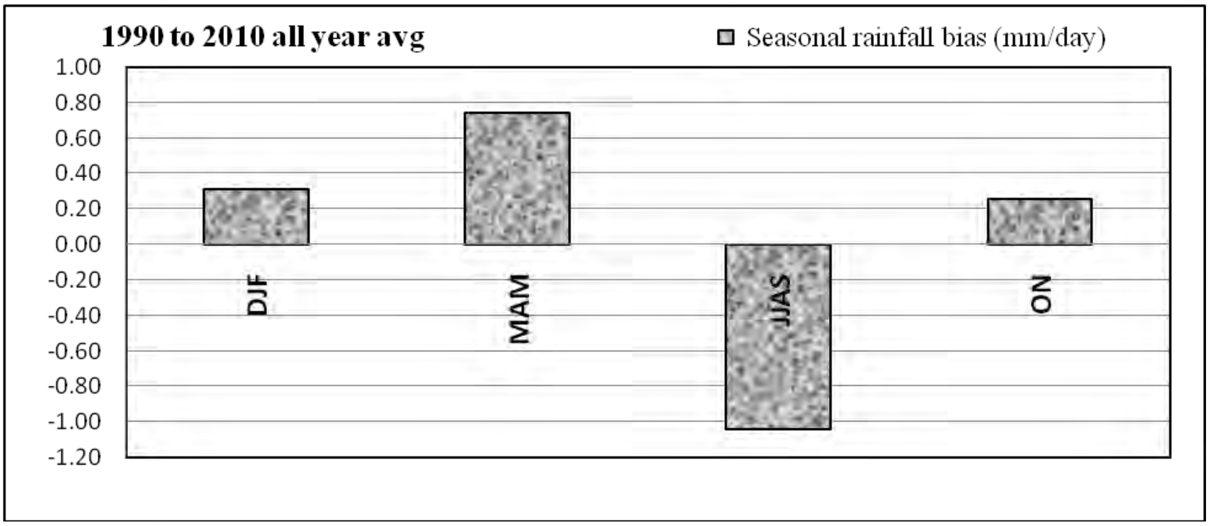

Figure 4.10 Seasonal rainfall biases

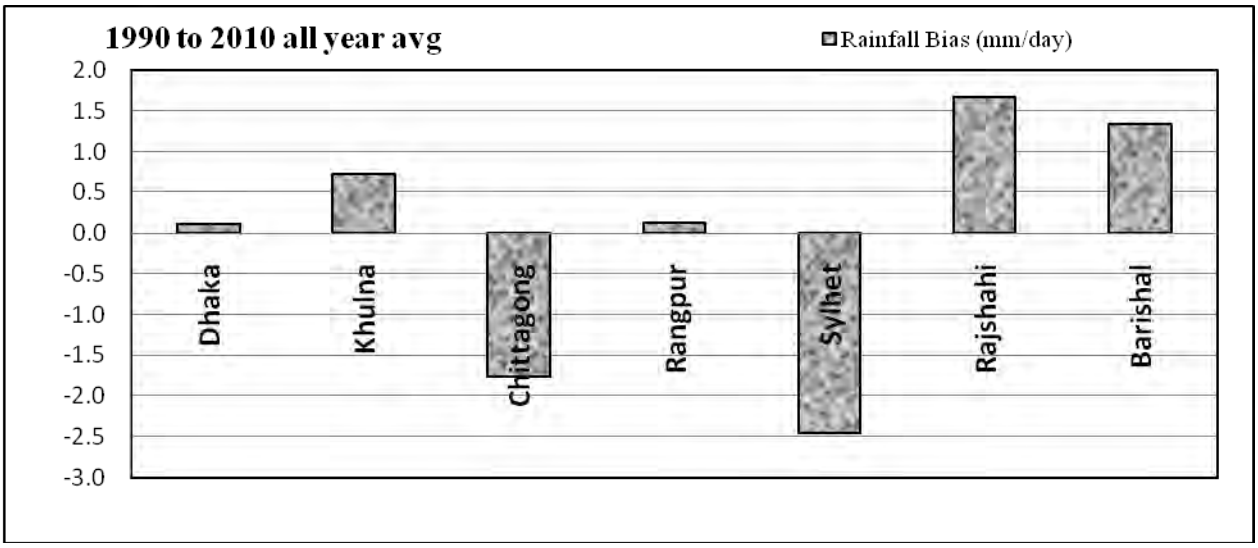

Figure 4.11 Regional rainfall biases

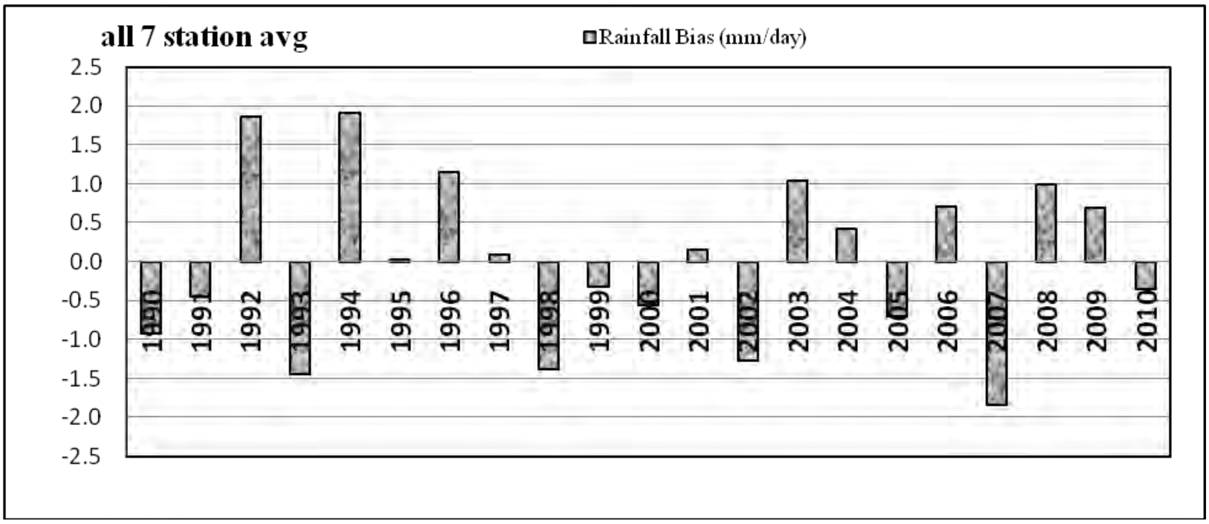

Figure 4.12 Annual rainfall biases

4.2.5 RAINFALL PATTERNS TO GENERATE FUTURE CLIMATE SCENARIOS

Seasons in Bangladesh are shifting a bit arbitrarily as a result of changes in rainfall patterns and temperature and posing a serious threat to the country's future food security, according to experts. The shifting of rainfall patterns in wet and dry season in coming years are explained here from corrected PRECIS data.

The slope (m_{RF}) and constant (C_{RF}) values of rainfall for individual month at different locations in Bangladesh are calculated by regression equation for the years between 1990-2010 as shown in Table 4. After that temperature model generated values (RFmodel) in 2015, 2025, 2035, 2045 and 2050 are corrected by these m_{RF} and C_{RF} values with regression equation and found projected rainfall (RFprojection) for the years 2015, 2025, 2035, 2045 and 2050.

The trend of rainfall obtained from PRECIS model output for the years 2015, 2025, 2030, 2045 and 2050 are shown in Figure 4.13 in reference to the observed period 1990 to 2010. The future rainfall of Bangladesh will be increased from the past during May to October but fall slightly in November and December. This increasing and decreasing rate are small in near future, But after some decades this increasing and decreasing rate are large than the present rate with fluctuated value. Decreasing rate of rainfall is from 0.2 to 0.7 mm/day so rainfall will remain same with slight change during dry season. Increasing rate of rainfall is from 1.7 to 2.1 mm/day in July and 3.4 to 5.8 mm/day in August.

The peak of rainfall is found in July or August whereas the historical observed rainfall peak of Bangladesh is found in July. The peak of rainfall is shifted from July to August in 2050 where the difference between August and July in 2050 is 0.22 mm/day. So the important notice is that in Bangladesh, rainfall during wet season will increase whereas it will remain close to historical amount during dry season. These results are consistent to the all other research.

Table 4 m_{RF} and C_{RF} values for rainfall averages from 1990-2010

		Jan	Feb	March	April	May	June	July	Aug	Sept	Oct	Nov	Dec
Dhaka	m_{RF}	-0.007	-0.046	-0.082	-0.043	-0.256	0.266	0.159	0.090	0.043	0.009	-0.044	-0.006
	C_{RF}	0.315	2.041	2.630	4.257	11.760	7.958	11.380	10.173	10.570	6.166	1.468	0.481
Khulna	m_{RF}	-0.023	-0.293	-0.080	-0.061	-0.146	-0.005	0.149	0.193	0.440	0.143	-0.018	-0.019
	C_{RF}	0.745	5.874	2.497	2.741	7.866	9.901	9.633	9.857	5.396	3.397	1.404	0.362
Chittagong	m_{RF}	0.008	-0.189	-0.138	-0.076	0.103	-0.027	0.133	0.293	0.225	0.085	-0.070	-0.026
	C_{RF}	0.161	3.928	3.108	4.479	10.690	19.780	21.570	14.880	7.077	6.327	2.634	0.735
Rangpur	m_{RF}	-0.014	-0.048	-0.001	0.080	-0.116	0.172	0.139	0.060	-0.036	0.195	-0.019	-0.004
	C_{RF}	0.419	1.331	0.914	3.419	10.360	13.550	11.940	10.540	15.960	4.796	0.466	0.230
Sylhet	m_{RF}	-0.017	-0.155	-0.161	0.291	0.016	-0.100	-0.037	0.607	-0.441	0.046	0.015	-0.010
	C_{RF}	0.430	4.479	6.189	8.897	17.920	27.130	25.930	17.240	21.480	5.319	0.741	0.396
Rajshahi	m_{RF}	-0.001	-0.077	0.000	-0.040	-0.012	-0.051	0.029	0.044	-0.017	0.065	-0.044	-0.038
	C_{RF}	0.200	1.835	0.724	1.894	4.734	8.951	10.010	7.200	10.190	3.305	0.889	0.611
Barishal	m_{RF}	-0.001	-0.149	-0.131	-0.124	-0.178	-0.143	0.113	-0.036	0.251	0.078	-0.026	-0.016
	C_{RF}	0.428	3.460	3.388	4.262	8.406	14.630	12.650	12.850	6.806	5.631	1.867	0.330

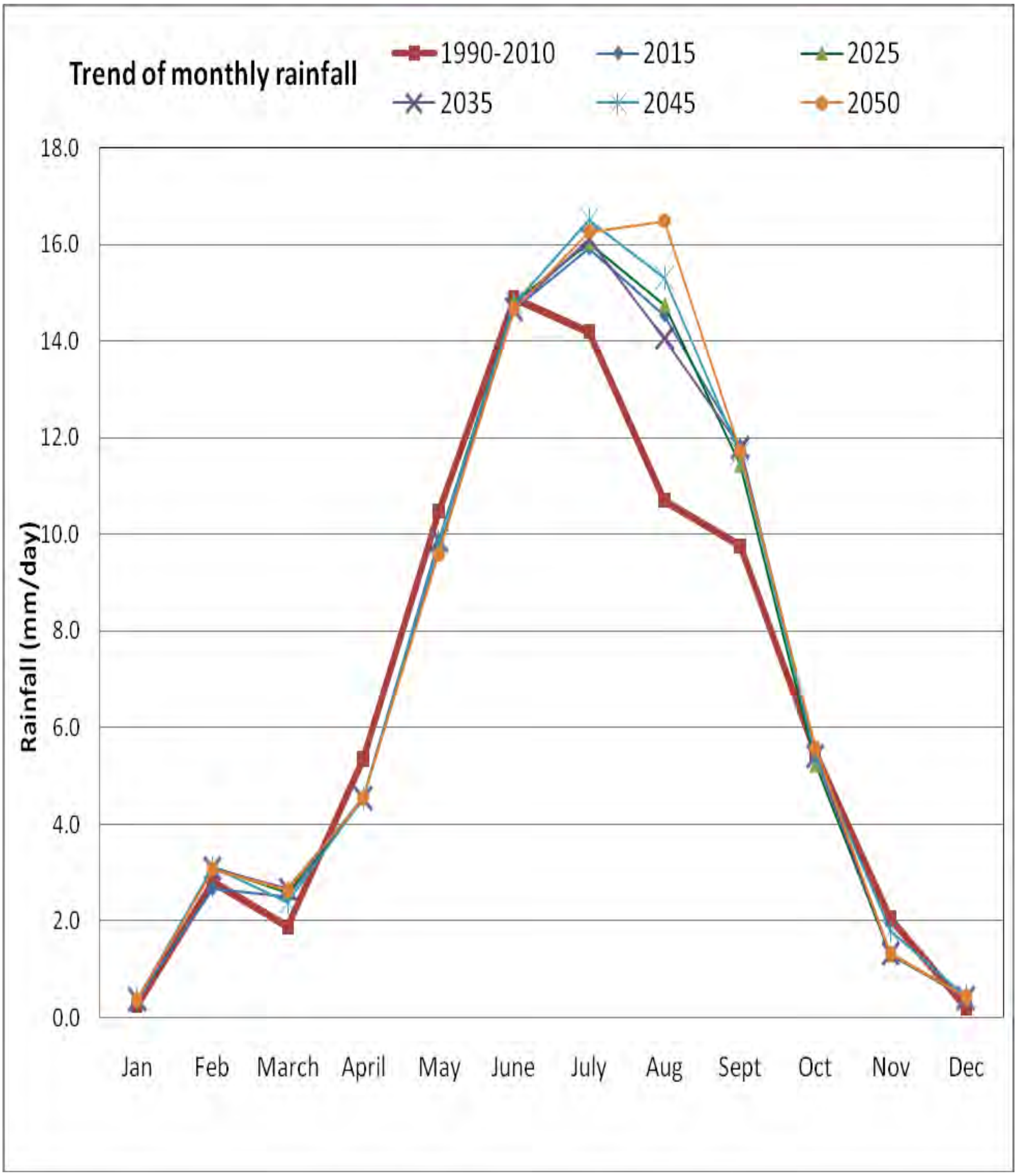

Figure 4.13 Trend of rainfall obtained from corrected PRECIS data for the future year

4.3 ASSESSMENT OF TEMPERATURE

Bangladesh is located in the tropical monsoon region and its climate is characterized by high temperature with excessive humidity and fairly marked seasonal variations. The maximum and minimum temperature obtained from PRECIS model output data for A1B scenario and observed data are compared discussed in this section.

4.3.1 MONTHLY TEMPERATURE

Comparison of monthly maximum temperature obtained from PRECIS and observations are shown in Figure 4.14 considering values from 7 selected regions over Bangladesh and averaged for the period 1990–2010 in degree Celsius (ºC). The PRECIS model underestimates maximum temperature during January to February. During March to June, it overestimates maximum temperature. In the months July and August, the PRECIS model estimates are almost closer to the observed maximum temperature. After that it underestimates maximum temperature again during September to December. The peak value of maximum temperature is 36.2 ºC in April obtained from PRECIS and 33.2 ºC in April obtained from observed data.

