IMPACT OF CLIMATE CHANGE ON AGRICULTURAL WATER DEMAND IN SELECTED AREAS OF BANGLADESH

Submitted by

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sadia

Mst. Sadia Karim

August, 2009

DEDICATED

TO

My beloved parents, husband and brother

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ABSTRACT

In recent times, several studies around the globe show that climatic change is likely to impact significantly upon freshwater resources availability. Demand for water has already increased manifold over the years due to urbanization, agriculture expansion, increasing population, rapid industrialization and economic development. At present, changes in cropping pattern and land-use pattern, over-exploitation of water storage and changes in irrigation and drainage are modifying the hydrological cycle in many climate regions and river basins. This research examines changes of water requirement due to climate change.

Outputs of HadCM2 and UKTR model were used to evaluate the impact of climate change on evapotranspiration. The climatic parameters of temperature, precipitation, relative humidity, sunshine duration and wind speed, climate scenarios from model were incorporated into the CROPWAT model and used to evaluate the potential impact of climate change on evapotranspiration to simulate the total CWR for the present and the future years in study area. This model calculated crop water requirements of major crops B.Aus, T.Aman and Boro.

From output value of HadCM2 the result shows that an increase in evapotranspiration increases the percentage change in crop water requirements in 2050 and 2070. Under current climate conditions, the average reference evapotranspiration (ETo) is 3.26 mm /day which will rise to 3.39mm/day in 2050 and 3.5 mm/day in 2070 which indicates average ETo will be 4.17 % more in 2050 and 7.49% higher in 2070 than that of the base climate condition at present. In addition, CWR of major season growing crops will also increase around 4% and 8% in 2050 & 2070 respectively. Results found from UKTR model are quite same. But increment of CWR found from HadCM2 in 2070 is more than that found from UKTR model.

Crop water demand must be met as this strongly determines crop emergence, development and survival in the tropical regions. However, more accurate knowledge about crop response to water is essential in a range of crops for applications for policies and investment strategies at national level. The information obtained from this research enhances understanding of crop water requirements, which will consequently help improve the productivity of both food and cash crops.

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LIST OF ABBREVIATIONS

ADB	Asian Development Bank
BARC	Bangladesh Agricultural Research Council
B AUS	Broadcast Aus
BUET	Bangladesh University of Engineering and Technology
CEGIS	Center for Environment and Geographic Information Services
CWR	Crop Water Requirement
ETo	Reference Evapotranspiration
ETc	Actual Evapotranspiration
FAO	Food and Agricultural Organization
GCM	General Circulation Model
GOB	Government of Bangladesh
GDP	Gross Domestic Product
GFDL	Geo Fluid Dynamic Laboratory
HYV	High Yielding Variety
HADCM2	Hadley Centre for Climate Prediction and Research's Climate Model 2
IPCC	Intergovernmental Panel on Climate Change
Kc	Crop coefficient
NAPA	National Adaptation Programme of Action
NWMP	National Water Management Plan
SRES	Special Report on Emission Scenario
T AMAN	Transplanted Aman
UNDP	United Nations Development Programme
WARPO	Water Resources Planning Organization

CHAPTER 1

INTRODUCTION

1.1 General

In recent times, several studies around the globe show that climatic change is likely to impact significantly upon freshwater resources availability. Demand for water has already increased manifold over the years due to urbanization, agriculture expansion, increasing population, rapid industrialization and economic development. At present, changes in cropping pattern and land-use pattern, over-exploitation of water storage and changes in irrigation and drainage are modifying the hydrological cycle in many climate regions and river basins (McCarthy *et al.*, 2001).An assessment of the availability of water resources in the context of future national requirements and expected impacts of climate change and its variability is critical for relevant national and regional long-term development strategies and sustainable development (McCarthy *et al.*, 2001). There is an increasing body of research that supports a picture of a warming world with significant changes in regional climate systems (GOB, 2005).

One of the most important factors in agriculture is water availability. Water is provided to the crops naturally through precipitation and subsurface moisture, but when these supplies prove to be inadequate for crop use, growers must resort to irrigation (WARPO, 2000). In recent years, water availability has become an issue in Bangladesh as periods of prolonged drought have stressed both agriculture and nonagricultural sectors in Bangladesh. As population in Bangladesh increases, so does water demand.

Bangladesh is richly endowed with water resources. Ninety percent or more of Bangladesh's annual runoff enters the country from outside its borders; there is a high degree of uncertainty about the quantum of the water that will be available from trans-boundary Rivers in future (WARPO, 2000).Generally, water scarcity is a dry season phenomenon when the availability becomes less than the demand, or the quality of the water restricts its use. Adverse effects of climate stimuli including variability and extreme events in the overall development of Bangladesh are significant and highly related to changes in the water sector. Most damaging effect of climate change is drought that is found to drastically affect crop productivity almost every year (Ahmed, 2000). Climate change induced challenges are scarcity of fresh water due to less rain and higher evapo-transpiration in the dry season. So it is very important to examine water demand and water availability in agriculture sector and also analyze drought prone area of high population density.

The changing hydrological conditions and agricultural practices in Bangladesh have gradually converted it into a drought prone country, which means in general terms, that water shortage conditions in the dry period is adversely affecting the social and economic development of Bangladesh (Ahmed and Alam,1999). The growing imbalance between water demand and supply in this period is expected to deteriorate further.

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 transpiration may stop resulting in crop loss. Therefore, reliable estimates of ET, along with knowledge of precipitation totals and soil moisture storage capacity, can provide estimates of water need via irrigation (Allen et al. 1998).

Irrigation is now recognized as an important component in the agriculture economy of mediterranean regions. As practiced by many growers, it is often based on traditional methods of distribution and application which fail to measure and optimize the supply of water needed to satisfy the variable requirements of different crops. Inadequate irrigation tends to waste water, nutrients and energy, and may cause soil degradation by water-logging and salinisation.

In order to achieve higher levels of profitable and sustainable production, it is essential to modernize existing irrigation systems in order to improve water management. Up-to-date methods of irrigation should likewise be based on sound principles and techniques for attaining greater control over the soil-crop-water regime and for optimizing irrigation in relation to all other essential agricultural inputs and operations.

As in open field, accurate predictions of crop water requirements are necessary for an efficient use of irrigation water in greenhouse crop production. Furthermore, under closed spaces as greenhouses, the predominant role of crop transpiration in decreasing the heat load during warm periods is a supplementary reason to develop irrigation scheduling that allows the maximization of the transpirational fluxes. For reliable estimates of water requirements, information is needed on the crop environment (climate, soil) and physiological behavior of the crops.

It is important to provide the proper amount of water 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. With the predicted decline in agricultural yields as a result of global warming, the pressure on natural habitats and biological resources from agricultural practices is expected to increase. Reduced yields will increase the demand for converting land to agricultural use, extracting water for irrigation, introducing more new and exotic plant and animal species and intensifying the use of chemical inputs. Further warming is expected to reduce crop productivity adversely.

According to the Third Assessment Report of IPCC, South Asia is the most vulnerable region of the world to climate change impacts (McCarthy *et al.*, 2001). The international community also recognizes that Bangladesh ranks high in the list of most vulnerable countries on earth. Bangladesh's high vulnerability to climate change is due to a number of hydro-geological and socio-economic factors that include: (a) its geographical location in South Asia; (b) its flat deltaic topography with very low elevation; (c) its extreme climate variability that is governed by monsoon and which results in acute water distribution over space and time; (d) its high population density and poverty incidence; and (e) its majority of population being dependent on crop agriculture which is highly influenced by climate variability and change. Despite the recent strides towards achieving sustainable development, Bangladesh's potential to sustain its development is faced with significant challenges posed by climate change (Ahmed and Haque, 2002). It is therefore of utmost importance to understand its vulnerability in terms of population and sectors at risk and its potential for adaptation to climate change.

1.2 Objectives of the Study:

Objectives of the study are mentioned below:

I. To construct the trend of major climate parameters from the achieved secondary data.

II. To assess reference evapotranspiration, crop water requirements using climate scenarios

III. To develop a methodology for assessing the impact of climate change on agriculture

IV. To apply CROPWAT irrigation water management model for evaluating the crop water requirements

V. To evaluate the impacts of potential climate change on total crop water requirements (CWR) using CROPWAT in conjunction with the climate scenarios

VI. To compare CWR during major crop growing season in the forecasted and real weather conditions. Comparison of Reference Crop Evapotranspiration under current and climate change conditions can be evaluated and percentage change of water demand of major season growing crops of study area due to climate change will be discovered.

1.3 Scope of the Study

Today climate change is a big issue in any part of the world and affects all human activities. Agricultural practices are affected by climate change, particularly in those countries which are dependent on rain fed agricultural systems. Hence to assess the impact of climate change on agriculture, the CROPWAT model was used to simulate crop water requirement for major season growing crops in Dinajpur district of Bangladesh. The CROPWAT model developed by the FAO Land and Water Development Division (FAO 1998) is a simple water balance model that simulates crop water stress conditions and estimates yield reduction based on well-established methodologies for determining crop evapotranspiration and yield responses to water. The advantage of using the CROPWAT model as a tool for assessing crop water use is that it is simple and easy to use, and linked to less intense data requirements . CROPWAT requires only monthly inputs of climate and rain data, coupled with crop parameters and soils data, to calculate water and irrigation requirements (Smith et al. 2000).

1.4 Organization of the Thesis

The present thesis report is organized as follows. Chapter 1 provides an introduction with background, objectives and organization of the study, Chapter 2 describes Literature Review on various issues like Climate Change Scenarios: Experience In The Use Of Model, Significance of Irrigation in Agriculture, Climate as a factor in crop production, evapotranspiration concepts, actual and potential adverse effects of climate change, Chapter 3 provides selection of study area, characteristics of study area, cropping practices and climate change scenarios of study area, application of CROPWAT model for calculating crop water requirement, meteorological factors determining ET, Chapter 4 describes climatic and crop data collection and analysis, climate change scenarios data analysis, Chapter 5 describes assessments of climatic parameters, evapotranspiration and crop water requirement of major crops, Chapter 6 provides the conclusion on the present study, limitation of the study, recommended interventions to minimize impacts and recommendations for the future studies.

CHAPTER 2

LITERATURE REVIEW

2.1 Introduction

Since climate change is a dynamic phenomenon, changes will occur over time, and implications will only be understood in future, it is not possible 'to define a changing climate' that might occur 'within a defined period in future'. In order to appreciate changing climate over a geographic region and/or a country, efforts are made to 'define one or more scenarios of a changing climate' in relation to the area in question. Of course, a set of key assumptions, which would have high sensitivity towards defining the scenario(s), are made prior to defining the scenario(s). Some of the key assumptions are based on 'plausible socio-econo-political pathways' which would shape up the future greenhouse gas emission regime. Each pathway identified in the process may, therefore, be considered to be an element of a scenario. These key assumptions and/or considerations are often stated in the form of verbose statements, bio-geo-physical equations, and complex models which incorporate both the statements and empirical equations. Since scenarios are based on assumptions, approximations, and considerations (social, political, economic, cultural etc.), a scenario 'cannot truly represent' a future climate. Rather it should represent a 'plausible future climate' in view of facilitating assessments of physical, environmental, social, economic and human aspects of the geographic region and/or country in question.

2.2 Climate Change Scenarios: Experience in the Use of Model

For Bangladesh, efforts have been made to develop climate change scenarios using various generic methods. In early stages of assessing climate change impacts, in absence of appropriate models and modeling facilities, researchers have used 'expert judgments' to come up with climate scenarios. With the proliferation of computer assisted Atmosphere-Ocean Global Circulation Models (AOGCM), scientifically more rigorous and acceptable scenarios have been developed in the second stage. Only in recent times, with further development of regional models as well as strengthening of computational capabilities, scenarios have been developed by using Regional Climate Models (RCM).

The following sub-sections highlight the three different set of scenarios which have been developed in Bangladesh at different stages of their development process.

2.2.1 Speculative scenario development

Scenarios based on 'expert judgments' portrayed speculative future climate. Following a sarcastic mode of analysis, scientists have developed these speculative scenarios and posed key questions: 'what would happen' to the bio-geo-physical system 'if' climate parameter(s) change by a given extent. Mahtab (1989) speculated that a general surface warming of 0.3 to 5°C would occur by the year 2050. It is also thought that rainfall would increase by 5 to 20%. For sea level rise, a range of 30 to 150 cm was assumed by the year 2050. However, Mahtab (1989) considered a median value by taking the mean of the two limits and adding 10cm for local subsidence, which provided for 100 cm 'net sea level rise' by the year 2050. Similarly, the effects of 2°C and 4°C change in average temperature were speculated for defining 'moderate' and 'severe' climate change scenarios, respectively (BCAS-RA-Approtech, 1994). The two scenarios also speculated a rise in peak monsoon rainfall by 18 and 33%, respectively. It was anticipated that the increase in monsoon rainfall would cause an increase in river discharge during peak flow periods by 8 and 15%, respectively, for the two scenarios. The corresponding sea level rise was speculated to be 30 and 100 cms, with a corresponding rise in cyclonic intensity by 10 and 25%, respectively. The same study also considered two other very important 'decision statements' to construct future scenarios: one dealing with water development in international rivers with sharing option (with the upstream neighbor), and the other having 'no sharing option' for the same. Based on these speculative considerations, a set of ten composite scenarios have been considered for the analysis (Huq *et al.*, 1996). Ali (1999) considered 2°C and 4°C changes in average temperature as lower and upper bound thresholds for 2010, respectively, in order to analyze impacts of climate change on cyclonic storm surge along the Bay of Bengal.

The same study speculated rise in sea level by 30 and 100cm, for the two scenarios, respectively. The base case however considered no change in sea level.

