Investigation of the effect of climate change on evapotranspiration rate in different hydrological regions of Bangladesh

By

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A thesis submitted to the Institute of Water and Flood Management (IWFM) of Bangladesh University of Engineering and Technology, Dhaka in partial fulfillment of the requirements for the degree of

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The thesis titled **'Investigation of the effect of climate change on evapotranspiration rate in different hydrological regions of Bangladesh'** submitted by Satyajit Nandi, Roll No. M10062803 P, Session October 2006, has been accepted as satisfactory in partial fulfillment of the requirement for the degree of M.Sc. in Water Resources Development on July 23, 2011.

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CANDIDATE’S DECLARATION

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

……………………….

Satyajit Nandi

Dedicated to my

Family

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ABSTRACT

Climate change may have ramification on agricultural production which is a key economic sector in Bangladesh and one of the main users of fresh water resources. The water requirement in agriculture depends on evapotranspiration rate of the specific area. The study areas include Barisal, Comilla, Jessore, Mymensingh, Rajshahi and Sylhet which are the representatives of six hydrological regions namely, South-Central, South-East, South-West, North-Central, North-West and North-East, respectively. In this study the evapotranspiration rate (ET_0) was calculated for four time periods: observed base line (1961-90, i.e., 30 years historical data of the study areas) and three future projections 2006-2035 (represented as 2020), 2036-2065 (represented as 2050) and 2056-2085 (represented as 2070). The data for the latter three periods were collected from PRECIS model. To compute the ET_0 value CROPWAT 8.0 software which is a decision support tool developed by the Land and Water Development Division of FAO was used.

The results of the analysis reveal that the average minimum and maximum temperate will be increased by 1.11 ^{0}C, 2.45 ^{0}C, 3.54 ^{0}C and 0.95 ^{0}C, 2.39 ^{0}C and 3.68 ^{0}C by the year 2020, 2050 and 2070, respectively. The relative humidity will be decreased about 0.7%, 3.44% and 5.79%. Most of the time period wind speed shows an increasing trend. Sunshine hour and radiation both show an increasing trend among all the observing stations. The maximum radiation will be 21.09 $MJm^{-2}day^{-1}$ by the year 2070 at Sylhet. The overall evapotranspiration rate will be increased by about 7.15%, 12.33 and 20.64% by 2020, 2050 and 2070, respectively. The ET_0 will be the highest at Jessore by the year 2070 about 5.14 mm/day. The annual rainfall will be increased about 14.04%, 15.61% and 18.94% by the year 2020, 2050 and 2070. The maximum rainfall will be observed at north-eastern region where as less amount of rainfall will be observed at north-western region of the country. Crop water requirement for rice will be increased at different seasons. At Sylhet, by the year 2070 maximum water will be required on dry season for Boro rice cultivation. Jessore will be the highest water required place on Kharif-I and Kharif-II season for cultivation of T. Aus and T. Aman, respectively. The irrigation demand for Boro rice cultivation will be reduced from the preset demand at different observing stations by the year 2020 and 2070. But it will be increased by the year 2070 about 15.26%, 18.91% and 19.14% at Barisal, Comilla and Jessore, respectively.

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Abbreviations and Acronyms

AET	Actual Evapotranspiration
AR4	The Fourth Assessment Report by IPCC
BBS	Bangladesh Bureau of Statistics
BMD	Bangladesh Meteorological Department
BUET	Bangladesh University of Engineering and Technology
DJF	December, January & February
ET_c	Crop Water Requirement
ET_0	Reference Crop Evapotranspiration
FAO	Food and Agriculture Organization
GCM	General Circulation Model
GDP	Gross Domestic product
HADCM3	Hadley Centre Coupled Model, version 3
IPCC	Intergovernmental Panel on Climate Change
IWFM	Institute of Water and Flood Management
JJAS	June, July, August & September
LE	Latent Heat
MAM	March, April & May
MoEF	Ministry of Environment & Forest
MoFDM	Ministry of Food and Disaster Management
NIR	Net Irrigation Requirement
NWMP	National Water Management Plan
ON	October & November
PET	Potential Evapotranspiration
PM	Penmen-Monteith method
PT	Priestlay-Taylor method
RCM	Regional Circulation Model
PRECIS	Providing Regional Climates for Impacts Studies
SMRC	SAARC Metrological Research Centre
WARPO	Water Resources Planning Organization

CHAPTER ONE
INTRODUCTION

1.1 Background and Present State of the Problem

In the complicated climate system, water cycle, also known as hydrological cycle, is one of the important subsystems which describes the constant movement of water above, on, and below the Earth's surface. The cycle operates across all scales, from the global to the river catchment and connects the movement of water along evapotranspiration, precipitation, surface runoff, subsurface flow and groundwater. The change of water cycle not only means climate change but also deeply impacts on the human activities and life, such as agriculture production, water resource utilization, meteorological disasters and extreme climate events which seriously threat to survival of people and society development.

Bangladesh is recognized worldwide as one of the country's most vulnerable to the impacts of climate change. Intergovernmental Panel on Climate Change (IPCC) has projected in their fourth assessment report that temperature of the world will increase by the end of the century between 1.1°C and 6.4°C and the rise of mean annual temperature will be 3.3 °C per century (Trenberth et al., 2007). Various studies have been carried out to assess the future temperature and rainfall of Bangladesh (Basak et al., 2009, Islam, 2009a, Mondal and Wasimi, 2004, Nasrin, 2009, MoEF, 2005, SMRC, 2003). Analysis from the observed data shows that daily maximum, minimum and mean temperatures have a positive trend (Islam, 2009a, Mondal and Wasimi, 2004). SAARC Meteorological Research Centre or SMRC (2003) showed increasing trend of mean maximum and minimum temperatures in some seasons and decreasing trend in some other seasons. The changes in temperature will have effect on the growth of the crops. More specifically, evapotranspiration depends on temperature of the area. Many studies have been carried out to estimate evapotranspiration with the change of climatic variables using historic data (Nasrin, 2009, Mondal and Wasimi, 2004). Basak et al. (2009) indicate that rice yield will be reduced over 20% and 50% for the years 2050 and 2070. According to Nasrin (2009), Net Irrigation Requirement (NIR) and ET_0 have the decreasing trend. Islam (2009b) has shown the predictions of change of mean daily temperature and change of mean rainfall (mm/day) over Bangladesh using PRECIS 1.7.1.

Agriculture is always vulnerable to unfavorable weather events and climatic conditions. Despite technological advances such as improved crop varieties and irrigation systems, weather and climate are still key factors in agricultural productivity. The impacts of climate change on agricultural food production are global concerns, and they are very important for Bangladesh. Bangladesh has primarily an agrarian economical country. Agriculture is the single most and the largest sector of Bangladesh's economy which accounts for about 21% of the GDP and about 50% of the labor force (BBS, 2008). As a result, most of the people of our country depend on agriculture for livelihood. A major portion of the water is consumed by agricultural sector. Agriculture in Bangladesh is already under pressure both from huge and increasing demands for food, and from problems of agricultural land and water resources depletion. One of the prime uses of water in agricultural sector is irrigation. Agricultural hydrology is very important for sustainable use of water. One of the main components of the water balance is the crop water loss via evapotranspiration (Yarahmadi, 2003). Evapotranspiration refers to water used by a crop for growth, tissue building, cooling purposes as well as soil evaporation (Alkais and Broner, 2005). To schedule irrigation properly, a grower must know the environmental demand for surface water. For the grower, this surface water loss occurs primarily through evapotranspiration (ET). The ET rate is a function of factors such as temperature, solar radiation, humidity, wind, and characteristics of the specific vegetation that is transpiring, which may vary significantly between vegetation types (Allen et al. 1998). If the demand for water (ET) exceeds the availability to the plant through precipitation or stored in the soil, then the transpiration may stop resulting in crop loss. Therefore, reliable estimates of ET, along with knowledge of precipitation in totals and soil moisture storage capacity, can provide estimates of water need via irrigation. Most of the studies that have been done so far are related to the effects of climate change on evapotranspiration rate based on historical data. But no systematic study has been done to identify the future values of climatic variables to estimate evapotranspiration rate. So there is necessity for the estimate of future evapotranspiration rate for the probable future stress of water on agriculture in Bangladesh.

1.2 Objectives of the study

The main objectives of the project are as follows:

1. To study the changes in future rainfall, temperature, wind speed and solar radiation due to climate change.
2. To estimate evapotranspiration rate based on the predicted regional climate change in Bangladesh.
3. To assess the regional differences in evapotranspiration rates.

1.3 Possible Outcomes of the study

It is important to provide the proper amount of water to crops via irrigation. Too much or too little water at the wrong stage of crop development can damage the crop and reduce yield. Additionally, the economic value associated with irrigating with the proper amount of water at the right time is considerable. A 1 mm loss of water through ET across 1 ha is equivalent to 10 m^3 (268,000 gallons) of water (Allen et al. 1998).If a grower optimizes the use of irrigation scheduling, the amount of money that can be saved in water purchase and or well operation is significant. As climate differs with its regional settings, the evapotranspiration rate will also differ for Bangladesh. For the upcoming environmental stresses on water, the evapotranspiration rate is very important to manipulate and compute the water requirement regionally to manage the national water demands effectively.

This study is expected to identify the evapotranspiration rate and to compare the regional differences. Moreover, regarding water balance, this study will help make a decision for development plan in the sector of irrigation.

1.4 Limitations of the study

The main limitations of the study are

- The representative stations were selected from different hydrological regions. The result of study would be more precise if all stations were taken in each region. Due to lack of data and time more than one station could not be taken.

- The desired time series data were not found to predict long term changes of the climatic variables in each station. Therefore, the result of the station data was not tuned properly.
- Future climate data has been taken from PRECIS (50km grid) model where an only A1B scenario was taken into consideration. The locations of grid were near to the study area. The study result could be tuned more accurately, if grid points were taken with higher resolution and other scenarios were considered.
- As the prediction of climate change in future scenarios have been done based on model results, there is much uncertainty in the predicted results. Further study can be done to cross-check the results.
- In this study the decadal change of the climatic variables are not considered.

1.5 Organization of the Chapters

The thesis contains eight chapters. The organization of the chapters is as follows:

Chapter one provides the background of the study and present state of the problems. It also draws attention to the objectives of the study with limitations and organization of the chapters. Chapter two will examine the concept of evapotranspiration (ET) and its factors in more detail and provide more details into the concept of reference evapotranspiration (ET_0) and of the measurement and estimation of ET_0. It also contains the general phenomena of climate change and PRECIS model. The chapter also reviews the literature of changes of evapotranspiration and the effect of change in variables on evapotranspiration. Chapter three discusses the methodology in detail used to compute evapotranspiration. The chapter also discusses the methodology of extracting future climatic variables which were used to predict the future evapotranspiration rate. Chapter four presents the climatic characteristics of the selected hydrologic regions. Chapter five describes results of the evapotranspiration rate using existing station data and also compares the regional differences in Bangladesh. Chapter six describes the results of predicted evapotranspiration rate with regional differences using predicted climatic data. The findings from existing data and predicted data series are also analyzed. Finally, chapter seven concludes the results of the study and provides recommendations for further study.

CHAPTER TWO
LITERATURE REVIEW

2.1 Introduction

This chapter provides a brief literature review of evapotranspiration and climate change scenarios. The modified FAO Penman-Monteith method has been used to analyze evapotranspiration rate. According to Allen et al., (1998), the FAO Penman-Monteith method is the sole standard method for computation of the reference evapotranspiration. In addition, a brief description of the climate change and a literature review on the currently available PRECIS models are also presented.

2.2 Climate Change

2.2.1 Climate

Climate change is a change in the statistical distribution of weather over periods of time http://en.wikipedia.org/wiki/Durationthat range from decades to millions of years. It can be a change in the average weather or a change in the distribution of weather events around an average (as for example, greater or fewer extreme weather events). These quantities are most often surface variables such as temperature, precipitation and wind, but in a wider sense the "climate" is the description of the state of the climatic system.

2.2.2 Water Cycle and Climate Change

According to the fourth Assessment Report (AR4) by Intergovernmental Panel on Climate Change (IPCC) temperatures at the surface have risen globally and with important regional variations during 1850 to 2006 by instrumental observations. For the global average, two phases warming in the last century occurred from the 1910s to the 1940s and from the 1970s to 2006 (Trenberth et al., 2007). In the latest phase, the increment of temperature is 0.55°C and stronger than that of the first phase. Apart from the temperature, many evidences such as increasing of sea level, recessing of the glaciers and widespread melting of perpetual snow show the indubitable warming in climate system. Even though a great uncertainty about the magnitude of future increases, most assessments indicate that climate would go on warming in the future. Climate warming and its impacts which are essential to our life currently and in the future are concerned by more and more people than ever before.

In the complicated climate system, water cycle, also known as hydrological cycle, is one of the important subsystems which describes the constant movement of water above, on, and below the Earth’s surface. The cycle operates across all scales, from the global to the river catchment and connects the movement of water by evapotranspiration, precipitation, surface runoff, subsurface flow and groundwater. The change of water cycle not only means climate change but also deeply impacts on the human activities and life, such as agriculture production, water resource utilization, meteorological disasters and extreme climate events which seriously threat to survival of people and society development.

2.3 Evapotranspiration

2.3.1 Definition of evapotranspiration

Evapotranspiration (ET) is the process of returning water back to the atmosphere through evaporation from open water, soil, and plant surfaces, and transpiration from plants. Theoretically, evaporation is a diffusive process that follows Fick’s first law and can be written as a function of vapor pressure deficit (at evaporating surface and overlying air) and wind speed. Evaporation is accompanied by heat loss from evaporating surface in the form of latent heat, which can be compensated by radioactive or sensible-heat transfer or by heat transfer from within the evaporating body to the surface (Dingman, 2002). The rate of latent heat (LE) is related to the evaporation rate using the latent heat of vaporization and the mass density of water. Physically, the four basic factors involving the evaporation mechanism include energy availability, water availability, vapor pressure gradient, wind, and the atmospheric conductance. Any other parameters that influence the above factors also influence the evaporation process (Dingman, 2002).

Transpiration is the evaporation of water from the vascular system of the plants into the atmosphere as a consequence of the photosynthesis process. It involves the absorption of water from soil through roots and its translocation through the vascular system of the roots, stem, and branches to the leaves. The water moves from the vascular system of the leaf to the walls of stomata where evaporation takes place. Water vapor is then released to the atmosphere through the openings of the leaf, called stomata. Transpiration is limited by energy availability, water availability, humidity, temperature, ambient CO_2 concentration, and wind speed. Plant species come into play by influencing the leaf conductance and the plant adaptation to water availability (Dingman, 2002).

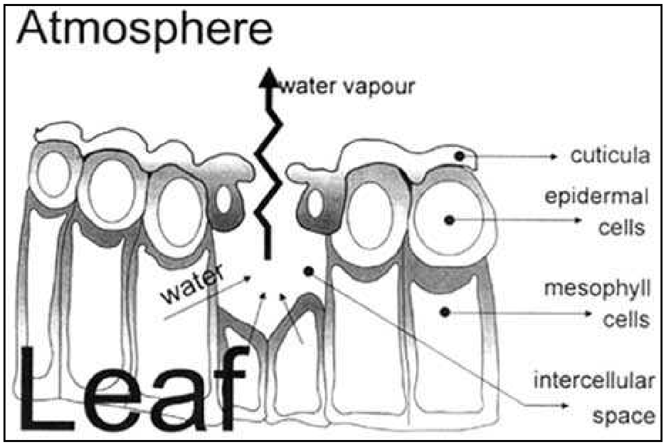


Figure 2.1: Schematic representation of stomata. [Source: FAO, (2009)]

When unlimited water is available, the rate of ET is mostly controlled by the atmospheric conditions, and ET might be near the maximum rate. However, when the soil water becomes limited, the soil water content starts to control the rate of ET and may stop the process when the transport of water through the soil becomes critical (Dingman, 2002). Since in real situations the water is usually not unlimited, the rate of ET under the limited water supply conditions is said to be the actual rate of evapotranspiration (AET).

Thus evapotranspiration is a collective term for all the processes by which water in the liquid or solid phase at or near the earth's land surfaces becomes atmospheric water vapor (Dingman, 2002). It combines evaporation and transpiration. Reference crop evapotranspiration, reference evapotranspiration, or potential evapotranspiration is the evapotranspiration rate from a reference surface without the limitation of water supply. Actual evapotranspiration or terrestrial evapotranspiration describes all the processes by which liquid water at or near the land surface becomes atmospheric water vapor under natural condition. Comparing to the pan evaporation, free water evaporation and potential evapotranspiration, the actual or terrestrial evapotranspiration is also affected by water availability and surface condition in addition to climate factors.

Accurate estimations and better understanding of evapotranspiration are required in hydrologic studies and water resources modeling under stationary and changing climate conditions. In hydrological models, either pan evaporation or free water evaporation or potential evapotranspiration is usually used as one of the inputs, while actual evapotranspiration is one of the outputs.

2.3.2 Factors which affect Evapotranspiration

There are several factors depends of change in evapotranspiration. Climatic parameters or weather parameter, crop characteristics, management aspects are factors affecting evaporation and transpiration.

Climatic Parameter

The principal climatic parameters affecting evapotranspiration are radiation, air temperature, humidity and wind speed. Several procedures have been developed to assess the evaporation rate from these parameters. The evaporation power of the atmosphere is expressed by the reference crop evapotranspiration (ET_0). The reference crop evapotranspiration represents the evapotranspiration from a standardized vegetated surface.

Crop Factor

The crop type, variety and development stage should be considered when assessing the evapotranspiration from crops grown in large, well-managed fields. Differences in resistance to transpiration, crop height, crop roughness, reflection, ground cover and crop rooting characteristics result in different ET levels in different types of crops under identical environmental conditions. Crop evapotranspiration under standard conditions (ETc) refers to the evaporating demand from crops that are grown in large fields under optimum soil water, excellent management and environmental conditions, and achieve full production under the given climatic conditions.

Management and Environmental conditions

Factors such as soil salinity, poor land fertility, and limited application of fertilizers, the presence of hard or impenetrable soil horizons, the absence of control of diseases and pests and poor soil management may limit the crop development and reduce the evapotranspiration. Other factors to be considered when assessing ET are ground cover, plant density and the soil water content.

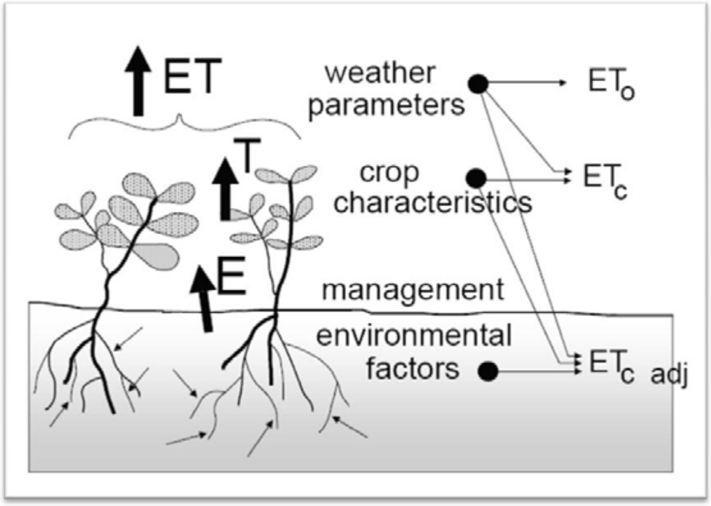


Figure 2.2: Factors affecting evapotranspiration with reference to related ET concept. [Source: FAO (2009)]

The effect of soil water content on ET is conditioned primarily by the magnitude of the water deficit and the type of soil. On the other hand, too much water will result in water logging which might damage the root and limit root water uptake by inhibiting respiration.

2.3.3 Modeling of Evapotranspiration

Many methods have been developed, revised, and proposed for the estimation of ET in different climatic conditions using different predictor variables. Jensen and Allen (2000) reviewed the evolution of different types of ET estimation methods. Conventional ET models are basically categorized into physically based and empirical models. Some examples of the physically based ET models include the equations developed by Penman (1948), Monteith (1965, 1973), Shuttleworth and Wallace (1985), and Granger and Gray (1989).

Empirical models were developed with the aim of proposing simpler ET equations, which require fewer input variables that are also routinely available. Attempts for empirical modeling of evapotranspiration resulted in various methods: temperature-based (Thornthwaite, 1948; Blaney and Criddle, 1950; Hargreaves and Samani, 1985, Xu and Singh, 2001), radiation (and temperature)-based (Priestley and Taylor, 1972; Xu and Singh, 2000), water budget-based (Guitjens, 1982; Dingman, 2002), and mass-transfer-based (Harbeck, 1962; Singh and Xu, 1997). The empirical models have the advantages of being simple and using a small number of meteorological variables; however, reasonable estimation of model parameters is required for local applications. This is considered to be a limitation for the empirical ET prediction models.

Some equation-based ET models have also been adapted for the estimation of Actual Evapotranspiration (AET), such as Penman-Monteith (PM) equation (Monteith, 1973) and the work conducted by Shuttleworth and Wallace (1985). In the PM method, the model parameters (e.g. aerodynamic resistance of leaf surface) should be specified for the estimation of AET in cases where the theoretical assumptions of PM method are not valid (e.g. low soil moisture conditions). Priestley-Taylor (PT) method (Priestley and Taylor, 1972) was also adapted for the estimation of AET using an empirical parameter (Pauwels and Samson, 2006). A strong dependence was found between the empirical parameter of PT method and the soil moisture condition by Gavin and Agnew (2004). The proposed AET models mainly require extensive predictor variables, such as meteorological parameters, soil moisture information, leaf area, and canopy aerodynamic characteristics. The most encountered problem in the application of the currently available models is the lack of the required information. According to Poulovassilis et al. (2001), determination of critical parameters (e.g. threshold soil moisture and threshold leaf water potential) is also a serious obstacle in AET estimation using the available models.

Penman (1948) derived a sound physically based evaporation model by combining the energy-balance method with the mass-transfer method. The Penman evaporation model was later modified by Monteith (1965) to take into account the vegetation surface and the aerodynamic resistance terms, which resulted in the well-known Penman-Monteith (PM) equation for the estimation of ET. The PM method proved to be superior to about 20 other methods based on the regression analysis of lysimeter measurements (Jensen et al., 1990).