Comparison of monthly minimum temperature obtained from PRECIS and observations are shown in Figure 4.15. The PRECIS model underestimates minimum temperature during January to February. During March to July, it overestimates minimum temperature. In the months August and September, the PRECIS model estimates are almost closer to the observed minimum temperature. After that it underestimates minimum temperature again during October to December. The peak value of minimum temperature is 27.9 ºC at June obtained from PRECIS and 26 ºC in August obtained from observed data.

From Figure 4.14 and 4.15, it is seen that the pattern of monthly maximum temperature obtained from PRECIS are nearly similar to the pattern of monthly minimum temperature obtained from PRECIS.

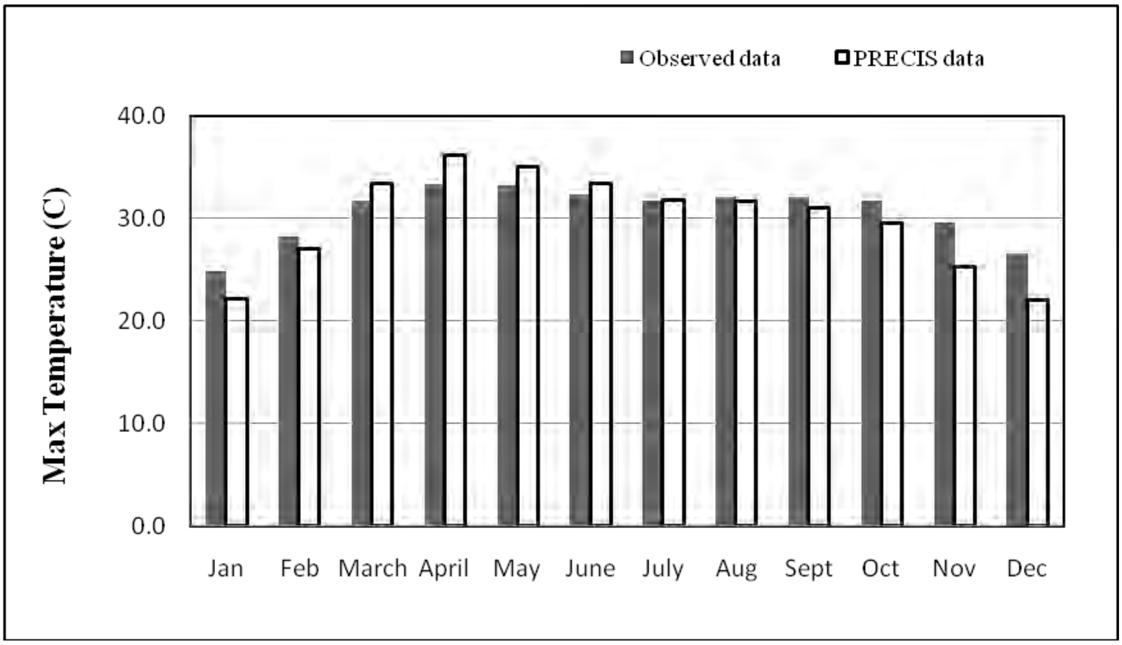

Figure 4.14 Comparison of monthly maximum temperature obtained from PRECIS and observations.

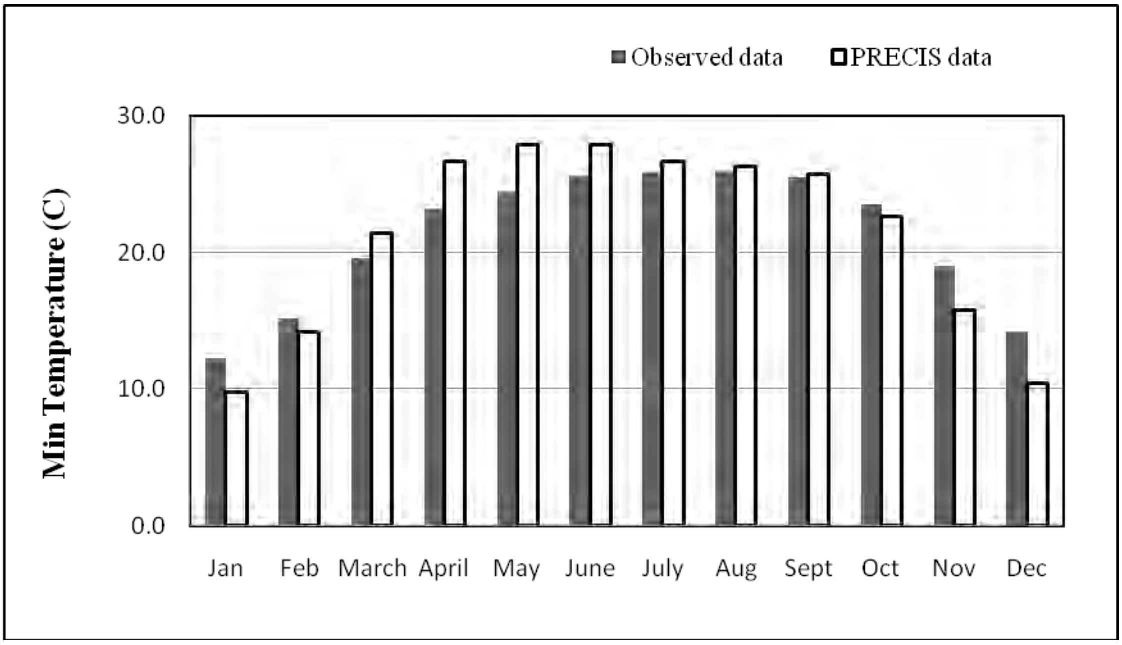

Figure 4.15 Comparison of monthly minimum temperature obtained from PRECIS and observations.

4.3.2 SEASONAL TEMPERATURE

Comparison of seasonal maximum temperature obtained from PRECIS and observations are shown in Figure 4.16 considering values from 7 selected regions over Bangladesh and averaged for the period 1990–2010 in degree Celsius. The PRECIS model underestimates maximum temperature during post-monsoon (ON) and winter (DJF) periods whereas during pre-monsoon (MAM) period it overestimates the observed maximum temperature. During the monsoon (JJAS) period, PRECIS model simulated values are almost the same as the observed values.

Comparison of seasonal minimum temperature obtained from PRECIS and observations are shown in Figure 4.17 considering values from 7 selected regions over Bangladesh and averaged for the period 1990–2010 in degree Celsius. The PRECIS model underestimates minimum temperature during post-monsoon (ON) and winter (DJF) periods whereas during pre-monsoon (MAM) period it overestimates the observed minimum temperature. During the monsoon (JJAS) period, PRECIS model simulated values are almost the same as the observed values.

The maximum and minimum temperature in different seasons at different regions over Bangladesh is tabulated in Table 5 and Table 6 respectively. From Table 5 it is seen that during pre-monsoon period, maximum temperature is overestimated by PRECIS in the southeastern and northeastern regions of the country whereas underestimated in all other regions of the country but overall for BD, it is underestimated during pre-monsoon period. In case of minimum temperature as shown in Table 6, minimum temperature is overestimated by PRECIS in the southeastern region of the country during post-monsoon and winter periods whereas overall for BD it is underestimated in post-monsoon and winter periods.

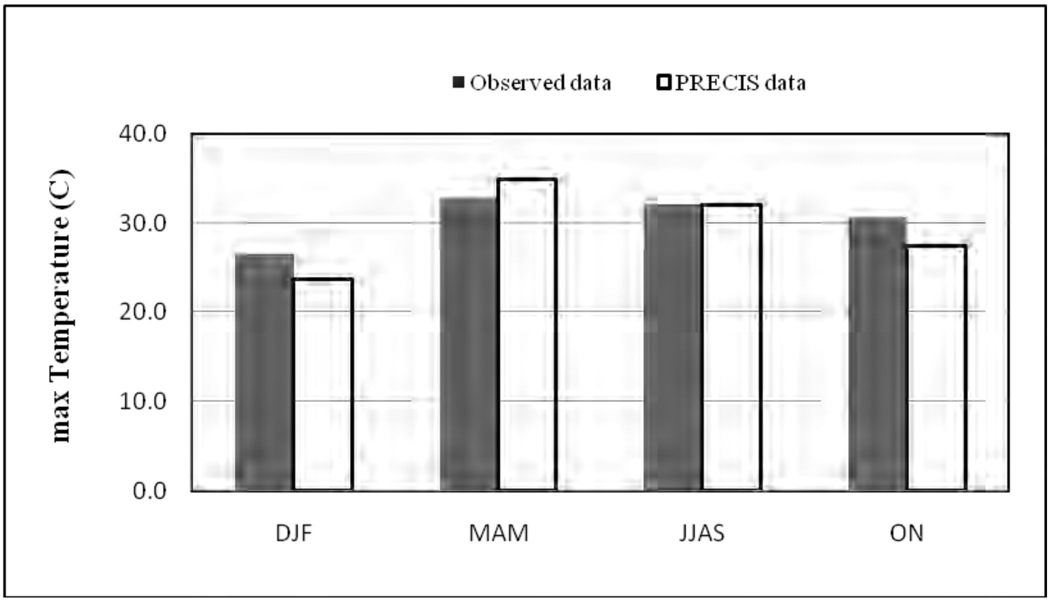

Figure 4.16 Comparison of seasonal maximum temperature obtained from PRECIS and observations

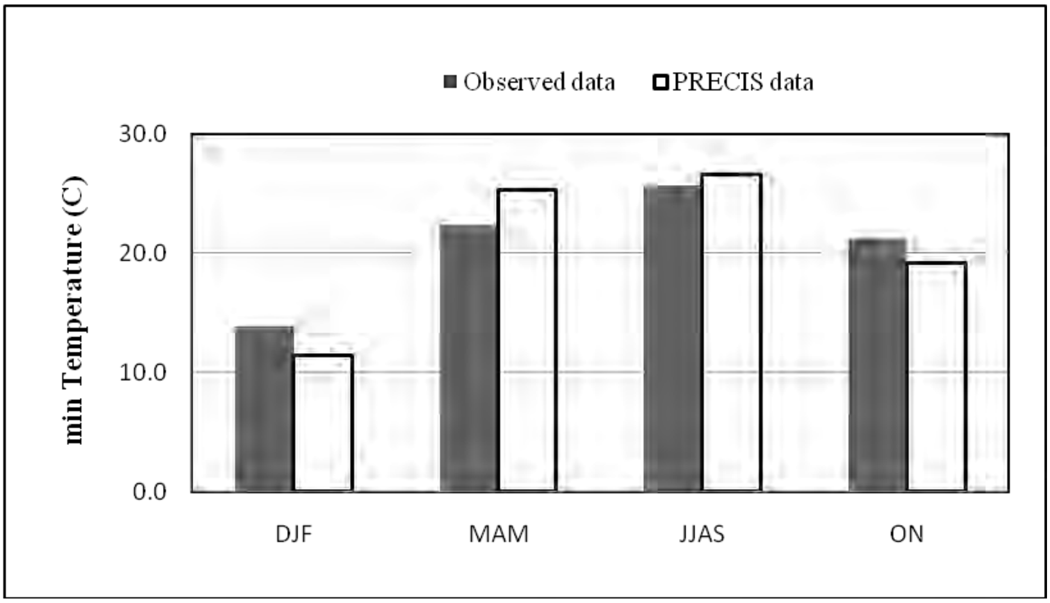

Figure 4.17 Comparison of seasonal minimum temperature obtained from PRECIS and observations

Table 5 Maximum temperature in different seasons and at different regions over Bangladesh

		Maximum temperature (ºC) averages from 1990-2010								
		Dhaka (C)	Khulna (S-W)	Chittag (S-E)	Rangpur (N-W)	Sylhet (N-E)	Rajshahi (W)	Barishal (S)	BD	BD seasonal bias
DJF (winter)	observed	26.5	27.1	27.6	24.9	26.8	25.9	27.0	26.6	
	PRECIS	23.7	25.0	21.2	23.6	22.4	24.9	25.0	23.7	-2.9
MAM (pre Monsoon)	observed	33.2	34.2	32.0	31.2	31.1	34.7	33.2	32.8	
	PRECIS	36.0	37.9	29.6	34.9	30.2	38.5	36.9	34.8	2.0
JJAS (monsoon)	observed	32.2	32.6	31.6	32.0	31.9	33.0	31.7	32.1	
	PRECIS	33.0	32.4	29.2	32.1	31.9	32.7	32.4	32.0	-0.2
ON (post monsoon)	observed	30.7	31.1	31.2	29.8	30.6	30.5	30.9	30.7	
	PRECIS	28.0	28.4	25.7	26.6	27.4	27.1	28.5	27.4	-3.3

Table 6 Minimum temperature in different seasons and at different regions over Bangladesh

		Minimum temperature (ºC) averages from 1990-2010								
		Dhaka (C)	Khulna (S-W)	Chittag (S-E)	Rangpur (N-W)	Sylhet (N-E)	Rajshahi (W)	Barishal (S)	BD	BD seasonal bias
DJF (winter)	observed	14.8	14.1	15.6	12.6	14.4	12.1	13.7	13.9	
	PRECIS	10.4	11.5	17.0	9.1	10.1	10.4	11.6	11.4	-2.4
MAM (pre Monsoon)	observed	23.2	23.5	23.3	20.7	21.0	21.8	23.1	22.4	
	PRECIS	25.1	26.5	27.7	23.0	23.2	25.0	26.3	25.3	2.9
JJAS (monsoon)	observed	26.2	26.2	25.5	25.7	25.0	26.0	25.7	25.7	
	PRECIS	26.4	26.5	28.0	26.2	26.0	26.5	26.5	26.6	0.9
ON (post monsoon)	observed	21.8	21.8	22.3	20.3	21.1	20.4	21.4	21.3	
	PRECIS	18.8	19.1	23.0	17.3	18.6	18.0	19.2	19.2	-2.1

4.3.3 ANNUAL TEMPERATURE

Comparison of annual maximum temperature obtained from PRECIS and observations are shown in Figure 4.18 considering values from 7 selected regions over Bangladesh in degree Celsius (ºC). The PRECIS model underestimates maximum temperature in all years except in 2004 and 2008. The PRECIS model underestimates substantially for 8 years (1990, 1993-95, 1997-99 and 2005) out of twenty one years.

Comparison of annual minimum temperature obtained from PRECIS and observations are shown in Figure 4.19 considering values from 7 selected regions over Bangladesh in degree Celsius (ºC). The PRECIS model overestimates minimum temperature in all years except it underestimates for 8 years (1994-96, 1998, 2001, 2002, 2005 and 2009) out of twenty one years. The PRECIS model overestimates substantially for 7 years (1990, 1992, 2000, 2003, 2004, 2007 and 2010) out of twenty one years whereas PRECIS model simulated values are almost the same as the observed values in1991 and 2008. The time sequence of both datasets as shown in Figure 4.18 and 4.19 is similar in trend i.e. temperature is increasing with time.