2.2.2 General circulation models: validation and outputs

In early 1990s, several attempts have been made to generate climate change scenarios by the use of available General Circulation Models (GCM). The BUP-CEARS-CRU (1994) study reported 0.5 degree C to 2 degree C rise in temperature by the year 2030 under 'business as usual' scenario of IPCC. The same modeling effort estimated 10 to 15% rise in average monsoon rainfall by the year 2030. The study could not draw an inference in relation to change in sea level; however it commented that both sedimentation and subsidence were likely to complicate an expected net change in sea level along the Bangladesh coast.

ADB (1994) study also made use of four GCMs: CSIRO9, CCC, GFDLH, and UKMOH. A host of IPCC scenarios available at that point have been considered which provided a number of scenarios. In order to avoid complications, only the IPCC IS92a and its results (modeling outputs) are summarized here. It was reported that, for 2010 the temperature would rise by 0.3 degree C and for 2070, the corresponding rise would be 1.5 degree C. The four models used for developing scenarios all provided different results for monsoon rainfall. The high-estimating GFDL model (GFDLH) projected 59% higher rainfall in South Asian monsoon with a corresponding withdrawal of dry season rainfall by 16%. CCC model, however, projected an increase of monsoon rainfall by 20% and withdrawal of dry season rainfall by 6%. Both considered a doubling of CO_2 concentration in the atmosphere (therefore, time independent). A time-dependent modeling provided a medium scenario for South Asian rainfall: the monsoon rainfall was projected to increase up to 5% by 2010 and between 5 to 30% by the year 2070, while the dry season rainfall was projected to vary between -10 to +10% by the year 2070. No change in dry season rainfall was projected for 2010. For the time dependent medium-scenarios, it was assumed that the concentration of CO_2would be 400 and 640 ppmv by the year 2010 and 2070, respectively (ADB, 1994).It is important to note here that the two above modeling experiments haven't tried validation of the GCM outputs for

Bangladesh. This is why the area-averaged results for the South Asian domain were used in a bid to develop climate change scenarios for Bangladesh. Recognizing the fact that, the extent of monsoon rainfall diminishes as the front advances towards northwestern parts of the sub-continent, technically one may argue that South Asian domain might not have represented the country-specific rainfall conditions.

The other major attempt to generate a model-driven climate change scenario was made under the 'Climate Change Country Studies Programme' (Ahmed *et al.*, 1996; Asaduzzaman *et al.*, 1997 and Huq *et al.*, 1998). A number of GCMs have been used including Canadian Climate Centre Model (CCCM), Geophysical Fluid Dynamics Laboratory equilibrium model (GFDL), and 1% transient model of GFDL (i.e., GF01). Observed climate data were supplied by the CLIM database, as provided by National Center for Atmospheric Research (NCAR), USA. The outputs of the three GCMs for the 1990 base year were validated against long-term 'climate normal', as provided in published report (FAO-UNDP, 1988). The downscaling of climate data for Bangladesh down from GCM scale was possible by comparing different GCM outputs. The GFDL 1% transient model represented the long-term climate normal the best and was considered for the development of time-bound climate change scenarios (Ahmed *et al.*, 1996).

Applying the same methodology, Ahmed and Alam (1998) reproduced the climate change scenarios, which were largely used for a number of subsequent national assessments. It was reported that the average increase in temperature would be 1.3 ^{o}C and 2.6 ^{o}C for the two projection years, 2030 and 2075, respectively. It was found that there would be a seasonal variation in changed temperature: 1.4 ^{o}C change in the winter and 0.7 ^{o}C in the monsoon months in 2030. For 2070 the variation would be 2.1 ^{o}C and 1.7 ^{o}C for winter and monsoon, respectively. It was reported that the winter rainfall would decrease at a negligible rate in 2030, while in 2075 there would not be any appreciable rainfall in winter. On the other hand, monsoon precipitation would increase at a rate of 12 per cent and 27 per cent for the two projection years, respectively. The following table summarizes the climate change scenarios developed by Ahmed and Alam (1998).

Table 2.1: Outputs of GCM exercise using GFD 01 transient model

Year	Average Temperature			Temperature increase			Average Precipitation			Precipitation increase		
	W	M	Ave	W	M	Ave	W	M	Ave	W	M	Ave
	(^0C)			(^0C)			Mm/Month			Mm/Month		
1990	19.9	28.7	25.7	0.0	0.0	0.0	12	418	179	0	0	0
2030	21.4	29.4	27.0	1.3	0.7	1.3	18	645	189	+6	47	10
2075	22.0	30.4	28.3	2.1	1.7	2.6	00	530	207	-12	112	28

Note: W stands winter (i.e., December, January, Ferbruary: DJF) and M stands for monsoon (I.E., June, July and August: JJA)
Source: Ahmed.A.U.and Alam.M., 1998

Mirza (1997) used a number of GCMs and developed climate change scenarios based on ensemble technique. The results have been used for the World Bank Study (WB, 2000). By the year 2030, the projected rise in monsoon temperature was 0.7 ^oC with a corresponding rise in winter temperature of 1.3 ^oC. WB (2000) results showed similarities with respect to result of Ahmed and Alam (1998). The corresponding rise in rainfall was projected at 11% for monsoon, while a decrease in rainfall by 3% was also projected for winter by the year 2030. For the year 2050, the study projected increase in temperature by 1.1 ^oC and 1.8 ^oC for monsoon and winter, respectively. For the same year, the projected changes for rainfall were 28% in monsoon and -37% in winter. These results have been adopted for the First Initial National Communication for Bangladesh (MOEF-2002). Moreover, a linear rise in sea level by 1mm/year was considered, which resulted in 30 and 50cm rise in sea level by the year 2030 and 2050, respectively.

Mirza (2002) considered an ensemble of GCMs, instead of validating outputs of any specific model for observed values of Bangladesh, and projected an ensemble scenario. In another modeling exercise, Mirza (2005) considered three 'temperature change scenarios' with 2 ^oC, 4 ^oC, and 6 ^oC changes in average temperature and then computed its response in relation to changes in rainfall over the South Asian subcontinent, particularly over Bangladesh. There have been huge variations in output results, varying from 0.8% to 13.5% increase in mean annual rainfall for the Ganges basin and -0.03% to 6.4% change for the same for the Brahmaputra basin for a 2°C temperature change scenario. There would be increasing mean annual rainfall in both the basins with increasing global warming, as reported by Mirza (2005). The UKTR model suggested as high as 63.3% increase in mean annual rainfall over the Ganges basin associated with a change in surface average temperature of 6°C. The corresponding change in Brahmaputra basin would be much less (Mirza, 2005).

Agrawala *et al.* (2003) have used another ensemble of a dozen GCMs, which were driven by MAGICC model using SCENGEN database. A total of 17 GCMs have been run initially for model validation for Bangladesh's observed data sets. An analyses of the results thus obtained revealed that only 11 of 17 models could best simulate current climate over Bangladesh. Consequently, the most suited ones have been selected for the study. It is important to note that the models have been run with the IPCC B2 SRES scenario (IPCC, 2001). An ensemble of results has been considered to provide an estimate of the degree of agreement across various models. Table-2.2 provides the results of validated ensemble model runs applicable for Bangladesh (Agrawala *et al.*, 2003).

Table 2.2: GCM projections for changes in temperature and precipitation for Bangladesh

Year	Temperature change (°C) mean (standard deviation)			Rainfall change (%) mean (standard deviation)		
	Annual	DJF	JJA	Annual	DJF	JJA
Baseline average 2030	1.0 (0.11)	1.1 (0.18)	0.8 (0.16)	3.8 (2.30)	-1.2 (12.56)	+4.7 (3.17)
2050	1.4 (0.16)	1.6 (0.26)	1.1 (0.23)	+5.6 (3.33)	-1.7 (18.15)	+6.8 (4.58)
2100	2.4 (0.28)	2.7 (0.46)	1.9 (0.40)	+9.7 (5.8)	-3.0 (31.6)	+11.8 (7.97)

Note: DJF represents the months of December, January and February, usually the winter months. JJA represents the months of June, July and August, the monsoon months.

Source: Agrawala *et al.*, 2003.

The results were compared with previous results (in Table-2.1) as provided by Ahmed and Alam (1998). The core findings appear to be consistent with the analysis presented above. Both the studies agreed that winter warming would be greater than summer warming. The two studies also estimated little change in winter precipitation and an increase in precipitation during the monsoon. The slightly higher monsoon precipitation projected by Ahmed and Alam (1998) compared to that by Agrawala *et al.* (2003) may be attributed to lower climate sensitivity in more recent climate models. In the former case, however, the climate forcing did not follow IPCC B2 SRES Scenario.

The climate models all estimate a steady increase in temperatures for Bangladesh, with little inter-model variance. Somewhat more warming is estimated for winter than for summer. With regard to precipitation whether there is an increase or decrease under climate change is a critical factor in estimating how climate change will affect Bangladesh, given the country's extreme vulnerability to water related disasters. The key is what happens during the monsoon. Most of the climate models estimate that precipitation will increase during the summer monsoon because air over land will warm more than air over oceans in the summer. This will deepen the low pressure system over land that happens anyway in the summer and will enhance the monsoon. It is notable that the estimated increase in summer precipitation appears to be significant; it is larger than the standard deviation across models. This does not mean that increased monsoons certain, but increases confidence that it is likely to happen. The climate models also tend to show small decreases in the winter months of December through February. The increase is not statistically significant, and winter precipitation is just over 1% of annual precipitation. However, with higher temperatures increasing evapo-transpiration combined with a small decrease in precipitation, dry winter conditions, even drought, are likely to be made worse(Agarwala *et al,* 2003) The National Adaptation Programme for Action (NAPA) for Bangladesh has been the latest attempt to develop a climate change scenario for the country. Instead of developing one or more scenarios the NAPA Core Team (GOB, 2005) adopted the results obtained by Agrawala *et al.* (2003) for changes in temperature, and modified the results of Agrawala *et al.* regarding changes in precipitation. The modification, however, was based on judgment of the NAPA Core Team and was not based on reflection of any GCM modeling exercise. The scenario provided by the NAPA document is given in Table-2.3 for comparison.

Table 2.3: Scenarios provided in NAPA document

Table 3: Scenarios provided in NAPA document

Year	Temperature change (°C) mean			Rainfall change (%) mean			Sea Level Rise (cm)
	Annual	DJF	JJA	Annual	DJF	JJA	
2030	1.0	1.1	0.8	5	-2	6	14
2050	1.4	1.6	1.1	6	-5	8	32
2100	2.4	2.7	1.9	10	-10	12	88

Source: Adopted from the Bangladesh NAPA Document (GOB, 2005).
Note: Despite the claim, the values in the shaded cells are not directly adopted from Agrawala et al. (2003). No explanation has been provided in relation to the deviations from the model-resolved ensemble data. Standard deviations were not shown.

The NAPA document has also provided a sea-level rise scenario for Bangladesh. Again, no explanation has been provided in support of the data. Apparently, the upper values of the IPCC SLR.

2.2.3 The use of regional climate models

Efforts are now being made to analyze the climate models specifically for Bangladesh. The challenge lies in resolving the physical equations (heat budget and laws of physics) for a finer grid, at higher resolutions (i.e., smaller grid sizes: at 50 Km X 50 Km grid size instead of 500 Km X 500 Km grid size). While one-way GCM nesting has been made possible due to advancement of model itself, robust computers are now available to resolve the equations more efficiently.

In the recent past, one attempt has been made under a South Asia regional modelling programme to develop climate change scenarios for the Brahmaputra basin of Bangladesh. A Regional Climate Model, the Hadley Centre Regional (Climate) Model version 2 (i.e., HadCM2) was run with a 50Km X 50Km grids. For the Brahmaputra basin, slightly increased rainfall was obtained for the monsoon and post-monsoon periods (Choudhury *et al.*, 2005). The surprising results were obtained for winter rainfall: unlike other model results, an increase in winter and pre-monsoon rainfall were observed for 2020 and 2050. It was perhaps due to especial downscaling technique, which considered area-averaged values for each parameter for the entire domain. For temperature, warming appeared to be inevitable and increasing over time. The post-monsoon and winter seasons showed higher values compared to values for the pre-monsoon and monsoon seasons. Overall, the changes in rainfall and temperature for 2020 were 9.1% and 1.4°C, with a corresponding increase by 22.7% and 2.8°C, respectively, by the year 2050.

In Bangladesh, two different Regional Climate Models, RegCM and PRECIS are now being attempted. Initial validations are in progress. Both the models are capable of resolving climatology at 50Km X 50Km scale, with a possibility of going further down up to 30Km X 30Km resolution. It is found that both the RCMs show cold bias towards resolving temperature over the country. The interesting common feature of RCM modeling is that, both the models could reasonably estimate total annual rainfall. However, large scale discrepancies have been observed in resolving winter, pre-monsoon and monsoon seasonal precipitations. Following parameterization of both the models to suit to generate local climatology, it is expected that the models will generate climate change data for any given time in future.

2.3 Significance of Irrigation in Agriculture

The pattern and behavior of climate and weather play a significant role in freshwater availability, agriculture, economic growth and performance, and livelihoods. Recent studies and the regional stakeholder consultation workshops have revealed that the erratic nature of rainfall and temperature has indeed increased (NAPA Regional Workshop reports 2005). Adverse effects of erratic nature of rainfall and temperature on agricultural productivity and availability of freshwater is already quite evident in many areas of Bangladesh.