FAO-24 Penman (Doorenbos and Pruitt, 1977) and Kimberly Penman (Wright, 1982, 1996) methods were developed afterwards following Penman's theoretical method. FAO-24 was shown, by different studies such as Jensen et al. (1990), Allen et al. (1998), and Walter et al. (2001), to lack global validity. The United Nation's Food and Agricultural Organization (FAO) recommended a PM-based approach, namely FAO-56 PM (Allen et al., 1998), as the standard method for the estimation of potential evapotranspiration from a reference surface (ET_0) (e.g. grass). The PM model basically estimates the rate of evapotranspiration from a wet and uniformly vegetated surface where unlimited water supply is available. A large number of empirical or semi-empirical equations have been developed for assessing crop or reference crop evapotranspiration from meteorological data. Some of the methods are only valid under specific climatic and agronomic conditions and cannot be applied under conditions different from those under which they were originally developed. Penman-Monteith method based on sound physical principle is a representation of the combination methods. It is usually considered as a standard method for comparison between the other methods. (Allen et al., 1998)

The Penman-monteith formula is the basis for the calculation of ET of crops in the FAO computer program CROPWAT (Smith, 1992). This is now widely used and accepted for the computation of ET. The National Water Management Plan (NWMP) has recommended using this formula to calculate evapotranspiration (WARPO, 2001).

2.3.4 Importance of evapotranspiration

Evapotranspiration is the second largest quantity in the water cycle. Its change would affect the whole water cycle. Latent heat is the energy consumption by the surface evapotranspiration. In surface energy balance, net radiation obtained by land surface is balanced by the sensible heat and latent heat exchanges with atmosphere. As the only connecting term between water balance and energy balance and because of complex interactions in the land-plant-atmosphere system, evapotranspiration is perhaps the most difficult and complicated component of the water cycle (Xu and

Singh, 2005) and also a very important indicator for climate changes (Peterson et al., 1995; Brutsaert and Parlange, 1998).

In surface water balance, approximately 60-80% of the precipitation on the earth's surface returns back into the atmosphere, where it becomes the source of future precipitation (Tateishi and Ahn, 1996). The lost water by evapotranspiration will affect the water yield of a region and available water resources. Comparing with traditional management based on the balance between water supply and demand, the water consumption based management is more efficient in utilization of water resource through reducing evapotranspiration to obtain the destination of reducing overall regional water consumption.

Evapotranspiration has been widely used in guiding agricultural irrigation schedule through the quantitative estimation to the crop water requirement achieving the aims of water saving and agricultural yield increasing (Doorenbos and Pruitt, 1977; Dingman, 2002). Evapotranspiration is also essential for understanding land surface processes in climatology (Chen et al., 2005). The dry and wet condition analysis of climate based on evapotranspiration is connected with the type of ecosystem which has a sensitive response to climate change.

2.3.5 Evapotranspiration and Climate change

Under the climate warming background, there is an expectation that evapotranspiration and precipitation will increase. The theoretical basis is the Clausius-Clapyeron relation which implies that specific humidity would increase approximately exponentially with temperature (Huntington, 2006). Obviously differences are found between the expectation and the evidence of pan observation in most places, which is named evaporation paradox.

Many studies have shown that pan evaporation and potential evapotranspiration had decreased over the past decades in many places of the world (Peterson et al., 1995; Thomas, 2000; Roderick and Farquhar, 2004; Xu et al., 2006; Fu et al., 2009).

Increases in cloud cover and thus decreases in net radiation have been identified as the most likely responsible for decreasing potential evapotranspiration in the United States and the former Soviet Union (Peterson et al., 1995).

In India, Chattopadhyay and Hulme (1997) also found that increases in relative humidity and decreases in radiation are both correlated with the decreasing trend in potential evapotranspiration. Milly and Dunne (2001) found that the annual average evaporation in the Mississipie River basin has increased by about 0.95 mm/year during 1949-1997.

Thomas (2000) analyzed the potential evapotranspiration by Penman-Monteith method based on 65 stations in China during 1954 and 1993. He found that northeast and southwest China have experienced a moderate evapotranspiration increase, while northwest and southeast China were associated with a decreasing trend. Different areas have different climate controlling factors.

Goyal (2004) studied long term meteorological parameters of 32 years (1971-2002) in Rajasthan, India. According to his study if temperature increased 20% then total evapotranspiration (ET) demand increased by about 14.8%. ET is less sensitive (11%) to increase in net solar radiation, followed by wind speed (7%) in comparison to temperature. On the other hand, increase in vapor pressure (20%) has a small negative effect on ET (-4.31%). A 10% increase in temperature and actual vapor pressure coupled with 10% decrease in net solar radiation could result even in marginal decrease of total ET (0.30%). Increase of 10% in temperature alone, with 10% decrease in net solar radiation, actual vapor pressure and wind velocity could also result in marginal decrease in total ET (0.36%). In the above study Penman–Monteith equation was used to estimate reference evapotranspiration, and sensitivity of ET in terms of change in temperature, solar radiation, wind speed and vapor pressure. Changes in precipitation have not been considered in this study.

In the context of Bangladesh, Nasrin (2009) estimated trends in ET_0 at different 10-day periods for the four different stations. The stations are Dhaka, Jessore, Bogra and Chandpur. According to her estimation, all stations show decreasing trend in ET value. The average ET decreasing percentages 2.3%, 2.5%, 0.8% and 3.3% at Dhaka, Jessore, Bogra and Chandpur per decade, respectively, were found while analyzing long term data (from 1961-2007). BRRI (1982) observed in the BRRI farm that average evaporation was 5.5 mm/day.

Mondal and Wasimi (2004) analysed the temperature data of 1960 to 1999 at 10 locations of Ganges Delta Area of Bangladesh (GDB) and found an increase in minimum temperature 0.98 ^{0}C and that in maximum temperature was found to be 1.63 ^{0}C during November to December for 2030 and the corresponding values are 1.35^{0}C and 2.25 ^{0}C for 2050. For later months (January-May), where it was assumed that the rate of increase in minimum temperature is twice that of maximum temperature, the increase in minimum temperature is 1.73 ^{0}C and that in maximum temperature is 0.87 ^{0}C for 2030 and the corresponding values are 2.4 ^{0}C and 1.2 ^{0}C for 2050. They have also estimated an increase in reference crop evapotranspiration (ET_0) of 3.0% by 2030 and about 4.1% by 2050 for GDB due to climate change. The authors used Penman-Monteith method for ET_0 computation, where the changes in maximum and minimum temperatures have been accounted for but other climatic factors, such as air humidity, wind speed and solar radiation were not taken into consideration.

IWFM and CEGIS (2008) also reported that the potential evapotranspiration would increase by 1.47%, 0.36%, 0.87% and 1.64% in the North-West, North-East, North-Central and South-West hydrological regions of Bangladesh, respectively, during dry season for the future period 2025 with respect to the baseline period of 1979 to 1999 using the Regional Circulation Model (RCM).

CCC (2009) predicts climate variables, rainfall and evapotranspiration rate at different location of Bangladesh. They estimated the increasing trend of rainfall in summer (March-May) and critical periods (11 March – 10 May) at eight different locations of the country. They also found in general increasing trends of annual and seasonal mean temperature in Bangladesh. The overall trend in mean annual temperature is found to be +0.10 and +0.21 ^{0}C per decade (equivalent to +1.03 and +2.14 ^{0}C per century) for data periods of 1948-2007 and 1980-2007, respectively.

The above studies show that the changes of evapotranspiration of different regions are strongly correlated with increasing or decreasing climatic variables such as temperature, sunshine hour, cloudiness, relative humidity and precipitation. They have significant impact on changes in evapotranspiration.

CHAPTER THREE
METHODOLOGY

3.1 Introduction

In this study the evapotranspiration rate was calculated for five time periods: observed base line (1961-1990, i.e., 30 years historical data of the study areas), model base line (1971-2010 which is represented as 1990) and three future projections (2006-2035 which is represented as 2020, 2036-2065 which is represented as 2050 and 2056-2085 which is represented as 2070). The data for the latter three periods were collected from PRECIS model. The observed baseline data (of 1961-1990) was used to develop the model base line. The model's baseline period data were calibrated with the observed data and finally that calibrated parameter was used in the model to generate future climatic data. To compute the ET_0 value CROPWAT 8.0 software which is a decision support tool developed by the Land and Water Development Division of FAO (FAO, 2009) was used.

3.2 Computation of Evapotranspiration

In this study to estimate reference evapotranspiration rate (ET_0) CROPWAT 8.0 has been used. CROPWAT 8.0 is a computer program for the calculation of the crop water requirements and irrigation requirements based on soil, climate and crop data. By using the climate data the evapotranspiration rate can be estimated by this software. Climate data includes maximum & minimum temperature, relative humidity, wind speed and sunshine hour.

According to the FAO all calculations procedures used in CROPWAT 8.0 are based on the two FAO publications of the Irrigation and Drainage Series, namely, No. 56 "Crop evapotranspiration – Guidelines for computing crop water requirements" and No. 33 titled " Yield response to water" (FAO, 2009).

3.2.1 Penmen-Monteith Method

The Penman-Monteith method is recommended as the sole standard method by FAO (Allen et al., 1998). The classic Penman-Monteith method combines both energy and mass balances to model reference evapotranspiration. It is based on fundamental physical principles, which guarantee the universal validity of the method.

The concept of reference evapotranspiration is introduced to study evaporative demand of the atmosphere independent of crop type, crop development and management practices (Allen et al., 1998). The reference surface is assumed to be a flat surface that is completely covered by a grass with an assumed uniform height of 0.12 m and an albedo of 0.23 under enough soil water supply (Allen et al., 1998). The formula is as following:

$$ET_0 = \frac{0.408\,\Delta(R_n - G) + \gamma \frac{900}{T+273} u_2 (e_s - e_a)}{\Delta + \gamma(1 + 0.34 u_2)} \qquad (1)$$

Where,

ET_0	reference evapotranspiration [mm day^{-1}]
R_n	net radiation at the crop surface [MJ m^{-2} day-1]
G	soil heat flux density [MJ m^{-2}day^{-1}]
T	mean daily air temperature at 2m height [$^\circ C$]
u_2	wind speed at 2m height [ms^{-1}]
e_s	saturation vapor pressure [kPa]
e_a	actual vapor pressure [kPa]
$e_s - e_a$	saturation vapor deficit [kPa]
Δ	slope vapor pressure curve [kPa$^\circ C^{-1}$]
γ	psychrometric constant [kPa$^\circ C^{-1}$]

The Equation (1) uses standard climatological records of solar radiation (sunshine), air temperature, humidity and wind speed. To ensure the integrity of computations, the weather measurements should be made at 2 m (or converted to that height) above an extensive surface of green grass, shading the ground and not short of water.

3.3 Site location and data

In this study six sites were selected to compare the regional differences in terms of reference evapotranspiration rate. To compute the value of ET_0, using FAO Penmen-Monteith method, altitude above sea level and latitude of the location is required. The values of the altitude and latitude were collected from Bangladesh Meteorological Department (BMD).

Apart from the site location, the FAO Penman-Monteith equation requires air maximum and minimum temperature, humidity, radiation and wind speed data. The average monthly climatic data of the selected stations were used. For the analysis, daily station data were collected from BMD. Future meteorological data (daily) were collected from PRECIS (Providing Regional Climate for Impacts Studies) model for the selected study areas. Monthly climatic data was computed by averaging daily data.

Temperature: The (average) daily maximum and minimum air temperatures in degrees Celsius (°C) were collected from BMD and predicted from PRECIS model.

Humidity: The (average) daily actual vapor pressure e_a in kilopascals (kPa) is required. The actual vapor pressure, where not available, can be derived from maximum and minimum relative humidity (%), psychrometric data (dry and wet bulb temperatures in °C) or dew point temperature (°C). In this study relative humidity (%) was used to calculate daily actual vapor pressure.

Radiation: The (average) daily net radiation expressed in megajoules per square meter per day ($MJm^{-2}day^{-1}$) is required. As these data are not commonly available but can be derived from the (average) shortwave radiation measured with a pyranometer or from the (average) daily actual duration of bright sunshine (hours per day) measured with a (Campbell-Stokes) sunshine recorder. Here the sunshine hour was used to calculate net radiation.

Sunshine hour: Sunshine hour is an important factor to estimate the solar radiation, which plays vital role in evapotranspiration. The station data of sunshine hour were collected from BMD. On the other hand, the sunshine duration is expressed by the ratio of the cloudiness of the atmosphere. It is the ratio of the actual duration of the sunshine, n, to the maximum possible duration of sunshine or daylight hours, N (FAO, 2009). In the absence of any clouds, the actual duration of sunshine is equal to the daylight hours (n = N) and ratio is one, while on cloudy days n and consequently the ratio may be zero (FAO, 2009). According to the same principle the cloud was estimated from long wave radiation from PRECIS to calculate the relative sunshine fraction. The formula is as below:

$$\frac{n}{N} = 1 - f \qquad (2)$$

Where,

n = actual duration of sunshine (hour)

N = maximum possible duration of sunshine (hour)

f = total cloudiness

As the day length (N) depends on the position of the sun, it is a function of latitude and date. The daily values of N throughout the year for different latitudes are plotted in Figure 3.1 (FAO, 2009).

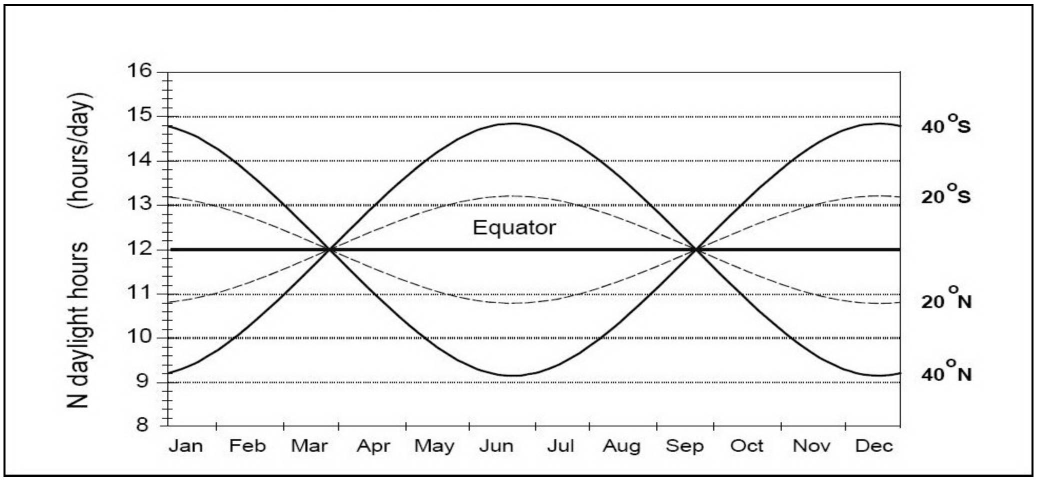


Figure 3.1: Annual variation of daylight hours at the equator, 20 and 40^0 north and south

According to the latitude and longitude the daylight hours have been calculated with the help of the "Sunrise and Sunset Calculation" website (http://www.exptech.com/sunrise.htm). The following Table 3.1 shows the values of daylight hours, where the 15th day of each month was considered the average day length of that month.

Table 3.1: Total day length (N, hour) at different location

Month	Barisal	Comilla	Jessore	Mymensingh	Rajshahi	Sylhet

January	10.87	10.83	10.85	10.75	10.77	10.73
February	11.38	11.35	11.37	11.30	11.32	11.30
March	11.97	11.97	11.97	11.97	11.97	11.97
April	12.65	12.67	12.67	12.70	12.70	12.72
May	13.20	13.25	13.23	13.32	13.30	13.33
June	13.52	13.57	13.53	13.65	13.62	13.67
July	13.40	13.45	13.43	13.53	13.50	13.53
August	12.93	12.97	12.95	13.02	13.00	13.03
September	12.30	12.30	12.30	12.32	12.32	12.32
October	11.65	11.63	11.63	11.60	11.62	11.60
November	11.07	11.02	11.03	10.95	10.97	10.95
December	10.75	10.70	10.72	10.62	10.63	10.60

Wind speed: The (average) daily wind speed in meters per second (ms-^{1}) measured at 2 m above the ground level is required. It is important to verify the height at which wind speed is measured, as wind speeds measured at different heights above the soil surface differ.

Most of the meteorological variables are assumed to be measured at a height of 2m (Ekström et al., 2007). But PRECIS gives wind speed data at 10m height. To overcome the height variables, a conversion factor was used to reduce the 10m wind speed into 2m height. A simplified conversion factor has been proposed by Allen et al. (1994) to reduce the height of wind, which is as follows:

$$\frac{U_2}{U_z} = \frac{4.87}{\ln(67.8 z_m - 5.42)} \qquad (3)$$

Where,

U_2 = wind speed at 2m height

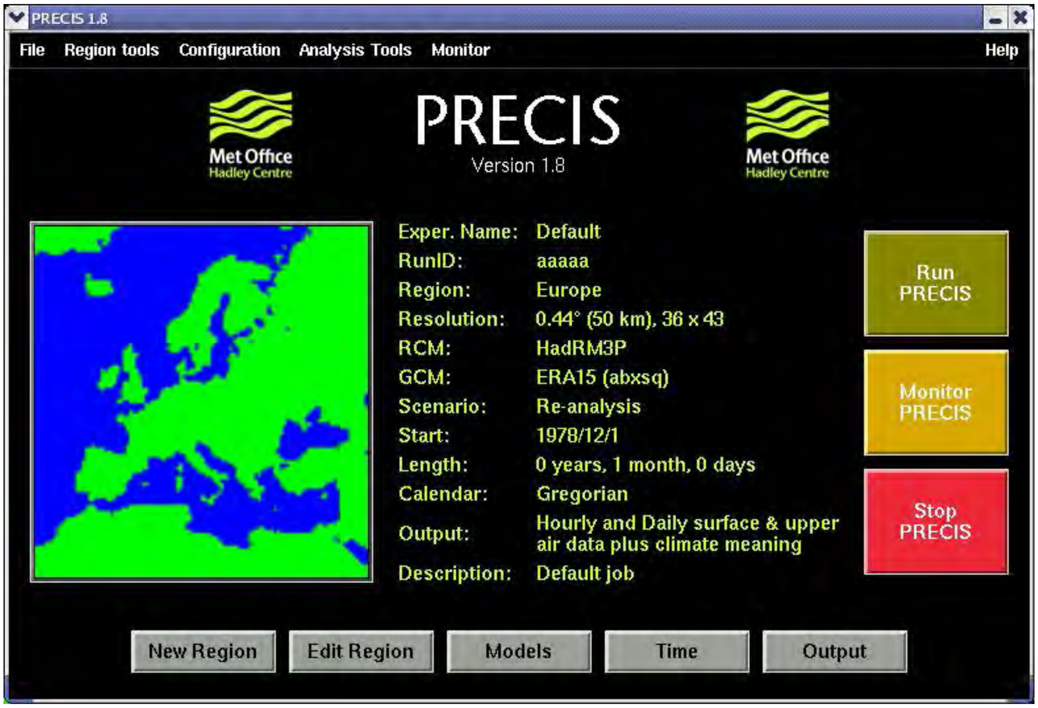
U_z = wind speed at zm height

z_m = height

This simplified conversion factor (Equation no. 3) has been used to estimate the wind speed at 2m height.

3.4 PRECIS Model

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

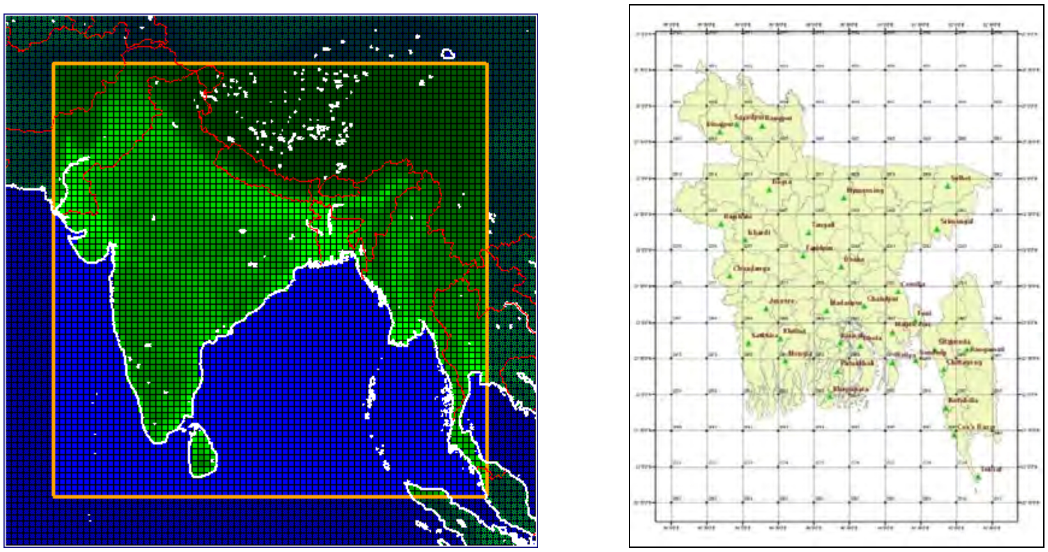


Exper. Name: Default
RunID: aaaaa
Region: Europe
Resolution: 0.44° (50 km), 36 x 43
RCM: HadRM3P
GCM: ERA15 (abxsq)
Scenario: Re-analysis
Start: 1978/12/1
Length: 0 years, 1 month, 0 days
Calendar: Gregorian
Output: Hourly and Daily surface & upper air data plus climate meaning
Description: Default job

Figure 3.2: The main PRECIS window

3.4.1 Regional Climate Model (RCM) Prediction

A Regional Climate Model, PRECIS (Providing Regional Climates for Impact Studies), has been simulated in IWFM (Institute of Water and Flood Management) simulation laboratory from which the primary climate prediction data were collected. PRECIS is developed by the Hadley Centre, UK which is physically based model to help generate high-resolution climate change information for Bangladesh. Figure 3.3(a) shows the simulation domain that includes Bangladesh and south Asia and 3.3(b) shows grid points of the domain over Bangladesh. The domain has 88×88 grid points with a 50 km horizontal resolution.