Comparison of regional maximum temperature obtained from PRECIS and observations are shown in Figure 4.20 averages from 1990–2010 in degree celsius. The PRECIS model simulated values are almost the same as the observed values at all regions except 2 regions in the northeastern and southeastern parts of the country. The PRECIS model underestimates considerably maximum temperature at northeastern and southeastern parts of the country.

Comparison of regional minimum temperature obtained from PRECIS and observations are shown in Figure 4.21. The PRECIS model overestimates minimum temperature highly at southeastern region. At centre zone of the country, it underestimates minimum temperature. In all other regions the PRECIS model estimates are almost closer to the observed minimum temperature.

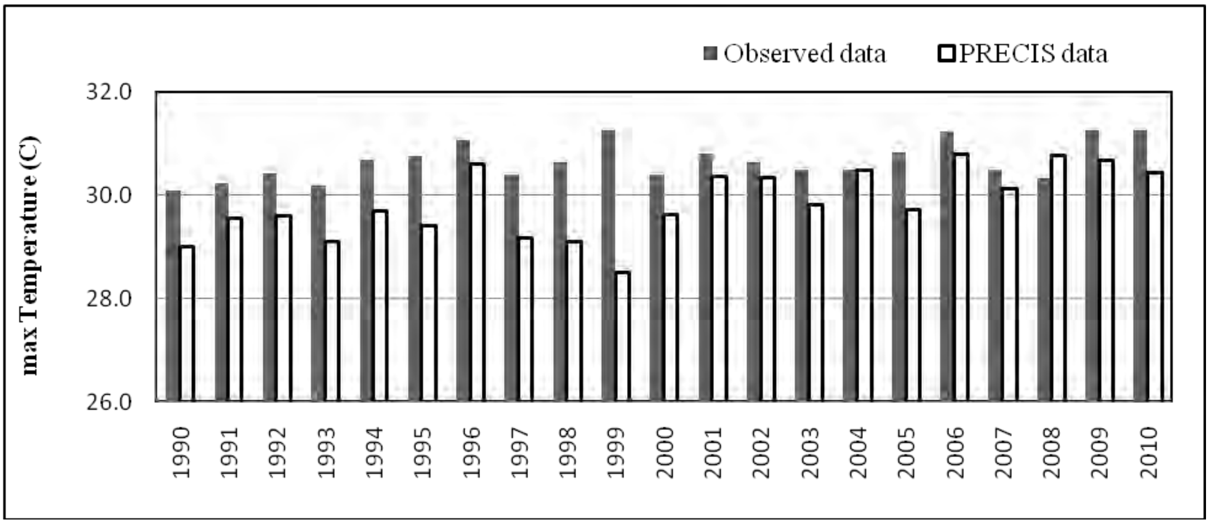

Figure 4.18 Comparison of annual maximum temperature obtained from PRECIS and observations

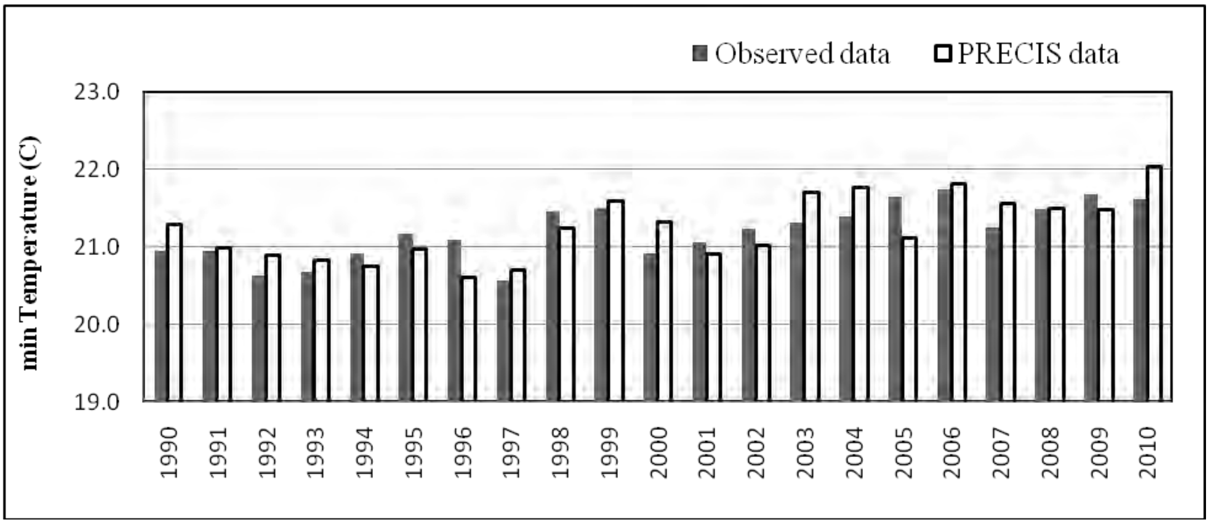

Figure 4.19 Comparison of annual minimum temperature obtained from PRECIS and observations

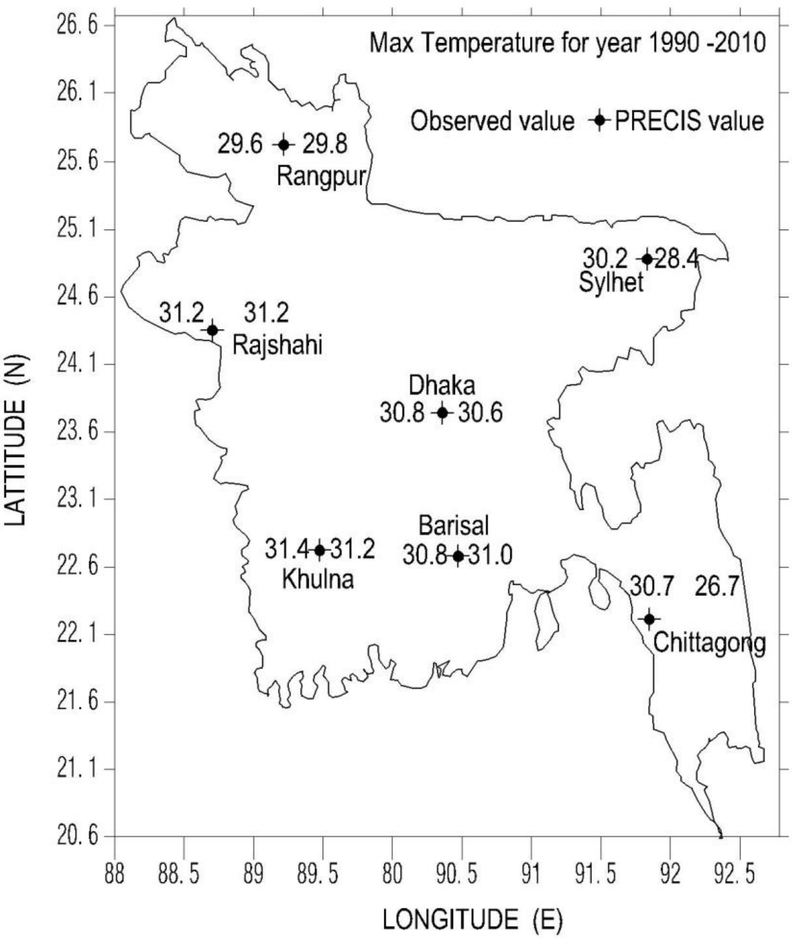

Figure 4.20 Comparison of regional maximum temperature obtained from PRECIS and observations

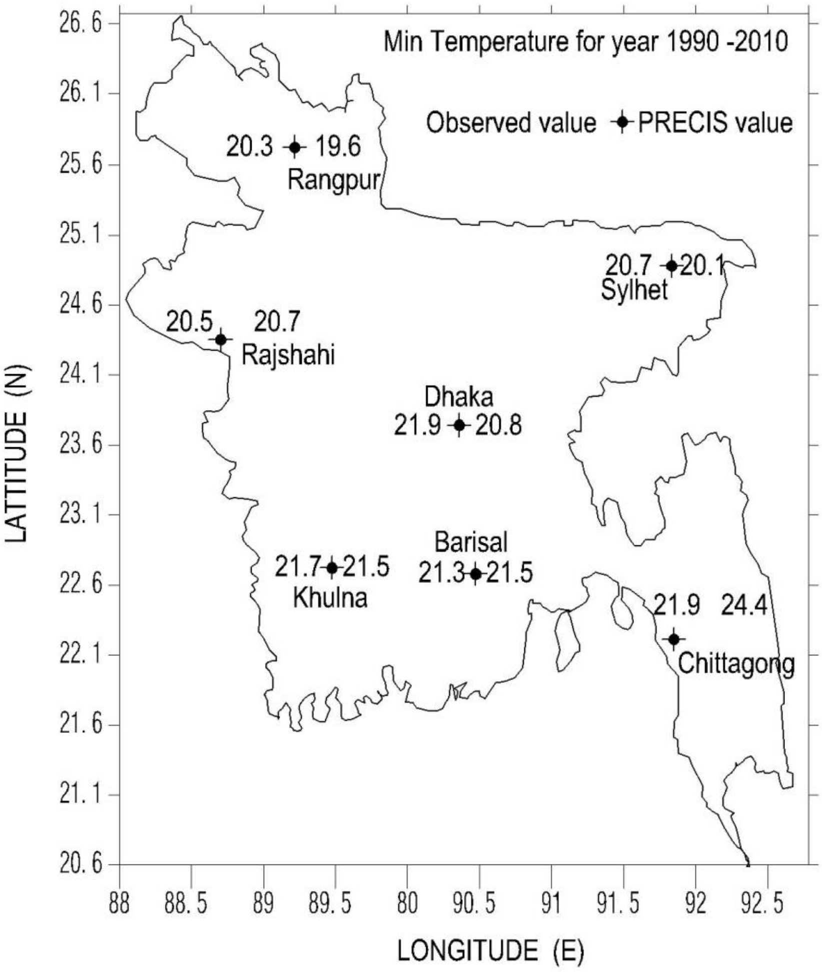

Figure 4.21 Comparison of regional minimum temperature obtained from PRECIS and observations

4.3.4 TEMPERATURE BIASES

Temperature biases are defined as the difference between temperature measured by PRECIS model values and observational BMD values. Monthly and seasonal maximum temperature biases are shown in Figure 4.22 and Table 5 respectively considering values from 7 selected regions over Bangladesh and averaged for the period 1990–2010 in degree Celsius (ºC). Monthly maximum temperature biases (Figure 4.22) are found +2.8 ºC in April and – 4.6 ºC in December whereas seasonal maximum temperature biases (Table 5) are found +2.0 ºC in pre-monsoon period and – 3.3 ºC in post-monsoon period.

Monthly and seasonal minimum temperature biases is shown in Figure 4.23 and Table 6 respectively considering values from 7 selected regions over Bangladesh and averaged for the period 1990–2010 in degree Celsius (ºC). Monthly minimum temperature biases (Figure 4.23) are found +3.5 ºC in April and – 3.9 ºC in December whereas seasonal minimum temperature biases (Table 6) are found +2.4 ºC in winter period and – 2.9 ºC in pre-monsoon period. It is found from the Figure 4.22, 4.23, and Table 5, 6 that, seasonal maximum and minimum temperature biases are lower than monthly maximum and minimum temperature biases. Therefore, it may be concluded that the PRECIS model provides better performance for seasonal maximum and minimum temperature than monthly maximum and minimum temperature.

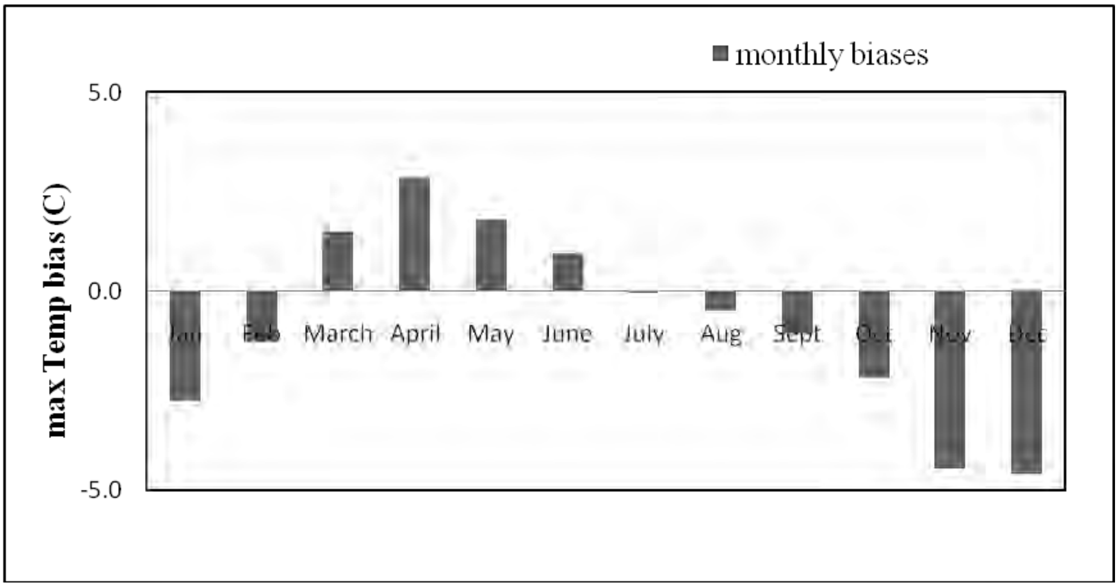

Figure 4.22 Monthly maximum temperature biases

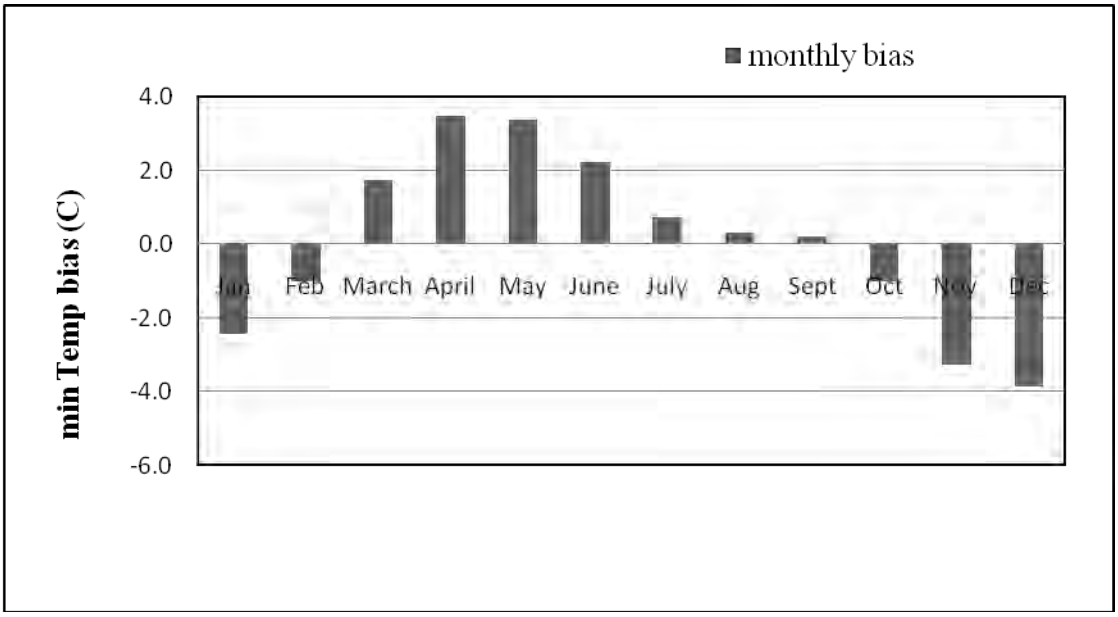

Figure 4.23 Monthly minimum temperature biases

Regional and annual maximum temperature biases are shown in Figure 4.24 and Figure 4.26 respectively considering values from 7 selected regions over Bangladesh and the years between 1990–2010 in degree Celsius (ºC). Regional maximum temperature biases (Figure 4.24) are found +0.2 ºC at southern region and – 3.9 ºC at southeastern region whereas annual maximum temperature biases (Figure 4.26) are found +0.4 ºC in 2008 and – 2.7 ºC in 1999.