Irrigation is a process that uses more than two-thirds of the Earth's renewable water resources and feeds one-third of the Earth's population (Stanhill 2002). Some 2.4 billion people depend directly on irrigated agriculture for food and employment. Irrigated agriculture thus plays an essential role in meeting the basic needs of billions of people in developing countries (FAO 1996). Although water resources are still ample on a global scale, serious water shortages are developing in the arid and semi-arid regions (Hall 1999). There is a need to focus attention on the growing problem of water scarcity in relation to food production. Sustainable food production depends on judicious use of water resources as fresh water for human consumption and agriculture become increasingly scarce. To meet future good demands and growing competition for clean water, a more effective use of water in both irrigated and rainfed agriculture will be essential (Smith 2000). Options to increase water-use efficiency include harvesting rainfall, reducing irrigation water losses, and adopting cultural practices that increase production per unit of water. Irrigation is an obvious option to increase and stabilize crop production. Major investments have been made in irrigation over the past 30 years by diverting surface water and extracting groundwater. The irrigated areas in the world have, over a period of 30 years, increased by 25 % (mainly during a period of accelerated growth in the 1970s and early 1980s) (FAO 1998). A major constraint to the understanding of the use of water is the difficulty associated with its measurement and quantification. Measurement and data collection of discharge in canals is difficult and fraught with potential errors. Necessary conditions for the optimal performance of regional water delivery systems include well-defined water rights; infrastructure capable of providing the service embodied in the water rights, and assigned responsibilities for all aspects of system operation .One or more of those conditions may be missing in some regional systems at the start of irrigation deliveries. In other systems problems may develop over time with changes in land ownership, cropping patterns, and the volume of water available for delivery in the system. Problems with cost recovery and inadequate maintenance also can reduce the efficiency of regional water-delivery systems. Water use for crop production is depending on the interaction of climatic parameters that determine crop evapotranspiration and water supply from rain (Smith 2000). Compilation, processing, and analysis of meteorological information for crop water use and crop production are therefore key elements in developing strategies to optimize the use of water for crop production and to introduce effective water-management practices. Estimating crop water use from climatic data is essential to, better water-use efficiency. Smith (2000) stated that agro-meteorology would play a key role in the looming global water crisis. Appropriate strategies and policies need to be defined, including strengthening of national use of climatic data for planning and managing of sustainable agriculture and for drought mitigation. The limitations of currently available methods for measuring rates of evaporation from natural and agricultural surfaces are well known; as is the resulting lack of information (local and global) on this major element in the hydrological cycle. A practical method (suitable for routine use in meteorological station networks) is to use calculations based on other meteorological measurements, like those used by the Penman-Monteith method (Stanhill 2002).

Because most of the Earth's irrigated land is in the underdeveloped world (where food, water, and skilled manpower are in short supply), it is important to use the simplest, cheapest, and most practical meteorological method to improve crop water-use efficiency in irrigation. Stanhill (2002) says that in these regions use of standard, correctly sited and maintained evaporation pans operating within a national network can provide the basis for a scheduling method in which the use of empirical crop coefficients is accepted. These coefficients reflect the local economic as well as agronomic, climatologic and hydrological (water quality) situation (Stanhill 2002).

2.4 Climate as a Factor in Crop Production

2.4.1 Temperature

Most plant processes related to growth and yield are highly temperature dependent. Crop species may be classified as either warm or cool season types. The optimum growth temperature frequently corresponds to the optimum temperature for photosynthesis. Temperature increases can have both positive and negative effects on crop yields. Higher temperature also affects the rate of plant development (vegetative growth) and hence speeds annual crops through the developmental process. Temperature increases, however, have also been found to reduce the yields and quality of many crops, particularly cereal and feed grains. For example, higher temperatures shorten the life cycle of grain crops, resulting in a shorter grain filling period, so the plants produce smaller and lighter grains, culminating in lower crop yields and perhaps poorer grain quality, i.e. lower protein levels (Wolfe 1995; Adams et al. 1998). This is because temperature increases are associated with higher respiration rates, shorter periods of seed formation and consequently lower biomass production.

For countries in higher latitudes, global warming will extend the length of the growing season, allowing earlier planting of crops in the spring, earlier maturation and harvesting, and the possibility of completing two or more cropping cycles during the same season. In the warmer lower latitude regions, increased temperatures may accelerate the rate at which plants release carbon dioxide in the process of respiration, resulting in less than optimal conditions for net growth. When temperatures exceed the optimum for biological processes, crops often respond negatively with a steep drop in net growth and yield. The accompanying accelerated physiological development may result in hastened maturation and reduced yield. In addition, Rosenzweig et al. (1993) find evidence for important threshold effects. Their findings indicate positive crop yield responses to temperature increases of 2^0 C but yield reductions are observed at a 4^{o}C increase. They also assert that crop impacts in lower latitudes tend to be more negative than crop impacts in higher latitudes, particularly with respect to wheat and maize yields. Rice yields are less variable than wheat and maize yield impacts. Wolfe (1995) concludes that, for farmers in the temperate regions, climate change and global warming will be beneficial and the resultant longer growing season will provide opportunities to grow a wider range of crops.

2.4.2 Precipitation

Agronomists and soil scientists are interested in precipitation and rainfall in particular as a source of soil moisture to crops. Water supply is usually the most critical factor determining yield. The effects of water shortages on production may vary according to the particular crop, the soil characteristics, the root system, and the severity and timing of shortages during the growth cycle (Ahn 1993). Reliability of rainfall, particularly at critical phases of plant development, accounts for much of the variation in agriculture's potential. Interannual or interseasonal rainfall variability is a major challenge to rain-dependent agricultural producers. In tropical agriculture, the high dependence on rainfall, coupled with low input use and degraded soils increases farmers' vulnerability to vagaries of weather. Climate change will also modify evaporation; runoff and soil moisture storage (Feddema & Freire 2001; Nicholson 2001).The occurrence of moisture stress during flowering, pollination and grain filling is harmful to crops, particularly to maize, soybean and wheat. The demand for water for irrigation is projected to rise in a warmer climate, leading to increased competition between agricultural and non-agricultural uses for water, falling water tables, and peak irrigation demands. Increases in precipitation may benefit semi-arid and other water shortage areas (e.g. Sahelian semi-arid regions such as northern Cameroon) by increasing soil moisture, but could aggravate problems in regions with excess water (e.g. in humid tropical regions such as southern Cameroon), while reduction in precipitation could have the opposite effect. Feddema and Freire (2001) further affirm that global warming will affect regional water sources and have a significant impact on river flow regimes. They further observe that reduced water holding capacity may result in increased water runoff during the wet season. Water lost to runoff may increase deficits during rainy seasons, thus causing crops to suffer higher water stress during the dry season. Intensified evaporation may further increase the hazard of salt accumulation in the soil. This may disrupt growing conditions and result in crop failures, with serious implications for food security. Under such conditions, agricultural productivity could be severely limited. Investment in dams, reservoirs, wells and pumps may be needed to develop irrigation networks in new locations. Other factors such as humidity and wind speed combine to influence crop water needs. Crop water needs are higher when it is dry than when it is humid, and crops grown in windy climates use more water than those in calm climates (Brouwer and Heibloem 1986). In most parts of sub-Saharan Africa, agricultural production is currently constrained by reduced soil moisture, e.g. in the West African Sahel and parts of southern Africa. Because water availability limits plant growth, further drying would reduce plant productivity (Schlesinger1990). The mean soil moisture (relative to soil water holding capacity) of the continent in the 1980s was about 9% lower than the average at the beginning of the century. Soil moisture in northern and southern Africa has decreased by about 12% since the 1960s, indicating that climate change may have reduced the availability of soil moisture in Africa (Cao et al. 2001). Soil warming may further cause declines in net primary productivity (NPP) as warming encourages microbial activity and can thus cause declines in the carbon stocks in soils (Oechel et al. 1993; Schimel et al. 1994).

2.5 Evapotranspiration Concepts

ETo is a climatic parameter expressing the evaporation power of the atmosphere. ETc refers to the evapotranspiration from excellently managed, large, well watered fields that achieve full production under the given climatic conditions. Due to suboptimal crop management and environmental constraints that affect crop growth and limit evapotranspiration, ETc under non-standard conditions generally requires a correction.

2.5.1 Reference crop evapotranspiration

The evapotranspiration rate from a reference surface, not short of water, is called the reference crop evapotranspiration or reference evapotranspiration and is denoted as ETo. The reference surface is a hypothetical grass reference crop with specific characteristics. The use of other denominations such as potential ET is strongly discouraged due to ambiguities in their definitions. The concept of the reference evapotranspiration was introduced to study the evaporative demand of the atmosphere independently of crop type, crop development and management practices (FAO, 1998). As water is abundantly available at the reference evapotranspiring surface, soil factors do not affect ET. Relating ET to a specific surface provides a reference to which ET from other surfaces can be related. It obviates the need to define a separate ET level for each crop and stage of growth. ETo values measured or calculated at different locations or in different seasons are comparable as they refer to the ET from the same reference surface. The only factors affecting ETo are climatic parameters. Consequently, ETo is a climatic parameter and can be computed from weather data (FAO, 1998). ETo expresses the evaporating power of the atmosphere at a specific location and time of the year and does not consider the crop characteristics and soil factors. The FAO Penman-Monteith method is recommended as the sole method for determining ETo. The method has been selected because it closely approximates grass ETo at the location evaluated, is physically based, and explicitly incorporates both physiological and aerodynamic parameters.

Evaporation and transpiration occur simultaneously and there is no easy way of distinguishing between the two processes. Apart from the water availability in the topsoil, the evaporation from a cropped soil is mainly determined by the fraction of the solar radiation reaching the soil surface. This fraction decreases over the growing period as the crop develops and the crop canopy shades more and more of the ground area. When the crop is small, water is predominately lost by soil evaporation, but once the crop is well developed and completely covers the soil, transpiration becomes the main process. At sowing nearly 100% of ET comes from evaporation, while at full crop cover more than 90% of ET comes from transpiration (FAO, 1998). A consultation of experts and researchers was organized by FAO in May 1990, in collaboration with the International Commission for Irrigation and Drainage and with the World Meteorological Organization, to review the FAO methodologies on crop water requirements and to advise on the revision and update of procedures (FAO, 1998). The FAO Penman-Monteith method to estimate ETo uses the equation no (2.1) below:

$$ET_0 = \frac{0.408\Delta(R_n - G) + \gamma \frac{900}{T+273} u_2 (e_s - e_a)}{\Delta + \gamma(1 + 0.34u_2)} \qquad (2.1)$$

Where

ETo reference evapotranspiration [mm day-1],

Rn 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 2 m height [°C],

u_2 wind speed at 2 m height [m s-1],

e_s saturation vapour pressure [kPa],

e_a actual vapour pressure [kPa],

$e_s - e_a$ saturation vapour pressure deficit [kPa],

Δ slope vapour pressure curve [kPa °C-1],

λ psychrometric constant [kPa °C-1].

2.5.2 Crop coefficient

The crop coefficient integrates the effect of characteristics that distinguish a typical field crop from the grass reference, which has a constant appearance and a complete ground cover. Consequently, different crops will have different Kc coefficients. The changing characteristics of the crop over the growing season also affect the Kc coefficient. Finally, as evaporation is an integrated part of crop evapotranspiration, conditions affecting soil evaporation will also have an effect on Kc. Factors determining crop coefficient are described below.

(a) Crop type

Due to differences in albedo, crop height, aerodynamic properties, and leaf and stomata properties, the evapotranspiration from full grown, well-watered crops differs from ETo. The close spacing of plants and taller canopy height and roughness of many full grown agricultural crops cause these crops to have Kc factors that are larger than 1. The Kc factor is often 5-10% higher than the reference (where Kc = 1.0), and even 15-20% greater for some tall crops such as maize, sorghum or sugar cane.Crops such as pineapples, that close their stomata during the day, have very small crop coefficients. In most species, however, the stomata open as irradiance increases. In addition to the stomatal response to environment, the position and number of the stomata and the resistance of the cuticula to vapour transfer determine the water loss from the crop. Species with stomata on only the lower side of the leaf and/or large leaf resistances will have relatively smaller Kc values. This is the case for citrus and most deciduous fruit trees. Transpiration control and spacing of the trees, providing only 70% ground cover for mature trees, may cause the Kc of those trees, if cultivated without a ground cover crop, to be smaller than one.

(b) Climate

Variations in wind alter the aerodynamic resistance of the crops and hence their crop coefficients, especially for those crops that are substantially taller than the hypothetical grass reference. The effect of the difference in aerodynamic properties between the grass reference surface and agricultural crops is not only crop specific. It also varies with the climatic conditions and crop height. Because aerodynamic properties are greater for many agricultural crops as compared to the grass reference, the ratio of ETc to ETo (i.e., Kc) for many crops increases as wind speed increases and as relative humidity decreases. More arid climates and conditions of greater wind speed will have higher values for Kc. More humid climates and conditions of lower wind speed will have lower values for Kc.

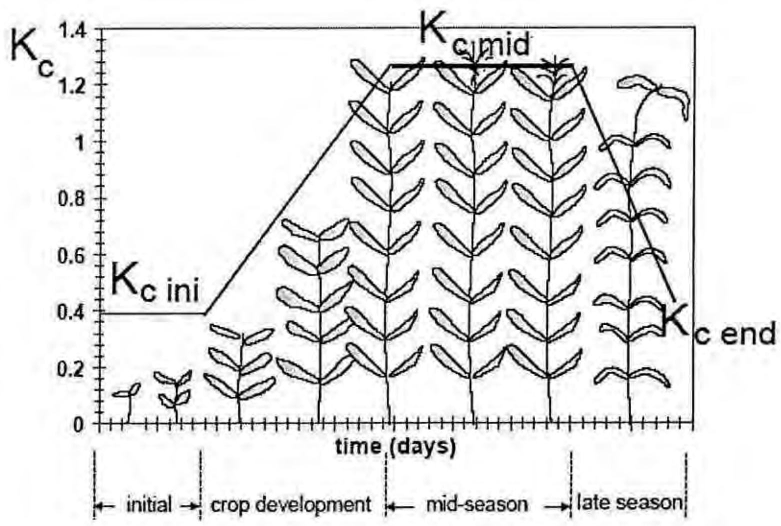
(c) Soil evaporation

Differences in soil evaporation and crop transpiration between field crops and the reference surface are integrated within the crop coefficient. The Kc coefficient for full-cover crops primarily reflects differences in transpiration as the contribution of soil evaporation is relatively small. After rainfall or irrigation, the effect of evaporation is predominant when the crop is small and scarcely shades the ground. For such low-cover conditions, the Kc coefficient is determined largely by the frequency with which the soil surface is wetted. Where the soil is wet for most of the time from irrigation or rain, the evaporation from the soil surface will be considerable and Kc may exceed 1. On the other hand, where the soil surface is dry, evaporation is restricted and Kc will be small and might even drop to as low as 0.1. Differences in soil evaporation between the field crop and the reference surface can be forecast more precisely by using a dual crop coefficient.