(a) (b)

Figure 3.3 (a): Domains of the PRECIS experiments over Bangladesh and (b) grids over the simulation domain

According to the IPCC (2000), the Special Report on Emissions Scenarios (SRES) cover a wide range of the main driving forces of future emissions, from demographic to technological and economic developments. The SRES scenarios include the range of emissions of all relevant species of greenhouse gases (GHGs) and sulfur and their driving forces. The A1 storyline and scenario family describes a future world of very rapid economic growth, global population that peaks in mid-century and declines thereafter, and the rapid introduction of new and more efficient technologies. Major underlying themes are convergence among regions, capacity building, and increased cultural and social interactions, with a substantial reduction in regional differences in per capita income. The A1 scenario family develops into three groups that describe alternative directions of technological change in the energy system. The three A1 groups are distinguished by their technological emphasis: fossil intensive (A1FI), non-fossil energy sources (A1T), or a balance across all sources (A1B).

The SRES A1B scenario of IPCC was used to derive the lateral boundary conditions of the simulation using three dimensional ocean-atmospheric coupled model (HadCM3Q) to generate prognostic variables over the simulated domains. This information was used to generate diagnostic variables (such as rainfall, temperature, wind speed etc.) using PRECIS model all over the domain. The regional climate model dynamically downscaled the data of the Global Climate Model (GCM) with a resolution of 50km from 250km from 1951 to 2100 over the study area.

3.5 Crop Water Requirement

To estimate crop water requirement (ET_c), reference evapotranspiration rate (ET_0) is to be estimated first. ET_c is obtained by the following formula no (4):

$$ET_C = K_c \times ET_0 \qquad (4)$$

Where,

$\mathbf{ET_c}$ **= actual crop evapotranspiration rate**

$\mathbf{ET_0}$ **= reference evapotranspiration rate**

$\mathbf{K_c}$ **= crop coefficient**

The reference evapotranspiration rate was predicted by the input values of climatic variables (minimum and maximum temperature, wind speed, sunshine hour, relative and humidity) into CROPWAT 8.0 software. In this study, to estimate crop water requirement, three varieties of rice were selected for three seasons which are Transplanted Aus (T. Aus), Transplanted Aman (T. Aman), and Boro from Kharif I, Kharif II and Rabi (dry) season, respectively. The water requirement for rice at different stages was calculated by using the crop coefficient values and length of growing stages (Table 3.2) and crop calendar (Figure 3.4).

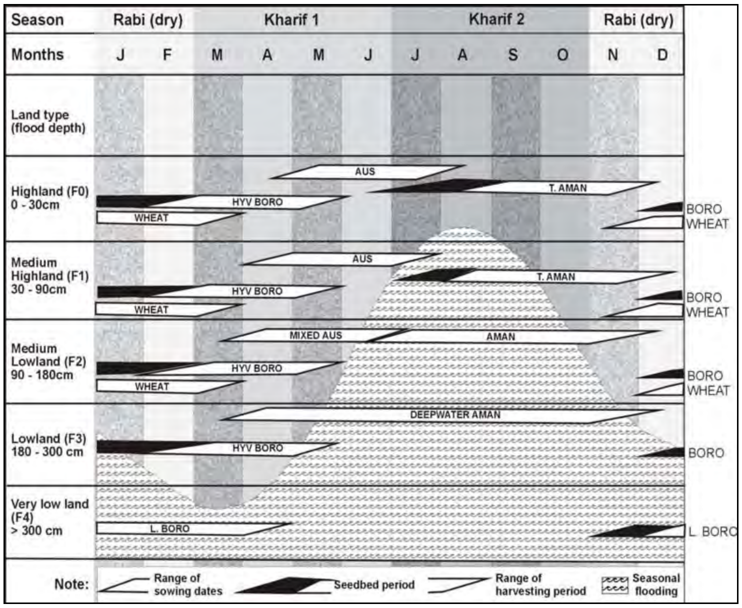


Figure 3.4: Generalized Flood phase/land type with crop calendar for rice corps. [Source: CCC (2009)]

Table 3.2: Length of the growing stages of transplanted rice crops [source: CCC (2009)]

Crop	Stages in days						Median Transplantation Date
	Nursery	Vegetation	Flowering	Yield Formation	Ripening	Total	
T. Aus	25	50	15	15	10	115	May-1
T. Aman	30	65	15	20	10	140	Jul-21
Boro	35	70	15	25	10	155	Jan-21

Table 3.3: Crop coefficient values for rice

Crop	K_c ini	K_c mid	K_c end
Rice	1.1	1.25	1.0

Mondal et at. (2008) used crop coefficient values for rice at different stages which was given in Table 3.3. The first two months of rice growing stage, initial crop coefficient value (K_c ini) will be used to estimate initial crop water requirement. The crop coefficient values at end stage (K_c end) are valid for the last four weeks of rice growing stage to calculate the end stage crop water requirement. The rest of the days, crop coefficient K_c mid will be used to compute crop water requirement at middle stage. The total crop water requirement is the sum of the crop water requirement at all stages.

CHAPTER FOUR

STUDY AREA

4.1 Introduction

To investigate evapotranspiration rate over Bangladesh six stations from six different hydrological regions were selected. The stations with respect to hydrological region are as follows:

1. Rajshahi from North-West region
2. Mymensingh from North-Central region
3. Sylhet from North-East region
4. Jessore from South-West region
5. Barisal from South-Central region
6. Comilla from South-East region

The above stations were selected based on availability of the station data and the

Figure 4.1: The Study Area showing different hydrological regions of Bangladesh [source: NWMP, 2001, WARPO]

future predicted data. The representative stations from each hydrological region will give a contemporary study and regional differences regarding the evapotranspiration rate in Bangladesh. Among the eight hydrological zones the remaining river and estuary and Eastern Hill tract region were not taken into consideration. The main focus of the study area was based on the use of the predicted future ET information for rice production and thus water requirement for irrigation. Rice is one of the most water consumer in Bangladesh for irrigation. As most of the rice production had been found on the selected study zones, the ET information would be helpful for policy maker to make necessary decision.

4.2 Climate of the study areas

4.2.1 Temperature and seasonality

The general characteristics of the seasons of Bangladesh have a subtropical monsoon climate characterized by wide seasonal variations in rainfall, moderately warm temperatures, and high humidity. Its climate is influenced primarily by monsoon and partly by pre-monsoon and post-monsoon circulations. The south-west monsoon originates over the Indian Ocean and carries warm, moist, and unstable air. The monsoon has its onset during the first week of June and ends in the first week of October, with some inter-annual variability in dates. Besides monsoon, the easterly trade winds are also active, providing warm and relatively drier circulation (Agrawala et al., 2003). In Bangladesh there are four prominent seasons, namely, winter, pre-monsoon, monsoon and post-monsoon. These are described below-

Winter (December to February)

Winter is relatively cooler and drier, with the average temperature ranging from a minimum of 7.2 to 12.8°C to a maximum of 23.9 to 31.1°C. In winter there is not usually much fluctuation in temperature which ranges from minimum of 7°C to 13°C to maximum of 24°C to 31°C. (BBS, 2008). The minimum temperature occasionally falls below 5°C in the north though frost is extremely rare. There is a south to north thermal gradient in winter mean temperature: generally the southern districts are 5°C warmer than the northern districts. In general, maximum summer temperatures range between 37°C and 41°C. April is the warmest month in most parts of the country.

Pre-monsoon (March to May)

Pre-monsoon is hot with an average maximum of 36.7°C, predominantly in the west for up to 10 days, very high rate of evaporation, and erratic but occasional heavy rainfall from March to June. In some places the temperature occasionally rises up to 40.6°C or more. The peak of the maximum temperatures are observed in April, the beginning of pre-monsoon season. In pre-monsoon season the mean temperature gradient is oriented in southwest to northeast direction with the warmer zone in the southwest and the cooler zone in the northeast.

Monsoon (June to early-October)

Monsoon is both hot and humid, brings heavy torrential rainfall throughout the season. About four-fifths of the mean annual rainfall occurring during monsoon. The mean monsoon temperatures are higher in the western districts compared to that for the eastern districts. Warm conditions generally prevail throughout the season, although cooler days are also observed during and following heavy downpours.

Post-monsoon (late-October to November)

Post-monsoon is a short-living season characterized by withdrawal of rainfall and gradual lowering of night-time minimum temperature.

4.2.2 Wind Speed

Winds are mostly from the north and northwest in the winter, blowing gently at one to three kilometers per hour in northern and central areas and three to six kilometers per hour near the coast. From March to May, violent thunderstorms, called northwesters, produce winds of up to sixty kilometers per hour. During the intense storms of the early summer and late monsoon season, southerly winds of more than 160 kilometers per hour cause waves to crest as high as 6 meters in the Bay of Bengal, which brings disastrous flooding to coastal areas.

4.2.3 Rainfall & Humidity

Bangladesh is characterized by heavy rainfall in the monsoon. With the exception of the relatively dry western region of Rajshahi, where the annual rainfall is about 160 centimeters, most parts of the country receive at least 200 centimeters of rainfall per year. Because of its location just south of the foothills of the Himalayas, where monsoon winds turn west and northwest, the region of Sylhet in northeastern Bangladesh receives the greatest average precipitation (Figure 4.2). About 80 percent of Bangladesh's rain falls during the monsoon season. The monsoons result from the contrasts between low and high air pressure areas that result from differential heating of land and water. During the hot months of April and May hot air raises over the Indian subcontinent, creating low-pressure areas into which rush cooler, moisture-bearing winds from the Indian Ocean.

Source: Brammer, 1996

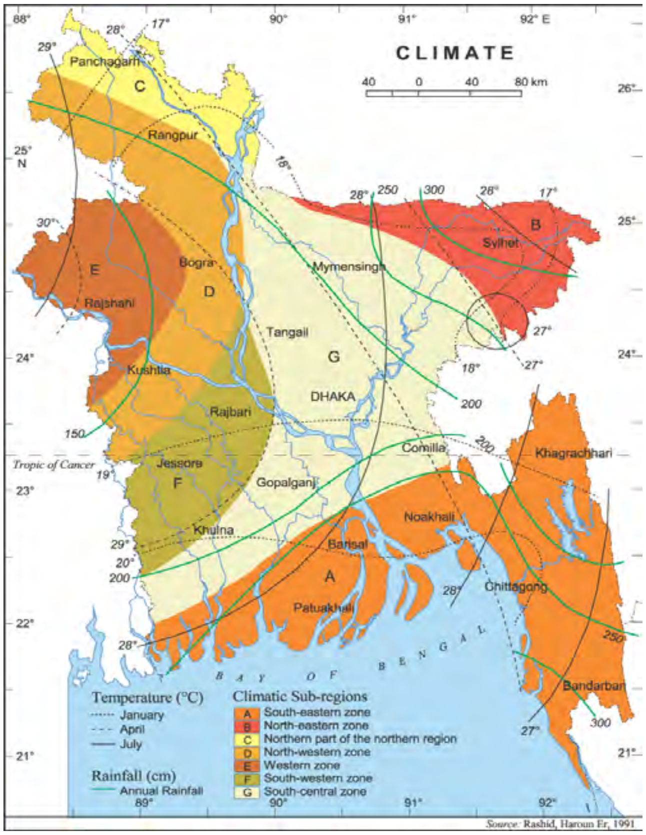
Figure 4.2: Annual Rainfall. (source: Brammer, 1996)

This is the southwest monsoon, commencing in June and usually lasting through September. Dividing against the Indian landmass, the monsoon flows in two branches, one of which strikes the western India. The other travels up the Bay of Bengal and over eastern India and Bangladesh, crossing the plain to the north and northeast before being turned to the west and northwest by the foothills of the Himalayas. The mean annual rainfall is about 2300mm, but there exists a wide spatial and temporal distribution. Annual rainfall ranges from 1200mm in the extreme west to over 5000mm in the east and north-east (MPO, 1991).

4.3 Climate Zone

On the basis of entire climatic condition Bangladesh can be divided into following seven distinct climatic zones (Figure 4.3). The familiar pattern of northwest to southeast isopleths is revealed in this classification.

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



Source: Rashid, Haroun Er, 1991

Figure 4.3: Climate Zone Map of Bangladesh. (source: Rashid, 1991)

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

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

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

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

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

South-central zone (G): In this zone rainfall is abundant, being above 1,900 mm. The range of temperature is, as can be expected, much less than to the west, but somewhat more than in South-eastern zone. This is a transitory zone between the South-eastern, North-western and South-western zones and most of the severe hail storms, and tornadoes are recorded in this area.

CHAPTER FIVE
OBSERVED CLIMATIC CONDITION AND ET

5.1 Introduction

In this study the BMD station data were analyzed. To analyze the evapotranspiration rate from existing data the climatic variables i.e. maximum and minimum temperature, wind speed, relative humidity, and sunshine hour were taken into consideration. From 1961 to 1990 is the period for existing data analysis. Only Sylhet station was selected to observe the general trends in maximum and minimum temperature, wind speed, relative humidity and sunshine hour. Most of the station data were available in Sylhet to observe trends in climatic variables effectively.

5.2 Trends in climatic variables

The thirty years average minimum and maximum temperature, relative humidity, wind speed and sunshine hour at Sylhet station was used to observe the trends. It was observed that the minimum temperature has an increasing trend in all months except September. An increasing trend was observed in maximum temperature in most of the months. Relative humidity has an increasing trend in every month. The wind speed has decreasing trend in all months except February and May. In sunshine hour, there was both increasing and decreasing trends. But most of the months have increasing trends (Appendix-A).

5.3 Regional differences in climatic variables

5.3.1 Temperature

The thirty years average maximum and minimum temperature of the selected stations were analyzed. The minimum temperature shows relatively similar pattern among all selective stations with limited difference in values (Table 5.1 and Appendix-B). According to the station data analysis, lowest value of minimum temperature was found 11.4 ^{0}C in January both from Rajshahi and Jessore which are western part of the country. Reversely highest value of minimum temperature was found in Rajshahi station in August about 26 ^{0}C (Table 5.1).

Table 5.1: Monthly average maximum and minimum temperature

Month	**Rajshahi**		**Mymensingh**		**Sylhet**		**Jessore**		**Barisal**		**Comilla**	
	Min	**Max**	**Min**	**Max**	**Min**	**Max**	**Min**	**Max**	**Min**	**Max**	**Min**	**Max**
January	11.4	24.8	12	24.8	12.3	25	11.4	25.8	12	25.6	12.3	25.6
February	13.2	28	14	27.5	14	27.3	14.1	28.8	15	28.3	15.1	28.1
March	17.8	33.3	18.2	31.4	17.9	30.5	19.5	33.5	20.1	32.1	19.7	31.5
April	22.8	36.4	22.1	32.8	20.8	30.7	23.6	35.8	23.7	33.2	23.1	32.4
May	24.2	35.2	23.3	31.8	22.7	30.7	24.9	35	24.9	33	24.3	32.6
June	25.7	33.3	25.3	31.3	24.4	30.5	25.8	32.9	25.7	31.4	25.2	31.3
July	25.9	31.9	25.7	31.2	24.9	30.6	25.8	31.8	25.6	30.7	25.3	30.7
August	26	32.1	25.8	31.5	25	31.1	25.7	31.8	25.6	30.7	25.2	31.1
September	25.7	32.2	25.4	31.4	24.4	30.9	25.5	32.2	25.6	31.4	25.2	31.5
October	23.2	31.4	23.5	31	22.2	30.5	23.3	31.7	23.6	31.2	23.4	31.1
November	17.8	29.1	18.4	29.1	17.9	28.8	17.9	29.6	18.6	29.2	18.9	29.5
December	12.7	25.8	13.4	25.9	13.7	26.1	12.8	26.3	13.3	26.1	13.6	26.4

It has been observed that, from October to January all stations show very close value of maximum and minimum temperatures. From that period temperature steadily declined and the country observed the winter season. But from March, the gradual increasing in temperature showed variation among the selected stations. The lowest values of temperature were observed in Sylhet station which is the north-eastern part of the country. The frequent rainfall characteristic of the north-east region of the country gave lower values both in minimum and maximum temperature.

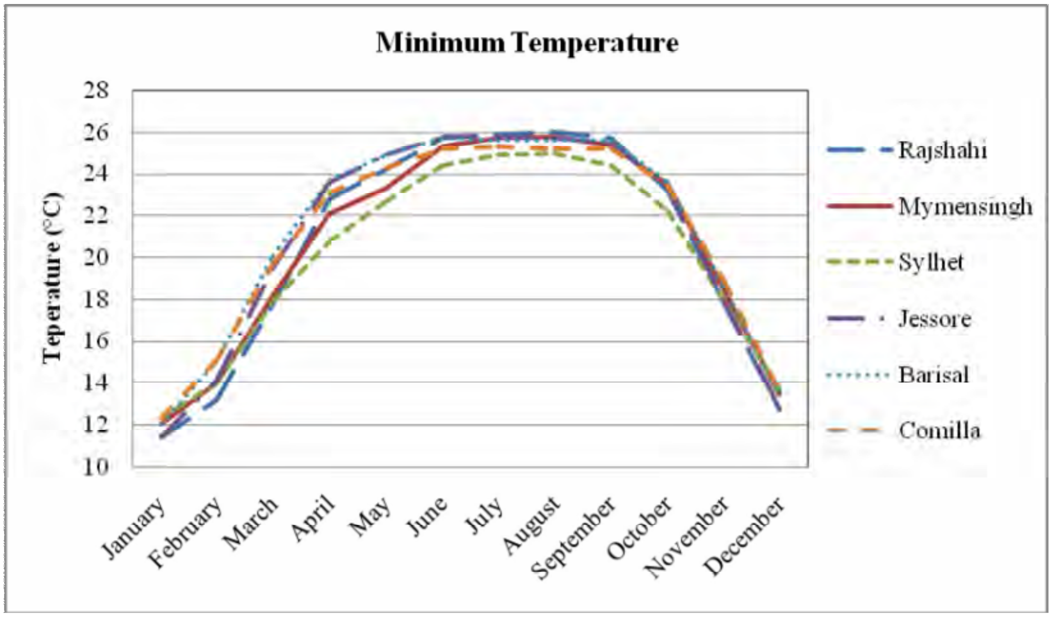


Figure 5.1: Monthly average minimum temperature

It has been observed that, most of the stations showed the highest temperature in April. In April the values in maximum temperature produced higher differences from the rest of the months of a year (Figure 5.1). The highest (36.4 ^{0}C) and lowest (24.8 ^{0}C) values of maximum temperature were found in Rajshahi. After April the temperature was reduced due to cloud cover and rainfall over the country. From the analysis of the 30 years of maximum temperature it was observed that, temperature is gradually increasing from eastern part to western part of the country. As a result, both Rajshahi (north-western region) and Jessore (south-western region) show highest temperature among all other observing stations of the country.

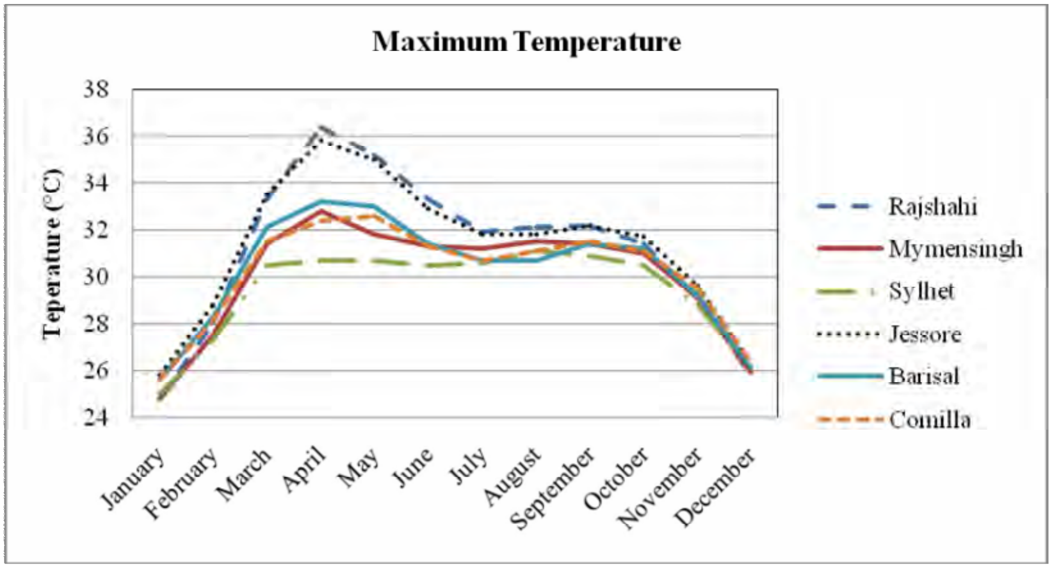


Figure 5.2: Monthly average maximum temperature

5.3.2 Relative Humidity

The 30 years average relative humidity shows the highest values in monsoon season among all the observing stations. From June to October relative humidity was observed more than 80% among the study area. The declining pattern of relative humidity from November to February was observed from all zones due to reduction of precipitation. The lowest humidity was observed in north-west region on March (about 57%). Low precipitation and high temperature on the north-western region makes relative humidity very low among the hydrological region of the country. The value of relative humidity varied from March to June among the observing stations due to variation of temperature and precipitation.

The maximum relative humidity was observed about 89% in south-central region (Barisal) on July and August. The variation in dry season may cause the variation in evapotranspiration rate among the selective stations.

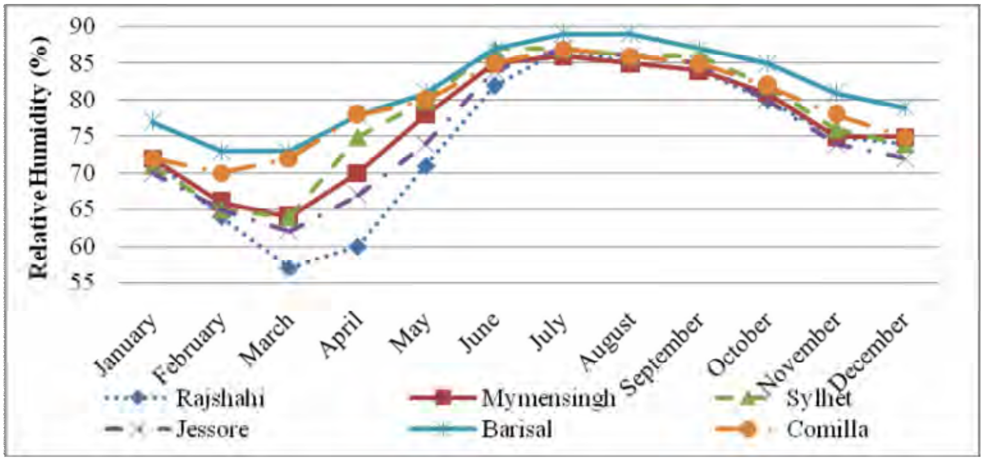


Figure 5.3: Relative Humidity

5.3.3 Wind Speed

In terms of wind speed the values in different stations didn't show similar patterns. The highest value was found in Jessore station and it was about 3.8 ms^{-1} in April (Figure 5.4, Appendix-B). Similarly, Jessore station had the highest average values in whole of the year among all other stations. It was observed that, the southern part of the country has more wind speed relative to the northern part of the country. The southern part of the country has more experience with the tropical cyclone. This tropical cyclone makes the wind speed highest in southern region.