Regional and annual minimum temperature biases are shown in Figure 4.25 and Figure 4.27 respectively considering values from 7 selected regions over Bangladesh and the years between 1990–2010 in degree Celsius (ºC). Regional minimum temperature biases (Figure 4.25) are found +2.5 ºC at southeastern region and – 1.1 ºC at centre region whereas annual minimum temperature biases (Figure 4.27) are found +0.4 ºC in year 2010 and – 0.5 ºC in year 2005.

It is seen from the Figure 4.24 to 4.26 that regional maximum and minimum temperature biases are higher than annual maximum and minimum temperature biases. So the PRECIS model provides reasonable validation for annual temperature averages for all regions than regional temperature averages for all years.

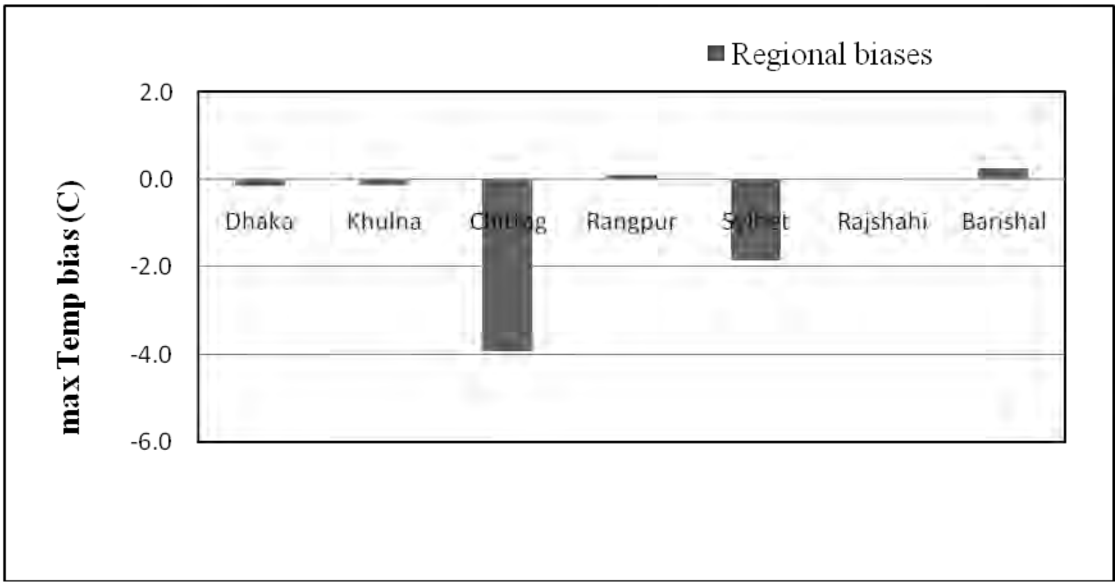

Figure 4.24 Regional maximum temperature biases

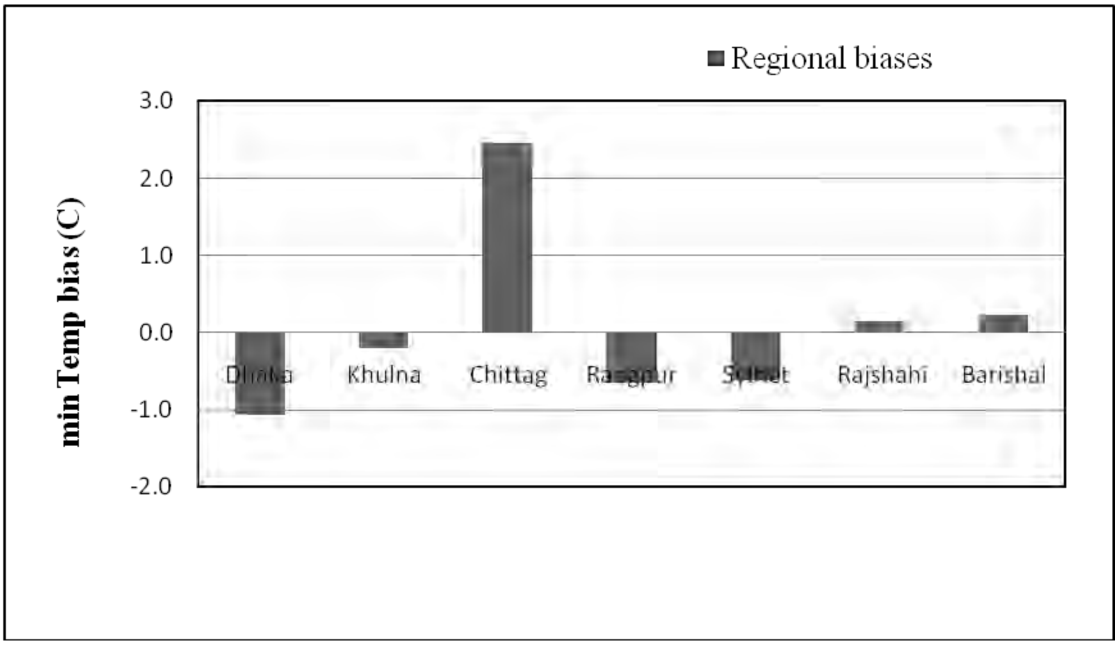

Figure 4.25 Regional minimum temperature biases

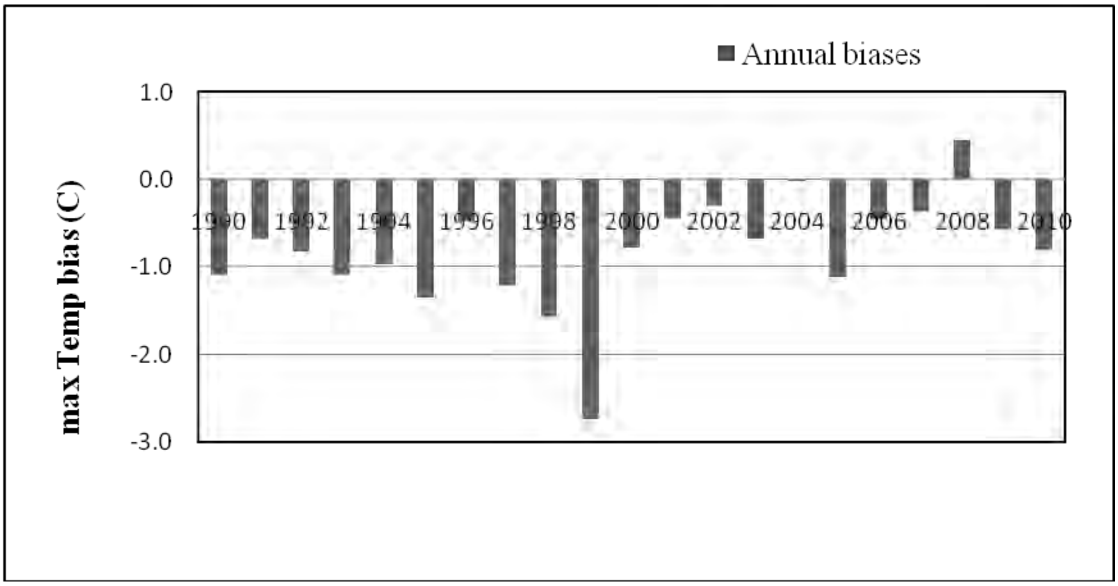

Figure 4.26 Annual maximum temperature biases

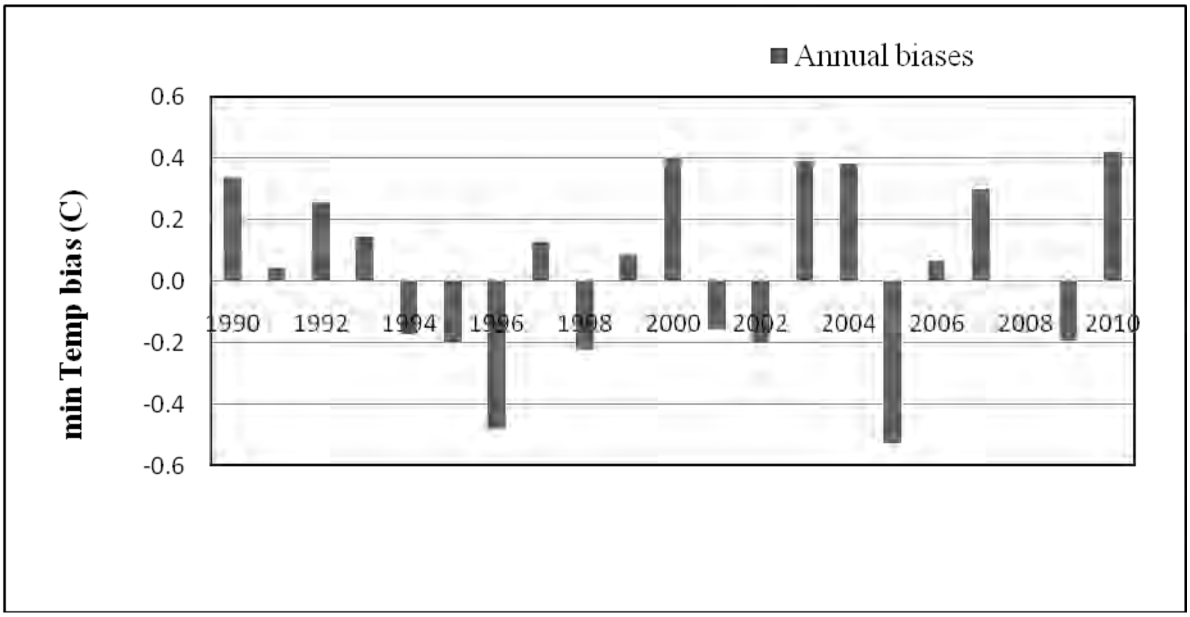

Figure 4.27 Annual minimum temperature biases

4.3.5 PROJECTED TEMPERATURE TO PREDICT GLOBAL WARMING

Any climatic change in Bangladesh will, of course, be a part of worldwide climatic changes. It is generally claimed that the temperature of the earth has been increasing since the beginning of the 20th century. This phenomenon, called global warming is attributed to the increase in atmospheric carbon dioxide (CO_2) due to the burning of fossil fuel. The prediction of global warming in future years from corrected PRECIS data are explained here.

The slope (m_{TX}) and constant (C_{TX}) values of maximum temperature for individual month at different locations in Bangladesh are calculated by regression equation for the years between 1990 to 2010 as shown in Table 7. After that temperature model generated values (TXmodel) for the years 2015, 2025, 2035, 2045 and 2050 are corrected by these m_{TX} and C_{TX} values with regression equation and found projected maximum temperature (TXprojection) in 2015, 2025, 2035, 2045 and 2050.

Similarly the m_{TN} and C_{TN} values of minimum temperature for individual month at different locations in Bangladesh are calculated by regression equation for the years between 1990 to 2010 as shown in Table 8. After that temperature model generated values (TNmodel) for the years 2015, 2025, 2035, 2045 and 2050 are corrected by these m_{TN} and C_{TN} values with regression equation and found projected minimum temperature (TNprojection) in 2015, 2025, 2035, 2045 and 2050.

The trend of maximum temperature obtained from corrected PRECIS model data for the years 2015, 2025, 2030, 2045 and 2050 are shown in Figure 4.28. The maximum temperature will be increased in all month in reference to the observed period 1990 to 2010 but fall slightly in November, December and January. This increasing rate is high in June which is the month of monsoon season. The projected maximum temperature is about 2.0 °C higher compared to historical value in June 2050. The deviation of this TXprojection lies between –1.3 °C to + 2.0 °C. Finally it is visualized that projected maximum temperature will increase from historical value which indicates the presence of global warming.

The trend of minimum temperature obtained from corrected PRECIS model data for the years 2015, 2025, 2030, 2045 and 2050 are shown in Figure 4.29. The projected minimum temperature almost follows the trend of historical data in October to December and January; whereas it will decrease in September in 2025. Almost in all years, a projected minimum temperature is higher compared to historical value in February to July. It will rise 0.7 °C in February 2030 and 1.6 °C in April 2050 respectively. The deviation of projected minimum temperature lies between –0.3 °C to + 1.7 °C. This is again the clear indication of global warming in coming years.

Now it is found that the maximum and minimum temperature will be increased in future year. The effects of increased temperature will have destructive to some areas may causes Global warming. It will cause the polar ice caps and Himalayan ice caps to melt at a slow pace. As a consequence, it is estimated that the sea level will rise. In that case, all low coastal plains and delta areas will be submerged, thereby reducing the area of fertile agricultural lands and food production, and increasing food shortage, hunger, poverty and human misery on a global scale. If this prediction comes true, then a significant area of the Bangladesh will be submerged by the Bay of Bengal. This information might be helpful for the nationwide agriculture planning and impact studies due to global warming.