2.5.3 Crop coefficient curve

After the selection of the calculation approach, the determination of the lengths for the crop growth stages and the corresponding crop coefficients, a crop coefficient curve can be constructed. The curve represents the changes in the crop coefficient over the length of the growing season. The shape of the curve represents the changes in the vegetation and ground cover during plant development and maturation that affect the ratio of ETc to ETo. From the curve, the Kc factor and hence ETc can be derived for any period within the growing season.

The generalized crop coefficient curve is shown in Figure 2.1. Shortly after the planting of annuals or shortly after the initiation of new leaves for perennials, the value for Kc is small, often less than 0.4. The Kc begins to increase from the initial Kc value, Kc ini, at the beginning of rapid plant development and reaches a maximum value, Kc mid, at the time of maximum or near maximum plant development. During the late season period, as leaves begin to age and senesce due to natural or cultural practices, the Kc begins to decrease until it reaches a lower value at the end of the growing period equal to Kc end.



Source: FAO 1998

Figure 2.1: Crop Coefficient Curve

2.5.4 Crop evapotranspiration under standard conditions

The crop evapotranspiration under standard conditions, denoted as ETc, is the evapotranspiration from disease-free, well-fertilized crops, grown in large fields, under optimum soil water conditions, and achieving full production under. The amount of water required to compensate the evapotranspiration loss from the cropped field is defined as crop water requirement. Although the values for crop evapotranspiration and crop water requirement are identical, crop water requirement refers to the amount of water that needs to be supplied, while crop evapotranspiration refers to the amount of water that is lost through evapotranspiration. The irrigation water requirement basically represents the difference between the crop water requirement and effective precipitation. The irrigation water requirement also includes additional water for leaching of salts and to compensate for non-uniformity of water application (FAO, 1998). Crop evapotranspiration can be calculated from climatic data and by integrating directly the crop resistance, albedo and air resistance factors in the Penman-Monteith approach. As there is still a considerable lack of information for different crops, the Penman-Monteith method is used for the estimation of the standard reference crop to determine its evapotranspiration rate, i.e., ETo. Experimentally determined ratios of ETc/ETo, called crop coefficients (Kc), are used to relate ETc to ETo or ETc = Kc ETo (FAO,1998). Differences in leaf anatomy, stomatal characteristics, aerodynamic properties and even albedo cause the crop evapotranspiration to differ from the reference crop evapotranspiration under the same climatic conditions he given climatic conditions. The FAO-CROPWAT program incorporates procedures for reference crop evapotranspiration and crop water requirements and allows the simulation of crop water use under various climate, crop and soil conditions (FAO, 1998). ETcrop is thus estimated through Kc and ETo over the growing season. 'Crop transpiration is determined by the typical crop physiological and morphological characteristics and increases over the growing season with the growth of the canopy surface. Soil evaporation decreases proportionally over the growing season as the ground surface is increasingly shaded by the crop canopy. The effect of both crop transpiration and soil evaporation are integrated into a single crop coefficient (Kc) incorporating crop characteristics and average effects of evaporation from the soil' (Kassam & Smith 2001). Calculation procedures for ETc consists of the following steps:

1) Derivation of some climatic parameters from the daily maximum (Tmax) and minimum (Tmin) air temperature, altitude (z) and mean wind speed (u2).
2) Calculation of the vapour pressure deficit (es-ea). The saturation vapour pressure (es) is derived from Tmax and Tmin, while the actual vapour pressure (ea) can be derived from the dew point temperature (Tdew), from maximum (RHmax) and minimum (RHmin) relative humidity, from the maximum (RHmax), or from mean relative humidity (RHmean).
3) ETo is obtained by putting value as input in CROPWAT
4) Identifying crop management data and selecting the corresponding Kc coefficients;
5) Constructing the crop coefficient curve (allowing one to determine Kc values for any period during the growing period); and Calculating ETc as the product of ETo and Kc.

2.6 Actual and Potential Adverse Effects of Climate Change

2.6.1 Present impact of climate variability and extreme

Most damaging effects of erratic behavior of present climate and extreme events are flood, drought, and heat stress that are found to drastically affect crop productivity in almost every year. About 1.32 m ha of cropland is highly flood-prone and about 5.05 m ha moderately flood-prone. Besides crops, perennial trees and livestock are damaged by flood every year. In two severe flood years of 1974 and 1987, the shortfalls in production from trend were about 0.8 and 1.0 Mmt of rice, respectively. During 1984,flood affected both Aus and Aman rice crop and the shortfall was about 0.4 Mmt. Drought of different intensities occurs in Kharif, Rabi and pre-Kharif seasons cause damage to 2.32 m ha of T. aman and 1.20 m ha of rabi crops annually. Yield reductions due to drought vary from 45-60% in T.Aman and 50-70% in rabi crops in very severe drought situation. In the severe drought year of 1979 the shortfall was about 0.7 million tons (Boro of 1978 was 79 and Aus of 1979 was 80).

During 1981 and 1982 drought affected the production of monsoon crop (Aman) only and the shortfalls from the trend were 0.5 and 0.3 Mmt, respectively.

2.6.2 Potential future vulnerability

Over the last decade a number of studies have been carried out on impacts, vulnerability and adaptation assessment for Bangladesh to climate change and sea level rise. Regional stakeholder consultation workshops have identified vulnerability of different sectors in the context of climate variability and change.

Much of the future vulnerability due to climate change will not necessarily add any new climatic hazards to the already well known ones of floods, droughts and cyclones, but will enhance both the frequency as well as intensity of such climatic events in future. In addition these better known climatic hazards some new features of vulnerability to climate change in future will also be added, namely: (i) the extension of such hazards as floods, droughts and cyclones which are familiar to today in some parts of the country to other parts of the country to areas and communities who do not have the coping resilience as the more hazard-prone areas have developed over the years, and (ii) a number of slowly occurring hazards will also be exacerbated including salinity intrusion and water logging which will again add to current problems being faced and extend them to areas which are not facing them at present(Karim,1996). The climate related hazards (both those due to natural variability as well as those due to climate change will in turn be compounded by other factors including land use patterns, water management and control of river flows upstream. Some of the specific vulnerabilities due to climate change impacts are described below.

2.6.2.1 Water resources

Water related impacts due to climate change and sea level rise are likely to be some of the most critical issues for Bangladesh, especially in relation to coastal and riverine flooding, but also in relation to the enhanced possibility of winter (dry season) drought in certain areas. The effects of increased flooding resulting from climate change will be the greatest problem faced by Bangladesh as both coastal (from sea and river water), and inland flooding (river/rain water) are expected to increase. In addition, changes of the riverbed due to sedimentation and changes in morphological processes due to seasonal variation of water level and flow are also critical for Bangladesh

2.6.2.2 Crop agriculture and food security

Various studies indicate that a rise of 1 to 2^0C in combination with lower radiation causes sterility in rice spikelets. High temperature was found to reduce yields of HYVs of aus, aman and boro rice in all study locations and in all seasons and it was particularly evident at a 4^0C rise. Climate changes, especially in temperature, humidity and radiation, have great effects on the incidence of insect pests, diseases and microorganisms. A change of 1^0C changes the virulence of some races of rust infecting wheat. The production of crop in Bangladesh is constrained by too much water during the wet season and too little during the dry season. Presently total irrigated area is 4.4 million ha which is more than 50 % of the potentially irrigable area of 7.12 million ha cultivated area. This area is being irrigated through surface and ground water resource. Irrigation coverage through Shallow tubewells (STWs) during dry period is growing very fast following the recent policy of privatization (Karim, 1996). As a result, the groundwater table in Bangladesh is declining at a rapid rate causing STWs non-operating in many parts of the country during dry period. Lack of surface water during the dry season limits the function of Low Lift Pumps. The simulation study conducted under the climate change country study assessed the vulnerability of food grain production due to climate change in Bangladesh. Two general circulation models were used for development of climate scenarios. The experiments considered impact on three high yielding rice varieties and a high yielding wheat variety. Sensitivity to changes in temperature, moisture regime and carbon dioxide fertilization was analysed against the baseline climate condition. The GFDL model predicted about 17 % decline in overall rice production and as high as 61 per cent decline in wheat production compared to the baseline situation (Karim, 1996). The highest impact would be on wheat followed by rice (aus variety). This translates to a reduction of 4.5 million tons of rice at the present level of production. Of the three varieties of rice grown in Bangladesh, the aus rice(grown during the summer, monsoon period under rain-fed conditions) seems to be the most vulnerable. The other model, Canadian Climate Change Model (CCCM) predicted a significant but reduced shortfall in food-grain production. It should be noted, however, that this scenario was based on projecting existing cropping patterns into the future-which is not necessarily what will happen, as there are signs of significant changes in cropping patterns already occurring. It was noticed that temperature increase of 4 degree C would have severe impact on food-grain production, especially for wheat production. On the other hand, carbon-dioxide fertilization would facilitate food-grain production. A rise in temperature would cause significant decrease in production, some 28 % and 68 % for rice and wheat, respectively. Moreover, doubling of atmospheric concentration of CO_2 in combination with a similar rise in temperature would result into an overall 20 % rise in rice production and 31 % decline in wheat production. It was found that boro rice would enjoy good harvest under severe climate change scenario (Karim et, al., 1999). The apparent increase in yield of boro (dry season rice crop generally grown under irrigated conditions and includes high yielding varieties) and other crops might be constrained by moisture stress. A 60 % moisture stress on top of other effects might cause as high as 32 % decline in boro yield, instead of having an overall 20 % net increase. It is feared that moisture stress would be more intense during the dry season, which might force the Bangladeshi farmers to reduce the area for boro cultivation. Shortfall in food grain production would severely threaten food security of the poverty-ridden country. Under a severe climate change scenario the potential shortfall in rice production could exceed 30 % from the trend, while that for wheat and potato could be as high as 50 % and 70 %, respectively (Karim, 1996). Under a moderate climate change scenario the crop loss due to salinity intrusion could be about 0.2 Mt (Habibullah et al., 1998). Considering the loss of production due to such effects, one may find these to have relatively higher intensity than the floods. However, the loss incurred in other sectors could be much higher in case of floods. The effect of low-flow on agricultural vulnerability is considered to be much less intense compared to other effects. The ultimate impacts of loss of food grain production would increase import of food which will require spending hard currency. The agricultural production (especially of cereal crops such as rice and wheat) play a significant role in providing food security to the country in general (and to the poor and most vulnerable groups in particular). During times of food scarcity the government releases rice and wheat to poor groups through food-for-work schemes. These fall-back capacities of the government to provide food to the very poorest and most vulnerable may become less possible with lower production and availability of rice and wheat under climate change conditions in future.

CHAPTER 3

METHODOLOGY

3.1 Introduction

To address the climate change impact on water demand in agriculture sector a research protocol is first postulated as shown in the flow diagram in figure 3.1.It starts with a historical assessment of some hydro-climatic attributes in the study area to identify their interrelationships and trends. The study uses future scenarios of climate parameters and CROPWAT model to explore the issues arising from the research questions. Climate scenarios have been obtained from climate model HadCM2and UKTR. CROPWAT model will be applied for estimating Crop Water Requirement using climate data, crop data and soil data.

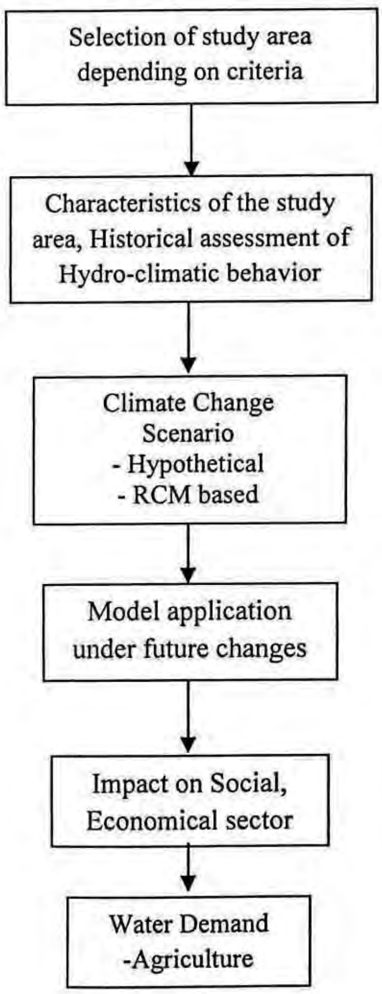


Figure 3.1: Research Methodology

3.2 Selection of Study Area

Indicator analysis of North-West was carried out considering different socio-economic and environmental parameters (Appendix C) and after analyzing Dinajpur district was found as number one rank. Data of Socio-Economic and Environmental parameters were collected from CEGIS.