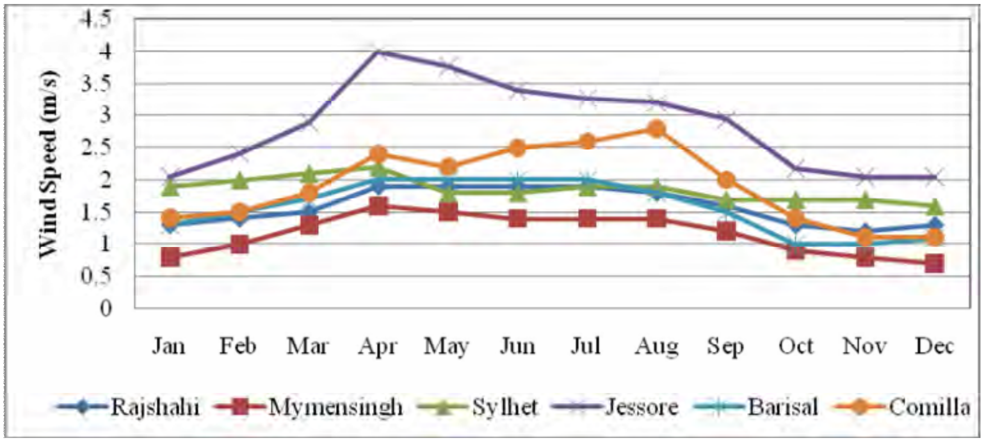


Figure 5.4: Wind Speed

The lowest value of wind speed was observed in Mymensingh station which is the north-central part of the country. The average value of wind speed in Mymensingh was found 1.26 m/s. The average value was observed between 0.7 m/s to 1.6 m/s for the whole year. This lower value of wind speed might have resulted the lowest evapotranspiration rate among the selected stations.

On April the wind speed was found the highest for each station. On that period the storm effect increased the wind speed compared to that of other periods. The average values of wind speed from 30 years data did not consider the direction of the wind.

5.3.4 Sunshine hour

Sunshine hour depends on the cloud cover of the region. If cloud cover increases the sunshine hour will be decreased. On the other hand, if the cloud cover decreases then sunshine hour will be increased. From the analysis of the 30 years data of the selected stations, it is observed that, sunshine hour decreases from May and attains the lowest value in July. The lowest value found in Sylhet is about 3.6 hour in July. This is because from May, cloud cover increases and sunshine decreases. North-eastern part is the highest precipitation zone of the country and one of the reasons for such precipitation is cloud cover. The cloud cover prevents sunshine to penetrate and reduces sunshine hour of the area. That is why, at monsoon, the sunshine hour decreases among all of the stations.

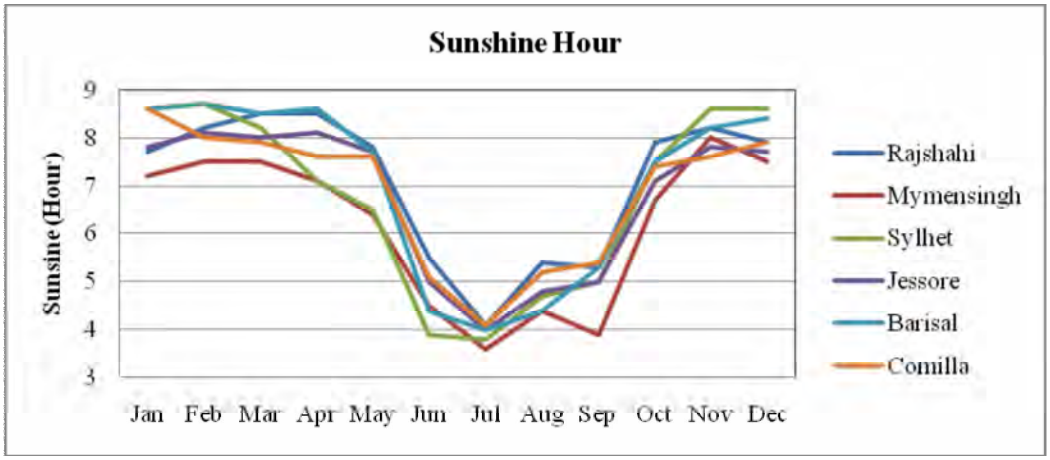


Figure 5.5: Sunshine hour

From January to April sunshine hour shows variations among all the selected stations. The variations were observed from 7.1 – 8.6 hours with Mymensingh showing the minimum values during that period (Figure 5.5). The average value of sunshine hour is lower in Mymensingh region which is the north-central region of the country.

5.3.5 Solar radiation

In this study solar radiation was computed from FAO CROPWAT 8.0 software. The climatic data were used as an input value for computation of the solar radiation. The solar radiations of the selected stations are as given in Appendix-B.

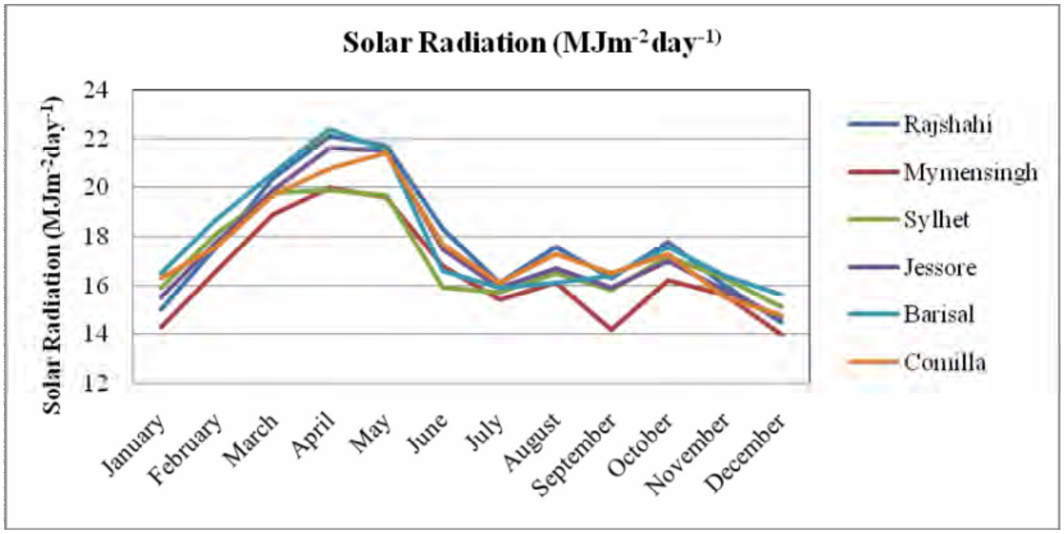


Figure 5.6: Solar radiation

The computed radiation data increased from January to April and later on it decreased gradually and produced little variation in values. From July to December the radiation has a zigzag pattern (Figure 5.6). The maximum value of radiation was observed from March to May. On that period the solar radiation value increased due to combined effect of climatic variables. Highest temperature, wind speed and sunshine hour and lowest relative humidity made solar radiation increased and gave maximum value for those months. According to Figure-5.7, the average value of radiation was taken in secondary axis to analyze the variation of the radiation among different stations. The computed average value of radiation was found minimum in Mymensingh station (about 16.5 $MJm^{-2}d^{-1}$) and maximum in Barisal station (17.9 $MJm^{-2}d^{-1}$). From monthly observation of the solar radiation data, Barisal station which is the representative part of the south-central region of the country gave the highest value (about 22.4 MJm^{-2}d^{-1}). At Mymensingh, the lowest value of solar radiation was observed among the observing stations on December (about 14 MJm^{-2}d^{-1}). This lowest value of radiation was observed due to lowest wind speed & temperature and combination of the other climatic variables.

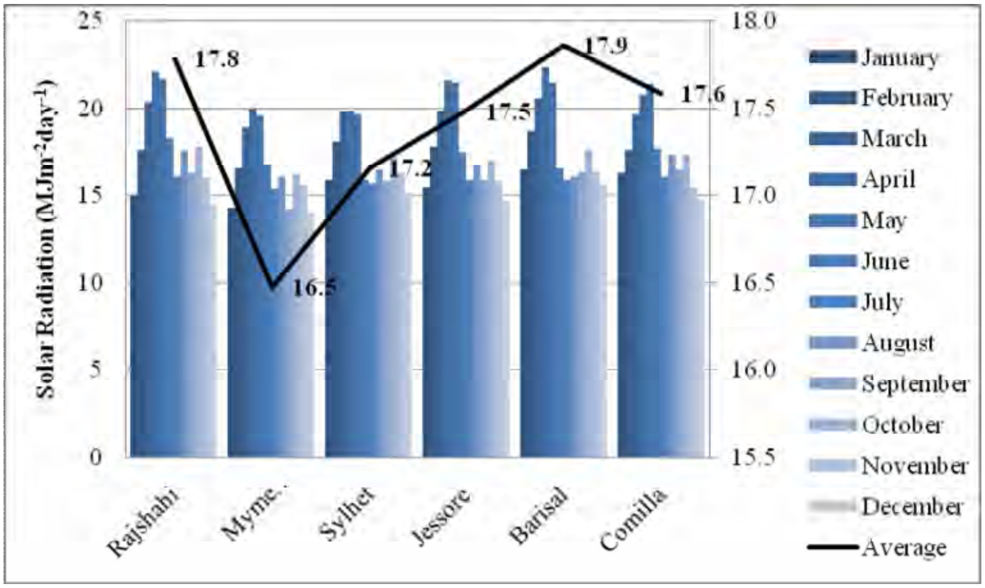


Figure 5.7: Radiation with average value

5.3.6 Reference Evapotranspiration rate ET$_0$

The historic (1961-1990) ET$_0$ value was analyzed and summarized in Appendix-B. In Mymensingh the north-central part of the observing stations gave the lowest value of evapotranspiration rate of about 2.26 mm/day in January. The combination effect of climatic variables such as low temperature, lowest wind speed and solar radiation gave the lowest ET value in Mymensingh among the study areas. Meanwhile, the highest evapotranspiration rate was found about 5.93 mm/day at Jessore in May. The long term average vale (30 years) of reference evapotranspiration rate was computed. The highest ET$_0$ was found in Jessore station (about 4.16 mm/day). In Mymensingh station, the average lowest value was computed to be about 3.44 mm/day. The second highest value was found in Rajshahi station (about 3.93 mm/day). The second lowest value was in Sylhet station. It was also observed that, western part of the country had more ET value from the eastern zone of the country.

Evapotranspiration rate is an important factor for water requirement by any plant. The highest value of ET results the highest water demand. It was observed that from March to May the evapotranspiration rate was the highest among all the stations. On this pre-monsoon period the highest ET value increased water requirement and gave water stress on irrigation sector.

Table 5.2: Observed Reference Evapotranspiration rate.

Month	Rajshahi	Mymensingh	Sylhet	Jessore	Barisal	Comilla
January	2.53	2.26	2.87	3.00	2.69	2.77
February	3.33	2.97	3.66	3.93	3.42	3.35
March	4.62	4.05	4.56	5.11	4.43	4.30
April	5.78	4.68	4.53	5.73	5.04	4.80
May	5.45	4.43	4.33	5.93	4.92	4.89
June	4.42	3.80	3.56	4.37	3.79	4.06
July	3.75	3.53	3.52	3.77	3.54	3.68
August	4.01	3.68	3.71	3.87	3.54	3.93
September	3.75	3.27	3.51	3.79	3.61	3.76
October	3.83	3.42	3.63	3.92	3.67	3.72
November	3.14	2.94	3.27	3.49	3.13	3.09
December	2.56	2.27	2.74	2.97	2.60	2.59
Average	**3.93**	**3.44**	**3.66**	**4.16**	**3.70**	**3.75**

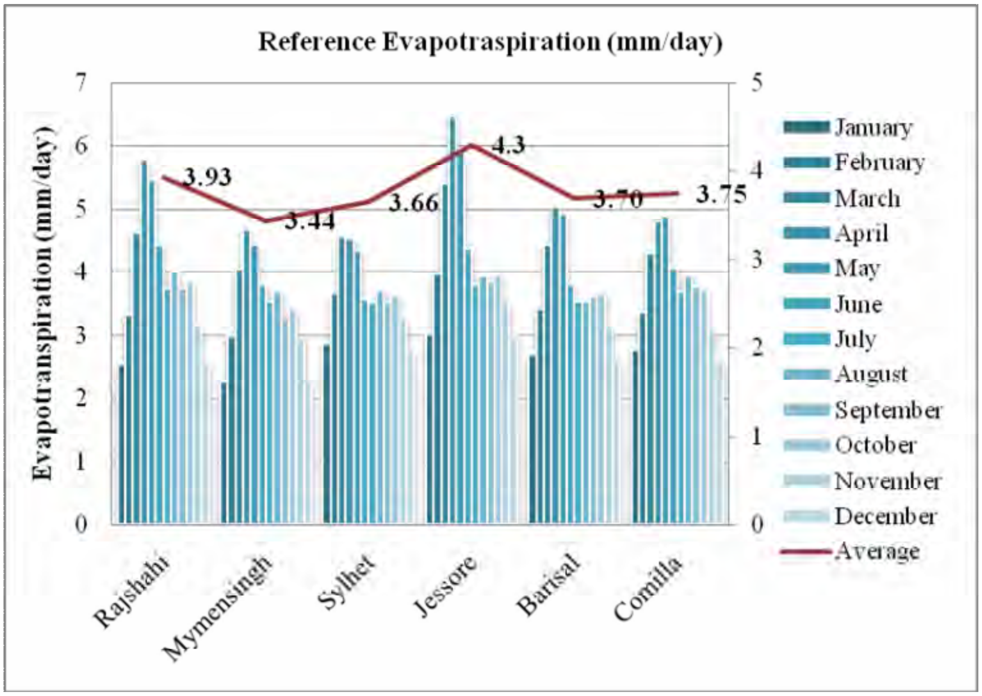


Figure 5.8: Reference evapotranspiration rate

CHAPTER SIX

CLIMATE CHANGE SCENARIOS AND ITS IMPACT ON ET

6.1 Introduction

To predict the future evapotranspiration it is necessary to predict the climatic variables. The climatic variables are maximum and minimum temperature, wind speed, relative humidity and sunshine hour. From PRECIS model the future data have been predicted with different time frames. The future projections are 2006-2035 (representing 2020), 2036-2065 (representing 2050), 2056-2085 (representing 2070). The future data has been corrected by bias correction from the values of observing data and analyzed the significance level by student t-test. From the statistical t-test, it was analyzed after bias correction, whether there is any significant difference between the means of the two sets of data. The average values of these future projections will be representing the three different time periods. According to this time periods the climate variables were predicted for different locations of Bangladesh representing different hydrological regions.

6.2 Climatic variables

6.2.1 Maximum and Minimum Temperature

Temperature is one of the controlling climatic variables for evapotranspiration. From PRECIS model maximum temperature (T.max) and minimum temperature (T.min) were predicted at different time periods at different locations of Bangladesh. The temperature data was the direct output of the PRECIS model.

Table 6.1: Minimum and Maximum temperature at predicted time periods.

Locations	**Minimum Temperature**				**Maximum Temperature**			
	Observed Year	**Year 2020**	**Year 2050**	**Year 2070**	**Observed Year**	**Year 2020**	**Year 2050**	**Year 2070**
Barisal	21.53	22.66	24.02	25.12	30.57	31.44	32.80	34.08
Comilla	21.31	22.42	23.72	24.80	30.40	31.27	32.74	34.06
Jessore	21.27	22.46	23.86	25.06	31.66	32.73	34.18	35.70
Mymensingh	20.95	22.02	23.32	24.36	30.21	31.15	32.71	33.93
Rajshahi	20.91	22.03	23.47	24.61	31.47	32.53	34.06	35.45
Sylhet	20.32	21.37	22.62	23.54	29.55	30.41	31.75	32.75

According to the analysis it was clearly observed that the average annual minimum and maximum temperatures had an increasing trend for all of the observing stations (Figure 6.1). On an average, both minimum and maximum temperatures will be increased more than 2^{O}C from year 2020 to 2070. At year 2070 the maximum temperature will be 35.70^{0}C at Jessore, which is the south-west hydrological zone of the country. The minimum temperature will be observed at Sylhet (about 23.54^{0}C) among all other zones of the study area. Both maximum and minimum temperatures had increasing patterns among the hydrological zones of the country.

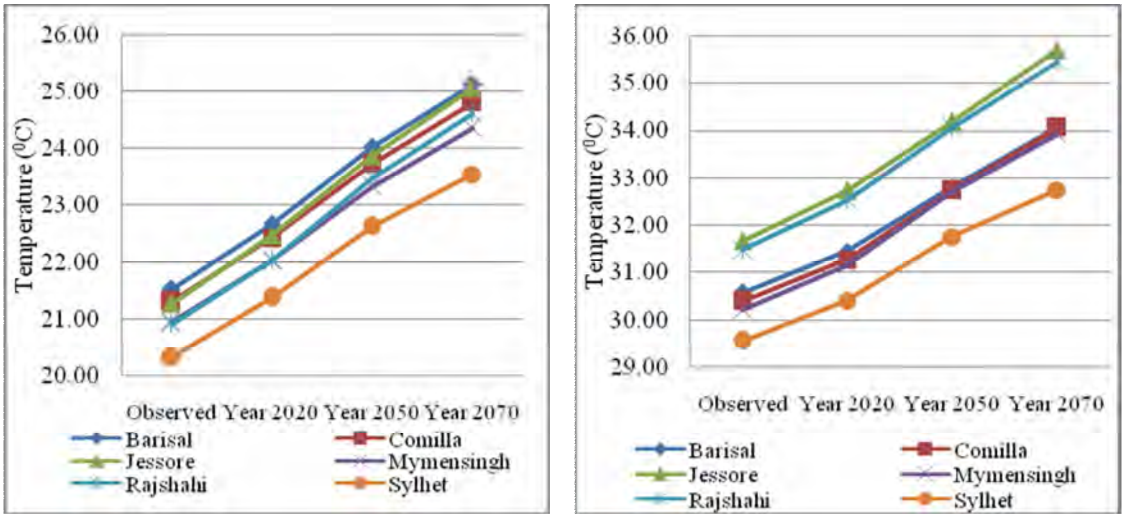


Figure 6.1: Predicted minimum (left) & maximum (right) temperature (^{0}C) at different time periods.

Sylhet, which is the representative part of the north-east region of the country, always observed the lowest values in temperature; this was due to the heavy rainfall in that area. The south-central region of the country is very near to the Bay of Bengal where minimum temperature will be the highest among all other observing zones of the country. The average minimum temperature will be increased 1.11 ^{0}C, 2.45 ^{0}C and 3.54 ^{0}C by the year 2020, 2050 and 2070 from the present value (present T.min is about 21.05 ^{0}C). The maximum temperature of the country also shows an increasing trend (Appendix-D). By the year 2020, 2050 and 2070 the maximum temperature will be increased by 0.95 ^{0}C, 2.39 ^{0}C and 3.68 ^{0}C, respectively. The western part of the country will experience the highest maximum temperature for the predicted years which will be one of the important factors for evapotranspiration rate. The increasing pattern of temperature at south-western part of the country may have an effect on salinity increase as well as ecosystem of the mangrove forest. According to t-test, it was found that, there is no significant difference between model data and observed data for temperature.

6.2.2 Relative Humidity

Relative humidity is an important climatic variable for evapotranspiration. PRECIS gives the relative humidity directly. From PRECIS model analysis, relative humidity shows decreasing trend from year 2020 to 2070 prediction (Figure 6.2). By year 2020, 2050 and 2070 relative humidity will be decreased by about 0.7%, 3.44% and 5.79%, respectively. This decreasing characteristic of relative humidity was predicted in all stations. At Barisal station (i.e. south central) the relative humidity will be the highest in 2020 (about 81%) among all other regions of the country. The lowest value of relative humidity (68%) will be observed at north-west region of Bangladesh i.e. in Rajshahi by the year 2070. Only Jessore gives non-significant t-test result among the selected study areas.

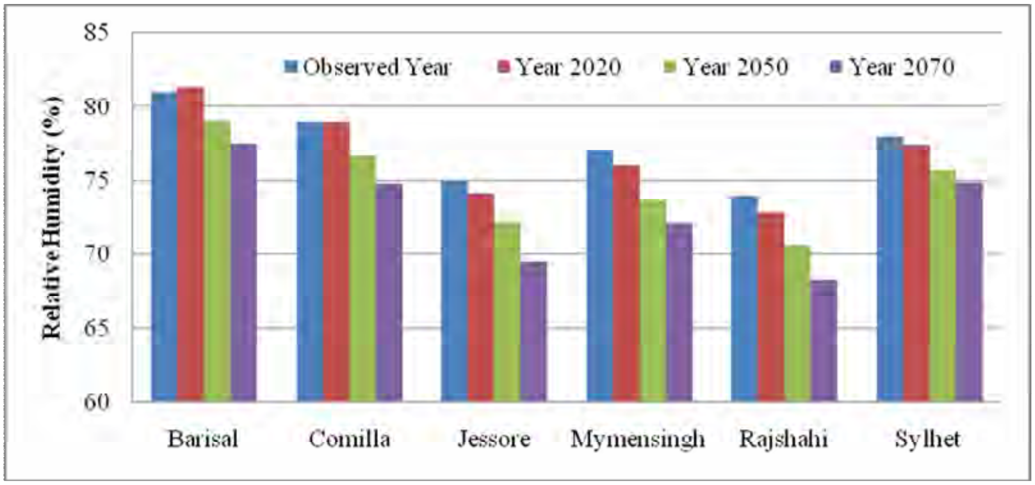


Figure 6.2: Relative Humidity at different time period

At different months, the values of relative humidity could not be characterized whether increasing or decreasing. But the average value of the representative year shows negative trend. The value of relative humidity at south-central region of the country (representative location is Barisal) increases from June to August in a year and gives the lowest vale in dry season i.e. November to January. At Comilla the humidity value was found the highest on July of each predicted year and shows lowest value in January. In March, other four locations (Jessore, Mymensingh, Rajshahi and Sylhet) show the lowest humidity. The highest value was found between June to August of the respective year. The lower values of relative humidity cause higher values of the evapotranspiration rate. So for dry season decreasing relative humidity causes increasing water demand for plants.