Table 7 m_{TX} and C_{TX} value for maximum temperature averages from 1990-2010

		Jan	Feb	March	April	May	June	July	Aug	Sept	Oct	Nov	Dec
Dhaka	m_{TX}	-0.029	0.054	0.050	0.043	0.085	0.048	0.029	0.039	0.015	0.003	0.005	-0.017
	C_{TX}	24.970	27.760	31.730	33.440	32.530	33.250	31.530	31.710	31.920	31.730	29.600	26.660
Khulna	m_{TX}	-0.021	0.044	0.034	0.034	0.070	0.051	0.004	0.037	0.032	0.014	0.014	-0.011
	C_{TX}	25.520	28.540	32.450	34.460	34.060	33.830	32.120	31.910	32.190	32.080	29.880	26.510
Chittagong	m_{TX}	0.044	0.084	0.090	0.027	0.001	-0.001	-0.015	-0.012	0.004	0.024	0.054	-0.044
	C_{TX}	25.750	27.980	30.220	31.990	32.570	32.770	31.250	31.700	31.940	31.830	29.780	26.200
Rangpur	m_{TX}	-0.026	0.043	0.005	-0.063	0.044	-0.002	0.021	0.022	0.073	0.038	0.024	0.017
	C_{TX}	23.160	25.920	30.180	32.190	31.390	32.870	31.650	32.070	30.990	30.370	28.470	25.220
Sylhet	m_{TX}	0.038	0.141	0.135	0.042	0.090	0.023	0.050	0.034	0.066	0.067	0.038	0.058
	C_{TX}	25.160	26.460	29.330	30.740	30.290	32.000	31.280	31.930	31.290	30.890	29.230	26.290
Rajshahi	m_{TX}	-0.044	0.043	0.050	0.010	0.012	0.065	0.011	0.001	0.031	0.001	-0.001	-0.014
	C_{TX}	24.310	27.590	32.380	35.840	35.050	34.380	32.390	32.860	32.240	31.650	29.390	26.020
Barishal	m_{TX}	0.013	0.069	0.068	0.050	0.075	0.058	0.024	0.044	0.039	0.025	0.012	0.007
	C_{TX}	25.240	28.020	31.580	33.070	32.670	32.630	31.000	31.060	31.370	31.560	29.740	26.870

Table 8 m_{TN} and C_{TN} value for minimum temperature averages from 1990-2010

		Jan	Feb	March	April	May	June	July	Aug	Sept	Oct	Nov	Dec
Dhaka	m_{TN}	0.047	0.047	0.074	0.081	0.044	0.007	0.016	0.001	0.010	0.033	0.025	0.121
	C_{TN}	12.61	15.78	20.06	23.06	24.37	26.27	26.21	26.38	25.75	23.60	19.29	13.65
Khulna	m_{TN}	0.108	0.080	0.095	0.111	0.047	0.036	0.017	0.010	0.020	0.001	0.006	0.070
	C_{TN}	11.050	14.910	19.630	23.130	24.860	25.810	26.000	26.160	25.700	24.110	19.450	13.380
Chittagong	m_{TN}	0.033	0.009	0.050	0.090	0.004	0.014	0.016	0.012	0.011	0.010	0.004	0.059
	C_{TN}	13.710	16.560	20.220	22.980	25.010	25.420	27.230	25.370	25.210	24.160	20.440	15.340
Rangpur	m_{TN}	0.052	0.067	0.099	0.078	0.021	0.011	0.021	0.001	0.030	0.056	0.078	0.105
	C_{TN}	10.380	12.750	16.340	20.460	23.210	25.430	26.040	26.230	25.040	22.130	16.980	12.250
Sylhet	m_{TN}	0.047	0.050	0.082	0.081	0.065	0.043	0.054	0.041	0.072	0.056	0.023	0.067
	C_{TN}	12.440	14.510	17.900	20.390	22.270	24.100	27.230	24.960	24.030	22.580	18.810	14.270
Rajshahi	m_{TN}	0.037	0.044	0.105	0.114	0.030	0.021	0.028	0.024	0.039	0.025	0.028	0.078
	C_{TN}	9.961	12.750	16.840	21.730	24.180	25.630	25.810	25.960	25.150	22.760	17.420	11.940
Barishal	m_{TN}	0.026	0.001	0.050	0.080	0.066	0.062	0.048	0.059	0.048	0.004	-0.014	0.029
	C_{TN}	11.620	15.400	19.910	22.980	24.200	25.080	26.070	25.160	24.870	23.630	19.180	13.350

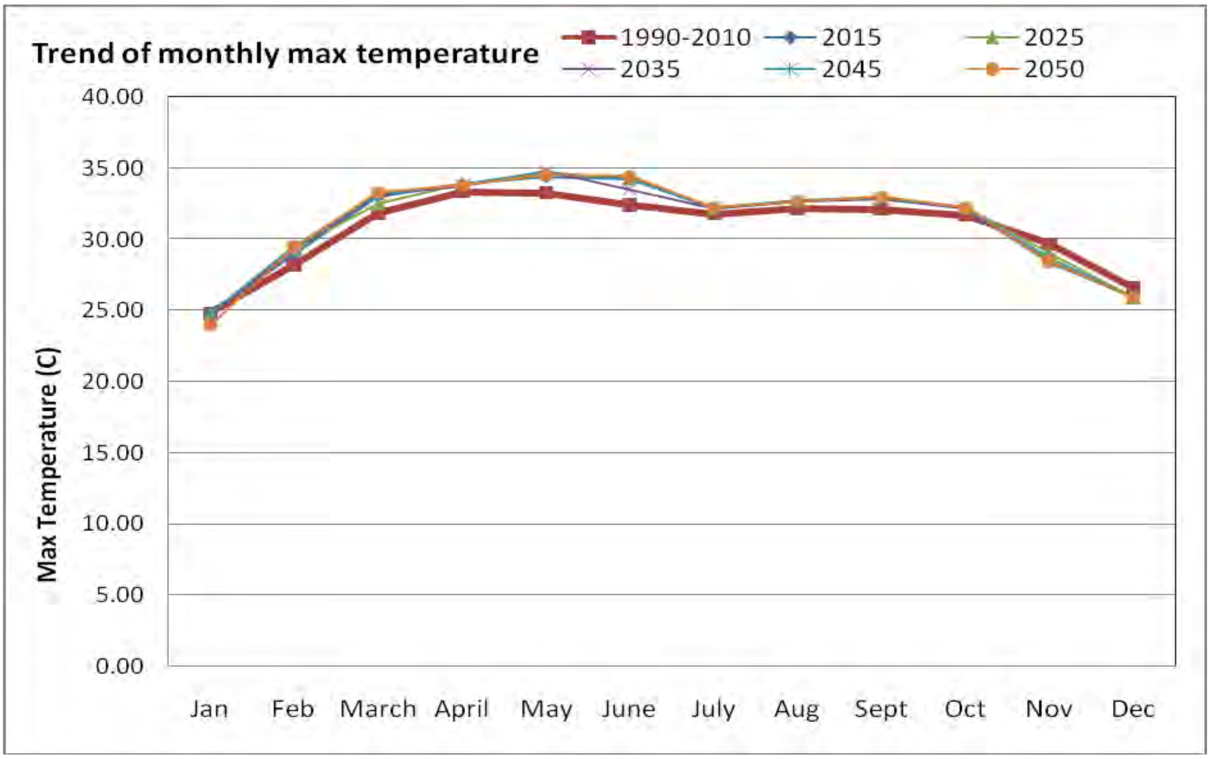

Figure 4.28 Trend of maximum temperature obtained from corrected PRECIS data for the future year

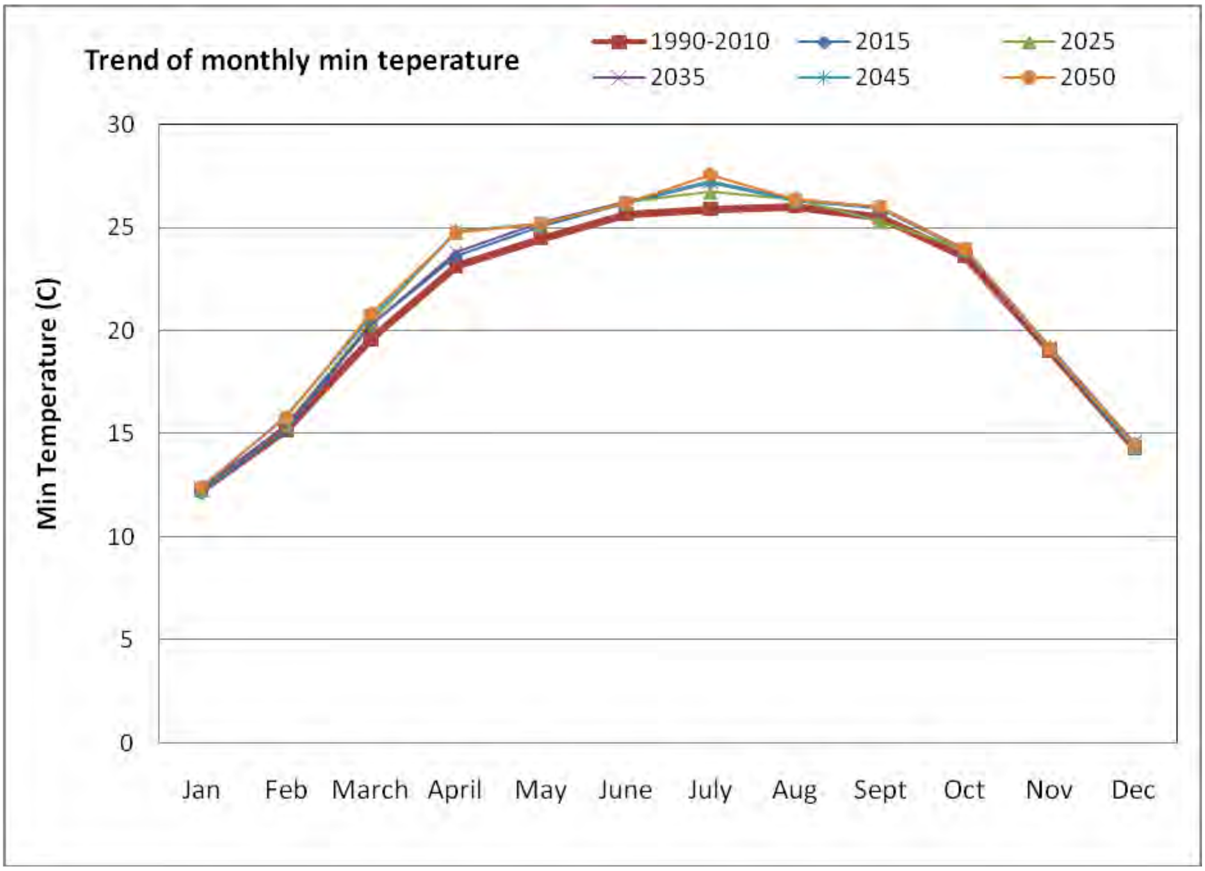

Figure 4.29 Trend of minimum temperature obtained from corrected PRECIS data for the future year

CHAPTER 5
CONCLUSION AND RECOMMENDATIONS

5.1 CONCLUSION

The main objective of the study is to determine the validation of PRECIS regional climatic model for climatic parameters rainfall and temperature in Bangladesh for recent year. PRECIS model outputs is analyzed from 1990-2010 for monthly rainfall and minimum and minimum temperature at seven observational sites throughout the country and compared with the surface observational data collected from the Bangladesh Meteorological Department.

Regional analysis with gridded observational data makes PRECIS overestimation in calculating rainfall at different regions of the country except at a few locations it underestimates. Annual rainfall averages from seven locations over Bangladesh provide reasonable validation of PRECIS in Bangladesh than regional variation. Regional biases are determined 2.5 mm/day and 1.7 mm/day at northeastern and southeastern side respectively and the value is underestimated and overestimated by PRECIS. In all seasons PRECIS model simulated values are very close with observational amounts whereas during the monsoon period model underestimates rainfall. Annual rainfall during 1990-2010 provides PRECIS overestimation considerably as 1.9 mm/day in 1994.

In determining temperature at different regions of the country, regional analysis with gridded observational data makes PRECIS underestimation except at some regions it overestimates for year 1990-2010. The minimum temperature data averages from all observational sites provide more reasonable validation of PRECIS in Bangladesh than maximum temperature. Annual biases are found 2.7 degree celsius in 1999 to 0.4 degree celsius in 2008 for maximum temperature, where 0.5 degree celsius in 2005 to 0.1 degree celsius in 1999 for minimum temperature. Therefore, PRECIS can be used to generate future climate scenarios and those scenarios can be used in rainfall and temperature forecasting with some tolerance of biases at different locations of Bangladesh.

PRECIS projected rainfall and temperature in 2015, 2025, 2035, 2045 and 2050 indicates that in Bangladesh rainfall and temperature will be increased throughout the country in future. The rate of increase in rainfall will vary from 1.7 to 5.8 mm/day in wet seasons and rate of decrease in rainfall will vary from 0.2 to 0.7 mm/day in dry seasons and respectively, whereas maximum and minimum temperature values vary by 1.7 to 2.0 degree celsius. This is the clear indication of global warming in coming years. This work decisively disclosed that the technique for annual forecasting of meteorological parameters like rainfall and temperature is acceptable in Bangladesh. PRECIS can be used for the key messages for stakeholders and policy and decision makers. Finally, PRECIS is adoptable in impact studies of future climate change in Bangladesh.

5.2 RECOMMENDATIONS

Based on the result and discussion the following recommendation are suggested for future investigation and study

- Seven locations are used in this study. These results suggest for extending the work for other locations of Bangladesh in a consecutive research project.
- High resolution and averages from a number of ensembles are suggested for the better projection of any meteorological parameters in application purposes.
- Assessment of temperature and rainfall are determined in this study. Assessment of other climatic parameters like relative humidity, wind speed etc can be determined with PRECIS data.
- In this work it is found that the simulation is not always in the same nature i.e., the bias is not systematic. So, average for long-term data may provide the reasonable validation.
- Till to date, there is no simulation technique which can be used with hundred percent accuracy. Therefore, this work strongly suggests applying the PRECIS outputs with proposed calibration and parallel consideration of other techniques.