Socio-Economic Parameters are mentioned below

- Gross value added of Agriculture (crops) (Million Taka) :(GDP - taxes on products + subsidies on products = GVA) 35 % weight age is taken for this criteria for finding most important area for research.
- Major Gross Cropped Area (acre): This represents the total area sown once and/or more than once in a particular year, i.e. the area is counted as many times as there are sowings in a year. This total area is known as gross cropped area.30 % weight age taken for this parameter.
- Literacy Rate: The traditional definition of literacy is considered to be the ability to read and write, or the ability to use language to read, write, listen, and speak. In modern contexts, the word refers to reading and writing at a level adequate for communication, or at a level that lets one understand and communicate ideas in a literate society, so as to take part in that society
- Population Density/SqKm:

Environmental parameters are mentioned below

- Net cultivated area (%): This consists of net area sown and current fallows.20 % weightage is taken for this parameter
- Temporary cropped area (%): This consists of total area cultivate crops with a less than one year growing cycle.
- Irrigated area (%): The area is assumed to be irrigated for cultivation through such sources as canals (Govt. & Private), tanks, tube-wells, other wells and other source. Maximum weight age is given to this parameter which is 25%.

- Land type: Different types of land are considered for analyzing. Weight age given for High Land 10 % Medium High Land 15 % Medium Low Land 10% Lowland 5%.

3.3 Characteristics of Study Area

This study was carried out at the Dinajpur District. The Zilla is bounded on the north by the Panchagor and Thakurgaon, on the south by Gaibandha and Joypurhat and India, and the west by Thakurgaon and India. The total area of the Zilla is about 3437.98 sq. km of which 19.45 sq. km is riverine and 78.87 sq. km is under forest. The zilla lies between $25^0 10'$ and $26^0 04'$ north latitudes and between $88^0 23'$ and $89^0 18'$ east latitudes. The total population of the Zilla is about 2,260,131 with an annual growth of population of 2.28. Total number of household is 430,357, of which 71.40% is farm household and 28.60% non-farm household. 36.74% of the farm households are marginal farmers having 0.05-2.49 acres of land, 27.72% medium farmers having 2.50-7.5 acres of land and 6.93% are large farmers having 7.5-above acres of land. Population growth, limited migration and Islamic inheritance laws results in steady fragmentation of land holdings. Agriculture plays a critical role in the North-West economy. 85% of total population of this area is very dependent on agriculture. The most important activity in agriculture is grain production. Rice is cultivated in 82% of total land of Dinajpur.

3.3.1 Cropping practices in dinajpur

Agriculture is the main economic activity in Dinajpur. Over 80% of the population is involved in it, and agricultural products contribute significantly to household and national incomes. Because of the variety of physical conditions in Dinajpur, cropping systems and crops vary considerably.

(a) Kharif-I: The Kharif-I season includes the period of early monsoon. Usually most of the crops of this season grow under rainfed conditions. During the insufficient rainfall during the early part of the season and uneven distribution, the crops of this season may suffer from drought. B.Aus, the major rainfed crop of this season also suffers from drought.

(b) Kharif-II: The Kharif-II season includes the period of late monsoon. The main crop of this season, which is T.Aman, depends on rainwater. Dry spells in this season hamper crop growth and cause yield reduction in some years, the transplanting of

T.Aman is delayed due to early drought in the season, resulting in a delay in harvesting as well. Consequently most critical time of the crop falls under the low rainfall period of November when the yield is most likely to be affected by drought.

(c) Rabi: A number of crops are grown in the Rabi season. Boro is the primary irrigated rice crop grown in this season; this crop has the highest record of water demand among all crops.

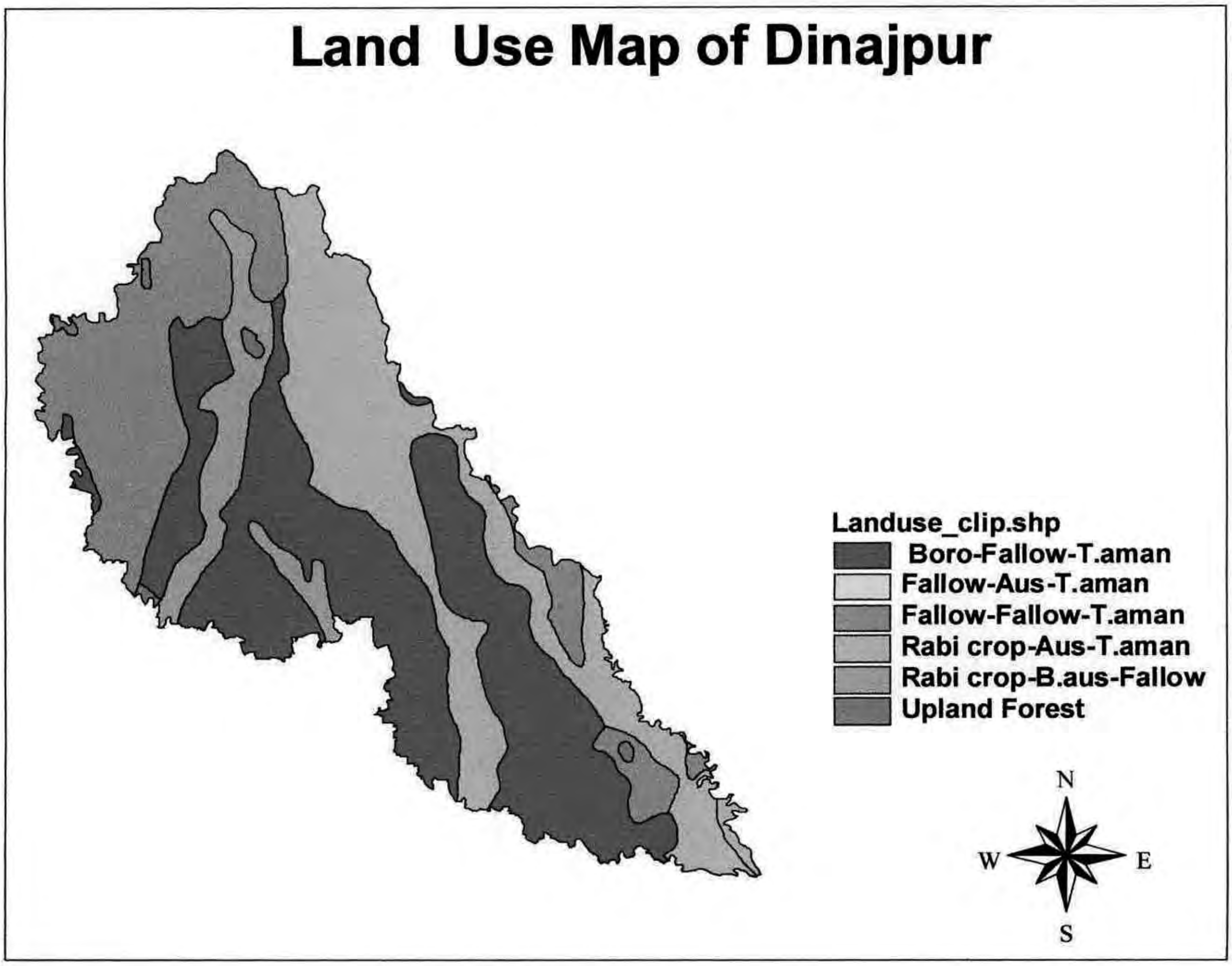


Figure 3.2 Land Use Map of Dinajpur

3.3.2 Present climate

The study area has an almost uniformly humid, warm, tropical climate. There are four prominent seasons, namely, winter (December to February), Pre-monsoon (March to May), Monsoon (June to August), Post-monsoon (September to November). The general characteristics of the seasons are as follows:

• Winter is relatively cool and dry, with the average temperature ranging from a minimum of 10.39°C to 12.58°C to a maximum of 23.9°C to 26.98°C .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.

• Pre-monsoon is hot with an average maximum of 36.7°C, 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 (WAPRO, 2000). The peak of the maximum temperatures is observed in April, the beginning of pre-monsoon season. In the 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 is both hot and humid, brings heavy torrential rainfall throughout the season (WAPRO, 2000). About four-fifths of the mean annual rainfall occurs during monsoon. The total rainfall in these months varies in different parts of the country. Warm conditions generally prevail throughout the season, although cooler days are also observed during and following heavy downpours.

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

3.4 Climate Change Scenarios

Efforts are now being made to analyze the climate models specifically for Bangladesh. The challenge lies in resolving the physical equations (heat budget and laws of physics) for a finer grid, at higher resolutions (i.e., smaller grid sizes: at 50 Km X 50 Km grid size instead of 500 Km X 500 Km grid size). While one-way GCM nesting has been made possible due to advancement of model itself, robust computers are now available to resolve the equations more efficiently (Ahmed, 2000).

In the recent past, one attempt has been made under a South Asia regional modelling programme to develop climate change scenarios for the Brahmaputra basin of Bangladesh(Ahmed,2000) .A Regional Climate Model, the Hadley Centre Regional Climate Model version 2 (i.e., HadCM2) and UKTR model were used in this study.

3.5 Application of CROPWAT Model for Calculating Crop Water Requirements

CROPWAT is a decision support system developed by the Land and Water development Division of FAO for planning and management of irrigation. CROPWAT Model was used to carry out standard calculations for reference evapotranspiration and crop water requirements (CWR). The model uses the Penman-Monteith method for calculating the reference crop evapotranspiration based on monthly climatic data (minimum and maximum air temperature, relative humidity, sunshine duration and wind). Application of model described in Figure-3.3.

Input, output data and calculation methods have been described as below:

(a) Input

Calculations of the crop water requirements are carried out with inputs of climatic, crop and soil data. For the estimation crop water requirements (CWR) the model requires:

I. ***Reference Crop Evapotranspiration*** (ETo) values measured or calculated using the FAO Penman-Montieth equation based on decade/monthly climatic data: minimum and maximum air temperature, relative humidity, sunshine duration and wind speed;

II. A ***Cropping Pattern*** consisting of the planting date, crop coefficient data files (including Kc values, stage days, root depth, depletion fraction) and the area planted (0-100% of the total area); a set of typical crop coefficient data files are provided in the program.

(b) Output

The output parameters for each crop in the cropping pattern are:

I. Reference crop evapotranspiration – Eto (mm/period)

II. Crop Kc - average values of crop coefficient for each time step

III. Crop water requirements – CWR (mm/period)

(c) Calculation procedures for Crop Water requirement:

Calculation procedure consists of the following steps:

I. CROPWAT model calculates ETo value by using meteorological data and crop data. The values of monthly Reference Crop Evapotranspiration (ETo) are converted into daily values.

II. The average values of crop coefficient for each time step are estimated by linear interpolation between the Kc values for each crop development stage.

III. The model calculates the Crop Water Requirements using the equation:

CWR= ETo *Kc*area planted.

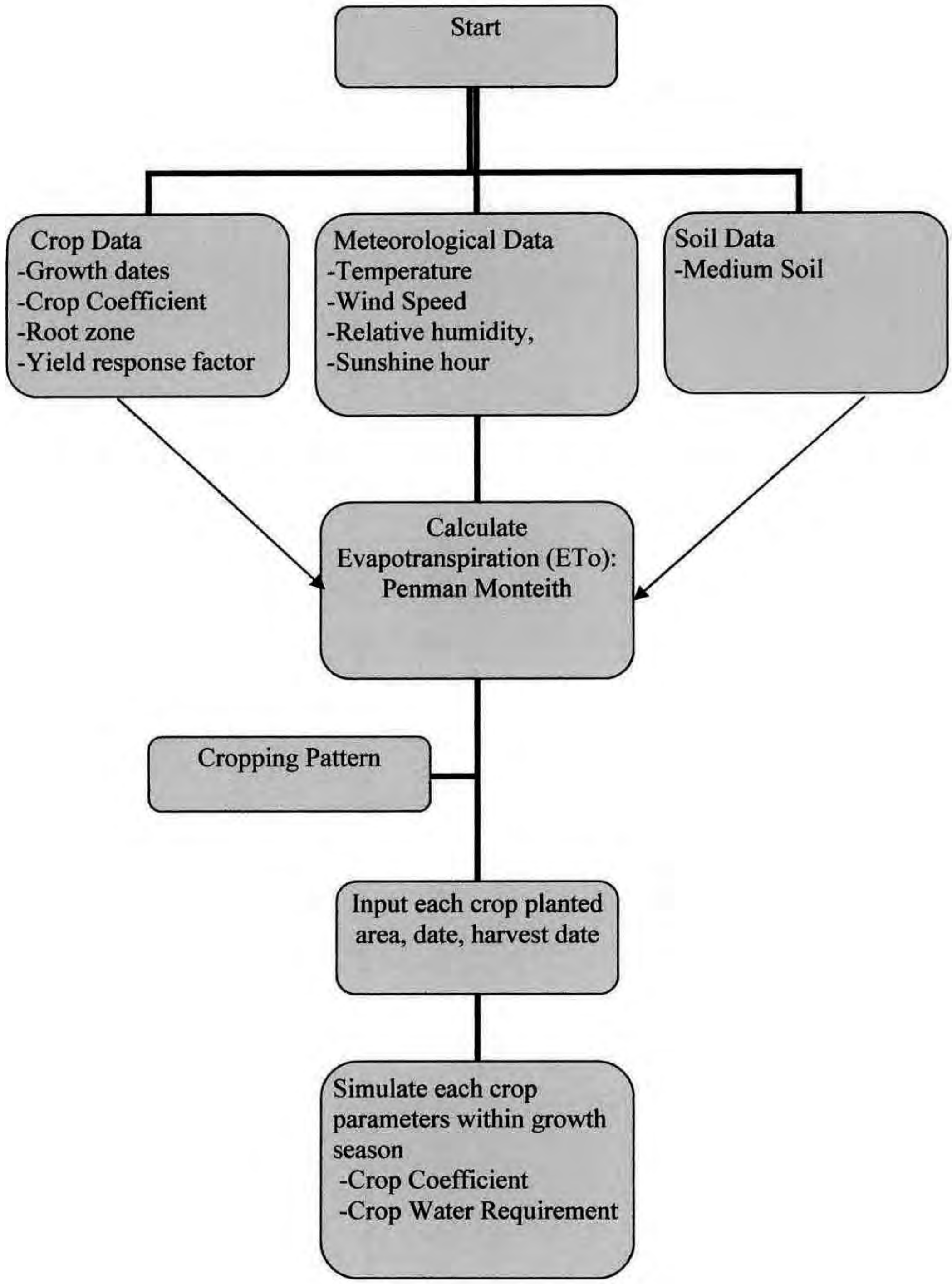


Figure 3.3: Application of CROPWAT Model

3.5.1 Meteorological factors determining ET

The meteorological factors determining evapotranspiration are weather parameters which provide energy for vaporization and remove water vapour from the evaporating surface. The principal weather parameters to consider are presented below.