6.2.3 Wind Speed

According to the simplified equation of wind speed (Equation no 3), the value was predicted. Average wind speed will be increased by the year 2020, 2050 and 2070 about 1.59%, 4.21% and 9.39%, respectively, in Bangladesh. At Jessore, wind speed is very high among all other stations. On the other hand Mymensingh has the lowest wind speed. Every observing station has slightly increased the wind speed by 2070 compared to the present value (Figure 6.3).

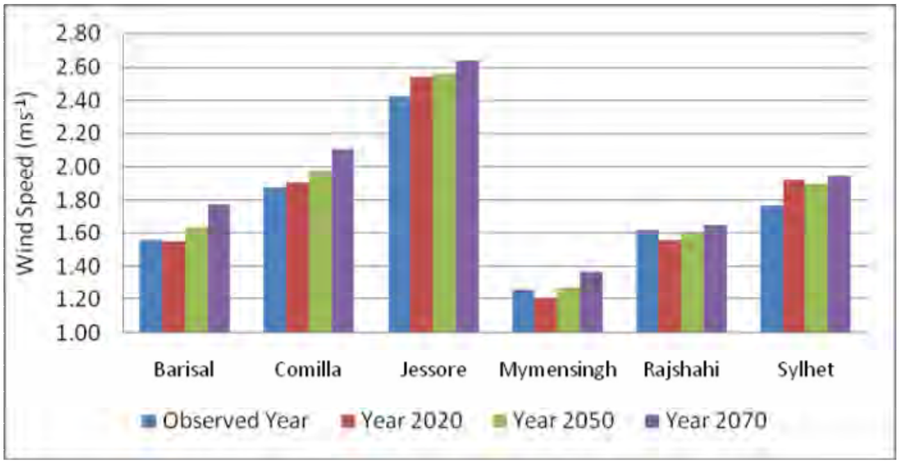


Figure 6.3: Wind speed variation at different locations of Bangladesh.

Jessore, the representative hydrological zone from south-west region, shows an increasing trend in wind speed. The increase rate will be 4.68%, 5.53% and 8.90% by year 2020, 2050 and 2070, respectively. Jessore and Mymensingh gave non-significant result on t-test (Table 6.2). The increasing characteristics will be the cause for increasing evapotranspiration rate. At Mymensingh, the north-central zone shows minimum values of wind speed among all the selected stations. The lowest value of wind speed will have an effect on evapotranspiration rate. The overall observation among the regions shows variation of wind speed. The southern part of the region shows greater value compared to that of the northern part of the country. The wind circulation on sea surface may be increased thus increasing the wind speed in the northern region of the country.

6.2.4 Sunshine Hour

According to the aforementioned Table 4.1 and Equation 2 the value of sunshine (in hour) was predicted. The annual sunshine hour will be increased all over the country (Figure 6.4). The increased rate will be 1.64%, 2.66% and 6.39% by year 2020, 2050 and 2070, respectively. The increased rate will be the highest in Jessore from 2.77% to 8.89% by the year 2070 among all other stations of the country. At north-western region, sunshine hours will attain the highest values of about 7.09, 7.22 and 7.28 hour by 2020, 2050 and 2070, respectively. Among the study areas, the north-central zone of the country will have the minimum value of sunshine hour. The maximum sunshine hour will be increased by about 6.45% in 2070. This highest value of sunshine hour will increase the evapotranspiration rate of the region. The reduction of cloud cover will increased the sunshine hour. The increased sunshine hour will also increase the temperature and decrease the relative humidity.

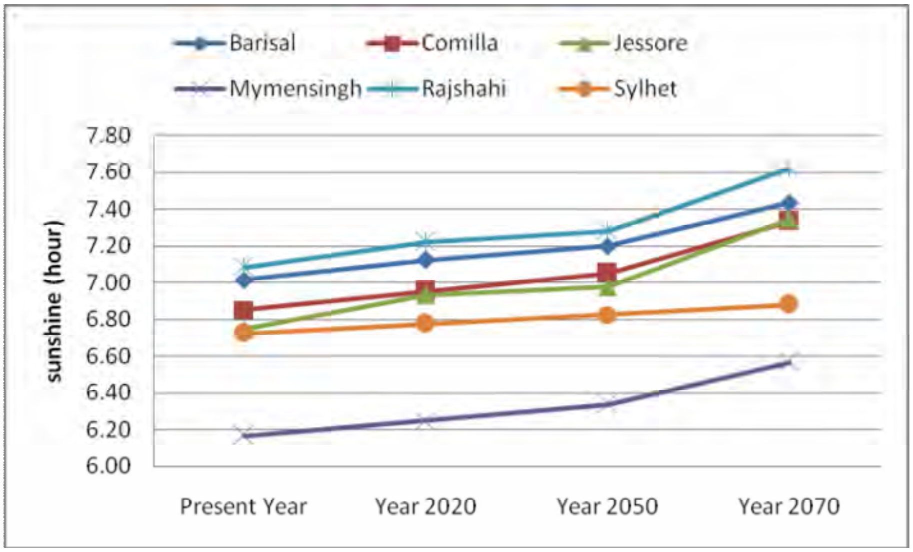


Figure 6.4: Trend of sunshine hour

6.2.5 Radiation

After prediction of the climatic variables, the solar radiation was computed from CROPWAT 8.0 software. The climatic data was used as input value for computation of solar radiation. The overall solar radiation of the country will be increased by 13.73%, 14.10% and 16.35% by the years 2020, 2050 and 2070, respectively, from the present value. Among the observing stations at north-eastern part of the country, there will be minimum variation of solar radiation from year 2020 to 2070 (Figure 6.5). But the maximum solar radiation was also observed in that region. This increasing radiation will have an increasing effect on evapotranspiration rate of that area.

The maximum radiation will be observed at north-eastern region of the country is about 21.09 $\mathrm{MJm^{-2}day^{-1}}$ by the year 2070. On the other hand the minimum value of radiation will be 18.53 $\mathrm{MJm^{-2}day^{-1}}$ at Mymensingh.

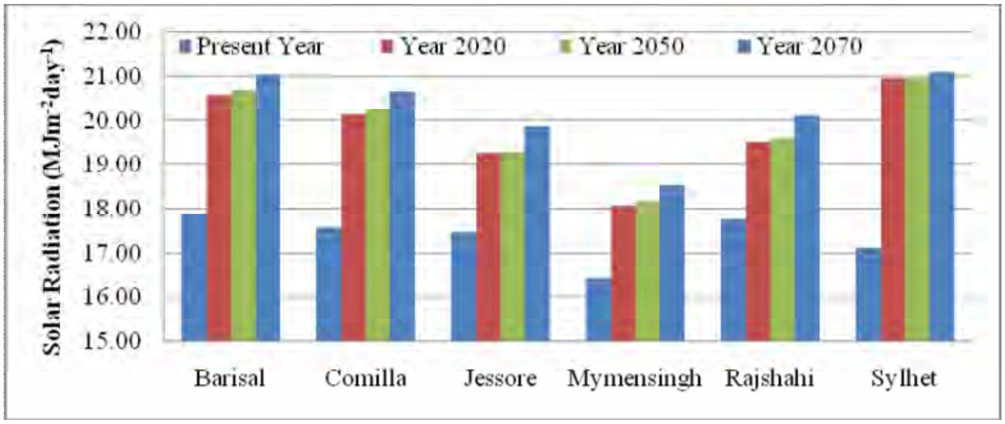


Figure 6.5: Predicted solar radiation at different locations of Bangladesh

6.3 Evapotranspiration Rate, ET_0(mm/day)

The evapotranspiration rate was predicted by the input values of climatic variables into CROPWAT 8.0 software. All observing stations except Rajshahi show an increasing rate of evapotranspiration till 2070. The predicted evapotranspiration rate for the country will be increased by about 0.27, 0.47 and 0.78 mm/day by 2020, 2050 and 2070, respectively. The evapotranspiration rate at Rajshahi will be decreased by about 7.4% and 2.24% by 2020 and 2050, respectively, from the present value (i.e. 4.00 mm/day). But by the year 2070 the value will be increased by about 0.26

mm/day from the present value. The highest annual evapotranspiration rate (about 5.14 mm/day) will be observed at Jessore by 2070.

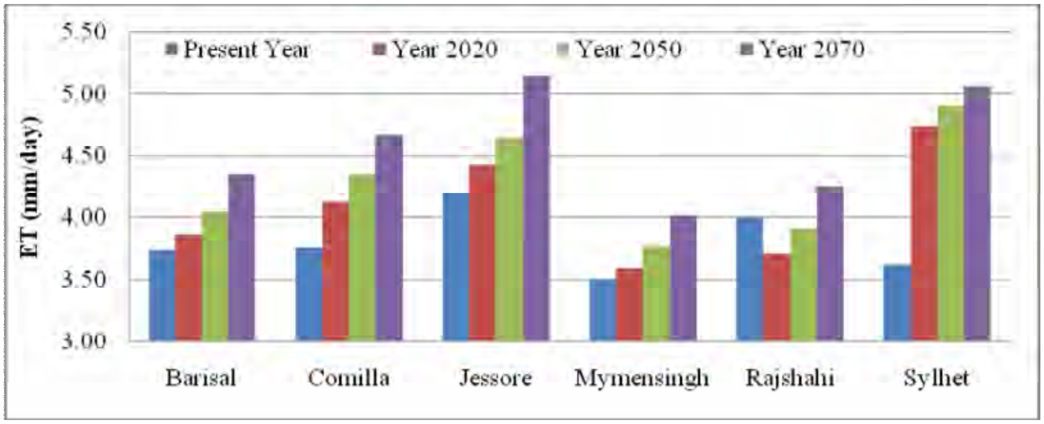


Figure 6.6: Annual evapotranspiration rate at different locations of Bangladesh

The monthly variations of evapotranspiration rate were also predicted (Figure 6.7). Except March and April the evapotranspiration rate will be increased for whole of the year. In March and April, the evapotranspiration rate will be decreased compared to the present value and reduce the water requirement for those particular months. Maximum variation will be observed in May and July by year 2070.

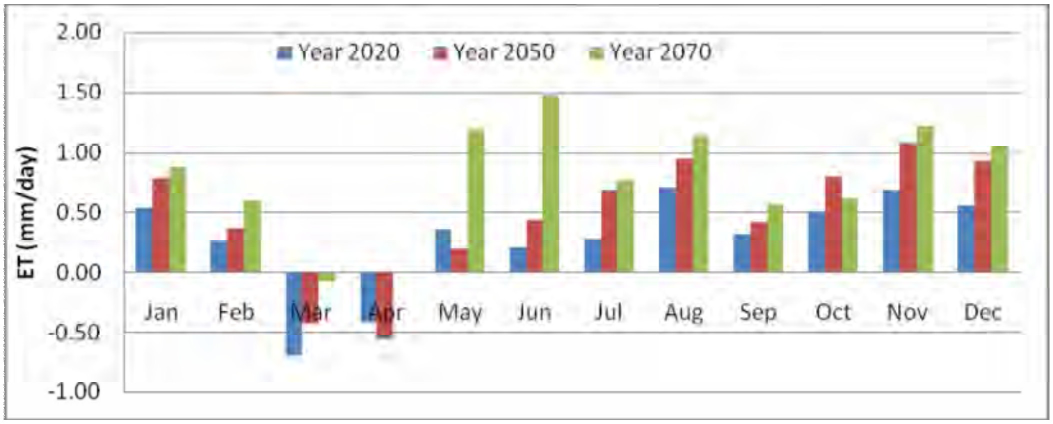


Figure 6.7: Monthly changes of evapotranspiration rate at different time span

6.4 Regional variations of evapotranspiration rate

The increasing trend of the ET value will be the cause of increase in water requirement of plants. At Mymensingh, the lowest values of evapotranspiration rate among the study area will be observed for predicted years. So the water stress will be the minimum on north-central region of the country compared to other observing regions (Figure 6.9-a). At present, the water requirement is the highest on western part, more specifically south-western part of the country because of the evapotranspiration rate. The regional differences among the observing stations were represented by the following Figure 6.8.

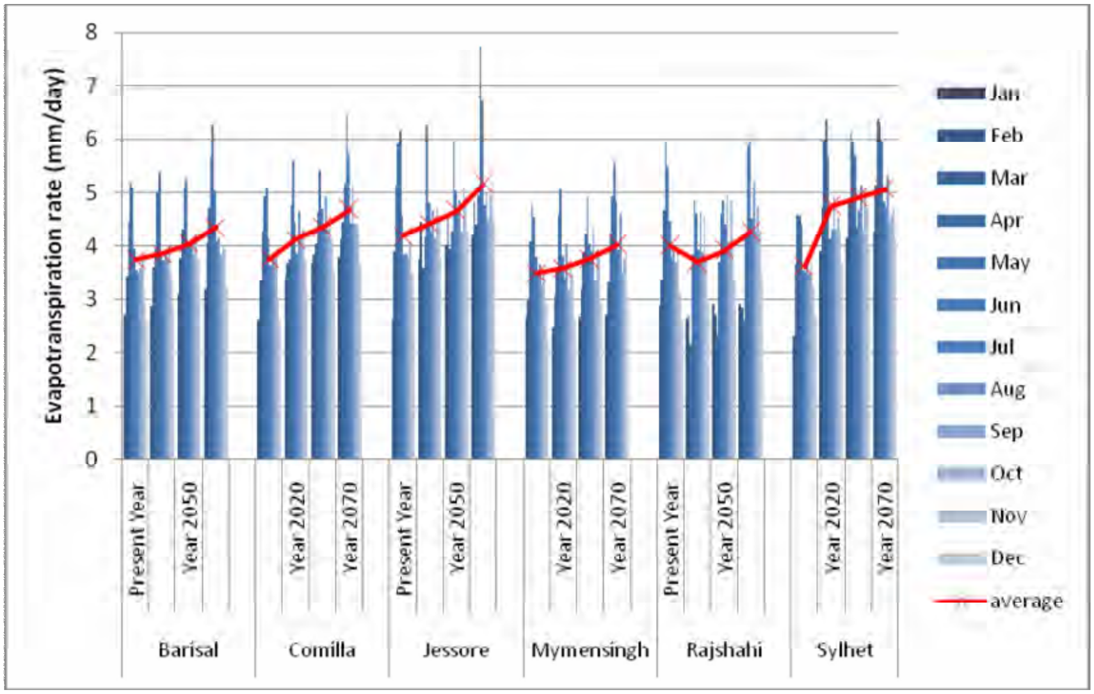
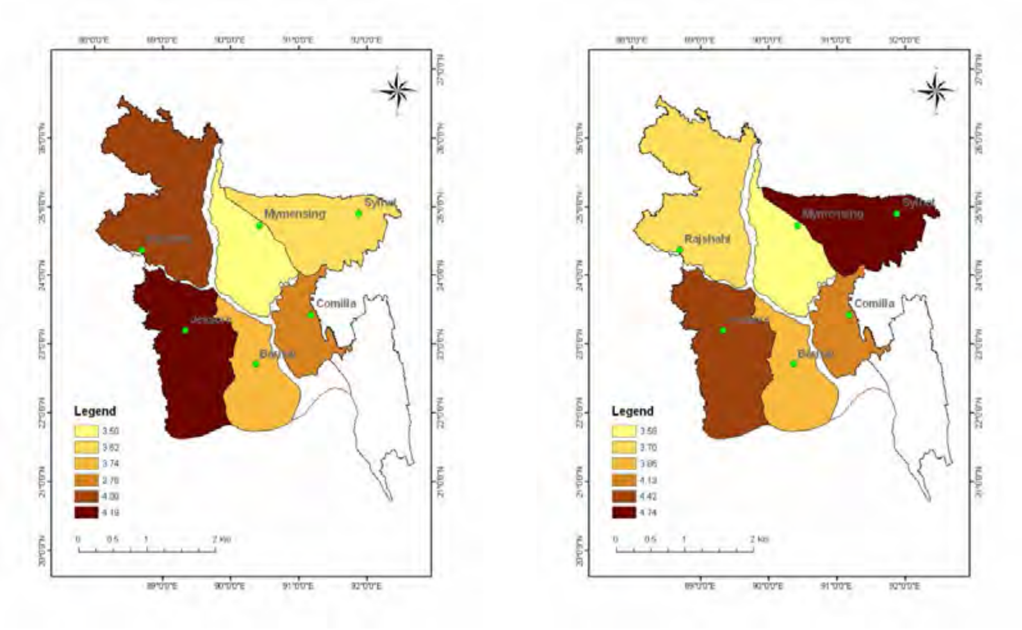
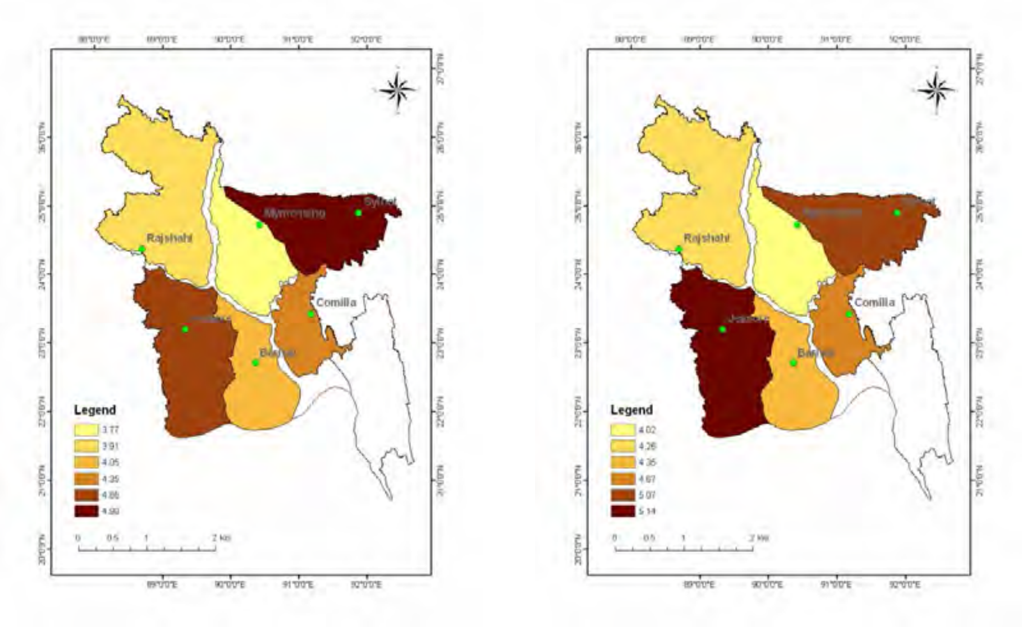


Figure 6.8: Regional variation of Evapotranspiration rate at different projections

By the year 2020 water requirement will be the highest at north-eastern region of the country. The second highest water required zone will be the south-western part of the country (Figure 6.9-b). But compared with the present value, the overall ET value will be increased among the observed stations. The most water required zone will be north-eastern part of the country where the evapotranspiration rate will be 4.90 mm/day (Figure 6.9-c). This is because of the combine effect of increasing temperature, sunshine hour and decreasing trend of relative humidity. The increasing trend of evapotranspiration rate on that region also indicates the increasing trend of water requirement for plants. The lowest ET value will be observed at north-central region (about 3.77 mm/day).



(a) Present condition (b) ET in 2020



(c) ET in 2050 (d) ET in 2070

Figure 6.9: Changes of evapotranspiration of various stations located at different hydrological zone

By the year 2070 the evapotranspiration rate will be the highest in south-western region of the country. The combination effect of the climatic variables especially higher wind speed and lower relative humidity of that region will resulting the highest

ET value (about 5.14 mm/day). The second highest ET value was observed in south-eastern part of the country. The lowest sunshine hour and wind speed combining with other climatic variables made ET value lowest at north-central region of the country. At north-western region the reduction of ET value by 2020 and 2050 will be the only difference compared with the other observing hydrological regions.

6.5 Rainfall

Rain is an important water source either for agriculture or for human consumption. Agricultural production is very much dependent upon rainfall. Rainfall is one form of precipitation that falls on the earth's surface. The precipitation of future periods has been estimated by PRECIS model. The observation values of rainfall were collected from BMD. The future values was analyzed and validated. The validation was done by the subtraction of the % change of the predicted rainfall from observation. It has been observed that, annual rainfall will be increased all over the country. The annual rainfall will be increased by 14.04%, 15.61% & 18.94% by 2020, 2050 and 2070, respectively, from the present value. The highest increase of rainfall will be at Mymensingh (about 16.75%) by 2020. On the other hand the minimum percentage of rainfall (about 8.30%) will be increased at Jessore compared to other observing stations. The heavy rainfall will be observed at north-eastern region of the country. The maximum mean annual rainfall will be at north-eastern region by year 2020, 2050 and 2070 about 11.87, 13.61 and 13.44 mm/day respectively. There will be minimum variation of rainfall by 2050 (about 13.03 – 19.89%). The increasing trend of rainfall will have very similar pattern among the observing station. The peak rainfall will be observed at June and July for all the 2020, 2050 and 2070 years.