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APPENDIX A: RAINFALL DATA

Table A1: OBSERVED DATA OF MONTHLY AVERAGE RAINFALL FOR STATION DHAKA

OBSERVED data
Station: Dhaka

Monthly Average Rainfall in mm/day

Year	Jan	Feb	March	April	May	June	July	Aug	Sept	Oct	Nov	Dec	avg.
1990	0.0	2.5	5.0	5.1	6.7	7.6	18.9	7.6	8.2	6.0	3.4	0.2	**5.9**
1991	0.9	0.6	1.5	1.8	17.4	10.7	10.1	9.7	23.1	12.5	0.5	3.5	**7.7**
1992	**0.0**	3.1	0.0	0.8	3.6	4.4	12.7	6.1	5.3	2.8	0.1	0.0	**3.2**
1993	0.0	3.6	2.9	3.8	18.5	16.8	13.9	14.4	13.9	7.2	0.6	0.0	**8.0**
1994	0.1	3.7	3.1	6.7	8.4	8.9	5.1	7.7	5.6	1.8	0.5	0.0	**4.3**
1995	0.3	2.1	0.0	2.9	8.8	7.9	11.0	12.0	6.8	2.9	3.7	0.0	**4.9**
1996	0.0	1.4	1.8	6.6	5.0	11.4	7.4	11.6	8.1	11.9	0.0	0.0	**5.4**
1997	0.1	0.5	2.0	4.4	5.0	8.3	18.0	7.2	14.7	1.0	0.0	0.7	**5.2**
1998	1.6	0.3	2.3	5.9	13.4	3.0	17.4	17.8	8.2	3.3	2.8	0.0	**6.3**
1999	0.0	0.0	0.0	0.7	14.3	11.6	17.9	9.2	12.0	11.8	0.4	0.0	**6.5**
2000	0.4	2.9	5.7	6.3	14.8	5.5	6.6	11.9	7.2	9.3	0.0	0.0	**5.9**
2001	0.0	0.1	1.1	1.5	13.4	12.9	6.7	6.8	7.0	5.5	0.6	0.0	**4.6**
2002	0.7	0.3	1.7	3.7	9.1	12.4	14.8	9.1	5.2	1.7	3.9	0.0	**5.2**
2003	0.0	1.7	2.7	4.1	4.7	15.8	6.2	6.6	8.8	4.5	0.0	1.5	**4.7**
2004	0.0	0.0	0.3	5.6	4.4	15.9	9.7	6.3	28.0	6.9	0.0	0.0	**6.4**
2005	0.0	0.2	2.1	3.0	9.7	8.6	17.8	12.0	17.1	13.9	0.1	0.0	**7.1**
2006	0.0	0.0	0.0	6.0	6.1	10.9	10.9	5.5	22.1	2.0	0.2	0.0	**5.3**
2007	0.0	2.1	0.4	5.4	6.2	20.9	25.0	16.2	6.0	10.7	3.7	0.0	**8.0**
2008	0.8	3.7	1.5	3.0	6.8	19.2	18.8	10.6	9.3	7.6	0.0	0.0	**6.8**
2009	0.0	0.1	1.3	0.5	5.6	5.7	21.9	14.2	9.9	2.5	0.1	0.0	**5.1**
2010	0.0	3.3	0.7	1.2	5.9	10.3	5.3	11.1	5.6	5.8	0.0	2.7	**4.3**
all year avg	**0.2**	**1.5**	**1.7**	**3.8**	**8.9**	**10.9**	**13.1**	**10.2**	**11.1**	**6.3**	**1.0**	**0.4**	

Table A2: PRECIS DATA OF MONTHLY AVERAGE RAINFALL FOR STATION DHAKA

PRECIS data Station: Dhaka

Monthly Average Rainfall in mm/day

Year	Jan	Feb	March	April	May	June	July	Aug	Sept	Oct	Nov	Dec	avg.
1990	0.2	2.5	1.3	5.6	7.1	12.6	13.5	9.9	6.2	6.5	1.6	0.6	**5.6**
1991	0.0	3.4	0.5	4.0	14.1	19.8	10.6	7.7	8.3	4.3	2.1	0.0	**6.2**
1992	0.0	2.4	0.5	3.9	8.6	13.6	8.0	6.7	9.4	6.8	1.8	0.3	**5.2**
1993	0.5	2.4	0.3	4.5	8.0	15.8	11.6	9.0	8.9	4.7	1.8	0.3	**5.6**
1994	0.6	3.8	0.9	6.0	11.8	10.8	13.1	11.2	9.9	5.8	1.6	0.4	**6.3**
1995	0.5	2.5	1.6	4.2	11.5	14.4	12.6	9.4	11.3	4.9	1.4	0.1	**6.2**
1996	0.0	2.6	0.3	4.1	6.6	21.0	16.4	9.0	12.2	5.6	1.9	0.0	**6.6**
1997	0.0	2.4	1.4	4.0	12.3	15.4	14.9	8.9	6.5	4.4	1.5	0.5	**6.0**
1998	0.5	2.4	0.0	5.5	9.0	11.2	10.9	8.8	10.5	4.7	2.1	0.0	**5.5**
1999	0.6	4.5	0.9	4.4	7.6	13.1	15.2	12.7	6.2	6.3	3.3	1.2	**6.3**
2000	0.3	2.6	0.2	3.9	6.2	10.6	10.9	12.1	9.3	8.3	1.4	0.0	**5.5**
2001	0.1	2.4	0.0	3.9	8.4	14.8	9.2	10.9	8.5	3.7	1.8	0.1	**5.3**
2002	0.0	2.5	0.0	4.1	6.8	12.4	15.3	7.7	7.4	5.4	2.2	0.0	**5.3**
2003	1.0	2.4	11.3	4.9	11.3	13.2	15.3	8.6	7.7	3.6	1.8	0.4	**6.8**
2004	0.1	2.6	3.8	7.6	15.9	13.9	11.0	9.5	10.0	5.5	2.0	0.3	**6.8**
2005	0.0	5.2	1.0	5.2	8.9	11.9	14.1	8.2	8.2	4.7	1.5	0.1	**5.8**
2006	0.0	2.4	0.5	4.1	15.6	10.7	9.8	7.7	8.4	4.2	2.2	0.0	**5.5**
2007	0.0	2.6	0.9	3.9	9.4	12.3	13.6	8.4	7.3	4.4	1.5	0.0	**5.4**
2008	0.1	2.4	7.5	4.0	6.4	16.1	10.9	7.6	10.1	8.3	2.3	0.1	**6.3**
2009	0.1	2.4	0.2	4.1	8.5	18.1	10.0	8.9	7.5	4.3	2.7	0.0	**5.6**
2010	0.0	2.5	0.4	4.0	7.9	9.1	12.0	9.7	9.6	4.5	3.1	0.4	**5.3**
all year avg	**0.22**	**2.81**	**1.60**	**4.56**	**9.61**	**13.85**	**12.33**	**9.16**	**8.73**	**5.28**	**1.98**	**0.23**	**5.9**

Table A3: OBSERVED DATA OF MONTHLY AVERAGE RAINFALL FOR ALL STATION

OBSERVED data   Station: All station

Monthly Average Rainfall in mm/day

Station	Jan	Feb	March	April	May	June	July	Aug	Sept	Oct	Nov	Dec	observed avg.
Dhaka	0.2	1.5	1.7	3.8	8.9	10.9	13.1	10.2	11.1	6.3	1.0	0.4	**5.8**
Khulna	0.5	2.6	1.6	2.1	6.3	9.8	11.3	9.7	10.2	5.0	1.2	0.2	**5.0**
Chittagong	0.3	1.8	1.6	3.6	11.8	19.5	23.0	15.9	9.6	7.3	1.9	0.4	**8.1**
Rangpur	0.3	0.8	0.9	4.3	9.1	15.5	13.5	11.2	12.0	7.0	0.3	0.2	**6.2**
Sylhet	0.2	2.8	4.4	12.1	18.1	26.0	24.0	19.5	16.6	5.8	0.9	0.3	**10.9**
Rajshahi	0.2	1.0	0.72	1.4	4.6	8.4	10.3	7.5	10.0	4.0	0.4	0.2	**4.1**
Barishal	0.4	1.8	1.9	2.9	6.4	13.1	13.9	10.4	9.6	6.5	1.6	0.1	**5.7**
all station avg	**0.3**	**1.8**	**1.8**	**4.3**	**9.3**	**14.7**	**15.6**	**12.0**	**11.3**	**6.0**	**1.0**	**0.3**	

Table A4: PRECIS DATA OF MONTHLY AVERAGE RAINFALL FOR ALL STATION

PRECIS data   Station: All station

Monthly Average Rainfall in mm/day

Station	Jan	Feb	March	April	May	June	July	Aug	Sept	Oct	Nov	Dec	precis avg.
Dhaka	0.2	2.8	1.6	4.6	9.6	13.8	12.3	9.2	8.7	5.3	2.0	0.2	**5.9**
Khulna	0.4	2.7	0.9	4.4	8.3	14.5	13.8	8.9	8.4	4.9	1.8	0.1	**5.8**
Chittagong	0.2	2.8	1.1	5.0	10.1	15.3	14.0	10.1	9.2	5.3	2.0	0.3	**6.3**
Rangpur	0.2	2.7	1.0	4.3	9.2	14.0	14.3	12.4	10.7	5.6	1.9	0.2	**6.4**
Sylhet	0.3	3.1	6.8	10.5	19.1	16.2	13.9	11.3	10.9	6.8	2.3	0.3	**8.4**
Rajshahi	0.1	2.7	0.7	4.2	7.7	13.4	13.4	10.3	9.0	4.6	2.3	0.2	**5.7**
Barishal	0.3	2.8	1.0	4.6	9.2	17.0	17.7	12.8	11.3	5.7	2.0	0.1	**7.0**
all station avg	**0.2**	**2.8**	**1.9**	**5.4**	**10.5**	**14.9**	**14.2**	**10.7**	**9.8**	**5.5**	**2.0**	**0.2**	

Table A5: OBSERVED DATA OF YEARLY AVERAGE RAINFALL FOR ALL STATION

OBSERVED data Station: all station

Monthly Average Rainfall in mm/day

Station	Dhaka	Khulna	Chittag	Rangpur	Sylhet	Rajshahi	Barishal	**observed all station avg.**
1990	5.9	5.6	8.0	7.1	12.1	5.0	6.8	**7.2**
1991	7.7	4.9	8.4	6.2	12.8	4.1	6.3	**7.2**
1992	3.2	2.3	6.6	1.6	9.7	2.4	4.2	**4.3**
1993	8.0	6.2	9.5	7.4	13.3	4.5	7.2	**8.0**
1994	4.3	3.1	6.1	3.6	9.9	3.3	4.8	**5.0**
1995	4.9	6.0	6.7	6.8	10.5	4.0	6.4	**6.5**
1996	5.4	3.9	8.3	5.4	11.0	3.5	4.9	**6.1**
1997	5.2	4.9	8.4	5.3	9.9	5.7	4.8	**6.3**
1998	6.3	5.7	10.8	6.6	12.0	4.2	8.0	**7.7**
1999	6.5	4.7	8.9	8.1	9.0	5.0	5.4	**6.8**
2000	5.9	4.6	9.6	4.8	12.9	4.8	4.7	**6.8**
2001	4.6	4.7	6.1	6.9	9.7	3.7	6.0	**5.9**
2002	5.2	7.2	7.6	8.7	10.2	4.0	7.0	**7.1**
2003	4.7	4.3	7.7	6.4	9.5	3.8	4.8	**5.9**
2004	6.4	5.4	8.1	7.4	11.5	4.9	6.8	**7.2**
2005	7.1	5.5	6.5	7.8	11.7	3.8	5.4	**6.8**
2006	5.3	5.6	6.5	4.4	9.8	3.1	5.5	**5.8**
2007	8.0	6.0	12.2	5.6	11.9	4.7	6.7	**7.9**
2008	6.8	4.5	8.4	5.1	9.3	3.6	5.2	**6.1**
2009	5.1	5.0	9.2	6.1	8.9	2.9	4.7	**6.0**
2010	4.3	4.5	5.8	6.5	13.5	4.4	4.3	**6.2**
all year avg	**5.8**	**5.0**	**8.1**	**6.1**	**10.9**	**4.1**	**5.7**	**6.5**

Table A6: PRECIS DATA OF YEARLY AVERAGE RAINFALL FOR ALL STATION

PRECIC data Station: all station

Monthly Average Rainfall in mm/day

Station	Dhaka	Khulna	Chittag	Rangpur	Sylhet	Rajshahi	Barishal	**precis all station avg.**
1990	5.62	5.38	6.02	5.95	9.07	5.55	6.45	**6.3**
1991	6.2	6.4	6.1	6.5	7.5	6.4	8.1	**6.8**
1992	5.2	5.2	5.2	8.7	6.4	5.9	6.6	**6.2**
1993	5.6	6.4	6.2	6.0	7.6	5.8	8.3	**6.6**
1994	6.3	5.8	6.7	6.4	10.1	5.7	7.3	**6.9**
1995	6.2	5.5	6.2	5.9	9.7	5.5	6.4	**6.5**
1996	6.6	5.8	6.4	8.2	9.3	6.8	7.4	**7.2**
1997	6.0	5.7	6.2	6.4	7.5	5.9	7.1	**6.4**
1998	5.5	5.1	5.8	6.2	9.5	5.5	6.3	**6.3**
1999	6.3	5.7	6.6	5.6	8.7	5.8	6.6	**6.5**
2000	5.5	5.8	6.1	7.1	6.6	6.0	6.3	**6.2**
2001	5.3	5.8	6.2	6.3	6.4	5.7	7.1	**6.1**
2002	5.3	5.7	6.0	5.5	6.6	5.3	6.7	**5.9**
2003	6.8	6.3	6.8	5.9	9.3	5.4	7.9	**6.9**
2004	6.8	6.2	7.0	6.4	14.0	5.9	7.0	**7.6**
2005	5.8	5.6	6.0	5.9	7.2	5.6	6.8	**6.1**
2006	5.5	5.2	6.3	6.2	10.3	5.4	6.5	**6.5**
2007	5.4	5.5	5.5	6.1	7.2	5.7	6.7	**6.0**
2008	6.3	6.5	7.9	6.4	8.6	5.6	8.4	**7.1**
2009	5.6	6.0	7.3	6.3	8.6	5.4	7.6	**6.7**
2010	5.3	5.3	5.4	6.0	7.0	5.5	6.4	**5.8**
all year avg	**5.9**	**5.8**	**6.3**	**6.4**	**8.4**	**5.7**	**7.0**	**6.5**

Table A7: MONTHLY AVERAGE RAINFALL FOR THE FUTURE YEAR

Monthly Average Rainfall in mm/day

Year	**Jan**	**Feb**	**March**	**April**	**May**	**June**	**July**	**Aug**	**Sept**	**Oct**	**Nov**	**Dec**
2015	0.38	2.68	2.51	4.54	9.67	14.66	15.92	14.53	11.83	5.40	1.34	0.45
2025	0.38	3.12	2.59	4.55	9.87	14.81	16.03	14.75	11.43	5.24	1.31	0.43
2035	0.38	3.09	2.66	4.54	9.88	14.66	16.11	14.05	11.79	5.40	1.34	0.43
2045	0.38	3.12	2.40	4.55	9.86	14.79	16.51	15.32	11.69	5.40	1.80	0.44
2050	0.38	3.08	2.65	4.56	9.59	14.65	16.25	16.47	11.72	5.58	1.34	0.45
all year avg	**0.38**	**3.02**	**2.56**	**4.55**	**9.78**	**14.71**	**16.16**	**15.02**	**11.69**	**5.41**	**1.43**	**0.44**