The principal weather 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.

(a) Temperature

The (average) daily maximum and minimum air temperatures in degrees celsius (°C) are required for study. Where only (average) mean daily temperatures are available, the calculations can still be executed but some underestimation of ET_0 will probably occur due to the non-linearity of the saturation vapour pressure - temperature relationship (FAO, 1998).

(b) Vapour pressure deficit ($e_s - e_a$)

The vapour pressure deficit is the difference between the saturation (e_s) and actual vapour pressure (e_a) for a given time period (FAO, 1998). As saturation vapor pressure is related to air temperature, it can be calculated from the air temperature. The relationship is expressed in equation (3.1):

$$e^0(T) = 0.6108 \exp\left[\frac{17.27T}{T + 237.3}\right] \qquad (3.1)$$

Where

$e^0(T)$ Saturation vapour pressure at air temperature

T Air temperature (o C)

exp [ ] 2.7183 (base of natural logarithm) rose to power [.]

Due to the non-linearity of the above equation, the mean saturation vapour pressure for a day, week, decade or month should be computed as the mean by using equation no (3.2) between the saturation vapour pressure at the mean daily maximum and minimum air temperatures for that period given in equation (3.3) and (3.4):

$$e_s = \frac{e^0(T_{max}) + e^0(T_{min})}{2} \quad (3.2)$$

Where

$$e^0(T_{max}) = 0.6108 \exp\left[\frac{17.27 T_{max}}{T_{max} + 237.3}\right] \quad (3.3)$$

$$e^0(T_{min}) = 0.6108 \exp\left[\frac{17.27 T_{min}}{T_{min} + 237.3}\right] \quad (3.4)$$

(c) Relative humidity

The (average) daily actual vapour pressure, ea, in kilopascals (kPa) is required. The relative humidity (RH) expresses the degree of saturation of the air as a ratio of the actual vapour pressure (e_a) to the saturation vapour pressure (e_s) at the same temperature (T) (FAO, 1998) given in equation no (3.5).

$$RH = \left({e_a}/{e_s} \right) \times 100 \quad (3.5)$$

(d) Wind speed

The (average) daily wind speed in meters per second (m s-1) measured at 2 m following equation no (6) above the ground level is required (FAO, 1998). 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. The calculation procedure to adjust wind speed to the standard height of 2 m is done equation no (3.6) (FAO, 1998).

$$u_2 = u_z \frac{4.87}{\ln(67.8Z - 5.42)} \quad (3.6)$$

Where

u_2 is wind speed at 2m above ground surface $[ms^{-1}]$

u_z is measured wind speed at z m above ground surface $[ms^{-1}]$

Z is height of measurement above ground surface $[m]$

3.5.2 Crop and management data

(a) Planting date

The planting date of a crop is an important factor that influences yield level. It depends on the local climate, land type, cropping pattern and variety of crops. An area may even have wide range of planting dates for the same crops. The approximate median planting dates of crop grown in study area have been used in the model.

(b) Growth stages

The parameter is incorporated in the model as the water requirements of crop vary with growth stages. Moreover, the different growth stages of crop are not equally sensitive to moisture deficits. Generally, the growing period of a crop is divided into four stages, i.e., the initial stage, the development stage, the mid-stage and the late season stage. The total length of the growing season and individual growth stages are dependent on the variety, local conditions, and the prevailing temperature (FAO, 1992).

(c) Crop coefficient (Kc)

The model contains decade wise crop-co-efficient in its database to convert reference evapotranspiration (ETo) values into potential crop Evapotranspiration (ETc).the estimate of crop water requirements depends upon the accuracy of the Kc value adopted. The Kc value is crop specific, and varies for a particular crop with growth stages. The value is the highest during mid-season when the crops develop a maximum canopy and root system. The decade-wise Kc values for different crops used to calculate CWR for each time step.

(d) Rooting depth (Z)

The rooting depth is a parameter that limits maximum soil depth to be considered in the model. This is the depth from which roots are capable of extracting soil moisture for growth and development. Root systems are characterized by the genetic factor of the crop. Rooting depth increases with the development of crops and attains the maximum depth before the beginning of the mid-season. As transplanted rice has a shallow fibrous root system, the same rooting depth has been assumed throughout the growing period.

(e) Allowable depletion (p)

This parameter is used in the model for computing number of stress days of a crop. Allowable depletion represents the critical soil moisture level up to which the total available moisture can be depleted without causing reduction of evapotranspiration. Allowable depletion is expressed as a fraction of the total available moisture. Water stress starts from this soil moisture level. Beyond the depletion level, the actual evapotranspiration becomes gradually smaller than maximum evapotranpiration which affects crop yield. Allowable depletion is expressed as a fraction of the total moisture.

(f) Yield response factor (ky)

The yield response to water deficit varies with the growth stages. In general, crops are more sensitive to water deficit during the early yield formation stages than the early and late stages. As a matter of fact, the higher value of the yield response factor is considered for the more sensitive stages of the crop. The factor also depends on the characteristics of the crops.

CHAPTER 4

DATA COLLECTION AND ANALYSIS

4.1 Introduction

Data analysis was done to prepare input data for calculating evapotranspration and CWR calculation in CROPWAT model. The CROPWAT model needs climatic and crop data. Climatic and Crop data were obtained from the CEGIS and BARC. A total of 40 years (1961-2000) climate data were analyzed and average values of climatic parameters were taken as current value. Also some other data such as latitude, longitude, according to the used meteorological station were put into model (CROPWAT needed data are in the Appendix A).

4.2 Climatic Data Analysis

The input parameters and variable used in the model are described below: The combined climatic impact of temperature, humidity, sunshine and wind speed on crop water requirement is given by reference evapotranspiration. Thus the model uses climatic data in the form of reference evapotranspiration.

(a) Temperature

Monthly average maximum and average minimum temperatures were prepared under current climate condition as input data for CROPWAT model. After getting the output value from climate models forecasted value of temperature for the year of 2050 and 2070 is calculated. Temperature data of current year and two forecasted years 2050 and 2070 have been used in CROPWAT model is formulated in Figure 5.1 and 5.2 and Table A 5.2, A 5.3 and A 5.4.

(b) Relative humidity

Relative Humidity is another input of climatological data into CROPWAT model has been presented in Table A5.3 and A 5.4. In this research mean monthly relative humidity is applied. Using data of vapor pressure and saturated vapor pressure of forecasted year 2050 and 2070 relative humidity for this two forecasted years have been calculated by using equation no (3.5). Vapour pressure data has been formulated in Table A 5.3 and A 5.4. Percentage change of relative humidity due to climate change has been presented in Figure 5.4 and Table A 5.3 and A 5.4.

(c) Wind speed

Wind speed is another parameter that is needed for the CROPWAT Model. Since the wind speed that applied in CROPWAT model at an elevation of 2m, recorded wind speed data converted in CROPWAT model formats by using equation no (3.6).Wind speed will also increase in future. Monthly wind speed variation is presented in Figure 5.6 and Table A 5.3 and A5.4.

(d) Sunshine

Sunshine duration also needed for CROPWAT model. Data of sunshine hour of study area have been used in Appendix B.

4.3 Crop and Management Data Analysis

(a) Planting date

The approximate median planting dates of crop grown in study area have been gathered from BARC are presented in Table A 5.9

(b) Growth stages

The length of development stages of different crops that are grown in study areas has been considered on the basis of available literature. The presented values have been adjusted on the basis of specific verities of crop, location and growing season, shown in Table A 5.9.

(c) Crop co-efficient (Kc)

The decade-wise Kc values for different crops grown in the study areas have been taken from Technical Report-2(MPO, 1987) and presented in Table A5.10.

(d) Rooting depth (Z)

The generalized data on the rooting depth of full-grown crops have been taken from the AEZ Report 6(UNDP/FAO, 1988) and are shown in Table A5.11.

(e) Allowable depletion(P)

The generalized data on the allowable depletion or fraction of available soil moisture of full-grown crops have been taken from the AEZ Report 6(UNDP/FAO, 1988) and are shown in Table A 5.11.

(f) Yield response factor (Ky)

The value of ky for different crops has been taken from the Irrigation Drainage paper 33(FAO 1986).The ky values for different crops based on individual growth stages are presented in Table A 5.12.

4.4 Climate Change Scenarios Data

Climate change scenarios comprise of greenhouse gas emission scenario and regional pattern of climate change. Future climate scenarios for projected yrs of 2050 and 2070 of HADCM2 and UKTR models have been collected from BARC shown in Table A 5.1.a and A 5.1.b.

(a) Emission scenario: IS92a emission scenario was selected for this study.

(b) Climate change projection: The results of the HADCM2 and UKTR transient experiment models were used for study area. Outputs obtained for forecasted yrs of 2050 and 2070. HADCM2 is regarded as one of the leading models in the world. UKTR has been broadly used for impact assessment studies in different countries. Output value of climatic parameters in future year of 2050 and 2070 obtained from the HadCM2 climate model and UKTR presented shown in Table A 5.1.

CHAPTER 5

RESULTS AND DISCUSSION

5.1 Introduction

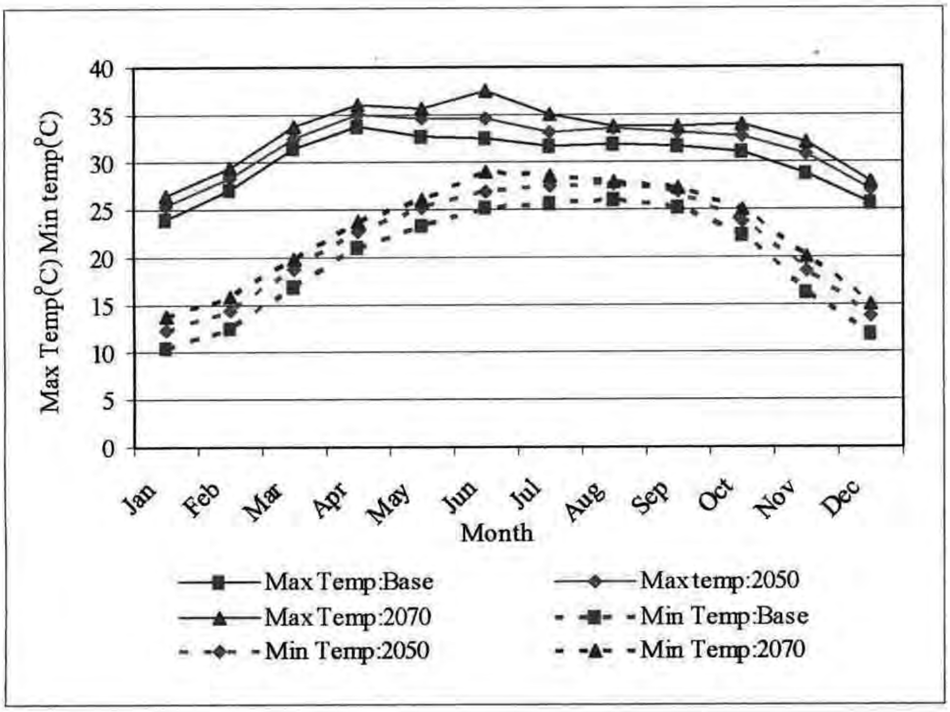
After analyzing output value of climatic parameters from HADCM2 and UKTR model it is seen that all climate parameters, evapotranspiration and crop water requirement will be changing in 2050 and in 2070. The following sub-sections highlight the different assessments found from the research in study area.

5.2 Assessment of the Impact of Climate Change on Climatic Parameters in Dinajpur using CROPWAT

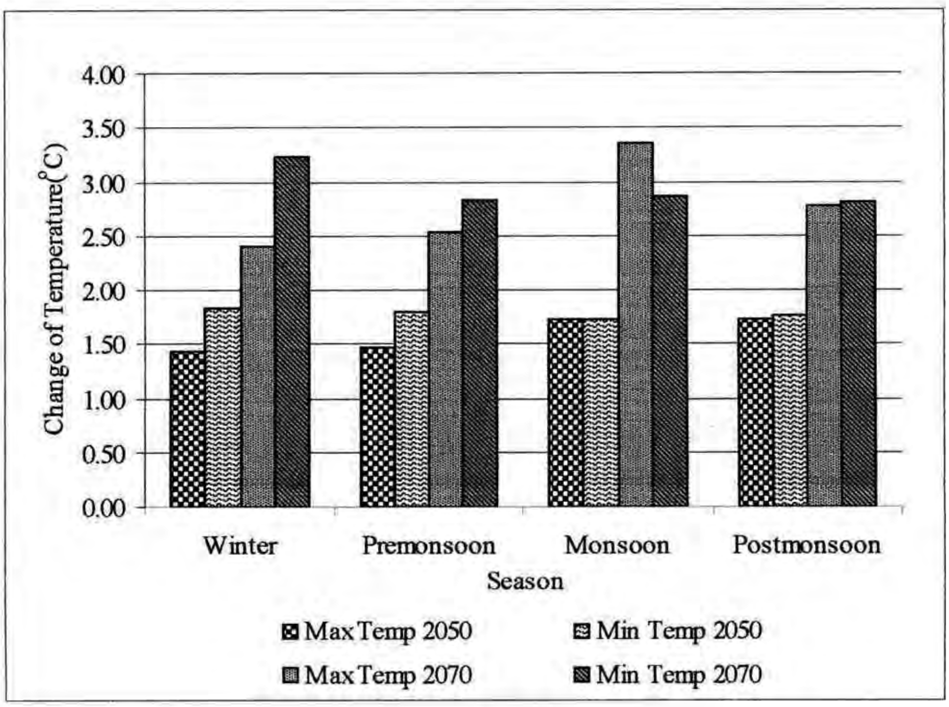
Figure 5.1 and 5.2 show that average maximum and average minimum temperature is increasing in 2050 and in 2070 using the HADCM2 and UKTR derived climate change scenarios under IS92a.