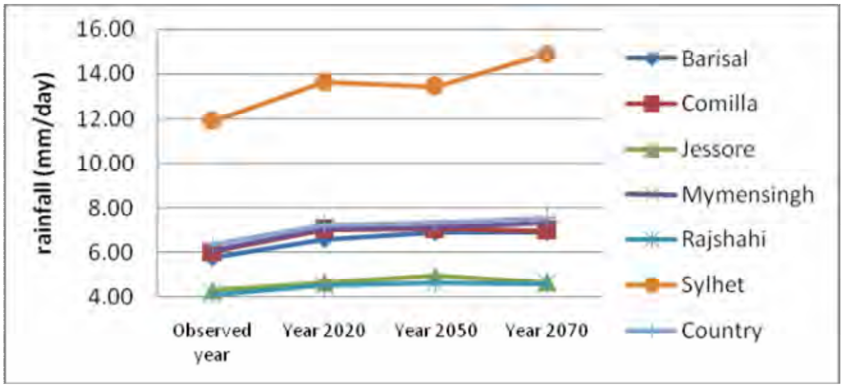


Figure 6.10: Mean annual rainfall at different time series

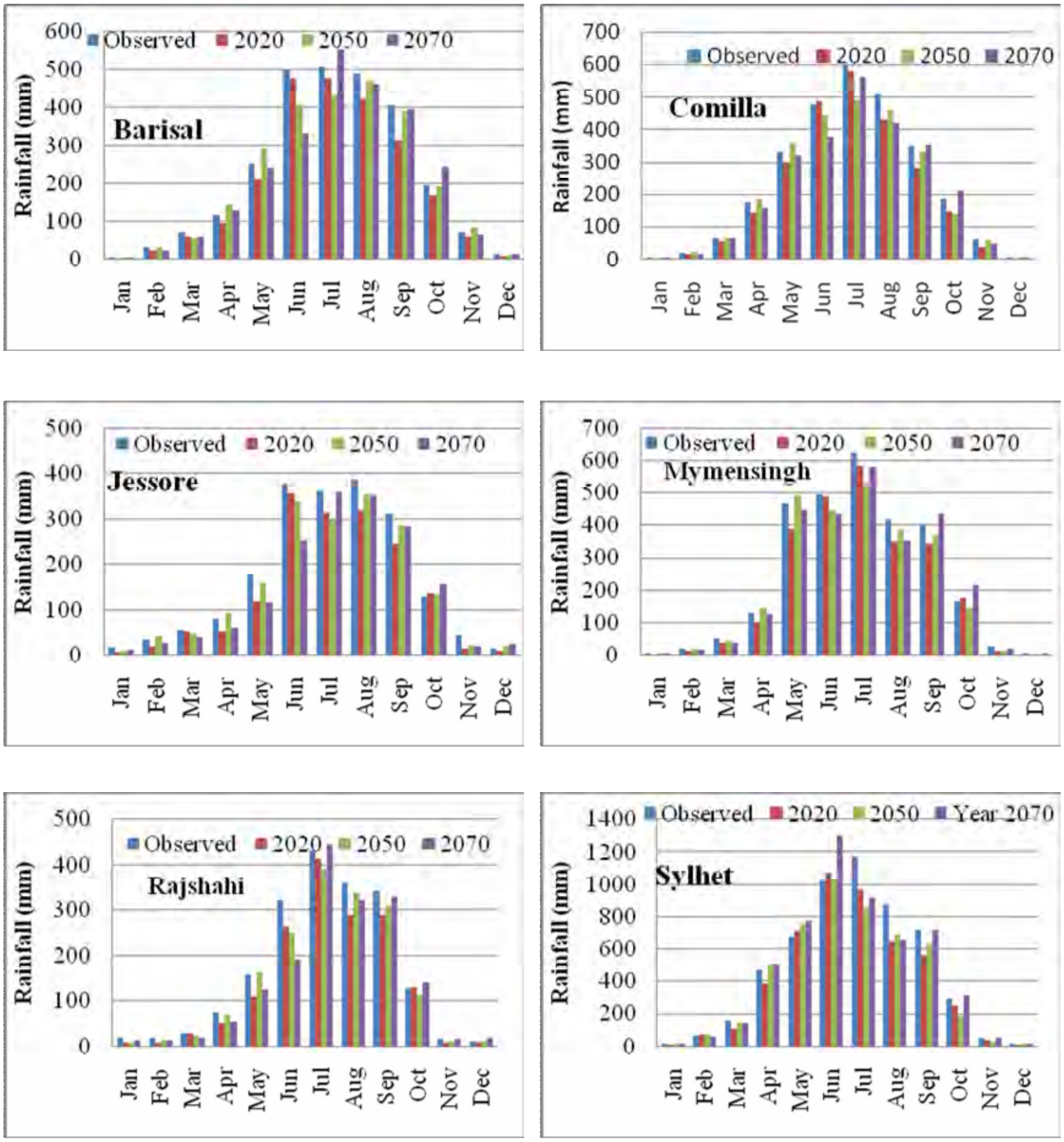


Figure 6.11: Monthly rainfall at different locations and time period

The projected seasonal and annual rainfall is analyzed. It seems that, the annual peak rainfall will be observed at July by year 2020 and 2070. But by the year 2050 the annual peak rainfall will be observed at June. After analysis of the seasonal rainfall at different time period it seems that, most of the rainfall will be observed at monsoon period (JJAS). During that period the maximum amount of rainfall will be observed by the year 2070 and 2020. But compared to the other two different time periods, the monsoon rainfall will be decreased by the year 2050 although it will be 11.18% larger than the present (monsoon period, JJAS) rainfall. At pre-monsoon (MAM) period rainfall will be the highest by the year 2050 compared to the other two projected years. The amount of rainfall will remain the same during post-monsoon (ON) and dry (DJF) periods.

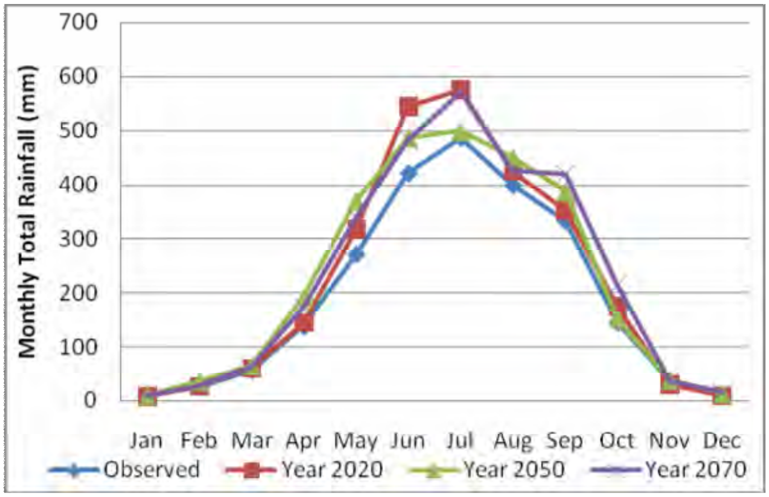


Figure 6.12: Annual cycle of projected rainfall

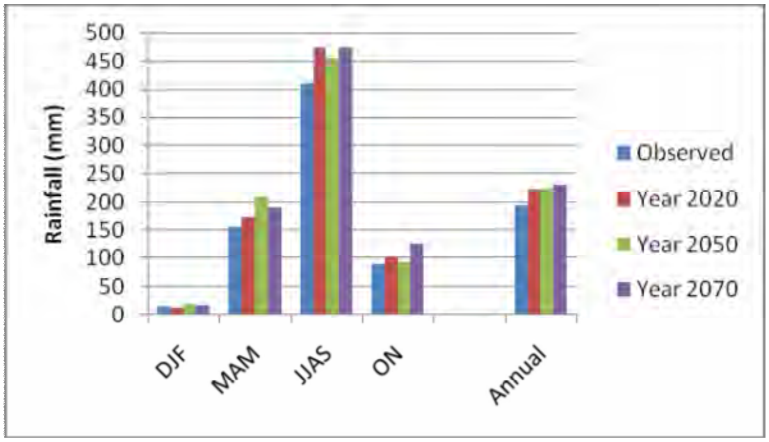


Figure 6.13: Seasonal and annual projected rainfall

6.6 Statistical t-test results

The observed and predicted data set (from 1961-1990) were used to analyze whether there is any significant difference between the means of the two sets of data by student t-test. The result of the significant test was given in Table 6.2.

Table 6.2: Significant t-test result

Climatic variables	Barisal	Comilla	Jessore	Mymensingh	Rajshahi	Sylhet
Minimum Temperature	0.87	0.84	0.88	0.95	0.87	0.98
Maximum Temperature	0.93	0.82	0.94	0.72	0.79	0.76
Relative Humidity	0.55	0.70	**0.46***	0.59	0.60	0.88
Wind Speed	0.61	0.59	**0.18***	**0.09***	0.74	0.62
Sunshine Hour	0.60	0.67	0.52	0.74	0.76	0.60
Evapotranspiration rate	0.70	0.89	0.91	0.92	0.72	0.96
Rainfall	0.55	**0.43***	0.67	0.58	0.61	**0.45***

**significantly differs between two sets of data.*

According to the result, it was observed that, there is no significant difference between the means of the two sets of temperature data at all selected stations. But at Jessore, predicted relative humidity and wind speed data were significantly differs from the observed data. At Mymensingh two means of wind speed data were also varied. Predicted rainfall data at Comilla and Sylhet differs from the observed data. A part from the mentioned variables and stations, other climatic variables and stations gave satisfactory t-test result. There is no significant difference between the means of observed and predicted data.

6.7 Crop Water Requirement

The crop water requirement depends on crop coefficient (K_c) which varies with the development stage of a crop. The crop water requirement for rice at different growing stages has been estimated. With the increase of the reference evapotranspiration rate the water requirement will also be increased for projected years. It has been estimated that, maximum water will be required on dry season for Boro rice by the year 2070 (about 892.73 mm). Water requirement for Kharif-I, Kharif-II and Rabi (dry) season at different location were predicted for projected year 2020, 2050 and 2070.

Table 6.3: Crop water requirement for T. Aus at Kharif-I season

Stations	Total Crop Water Requirement (mm)			
	Present	Year 2020	Year 2050	Year 2070
Barisal	516.52	540.61	557.77	629.22
Comilla	535.75	589.57	616.39	694.46
Jessore	594.10	640.05	655.49	780.65
Mymensingh	496.25	518.78	548.25	603.88
Rajshahi	568.65	571.85	596.59	692.15
Sylhet	484.84	605.94	631.14	663.06

Table 6.4: Crop water requirement for T. Aman at Kharif-II season

Stations	Total Crop Water Requirement (mm)			
	Present	Year 2020	Year 2050	Year 2070
Barisal	552.00	594.24	624.85	630.70
Comilla	568.69	659.81	706.58	717.89
Jessore	600.26	708.45	755.74	776.57
Mymensingh	527.51	562.81	605.90	617.26
Rajshahi	583.29	657.70	708.12	727.55
Sylhet	558.96	710.01	750.66	751.31

Table 6.5: Crop water requirement for Boro at Rabi (dry) season

Stations	Total Crop Water Requirement (mm)			
	Present	Year 2020	Year 2050	Year 2070
Barisal	776.26	770.57	795.43	901.89
Comilla	763.38	785.05	797.82	906.23
Jessore	899.44	818.58	835.85	994.37
Mymensingh	711.84	707.83	711.18	796.76
Rajshahi	841.71	628.78	631.45	742.22
Sylhet	724.91	958.98	959.03	1014.92

Among the observing stations, water requirement will be the highest by the year 2070 at Jessore about 780.65 mm and 776.57 mm on Kharif-I and Kharif-II season, respectively. The maximum water will be required for Boro rice at Sylhet by the year 2070 about 1014.92 mm. Water requirements for rice at other observing stations on Kharif-I, Kharif-II and Rabi season are tabulated on Table 6.3, 6.4 and 6.5, respectively. Water requirement for rice crop at different stages was observed. It has been observed that, maximum amount of water will be required on dry season for upcoming projected years. At north-east reason, water requirement for rice will be the highest on that season. Jessore is the maximum water required place on Kharif-I and Kharif-II seasons (Figure 6.14). From the present condition, percent change of water according to season has been analyzed. On that analysis, by the year 2020 water requirement will be decrease on dry season for rice. From the present condition, at Kharif-I season water requirement will be increased about 21.34% by the year 2070 (Figure 6.15).

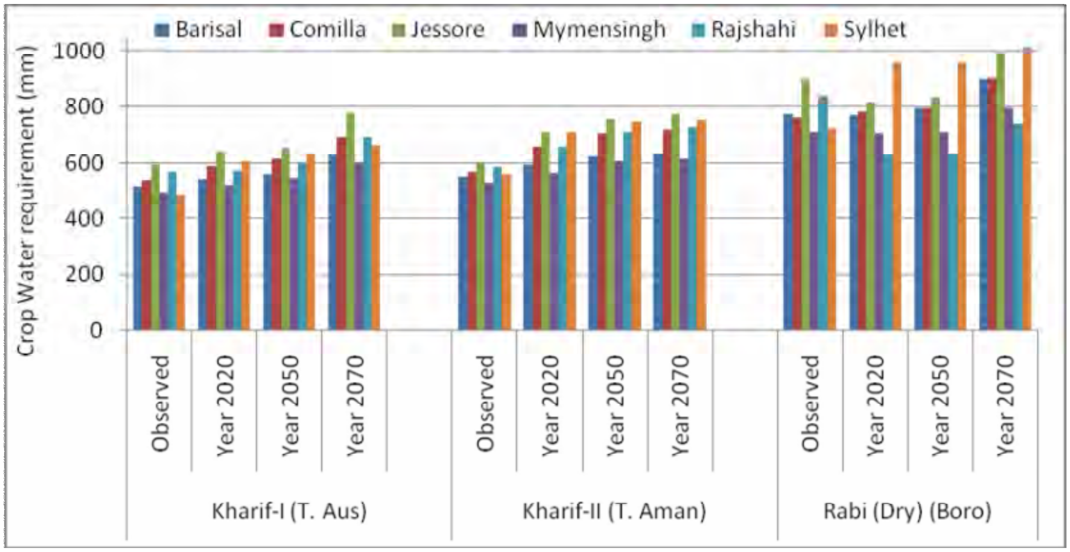


Figure 6.14: Crop water requirement for rice on different seasons

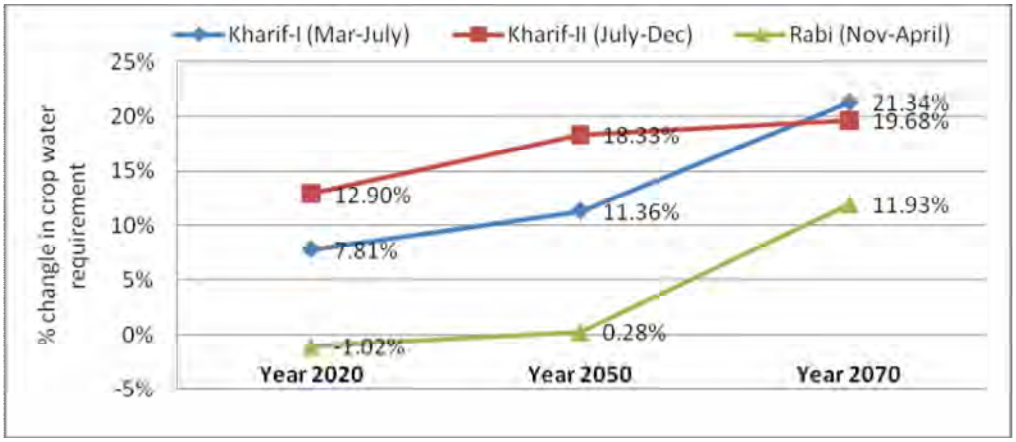


Figure 6.15: Percent change in crop water requirement for rice on different seasons

6.8 Irrigation water requirement

The net irrigation water requirement is the difference between the crop water requirement and rainfall. Irrigation water requirement for Boro rice at dry season for observing stations were predicted. According to the calculation no irrigation water will be required at Sylhet station up to 2070 (Figure 6.16). The rainfall over Sylhet at predicted time period will be sufficient at dry season for Boro rice production. The irrigation water demand will be decreased for other observing stations by the year 2020 and 2050. The highest irrigation water will be required at Jessore about 19.14%

by the year 2070 where as the present irrigation water requirement is 660.10 mm. From the present circumstances irrigation water will be increased by the year 2070 about 15.26% and 18.91% at Barisal and Comilla, respectively. The highest demand for irrigation will be decreased from present (336.98 mm) at Mymensingh about 47.36% by the year 2050 (Figure 6.17). Among the observing stations, Jessore will be the highest irrigation water required station by the year 2070 about 786.42 mm. With the increase of the rainfall irrigation water demand reduces even though there is an increasing trend in crop water requirement.

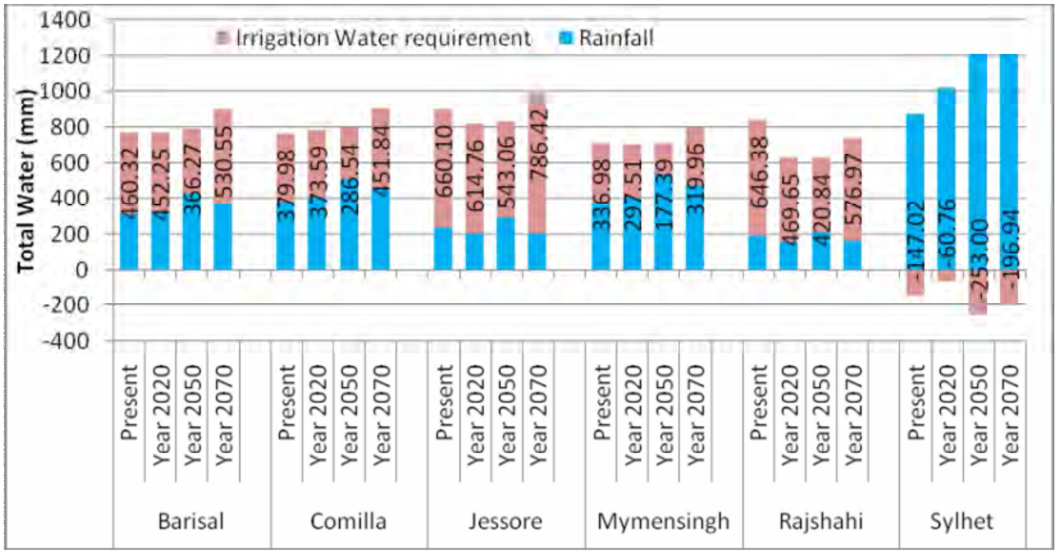


Figure 6.16: Irrigation water requirement and Rainfall

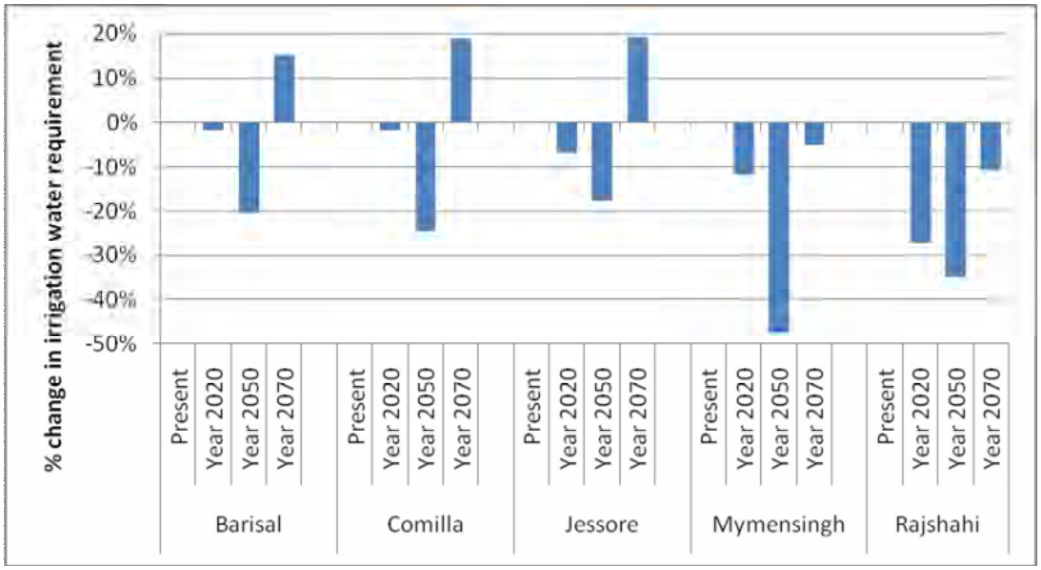


Figure 6.17: Percent change in Irrigation water requirement for Boro rice

CHAPTER SEVEN

CONCLUSION AND RECOMMENDATION

7.1 Conclusion

Climate change is an important issue for this decade. An agricultural production and water use much more depend on climate change. By this study the controlling climatic variables for evapotranspiration were analyzed for different future time periods. The findings show that, the combination effects of climatic variables were differing from region to region. The specific conclusions drawn from this study are summarized below.

The maximum and minimum temperatures have increasing trend. The minimum temperature will be the highest at south-central region of the country. In that region the minimum temperature will be increased by about 16.71% by 2070. Maximum temperature will be the highest in the south west region. The temperature will be raised by about 2.52 ^{0}C in the region by 2070. In most of the regions there will be some effect on relative humidity. It seems that, most of the time periods relative humidity will be slightly decreased. Overall relative humidity will be decreased by about 0.7, 3.44 and 5.79% by 2020, 2050 and year 2070, respectively. Wind speed has both decreasing and increasing trend. By the year 2020 wind speed will be decreased at north-center and north-western region of the country. But by 2070 it will be increased by about 8.80, and 1.70%, respectively. The maximum wind speed was predicted at south-west region of the country, to be 2.43, 2.54 and 2.56 m/s by the year 2020, 2050 and 2070, respectively. Sunshine hour and solar radiation will be increased among all the regions. The sunshine hour will be the highest at north-western region of the country. It seems that, by 2020, 2050 and 2070 the sunshine hour will be reached to about 7.22, 7.28 and 7.62 hours, respectively, in that region. The solar radiation at north-eastern region shows the highest values of about 20.97, 20.97 & 21.09 $MJm^{-2}day^{-1}$ by 2020, 2050 & 2070, respectively.

Evapotranspiration rate depends on the combine effect of climatic variables of minimum and maximum temperature, relative humidity, sunshine hour and wind speed. After analyzing evapotranspiration rate at different regions, most of them show an increasing trend. Only the north-western region shows decreasing trend by the year

2020 and 2050. But the next projection period, evapotranspiration rate is found to increase by about 0.26 mm/day from the present value of 4.00 mm/day. More specifically, increasing trend of temperature, wind speed, sun shine duration and decreasing trend of relative humidity, the combine effects of all these climatic variables increased evapotranspiration rate. From year 2020 to 2070, overall ET_0 rate will be increased by about 0.27 to 0.78 mm/day. The ET_0 will be the highest (about 5.14 mm/day) at Jessore by the year 2070. Among all other stations, Mymensingh shows minimum values of about 3.58, 3.77 & 4.02 mm/day by 2020, 2050 and 2070, respectively.