APPENDIX B: MAXIMUM TEMPERATURE DATA

Table B1: OBSERVED DATA OF MONTHLY AVERAGE MAXIMUM TEMPERATURE FOR STATION DHAKA

OBSERVED data
Station: Dhaka

Monthly Maximum Temperature in degree celsius

Year	Jan	Feb	March	April	May	June	July	Aug	Sept	Oct	Nov	Dec	avg.
1990	25.4	27.6	28.7	31.9	32.8	32.3	31.0	32.0	32.0	30.2	29.8	26.5	**30.0**
1991	24.2	29.0	32.5	33.8	31.8	31.5	32.1	31.9	30.6	31.2	28.3	24.9	**30.1**
1992	**23.9**	25.6	32.4	36.1	33.5	33.7	31.6	31.9	32.2	31.7	29.4	26.0	**30.7**
1993	24.4	28.9	30.9	33.0	31.5	31.7	31.4	31.1	31.5	31.5	29.5	27.1	**30.2**
1994	26.2	26.7	32.4	33.2	33.6	32.0	32.1	32.0	32.9	32.8	29.9	27.7	**31.0**
1995	25.3	28.1	33.7	36.4	34.9	32.8	31.7	32.4	32.4	33.0	29.8	27.0	**31.5**
1996	25.8	29.8	34.3	34.9	34.7	32.5	32.8	31.8	33.8	32.4	30.3	27.3	**31.7**
1997	25.0	27.9	33.2	31.0	33.6	33.3	31.8	32.7	31.5	32.2	30.4	24.9	**30.6**
1998	22.8	28.4	30.8	32.7	33.3	34.3	31.6	31.8	32.5	33.2	30.7	28.2	**30.9**
1999	27.0	31.4	34.9	36.0	32.7	32.5	31.3	31.7	31.6	31.8	30.4	27.2	**31.5**
2000	24.6	25.6	30.9	32.8	32.3	32.5	31.8	32.2	32.0	31.2	29.6	26.3	**30.1**
2001	24.3	28.8	32.7	34.4	31.9	31.0	31.7	32.4	31.9	31.8	28.9	25.9	**30.5**
2002	25.5	28.7	31.8	32.1	32.1	31.7	31.6	31.5	32.4	31.5	28.9	26.2	**30.3**
2003	21.6	28.1	30.1	34.0	33.9	31.4	32.5	32.5	31.7	31.2	29.8	26.1	**30.2**
2004	23.4	28.4	32.7	32.6	35.2	32.2	31.5	32.3	30.4	31.0	29.5	27.0	**30.5**
2005	24.4	29.2	32.3	34.4	33.2	33.4	31.4	32.0	32.8	30.5	29.1	27.1	**30.8**
2006	25.2	31.4	33.1	33.7	33.8	32.4	32.3	32.5	31.9	32.4	29.7	27.0	**31.3**
2007	24.4	27.2	31.3	33.7	34.7	32.5	31.4	32.5	32.1	31.5	29.1	25.8	**30.5**
2008	24.6	26.2	31.6	34.5	34.7	32.5	31.7	32.0	32.6	31.4	29.7	25.6	**30.6**
2009	25.9	29.8	33.4	35.6	34.6	34.5	32.3	32.5	32.5	32.3	30.2	26.1	**31.6**
2010	23.7	29.0	34.1	35.5	34.4	33.1	33.2	33.2	32.5	32.4	30.1	26.1	**31.4**
all year avg	**24.7**	**28.4**	**32.3**	**33.9**	**33.5**	**32.6**	**31.9**	**32.1**	**32.1**	**31.8**	**29.7**	**26.5**	

Table B2: PRECIS DATA OF MONTHLY AVERAGE MAXIMUM TEMPERATURE FOR STATION DHAKA

PRECIS data Station: Dhaka

Monthly Maximum Temperature in degree celsius

Year	Jan	Feb	March	April	May	June	July	Aug	Sept	Oct	Nov	Dec	avg.
1990	19.6	28.0	34.7	35.0	33.4	33.1	32.4	33.6	30.5	29.8	23.2	23.1	**29.7**
1991	21.9	25.8	34.7	40.0	33.4	34.9	33.6	32.5	30.9	30.4	24.2	21.8	**30.3**
1992	**23.4**	27.3	32.0	36.7	35.4	32.2	31.9	33.7	31.3	31.1	24.8	22.6	**30.2**
1993	21.1	26.7	31.9	31.4	35.1	36.4	32.2	32.2	31.6	29.6	24.8	22.5	**29.6**
1994	23.0	26.7	33.2	39.0	40.4	33.1	32.9	32.7	31.7	29.3	24.2	20.1	**30.5**
1995	20.4	25.6	33.3	39.7	35.0	34.5	31.2	32.9	30.8	32.0	26.6	22.5	**30.4**
1996	22.8	26.8	33.8	43.3	40.0	37.5	33.7	32.3	33.6	29.6	25.3	19.1	**31.5**
1997	19.9	25.5	35.0	35.9	35.3	31.6	34.0	34.0	32.6	30.7	25.8	19.7	**30.0**
1998	20.5	29.7	37.0	32.6	33.7	31.6	32.4	31.7	31.9	29.0	24.9	21.9	**29.7**
1999	20.1	27.2	32.4	31.2	31.5	32.4	32.5	32.0	32.6	28.3	24.3	24.1	**29.0**
2000	21.8	25.7	38.5	33.2	41.0	31.4	30.8	32.2	32.6	29.3	25.2	20.9	**30.2**
2001	22.4	26.5	34.7	37.8	38.1	35.4	32.5	34.3	32.5	32.3	24.4	20.9	**31.0**
2002	21.4	24.3	35.0	44.7	37.8	36.5	34.1	32.1	32.7	30.8	24.7	19.7	**31.1**
2003	22.9	27.2	36.7	37.2	34.5	32.1	33.1	34.0	31.3	31.1	26.6	22.1	**30.7**
2004	20.7	24.6	36.5	41.0	39.6	33.8	32.8	33.4	33.6	30.9	27.3	23.9	**31.5**
2005	21.5	25.9	29.2	37.8	32.0	35.3	32.6	32.4	31.7	31.8	28.3	24.2	**30.2**
2006	23.5	29.2	31.8	39.3	36.3	34.9	32.4	32.8	33.6	31.0	29.8	24.8	**31.6**
2007	22.7	25.4	36.2	38.7	39.4	34.8	33.4	33.4	30.8	29.4	24.3	22.3	**30.9**
2008	23.9	29.3	37.5	43.9	34.9	37.9	32.4	32.5	32.2	30.8	24.5	18.9	**31.6**
2009	24.2	29.5	32.1	36.3	36.6	35.8	33.7	34.0	33.9	31.4	27.1	24.1	**31.6**
2010	25.2	30.1	34.3	35.2	34.5	34.3	33.2	32.9	32.5	31.3	26.2	23.0	**31.1**
all year avg	**22.1**	**27.0**	**34.3**	**37.6**	**36.1**	**34.3**	**32.7**	**32.9**	**32.1**	**30.5**	**25.5**	**22.0**	

Table B3: OBSERVED DATA OF MONTHLY AVERAGE MAXIMUM TEMPERATURE FOR ALL STATION

OBSERVED data Station: All station

Monthly Maximum Temperature in degree celsius

Station	Jan	Feb	March	April	May	June	July	Aug	Sept	Oct	Nov	Dec	observed avg.
Dhaka	24.7	28.4	32.3	33.9	33.5	32.6	31.9	32.1	32.1	31.8	29.7	26.5	**30.8**
Khulna	25.3	29.0	32.8	34.8	34.8	33.3	32.2	32.3	32.5	32.2	30.0	26.9	**31.4**
Chittagong	26.2	28.9	31.2	32.3	32.6	31.8	31.1	31.6	32.0	32.1	30.4	27.7	**30.7**
Rangpur	22.9	26.4	30.2	31.5	31.9	31.8	31.9	32.3	31.8	30.8	28.7	25.4	**29.6**
Sylhet	25.6	28.0	30.8	31.2	31.3	31.3	31.8	32.3	32.0	31.6	29.7	26.9	**30.2**
Rajshahi	23.8	28.1	32.9	36.0	35.2	34.0	32.5	32.9	32.6	31.7	29.4	25.9	**31.2**
Barishal	25.4	28.8	32.3	33.6	33.5	32.2	31.3	31.6	31.8	31.8	29.9	27.0	**30.8**
all station avg	**24.8**	**28.2**	**31.8**	**33.3**	**33.3**	**32.4**	**31.8**	**32.2**	**32.1**	**31.7**	**29.7**	**26.6**	

Table B4: PRECIS DATA OF MONTHLY AVERAGE MAXIMUM TEMPERATURE FOR ALL STATION

PRECIS data Station: All station

Monthly Maximum Temperature in degree celsius

Station	Jan	Feb	March	April	May	June	July	Aug	Sept	Oct	Nov	Dec	precis avg.
Dhaka	22.1	27.0	34.3	37.6	36.1	34.3	32.7	32.9	32.1	30.5	25.5	22.0	**30.6**
Khulna	23.3	28.5	36.0	39.4	38.3	35.3	31.5	31.4	31.3	30.6	26.1	23.1	**31.2**
Chittagong	19.9	23.4	27.5	30.1	31.3	30.4	29.0	28.8	28.6	27.5	23.9	20.5	**26.7**
Rangpur	21.7	27.8	34.5	36.8	33.3	32.3	32.5	32.3	31.2	28.9	24.4	21.4	**29.8**
Sylhet	21.1	24.5	28.9	30.8	30.8	31.8	32.4	32.4	31.2	29.3	25.5	21.7	**28.4**
Rajshahi	23.2	29.2	36.9	40.4	38.1	34.7	32.3	32.3	31.5	29.4	24.7	22.3	**31.2**
Barishal	23.4	28.4	35.2	38.2	37.3	34.8	31.6	31.5	31.4	30.7	26.3	23.2	**31.0**
all station avg	**22.1**	**26.9**	**33.3**	**36.2**	**35.0**	**33.4**	**31.7**	**31.7**	**31.1**	**29.6**	**25.2**	**22.0**	**29.8**

Table B5: OBSERVED DATA OF YEARLY AVERAGE MAXIMUM TEMPERATURE FOR ALL STATION

OBSERVED data Station: all station
Monthly Maximum Temperature in degree celsius

Station	Dhaka	Khulna	Chittag	Rangpur	Sylhet	Rajshahi	Barishal	**observed all station avg.**
1990	30.0	30.9	30.0	29.2	29.6	30.9	30.0	**30.1**
1991	30.1	31.1	30.2	29.4	29.2	31.4	30.3	**30.2**
1992	30.7	31.2	29.9	29.6	29.6	31.6	30.5	**30.4**
1993	30.2	31.0	30.0	29.3	29.3	31.1	30.4	**30.2**
1994	31.0	31.4	30.5	30.0	30.2	31.2	30.6	**30.7**
1995	31.5	31.4	30.7	29.7	30.1	31.3	30.7	**30.8**
1996	31.7	31.7	30.9	30.1	30.3	31.6	31.2	**31.1**
1997	30.6	31.0	30.4	29.3	30.2	30.6	30.6	**30.4**
1998	30.9	31.2	31.1	29.6	30.1	31.0	30.8	**30.6**
1999	31.5	31.8	31.3	30.1	31.2	31.7	31.2	**31.3**
2000	30.1	31.6	30.8	29.5	29.4	30.7	30.7	**30.4**
2001	30.5	31.5	30.9	30.1	30.5	31.3	30.8	**30.8**
2002	30.3	31.6	31.1	29.3	30.3	31.0	30.8	**30.6**
2003	30.2	31.3	31.0	29.1	30.3	30.9	30.5	**30.5**
2004	30.5	31.1	30.8	29.2	30.2	31.2	30.5	**30.5**
2005	30.8	31.3	31.3	29.5	30.4	31.4	31.1	**30.8**
2006	31.3	31.7	31.6	29.9	31.1	31.8	31.3	**31.2**
2007	30.5	30.8	30.9	29.5	30.1	31.0	30.5	**30.5**
2008	30.6	31.0	29.5	29.3	30.3	31.0	30.6	**30.3**
2009	31.6	32.0	30.3	30.1	31.3	32.0	31.5	**31.3**
2010	31.4	32.2	30.6	30.6	30.9	31.7	31.4	**31.2**
all year avg	**30.8**	**31.4**	**30.7**	**29.6**	**30.2**	**31.2**	**30.8**	**30.7**

Table B6: PRECIS DATA OF YEARLY AVERAGE MAXIMUM TEMPERATURE FOR ALL STATION

PRECIC data Station: all station
Monthly Maximum Temperature in degree celsius

Station	Dhaka	Khulna	Chittag	Rangpur	Sylhet	Rajshahi	Barishal	**precis all station avg.**
1990	29.7	30.0	26.2	29.0	28.0	30.3	29.8	**29.0**
1991	30.3	30.6	26.5	30.0	28.2	30.7	30.4	**29.5**
1992	30.2	30.5	26.9	29.8	28.6	30.8	30.4	**29.6**
1993	29.6	30.7	26.4	28.8	27.3	30.7	30.2	**29.1**
1994	30.5	31.0	26.1	30.0	28.2	31.3	30.7	**29.7**
1995	30.4	31.0	26.1	29.1	27.4	31.0	30.8	**29.4**
1996	31.5	32.2	27.3	30.5	28.5	32.3	31.9	**30.6**
1997	30.0	30.3	26.4	28.7	28.4	30.2	30.2	**29.2**
1998	29.7	30.2	26.6	28.8	28.3	29.8	30.1	**29.1**
1999	29.0	29.8	26.1	28.2	27.4	29.3	29.6	**28.5**
2000	30.2	30.9	26.7	29.7	28.2	30.8	30.8	**29.6**
2001	31.0	32.1	27.2	30.2	28.6	31.6	31.8	**30.4**
2002	31.1	32.0	27.3	30.0	28.9	31.2	31.9	**30.3**
2003	30.7	30.9	26.7	29.5	28.9	31.0	30.9	**29.8**
2004	31.5	31.9	26.7	30.6	28.9	32.1	31.7	**30.5**
2005	30.2	31.2	26.4	30.0	28.0	31.3	30.9	**29.7**
2006	31.6	32.6	27.0	30.6	28.6	32.8	32.2	**30.8**
2007	30.9	31.3	27.1	30.1	28.6	31.7	31.1	**30.1**
2008	31.6	32.5	27.2	30.8	28.8	32.6	32.0	**30.8**
2009	31.6	32.2	27.5	30.1	29.1	32.2	32.0	**30.7**
2010	31.1	32.1	27.1	30.3	28.5	32.3	31.7	**30.4**
all year avg	**30.6**	**31.2**	**26.7**	**29.8**	**28.4**	**31.2**	**31.0**	**29.8**

Table B7: MONTHLY AVERAGE MAXIMUM TEMPERATURE FOR THE FUTURE YEAR

Monthly Maximum Temperature in degree celsius

Year	**Jan**	**Feb**	**March**	**April**	**May**	**June**	**July**	**Aug**	**Sept**	**Oct**	**Nov**	**Dec**
2015	24.79	29.00	33.01	33.87	34.38	34.23	32.20	32.67	32.87	32.17	28.42	25.95
2025	24.77	29.37	32.47	33.86	34.55	34.27	32.19	32.71	32.96	32.23	29.01	25.95
2035	24.77	29.24	33.20	33.79	34.85	33.57	32.22	32.73	32.86	32.18	28.51	25.95
2045	24.77	29.50	33.15	33.87	34.69	34.19	32.26	32.71	32.86	32.25	28.73	25.95
2050	23.97	29.48	33.32	33.79	34.54	34.43	32.23	32.63	32.96	32.22	28.46	25.95
all year avg	**24.61**	**29.32**	**33.03**	**33.84**	**34.60**	**34.14**	**32.22**	**32.69**	**32.90**	**32.21**	**28.62**	**25.95**