It was found from HADCM2 that the average increment of maximum temperature and minimum temperature would be 1.59° C and 1.78° C for the forecasted year of 2050 and average increment of maximum and minimum temperature would be 2.77° C and 2.93° C in forecasted year of 2070. Highest increment of maximum temperature found in June is 2.1 ° C in 2050 which climbed up to 4.9 ° C in 2070 and minimum temperature in November is 2.3 ° C in 2050 which would be increased to 3.7 ° C in 2070.

There would be a seasonal variation of maximum and minimum temperature. Highest average maximum temperature change of 1.73° C found in the monsoon (June, July and August) months and average minimum temperature 1.83° C change found in the winter (Dec, Jan and Feb) in 2050.For 2070 the highest changing value of average maximum temperature and average minimum temperature would be 3.37° C in monsoon and 3.23° C in winter.



(a)

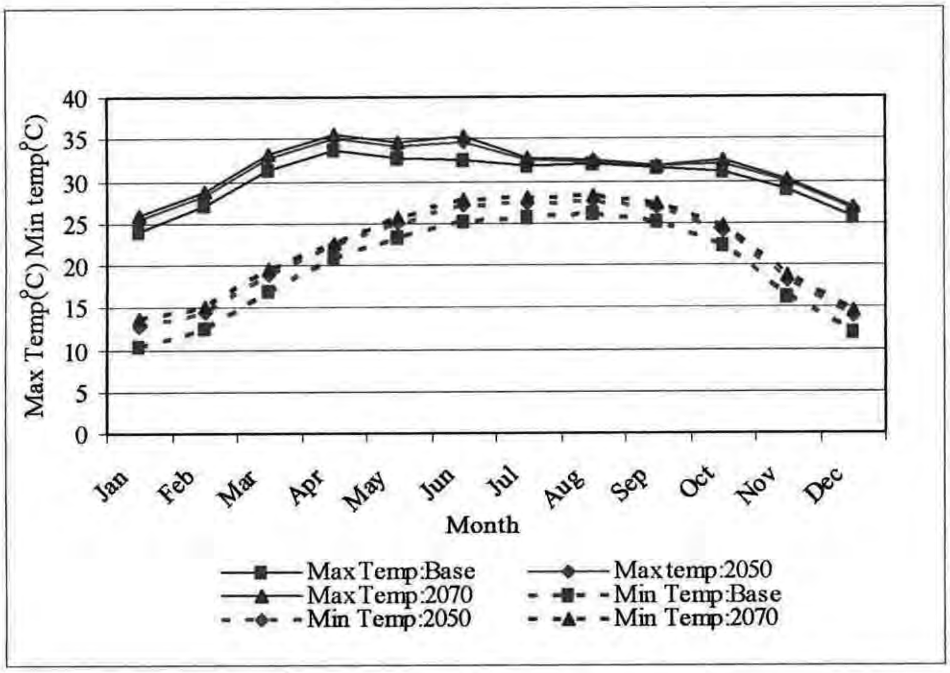


(b)

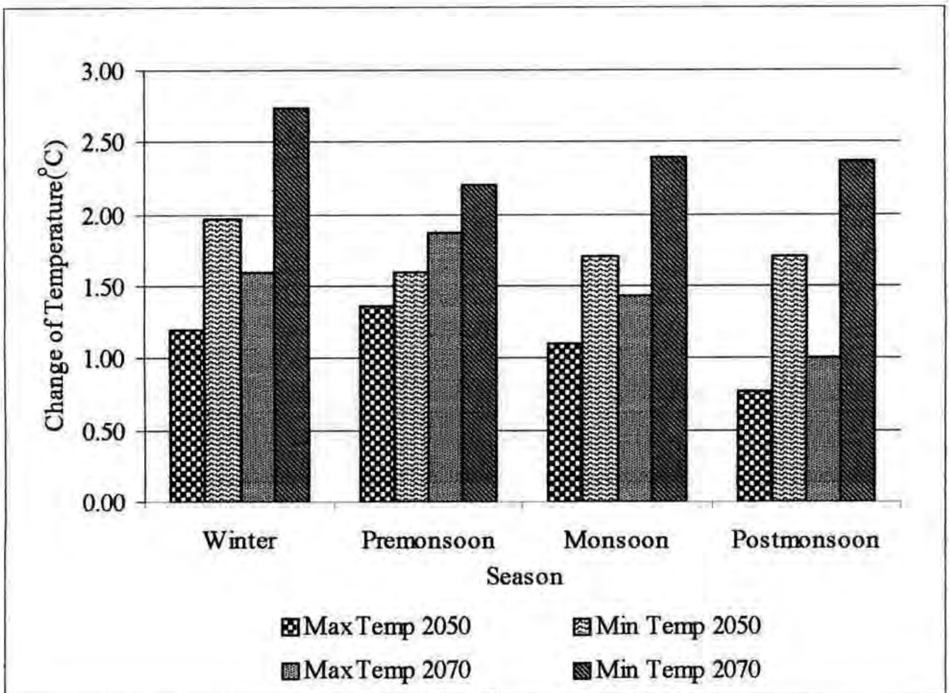
Figure 5.1: (a) Monthly maximum and minimum temperature in study area (b) Season wise variation of maximum and minimum temperature (HADCM2)

Changing pattern of average maximum and average minimum temperature found from UKTR model shown in Figure 5.2. From UKTR it is found that increment of average maximum temperature and average minimum temperature would be 1. 11° C and 1.74° C for the forecasted year of 2050 and 1.48° C and 2.43° C for the forecasted year of 2070, respectively. Highest increment of average maximum temperature found in June is 2.1 ° C in 2050 which climbed up to 2.8 ° C in 2070 and highest increment of average minimum temperature found in January is 2.3 ° C in 2050 which would be increased to 3.2 ° C in 2070.It was found that there would be a seasonal variation of average maximum and average minimum temperature in two forecasted years. Highest increment of average maximum temperature found 1.37 ^{0}C in pre-monsoon and minimum temperature found 1.97 ^{0}C in winter for the year of 2050 and highest increment of average maximum and average minimum temperature found 1.87 ^{0}C in pre-monsoon & 2.73 ^{0}C in the winter in 2070 respectively.

It is clear from Figure 5.2 (b) average minimum temperature shows higher value in winter season and average maximum temperature shows higher value in pre-monsoon season.



(a)



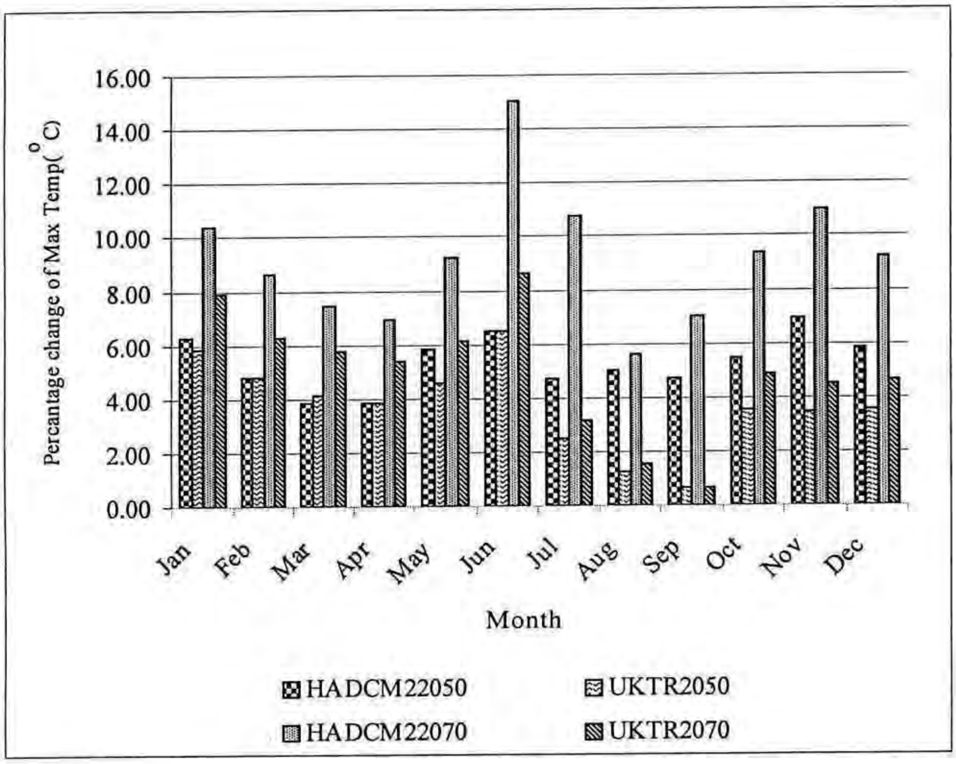
(b)

Figure 5.2: (a) Monthly maximum and minimum temperature in study area (b) Season wise variation of maximum and minimum temperature (UKTR)

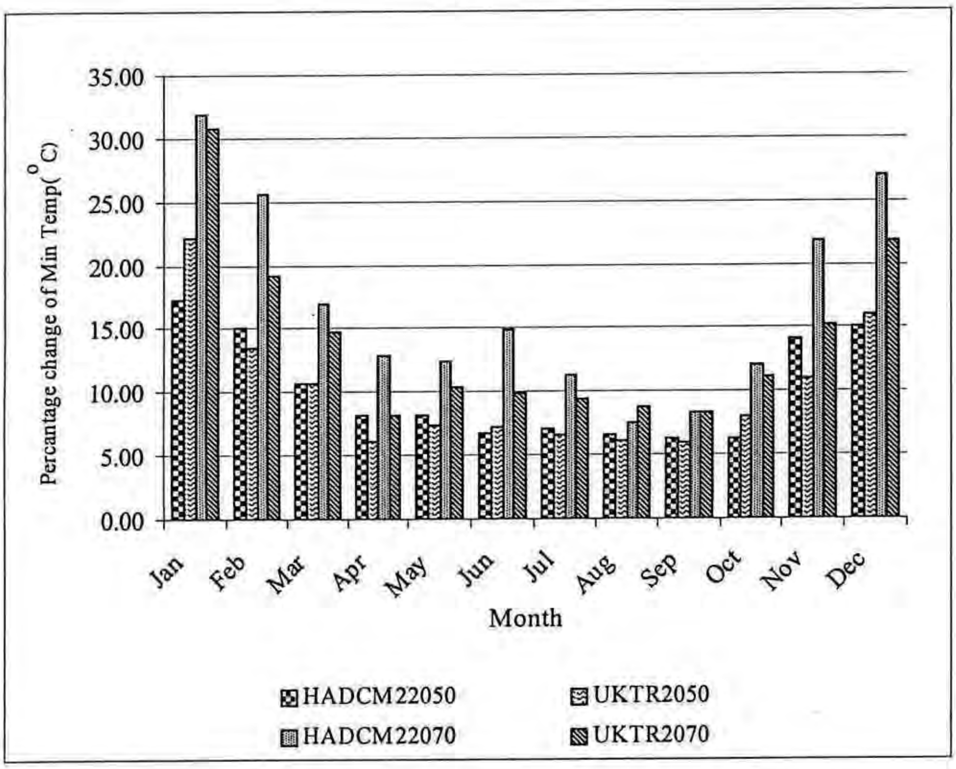
Percentage change of average maximum and average minimum temperature for two forecasted years have been formulated in Figure 5.3 and Table A 5.2.c. Percentage change of temperature of forecasted year 2070 shows higher value than that of 2050.

For HADCM2 model, maximum temperature increases by an average of 5% in 2050 and 9% in 2070 and minimum temperature increases by an average of 10% in 2050 and 17% in 2070.

For UKTR model, maximum temperature increases by an average of 4% in 2050 and 5% in 2070 and minimum temperature increases by an average of 10% in 2050 and 14% in 2070.