The annual rainfall of the present year is 6.35 mm/day which will be 7.24, 7.34 and 7.55 mm/day by 2020, 2050 and 2070, respectively. So mean annual rainfall will be increased. The maximum rainfall will be observed at north-eastern region of the country. At this region the annual mean rainfall will be 13.61, 13.44 and 14.93 mm/day by the year 2020, 2050 and 2070, respectively. Less amount of rainfall will be observed at north-western region of the country. The annual mean rainfall will be 4.52, 4.62 and 4.58 mm/day by 2020, 2050 and 2070, respectively. Maximum volume of rainfall will be observed in monsoon (JJAS) season with an increasing trend. The mean rainfall at monsoon season will be 15.51, 14.92 and 15.54 mm/day by 2020, 2050 and 2070, respectively. The north-east region will observe the highest increment of the evapotranspiration rate for projected years with the increase of the rainfall.

The increased evapotranspiration rate indicates the increase of water requirement for production of crops. It was expected that, with the increase of the evapotranspiration rate the crop water requirement will be increased. Water requirement for rice at different seasons was estimated and gave increasing demand of water at all stations. Most importantly, water requirement will be increased at Kharif-I (March-July) season by the year 2070 about 21%. But on Rabi (Nov-April) and Kharif-II (July-Dec) season, water demand for rice will be increased about 11.93% and 19.68%, respectively by the year 2070. On dry season for Boro rice cultivation the net irrigation water requirement will be the highest at Jessore about 786.42 mm by the year 2070. At Barisal and Comilla irrigation water will be increased from present demand about 15.26% and 18.91%, respectively. Among the observing station, no irrigation will be required at Sylhet. The heavy rainfall over Sylhet will be sufficient for crop water requirement on dry season. As evaporation process affects the soil moisture condition, the increased rate of evapotranspiration may also decrease the soil moisture and make soil dry. If the water demand on agricultural sector is properly managed and sustainably utilized, the production of growing crops will be increased.

7.2 Recommendations

Based on the aforementioned result and the experience gained during the study, the following recommendations are made.

1. In this study the climatic variables were analyzed for only the representative locations of the hydrologic region. Future studies should include other stations to make more reliable conclusions.
2. Different kinds of SRES scenarios and models can be used and compare the values of evapotranspiration rate.
3. The effects of evapotranspiration rate can be studied for different crops.
4. Further study can be done to predict irrigation water requirement for some selected crops.

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APPENDIX A

TRENDS IN CLIMATIC VARIABLES AT SYLHET

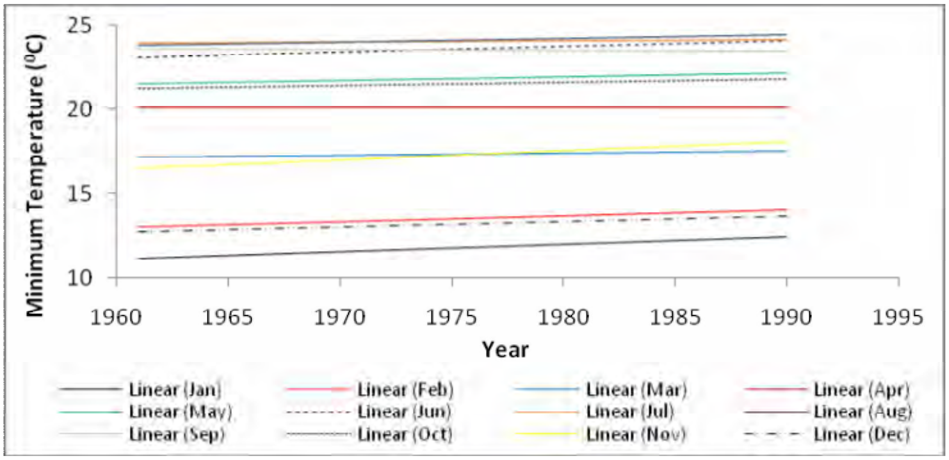


Figure A1: Trends in Minimum Temperature

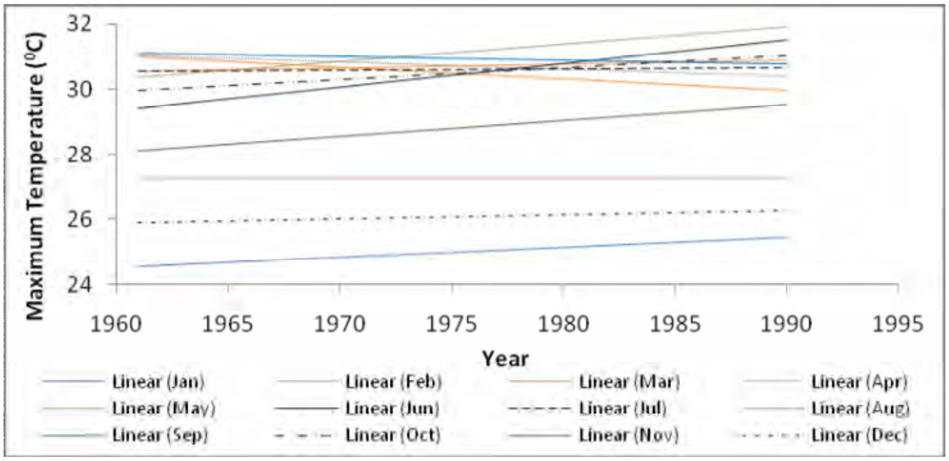


Figure A2: Trends in Maximum Temperature

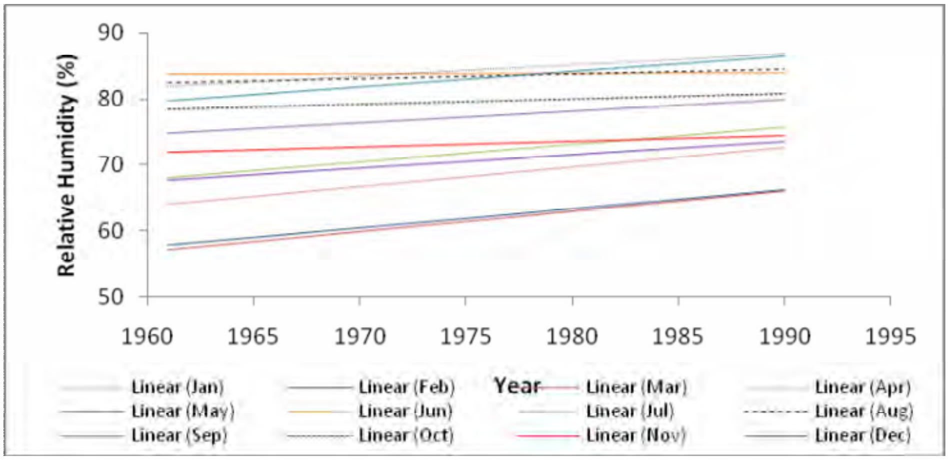


Figure A3: Trends in Relative Humidity

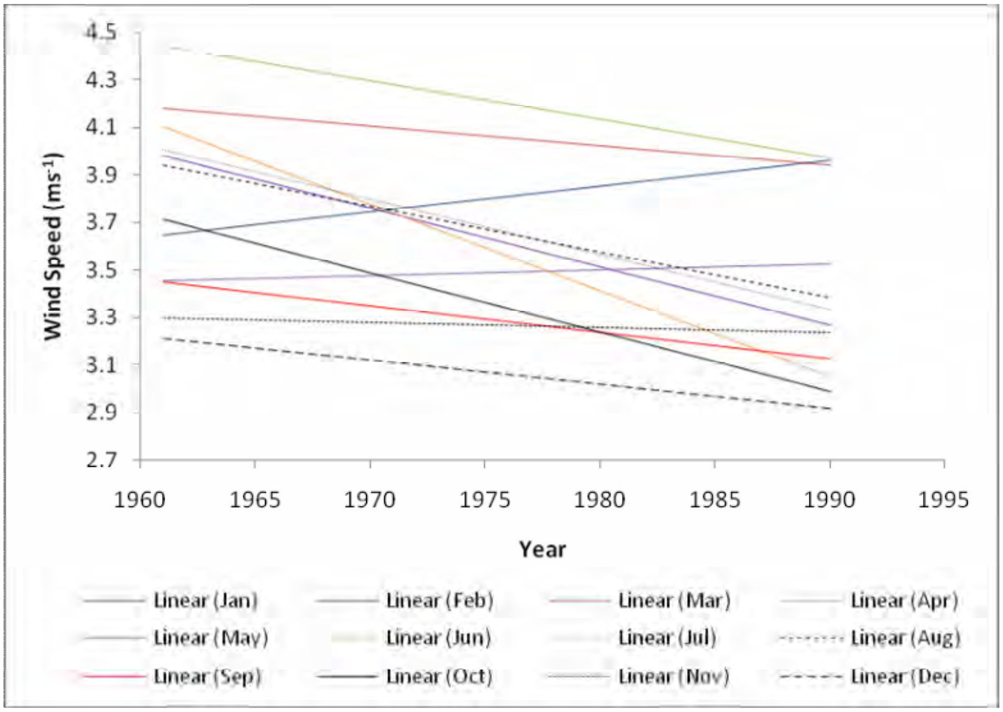


Figure A4: Trends in Relative Humidity

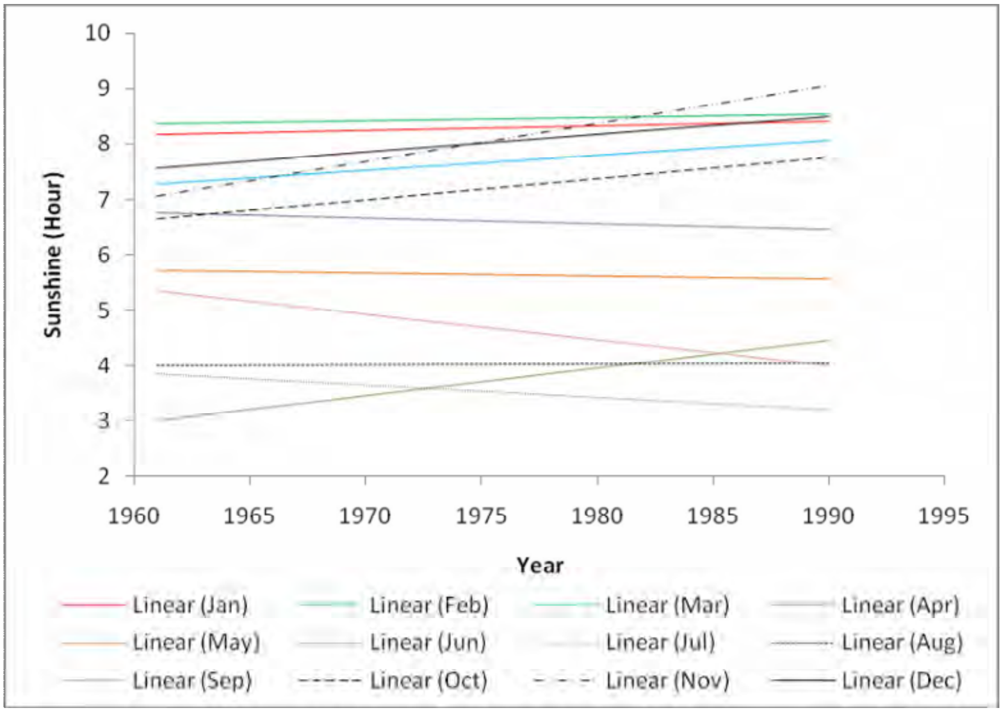


Figure A5: Trends in Sunshine (hour)

APPENDIX B

OBSERVED CLIMATIC VARIABLES

Table B1: Monthly average minimum temperature (Degree Celsius)

Month	Rajshahi	Mymensingh	Sylhet	Jessore	Barisal	Comilla
January	11.4	12	12.3	11.4	12	12.3
February	13.2	14	14	14.1	15	15.1
March	17.8	18.2	17.9	19.5	20.1	19.7
April	22.8	22.1	20.8	23.6	23.7	23.1
May	24.2	23.3	22.7	24.9	24.9	24.3
June	25.7	25.3	24.4	25.8	25.7	25.2
July	25.9	25.7	24.9	25.8	25.6	25.3
August	26	25.8	25	25.7	25.6	25.2
September	25.7	25.4	24.4	25.5	25.6	25.2
October	23.2	23.5	22.2	23.3	23.6	23.4
November	17.8	18.4	17.9	17.9	18.6	18.9
December	12.7	13.4	13.7	12.8	13.3	13.6

Table B2: Monthly average maximum temperature (Degree Celsius)

Month	Rajshahi	Mymensingh	Sylhet	Jessore	Barisal	Comilla
January	24.8	24.8	25	25.8	25.6	25.6
February	28	27.5	27.3	28.8	28.3	28.1
March	33.3	31.4	30.5	33.5	32.1	31.5
April	36.4	32.8	30.7	35.8	33.2	32.4
May	35.2	31.8	30.7	35	33	32.6
June	33.3	31.3	30.5	32.9	31.4	31.3
July	31.9	31.2	30.6	31.8	30.7	30.7
August	32.1	31.5	31.1	31.8	30.7	31.1
September	32.2	31.4	30.9	32.2	31.4	31.5
October	31.4	31	30.5	31.7	31.2	31.1
November	29.1	29.1	28.8	29.6	29.2	29.5
December	25.8	25.9	26.1	26.3	26.1	26.4

Table B3: Monthly average relative humidity (percentage)

Month	Rajshahi	Mymensingh	Sylhet	Jessore	Barisal	Comilla
January	72	72	71	70	77	72
February	64	66	65	65	73	70
March	57	64	64	62	73	72
April	60	70	75	67	78	78
May	71	78	80	74	81	80
June	82	85	87	84	87	85
July	87	86	87	87	89	87
August	85	85	86	86	89	86
September	84	84	86	85	87	85
October	80	81	82	80	85	82
November	75	75	76	74	81	78
December	74	75	74	72	79	75

Table B4: Monthly average wind speed (meter per second)

Month	Rajshahi	Mymensingh	Sylhet	Jessore	Barisal	Comilla
January	1.3	0.8	1.9	2.0	1.3	1.4
February	1.4	1	2	2.4	1.5	1.5
March	1.5	1.3	2.1	2.9	1.7	1.8
April	1.9	1.6	2.2	4.0	2	2.4
May	1.9	1.5	1.8	3.8	2	2.2
June	1.9	1.4	1.8	3.4	2	2.5
July	1.9	1.4	1.9	3.3	2	2.6
August	1.8	1.4	1.9	3.2	1.8	2.8
September	1.6	1.2	1.7	2.9	1.5	2
October	1.3	0.9	1.7	2.2	1	1.4
November	1.2	0.8	1.7	2.0	1	1.1
December	1.3	0.7	1.6	2.0	1.1	1.1

Table B5: Monthly average sunshine duration (hour)

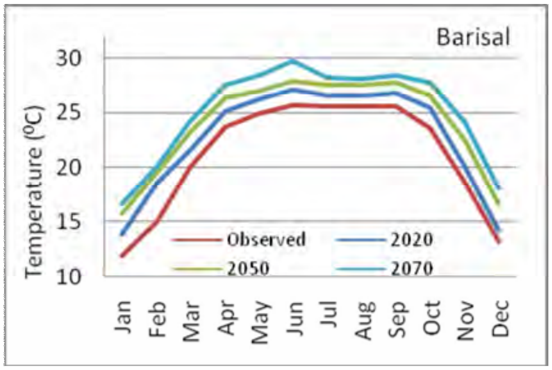
Month	Rajshahi	Mymensingh	Sylhet	Jessore	Barisal	Comilla
January	7.7	7.2	8.6	7.8	8.6	8.6
February	8.2	7.5	8.7	8.1	8.7	8
March	8.5	7.5	8.2	8	8.5	7.9
April	8.5	7.1	7.1	8.1	8.6	7.6
May	7.8	6.4	6.5	7.7	7.7	7.6
June	5.5	4.5	3.9	5	4.4	5.1
July	4.1	3.6	3.8	4	4	4.1
August	5.4	4.4	4.7	4.8	4.4	5.2
September	5.3	3.9	5	5	5.3	5.4
October	7.9	6.7	7.5	7.1	7.5	7.4
November	8.2	8	8.6	7.8	8.2	7.6
December	7.9	7.5	8.6	7.7	8.4	7.9

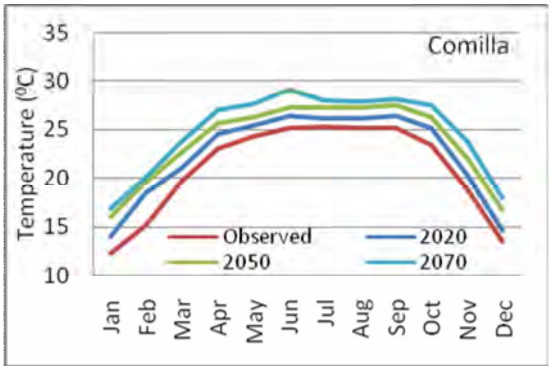
Table B6: Monthly average solar radiation (mega joule per meter squire per day)

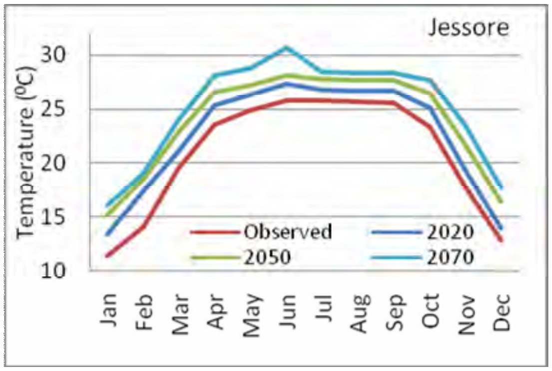
Month	Rajshahi	Mymensingh	Sylhet	Jessore	Barisal	Comilla
January	15	14.3	15.9	15.5	16.5	16.3
February	17.6	16.6	18.1	17.8	18.7	17.6
March	20.4	18.9	19.8	19.9	20.6	19.7
April	22.1	20	19.9	21.6	22.4	20.8
May	21.7	19.6	19.7	21.5	21.5	21.4
June	18.3	16.8	15.9	17.5	16.6	17.7
July	16.1	15.4	15.7	15.9	15.9	16.1
August	17.6	16.1	16.5	16.7	16.1	17.3
September	16.3	14.2	15.8	15.9	16.4	16.5
October	17.8	16.2	17.2	17	17.6	17.3
November	16	15.6	16.3	15.8	16.4	15.5
December	14.5	14	15.1	14.7	15.6	14.8
Average	17.8	16.5	17.2	17.5	17.9	17.6