APPENDIX C: MINIMUM TEMPERATURE DATA

Table C1: OBSERVED DATA OF MONTHLY AVERAGE MINIMUM TEMPERATURE FOR STATION DHAKA

OBSERVED data
Station: Dhaka

Monthly Minimum Temperature in degree celsius

Year	Jan	Feb	March	April	May	June	July	Aug	Sept	Oct	Nov	Dec	avg.
1990	14.2	17.3	19.7	22.7	24.9	26.7	26.0	26.8	26.3	23.6	21.6	16.0	**22.2**
1991	13.7	17.4	21.8	24.4	23.3	25.9	26.7	26.4	25.7	24.6	19.1	15.1	**22.0**
1992	**13.4**	15.9	21.9	25.0	24.2	26.5	25.9	26.4	26.1	23.8	18.6	12.4	**21.7**
1993	11.9	16.5	18.8	22.7	23.5	25.7	26.1	26.5	25.6	23.8	19.2	13.8	**21.2**
1994	13.0	14.0	21.0	22.8	25.2	26.4	26.7	26.5	25.8	23.4	18.8	12.5	**21.3**
1995	11.4	15.5	19.2	24.6	26.3	26.9	26.4	26.4	26.3	24.1	19.9	13.3	**21.7**
1996	12.2	15.1	22.1	24.0	25.8	25.4	26.7	26.2	26.2	23.0	18.2	14.0	**21.6**
1997	11.5	14.3	21.2	21.2	24.6	25.8	26.4	26.6	25.5	22.3	18.9	14.4	**21.1**
1998	12.7	15.9	18.4	22.9	25.3	28.1	26.4	26.8	26.3	25.4	20.6	14.9	**22.0**
1999	12.7	16.3	20.8	26.0	25.1	26.5	26.2	26.4	25.9	24.4	19.0	15.0	**22.0**
2000	14.0	16.1	20.6	23.5	24.2	25.5	26.5	26.4	25.8	24.5	20.2	15.1	**21.9**
2001	13.0	16.8	20.7	24.7	24.1	25.5	25.9	25.3	24.3	22.9	19.3	14.9	**21.5**
2002	14.7	16.6	20.2	22.4	23.9	25.8	25.1	25.2	25.3	23.1	19.8	16.1	**21.5**
2003	11.6	16.8	19.4	24.1	24.3	25.8	26.4	26.6	24.9	25.1	19.4	16.5	**21.7**
2004	14.0	15.8	22.3	23.9	26.4	25.0	25.4	26.5	25.5	23.4	18.6	16.4	**21.9**
2005	14.1	18.1	22.5	24.1	24.1	26.8	25.8	26.6	26.0	24.4	19.8	15.7	**22.3**
2006	13.4	19.3	21.8	23.8	25.0	26.1	26.7	26.5	25.8	24.7	19.9	15.9	**22.4**
2007	12.3	16.6	19.5	23.7	25.8	25.5	25.8	26.4	26.5	23.8	19.9	15.0	**21.7**
2008	14.6	15.1	21.9	24.5	24.9	26.3	26.3	26.5	26.2	23.9	19.0	17.0	**22.2**
2009	14.8	17.1	21.4	25.9	25.1	26.7	26.8	26.4	26.3	24.3	20.2	15.4	**22.5**
2010	12.8	16.1	23.3	26.4	26.0	26.7	27.5	27.0	26.6	25.1	20.9	15.5	**22.8**
all year avg	**13.1**	**16.3**	**20.9**	**24.0**	**24.9**	**26.2**	**26.3**	**26.4**	**25.9**	**24.0**	**19.6**	**15.0**	

Table C2: PRECIS DATA OF MONTHLY AVERAGE MINIMUM TEMPERATURE FOR STATION DHAKA

PRECIS data Station: Dhaka

Monthly Minimum Temperature in degree celsius

Year	Jan	Feb	March	April	May	June	July	Aug	Sept	Oct	Nov	Dec	avg.
1990	7.8	11.4	22.3	25.2	29.3	26.5	25.7	25.8	25.2	23.2	16.5	11.5	**20.9**
1991	6.4	14.4	22.0	25.9	26.3	25.7	25.8	25.6	25.3	22.5	19.0	8.5	**20.6**
1992	**6.6**	12.6	22.5	25.6	27.4	27.5	26.3	26.1	25.0	22.3	13.6	9.8	**20.4**
1993	7.5	9.2	19.6	26.9	28.2	26.4	25.9	25.4	24.3	21.9	16.0	12.7	**20.3**
1994	11.5	11.3	13.2	26.5	27.8	29.7	26.7	26.2	25.5	22.5	13.7	9.5	**20.3**
1995	7.6	11.7	20.0	27.5	27.2	27.4	26.2	25.6	25.6	22.1	16.1	8.6	**20.5**
1996	7.4	12.6	20.2	28.3	26.9	26.1	25.9	25.4	24.8	23.1	14.6	6.1	**20.1**
1997	7.8	10.1	18.8	26.4	27.7	28.2	26.5	25.9	25.6	21.6	14.1	9.4	**20.2**
1998	9.3	11.2	22.9	28.7	26.6	27.7	26.6	25.9	25.7	21.9	14.7	8.0	**20.8**
1999	8.6	13.5	18.7	25.3	29.0	28.4	26.9	27.1	26.2	24.5	14.7	10.5	**21.1**
2000	10.8	10.5	19.3	28.3	28.2	28.8	27.2	26.5	26.1	23.0	14.7	7.8	**20.9**
2001	9.2	10.5	21.1	25.9	27.2	26.2	26.3	26.3	25.5	21.8	15.8	10.3	**20.5**
2002	6.3	10.4	19.8	28.4	28.7	27.3	26.5	26.0	25.8	21.4	15.2	10.4	**20.5**
2003	9.9	15.9	22.1	26.1	26.7	27.8	26.3	26.2	25.1	23.9	15.6	11.7	**21.5**
2004	10.0	15.3	21.5	26.5	27.9	28.2	26.5	26.3	25.7	20.7	15.5	11.5	**21.3**
2005	8.1	12.4	20.3	25.8	29.0	27.9	26.6	26.5	25.5	21.4	13.6	9.5	**20.6**
2006	7.1	15.1	24.9	29.4	27.5	28.6	26.3	25.9	25.2	23.5	14.7	10.6	**21.6**
2007	11.5	16.8	20.6	25.5	27.7	28.0	26.6	26.4	25.8	21.8	13.7	8.4	**21.1**
2008	8.9	13.2	23.3	24.9	28.3	27.3	26.4	26.6	25.4	23.6	15.8	8.8	**21.0**
2009	9.3	14.3	21.4	26.9	27.7	27.8	26.6	26.2	26.1	21.9	15.2	8.6	**21.0**
2010	9.6	16.1	21.7	26.7	28.9	29.4	26.5	26.3	25.4	22.4	16.3	11.2	**21.7**
all year avg	**8.6**	**12.8**	**20.8**	**26.7**	**27.8**	**27.7**	**26.4**	**26.1**	**25.5**	**22.4**	**15.2**	**9.7**	

Table C3: OBSERVED DATA OF MONTHLY AVERAGE MINIMUM TEMPERATURE FOR ALL STATION

OBSERVED data Station: All station

Monthly Minimum Temperature in degree celsius

Station	Jan	Feb	March	April	May	June	July	Aug	Sept	Oct	Nov	Dec	observed avg.
Dhaka	13.1	16.3	20.9	24.0	24.9	26.2	26.3	26.4	25.9	24.0	19.6	15.0	**21.9**
Khulna	12.3	15.8	20.7	24.4	25.4	26.2	26.2	26.3	25.9	24.1	19.5	14.2	**21.7**
Chittagong	14.1	16.7	20.8	24.0	25.1	25.6	25.4	25.5	25.3	24.3	20.4	16.0	**21.9**
Rangpur	11.0	13.5	17.4	21.3	23.5	25.2	26.0	26.2	25.4	22.8	17.8	13.4	**20.3**
Sylhet	13.0	15.1	18.8	21.3	23.0	24.6	25.3	25.4	24.8	23.2	19.1	15.0	**20.7**
Rajshahi	10.4	13.2	18.0	23.0	24.5	25.9	26.1	26.2	25.6	23.0	17.7	12.8	**20.5**
Barishal	11.9	15.4	20.5	23.9	24.9	25.8	25.7	25.8	25.4	23.7	19.0	13.7	**21.3**
all station avg	**12.2**	**15.1**	**19.6**	**23.1**	**24.5**	**25.6**	**25.9**	**26.0**	**25.5**	**23.6**	**19.0**	**14.3**	

Table C4: PRECIS DATA OF MONTHLY AVERAGE MINIMUM TEMPERATURE FOR ALL STATION

PRECIS data Station: All station

Monthly Minimum Temperature in degree celsius

Station	Jan	Feb	March	April	May	June	July	Aug	Sept	Oct	Nov	Dec	precis avg.
Dhaka	8.6	12.8	20.8	26.7	27.8	27.7	26.4	26.1	25.5	22.4	15.2	9.7	**20.8**
Khulna	9.7	14.8	22.4	27.8	29.2	28.6	26.3	25.9	25.3	22.5	15.6	10.0	**21.5**
Chittagong	15.6	19.6	25.1	28.4	29.6	29.2	28.0	27.7	27.3	25.5	20.5	15.8	**24.4**
Rangpur	7.5	11.5	19.0	24.4	25.5	26.6	26.6	26.3	25.5	21.1	13.5	8.2	**19.6**
Sylhet	8.4	12.2	19.3	24.5	25.7	26.5	26.1	26.0	25.4	22.1	15.2	9.8	**20.1**
Rajshahi	9.0	13.0	20.4	26.5	28.1	28.1	26.4	26.1	25.4	21.6	14.4	9.3	**20.7**
Barishal	9.8	14.8	22.3	27.7	29.0	28.4	26.4	26.0	25.3	22.6	15.8	10.1	**21.5**
all station avg	**9.8**	**14.1**	**21.3**	**26.6**	**27.8**	**27.9**	**26.6**	**26.3**	**25.7**	**22.6**	**15.7**	**10.4**	

Table C5: OBSERVED DATA OF YEARLY AVERAGE MINIMUM TEMPERATURE FOR ALL STATION

OBSERVED data   Station: all station
Monthly Minimum Temperature in degree celsius

Station	Dhaka	Khulna	Chittag	Rangpur	Sylhet	Rajshahi	Barishal	**observed all station avg.**
1990	22.2	21.4	21.7	20.0	20.6	19.6	21.1	**21.0**
1991	22.0	21.7	22.0	19.9	19.9	19.8	21.3	**20.9**
1992	21.7	21.0	21.8	19.7	19.3	19.7	21.2	**20.6**
1993	21.2	21.4	21.0	19.9	20.3	20.1	20.9	**20.7**
1994	21.3	21.5	21.7	20.0	20.5	20.4	21.0	**20.9**
1995	21.7	21.5	22.3	20.1	20.8	20.6	21.1	**21.2**
1996	21.6	21.3	22.1	20.1	20.7	20.5	21.2	**21.1**
1997	21.1	20.9	21.5	19.6	20.1	20.2	20.6	**20.6**
1998	22.0	22.1	22.4	20.5	21.0	21.1	21.2	**21.5**
1999	22.0	21.9	22.2	20.7	21.3	21.1	21.3	**21.5**
2000	21.9	21.3	21.1	20.1	20.5	20.6	20.9	**20.9**
2001	21.5	21.8	21.4	20.3	20.9	20.6	20.9	**21.1**
2002	21.5	21.9	22.0	20.5	20.8	20.7	21.3	**21.2**
2003	21.7	22.0	21.9	20.4	20.8	20.7	21.6	**21.3**
2004	21.9	22.1	21.9	20.4	21.0	20.7	21.6	**21.4**
2005	22.3	22.4	22.4	20.5	21.0	21.0	21.9	**21.6**
2006	22.4	22.4	22.3	20.8	21.4	20.9	21.9	**21.7**
2007	21.7	21.9	21.8	20.6	20.8	20.6	21.4	**21.2**
2008	22.2	22.2	22.1	20.6	21.0	20.7	21.6	**21.5**
2009	22.5	22.4	22.2	20.7	21.3	20.7	21.9	**21.7**
2010	22.8	21.6	22.5	20.9	21.2	20.9	21.5	**21.6**
all year avg	**21.9**	**21.7**	**21.9**	**20.3**	**20.7**	**20.5**	**21.3**	**21.2**

Table C6: PRECIS DATA OF YEARLY AVERAGE MINIMUM TEMPERATURE FOR ALL STATION

PRECIC data Station: all station
Monthly Minimum Temperature in degree celsius

Station	Dhaka	Khulna	Chittag	Rangpur	Sylhet	Rajshahi	Barishal	precis all station avg.
1990	20.9	21.4	24.3	19.9	20.0	21.1	21.4	**21.3**
1991	20.6	21.1	24.2	19.3	20.3	20.1	21.2	**21.0**
1992	20.4	20.9	23.8	19.7	20.0	20.5	20.9	**20.9**
1993	20.3	21.2	24.1	19.2	19.5	20.2	21.2	**20.8**
1994	20.3	21.0	23.9	19.1	19.5	20.3	21.0	**20.7**
1995	20.5	21.2	24.2	19.4	19.8	20.3	21.3	**21.0**
1996	20.1	20.7	23.9	19.1	19.6	20.0	20.7	**20.6**
1997	20.2	20.8	24.2	19.1	19.6	20.2	20.8	**20.7**
1998	20.8	21.5	24.3	19.8	20.1	20.8	21.5	**21.2**
1999	21.1	21.9	24.8	20.0	20.3	21.1	21.9	**21.6**
2000	20.9	21.7	24.8	19.6	20.2	20.4	21.7	**21.3**
2001	20.5	20.9	24.1	19.6	19.9	20.3	21.0	**20.9**
2002	20.5	21.4	24.2	19.5	19.9	20.3	21.4	**21.0**
2003	21.5	22.2	24.2	20.2	20.7	21.1	22.1	**21.7**
2004	21.3	22.2	24.6	20.1	20.4	21.5	22.2	**21.8**
2005	20.6	21.4	24.6	19.5	19.8	20.5	21.4	**21.1**
2006	21.6	22.1	24.8	20.2	20.7	21.2	22.1	**21.8**
2007	21.1	22.0	24.9	19.5	20.6	20.8	22.0	**21.5**
2008	21.0	21.9	24.6	19.8	20.0	21.2	21.9	**21.5**
2009	21.0	21.9	24.6	19.8	20.5	20.7	21.9	**21.5**
2010	21.7	22.6	24.7	20.2	20.9	21.5	22.6	**22.0**
all year avg	**20.8**	**21.5**	**24.4**	**19.6**	**20.1**	**20.7**	**21.5**	**21.2**

Table C7: MONTHLY AVERAGE MINIMUM TEMPERATURE FOR THE FUTURE YEAR

Monthly Minimum Temperature in degree celsius

Year	Jan	Feb	March	April	May	June	July	Aug	Sept	Oct	Nov	Dec
2015	12.14	15.20	20.30	23.63	25.05	26.17	27.19	26.32	25.96	23.88	19.08	14.29
2025	12.24	15.39	20.40	24.75	25.13	26.18	26.70	26.32	25.28	23.92	19.18	14.38
2035	12.32	15.42	20.29	23.81	25.21	26.22	27.21	26.33	25.97	23.91	19.17	14.58
2045	12.38	15.85	20.65	24.79	25.18	26.16	27.23	26.33	25.98	23.92	19.15	14.52
2050	12.43	15.77	20.81	24.74	25.21	26.21	27.55	26.35	26.01	23.97	19.11	14.45
all year avg	**12.30**	**15.53**	**20.49**	**24.34**	**25.16**	**26.19**	**27.18**	**26.33**	**25.84**	**23.92**	**19.14**	**14.44**