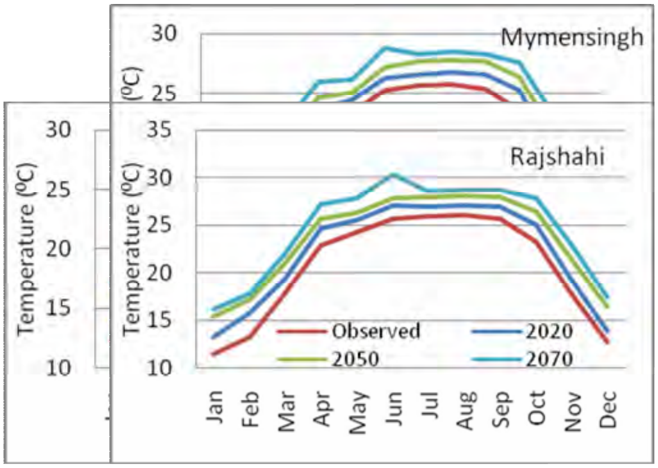
APPENDIX C

MODEL RESULTS OF MINIMUM TEMPERATURE (DEGREE CELSIUS) AT DIFFERENT LOCATIONS



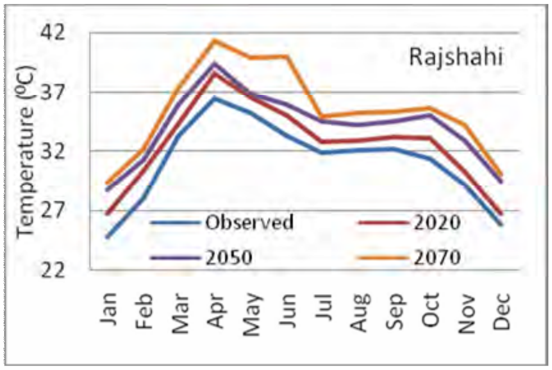


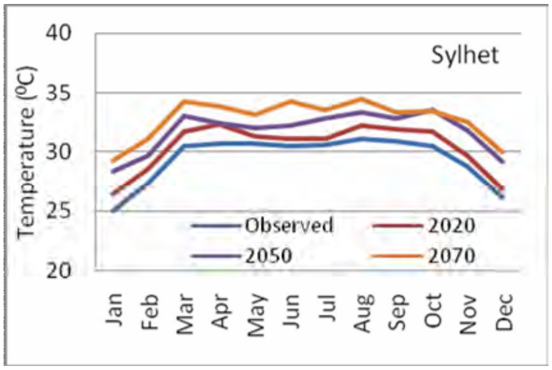


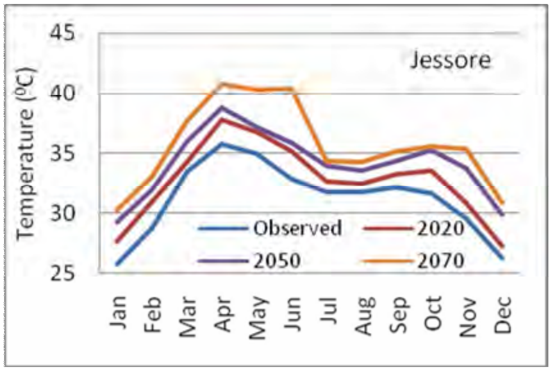


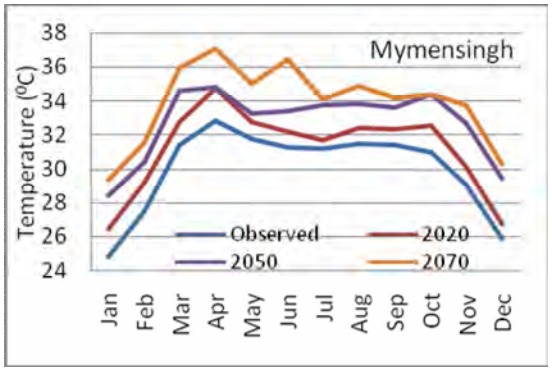
APPENDIX D

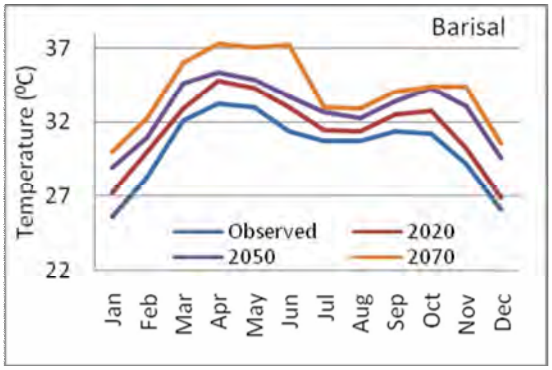
MODEL RESULTS OF MAXIMUM TEMPERATURE (DEGREE CELSIUS) AT DIFFERENT LOCATIONS

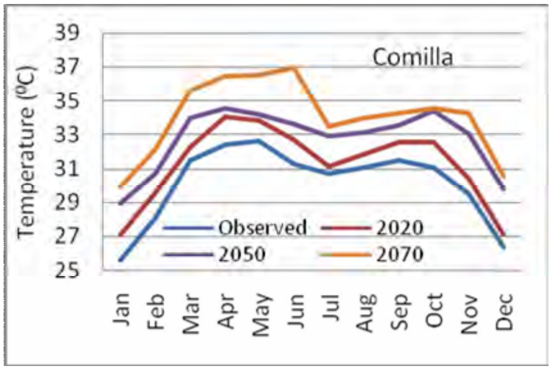






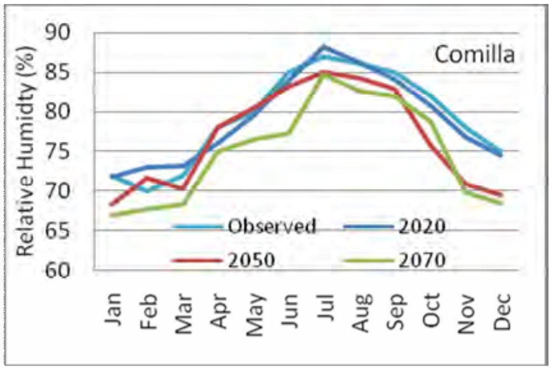


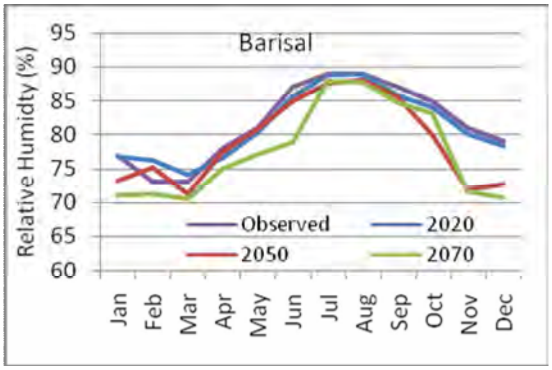


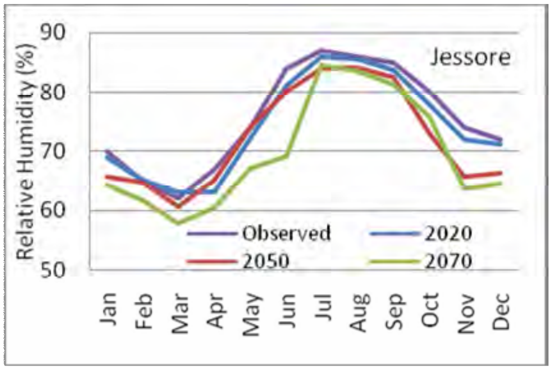


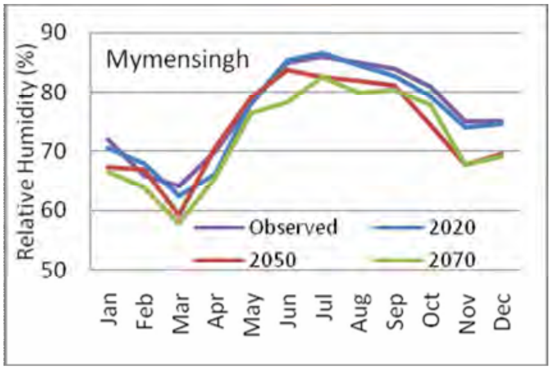
APPENDIX E

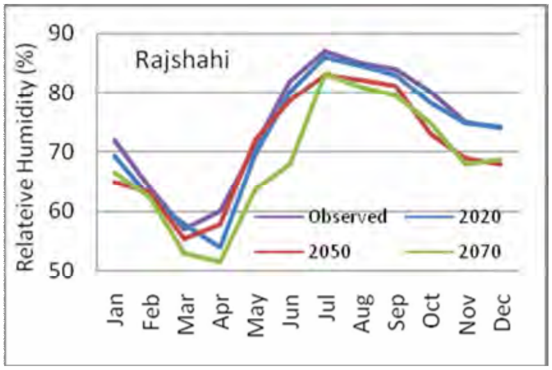
MODEL RESULTS OF RELATIVE HUMIDITY (PERCENTAGE) AT DIFFERENT LOCATIONS

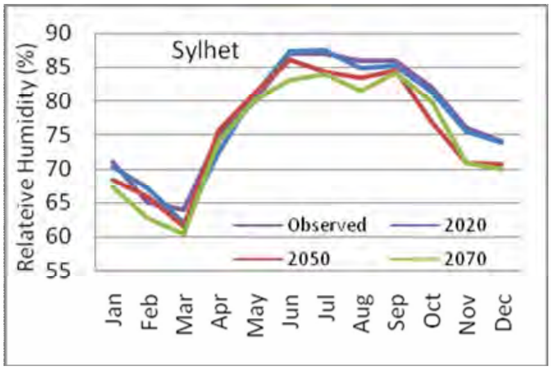






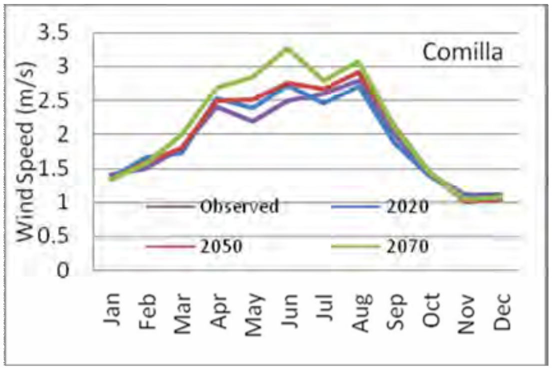


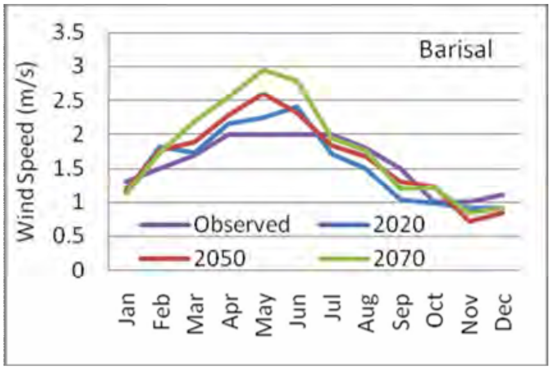


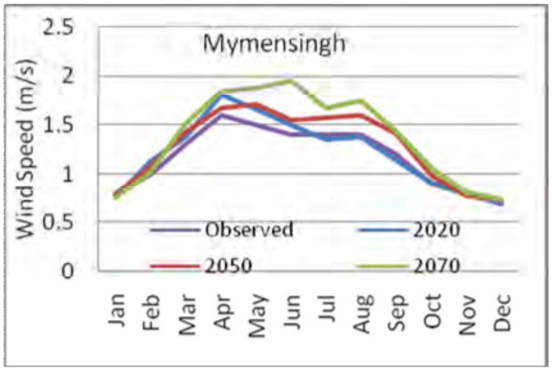


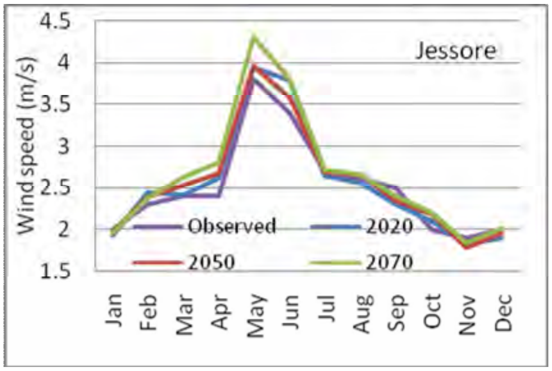
APPENDIX F

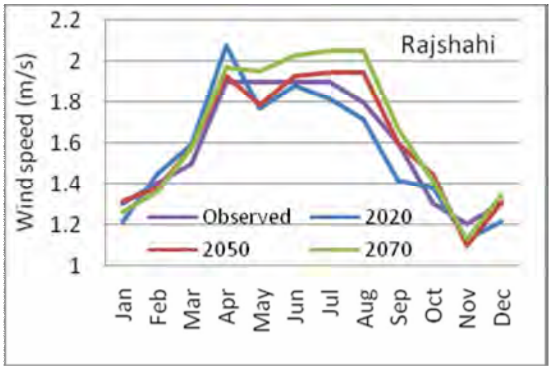
MODEL RESULTS OF WIND SPEED (METER PER SECOND) AT DIFFERENT LOCATIONS

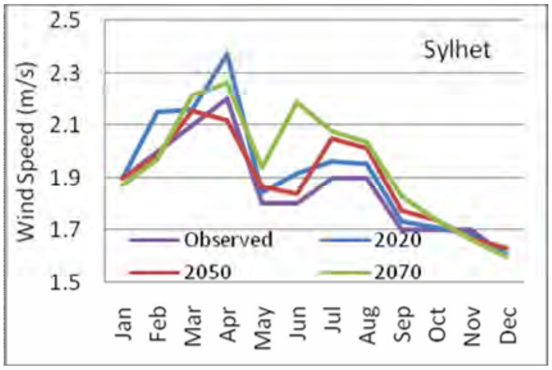






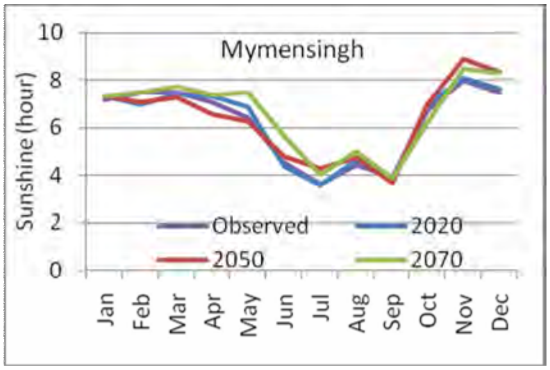


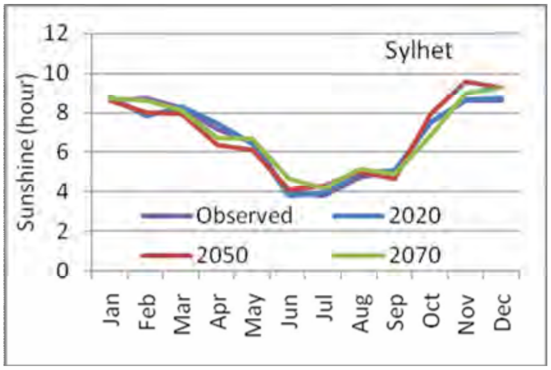


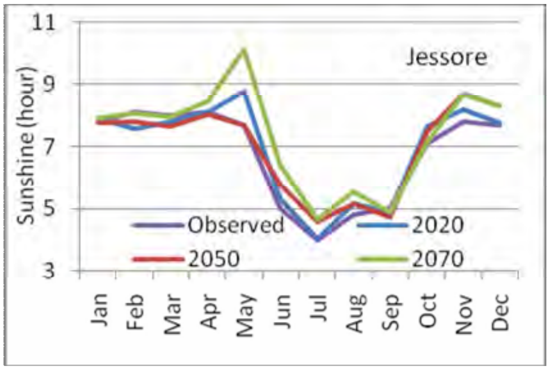


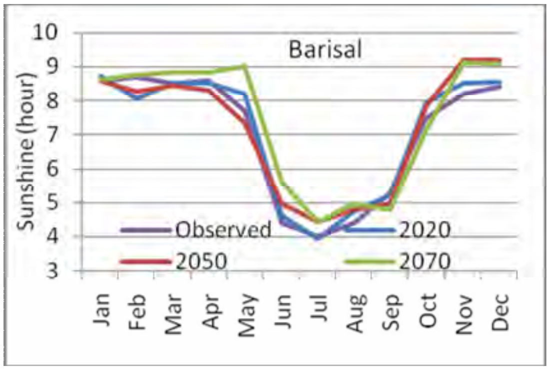
APPENDIX G

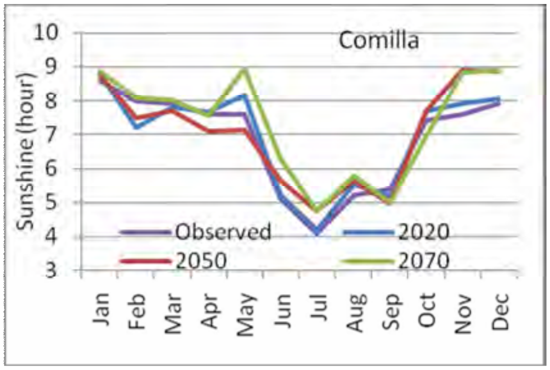
MODEL RESULTS OF SUNSHINE DURATION (HOUR) AT DIFFERENT LOCATIONS

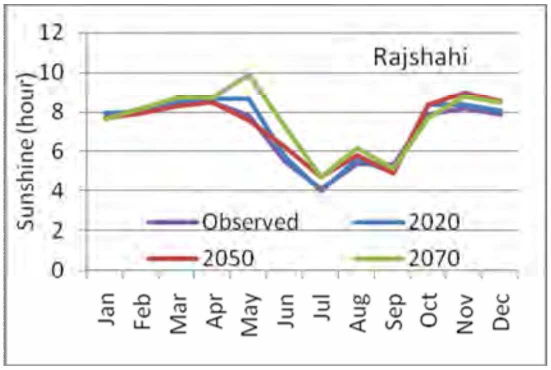






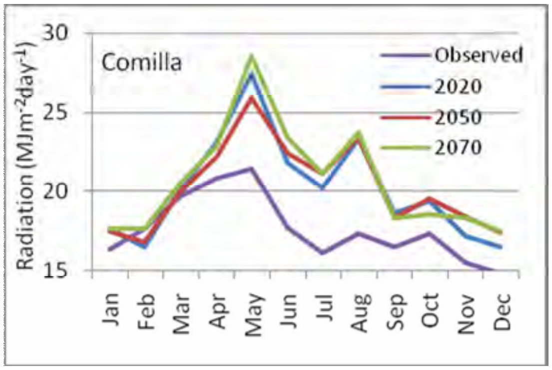


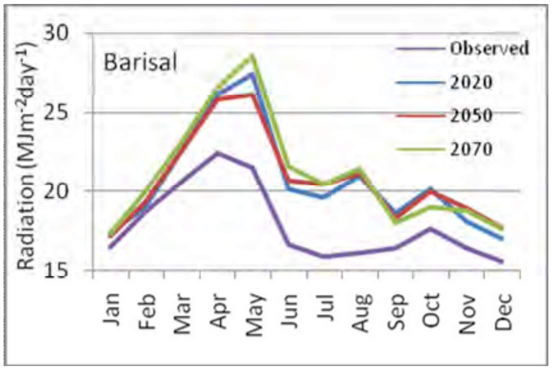


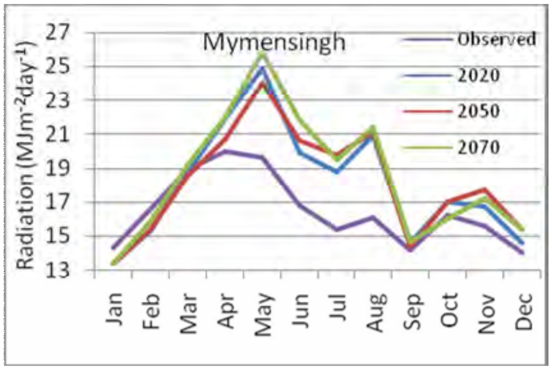


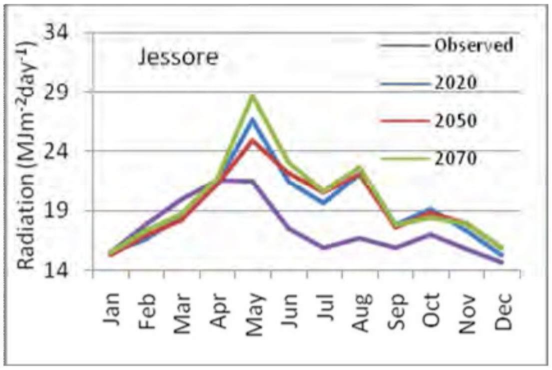
APPENDIX H

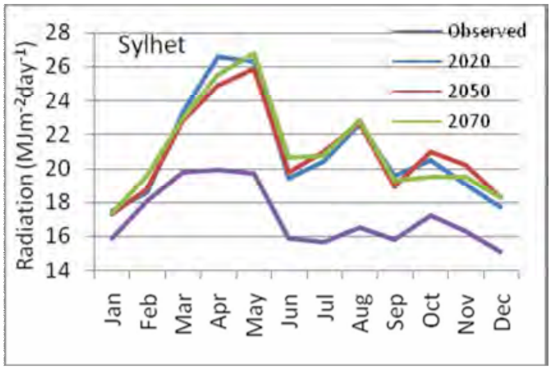
MODEL RESULTS OF RADIATION (MEGA JOULE PER METER SQUIRE PER DAY) AT DIFFERENT LOCATIONS

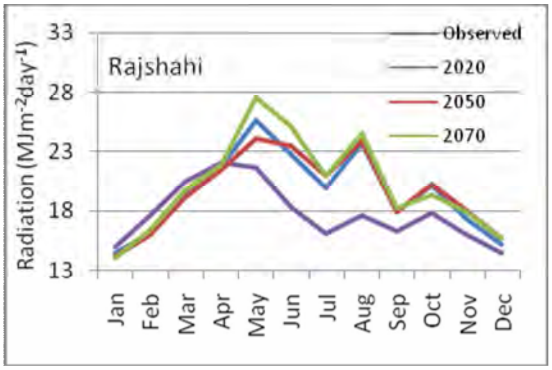






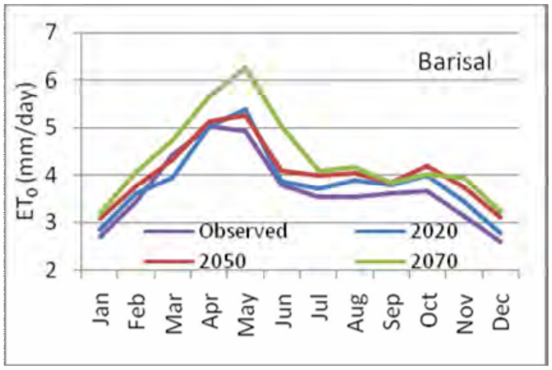


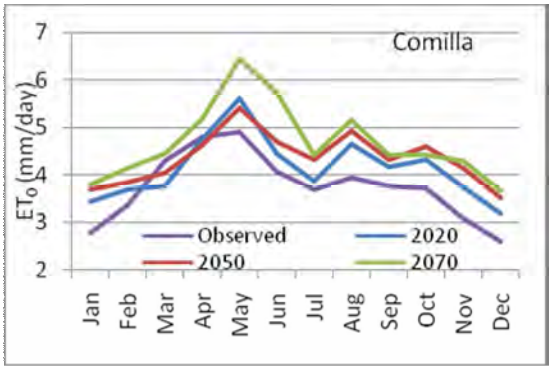


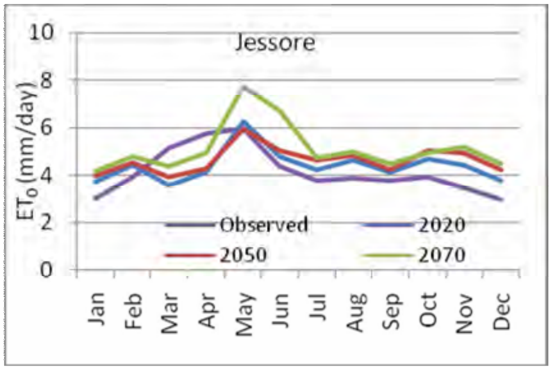


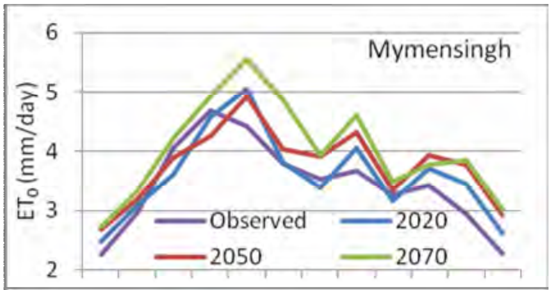
APPENDIX I

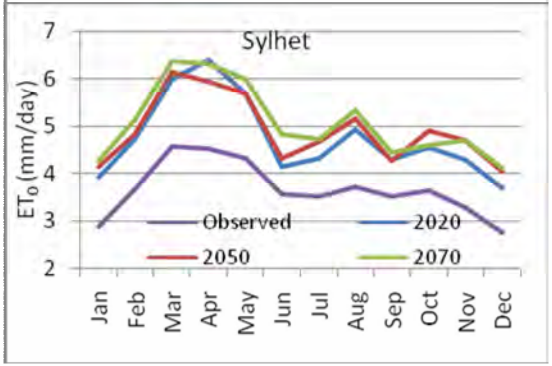
MODEL RESULTS OF EVAPOTRANSPIRATION RATE (MILLIMETER PER DAY) AT DIFFERENT LOCATIONS

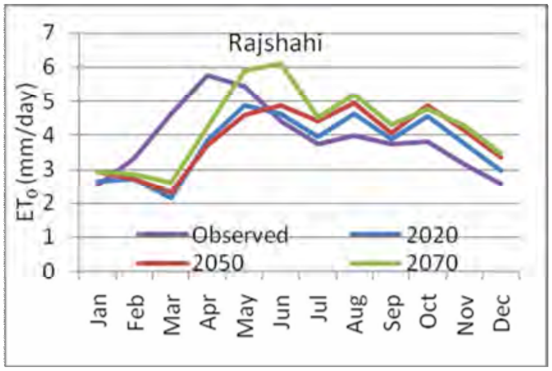











Rajshahi
ET0 (mm/day)
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2070