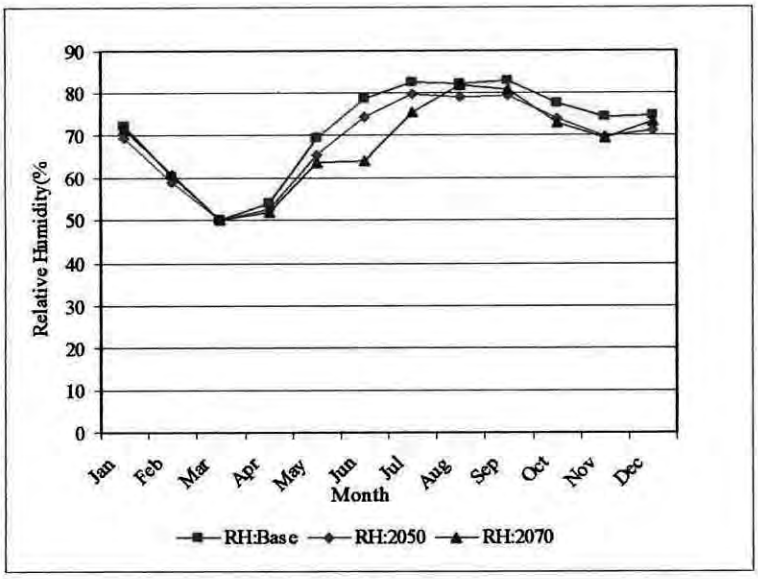
(a)



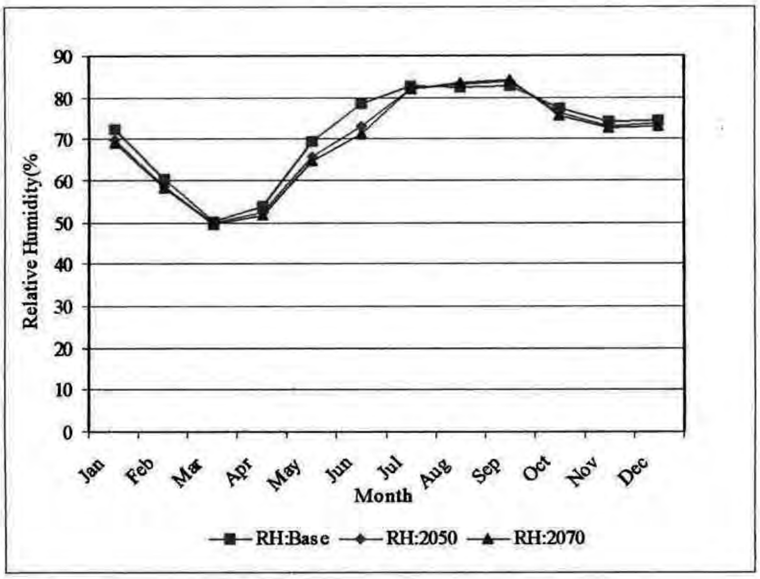
(b)

Figure 5.3: Percentage change of average (a) Maximum temperature and (b) Minimum temperature

Variation of monthly relative humidity presented in Figure 5.4. From graph it is found that average maximum relative humidity showing higher value in post monsoon months. Relative humidity behaves in a manner opposite to that of vapour pressure deficit. Pattern of changing relative humidity value is quite similar for 2050 and 2070.

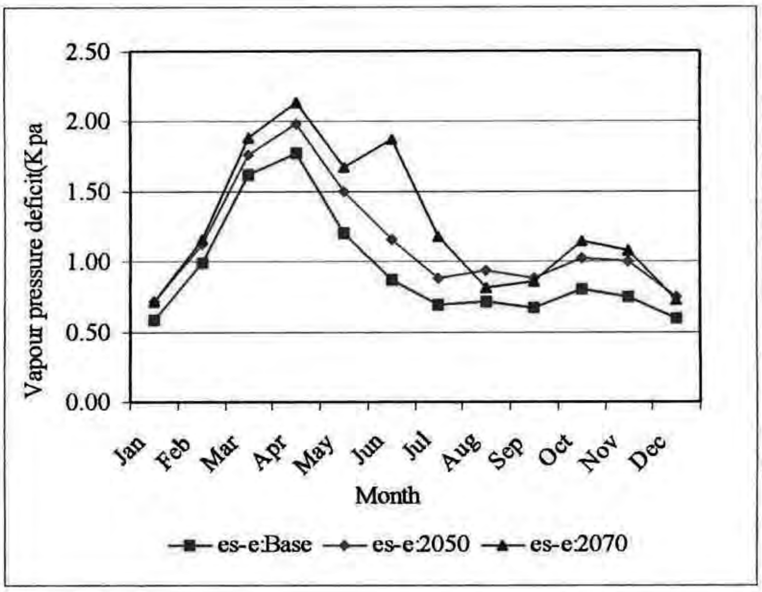


(a)

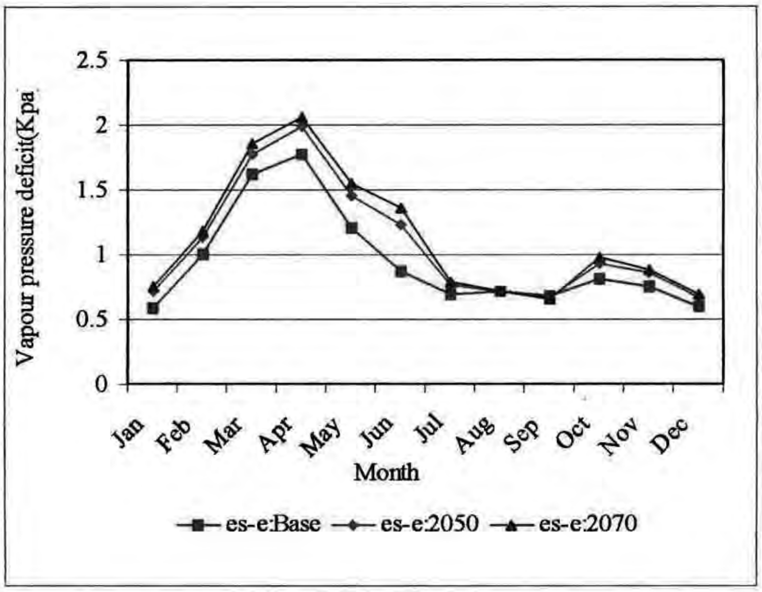


(b)

Monthly Figure 5.4: Monthly Relative humidity in study area (a) HADCM2 (b) UKTR variation of average vapor pressure deficit has been formulated in Figure 5.5.Highest value of average vapor pressure deficit found 1.77 Kpa in April month which will be increasing to 1.99 Kpa in 2050 and 2.14 Kpa in 2070 using HADCM2 model output. Using output value of UKTR model maximum average monthly vapor pressure deficit is found to be rising to 1.98 Kpa in 2050 and 2.06 Kpa in 2070 in April month.



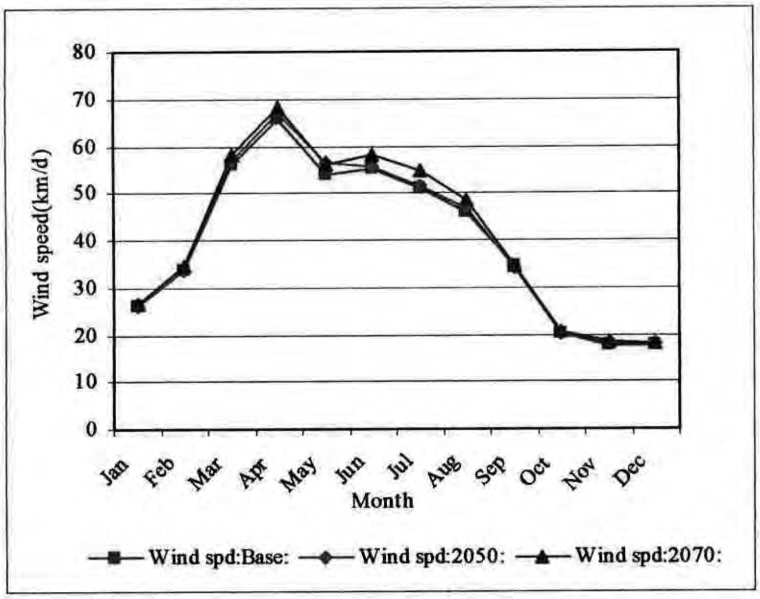
(a)



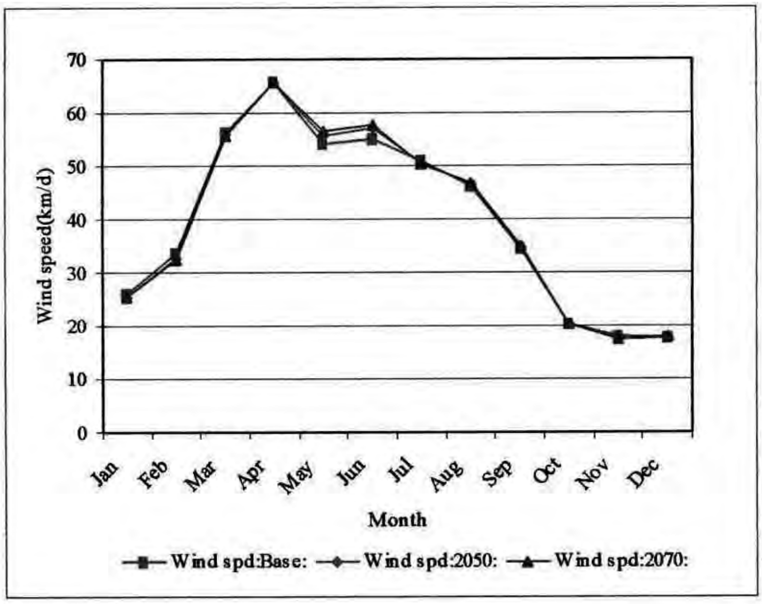
(b)

Figure 5.5: Monthly vapour pressure deficit in study area (a) HADCM2 (b) UKTR

Variation of monthly average wind speed has been formulated in Figure 5.6.Highest value of average wind speed found 65.6 Km/d in April month under current climate which will be rising to 67 Km/d in 2050 and 68 Km/d in 2070 using HADCM2 model output. Using output value of UKTR model maximum average monthly wind speed will remain same in 2050 and in 2070 respectively in April month. Changes of values of wind speed are very insignificant.



(a)



(b)

Figure 5.6: Monthly wind speed in study area (a) HADCM2 (b) UKTR

5.3 Assessment of the Impact of Climate Change on Evapotranspiration in Dinajpur using CROPWAT

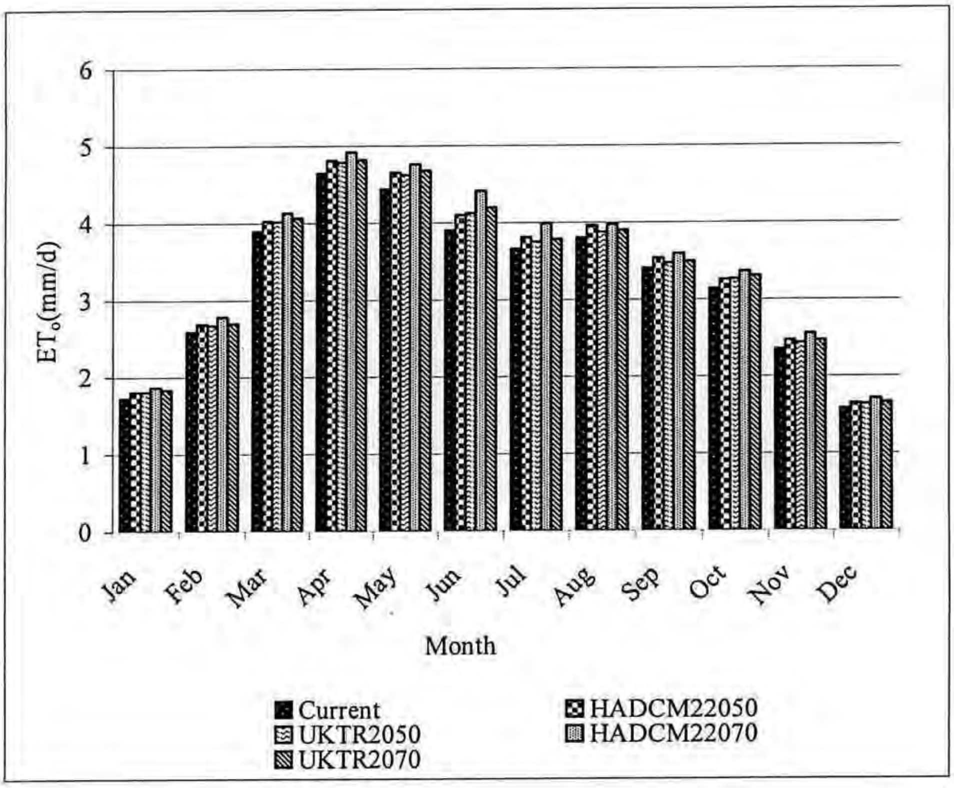
Outputs of HadCM2 and UKTR model was used to evaluate the impact of climate change on evapotranspiration. The baseline climate data, climate scenarios from model were incorporated into the CROPWAT model and used to evaluate the potential impact of climate change on Evapotranspiration in Dinajpur. The climate parameters of temperature, precipitation, relative humidity, sunshine duration and wind speed were used in CROPWAT model for calculating evapotranspiration.

Figure 5.7(a) shows the variation of reference crop evapotranspiration (ETo) over the year and it is readily seen that the higher the projected temperature rise, the higher the increase in ETo. ETo values for 2050 and 2070 year found by using output climatic parameters of HADCM2 model and UKTR model were compared to the original ETo to evaluate the impact of climate change on evapotranspiration have been formulated in Table A 5.5 & Figure 5.7. It is noted that at higher temperature projection by the HADCM2 and UKTR model the amounts of the above parameters were highest. This indicates that the more the temperature increases, the higher the values of the parameter will be increased. This is probably consequence of the interrelationship between atmospheric temperature and water vapor content. High temperature increases the capacity of the air/atmosphere to accommodate water vapor, hence the increased atmospheric demand for water vapor, which consequently implies high crop evapotranspiration rates.

In case of HADCM2 model, under current climate conditions the average reference evapotranspiration (ET_0) is 3.26 mm/d which climbed up to 3.4 mm /day in 2050 and 3.5 mm/day in 2070 which indicates that avg reference evapotranspiration (ET_0) will be 4.21 % more in 2050 and 7.6% higher in 2070 than that of base climate conditions, shown in Figure 5.7 (a) & (b) and Table A 5.5 .a and A 5.5.b.

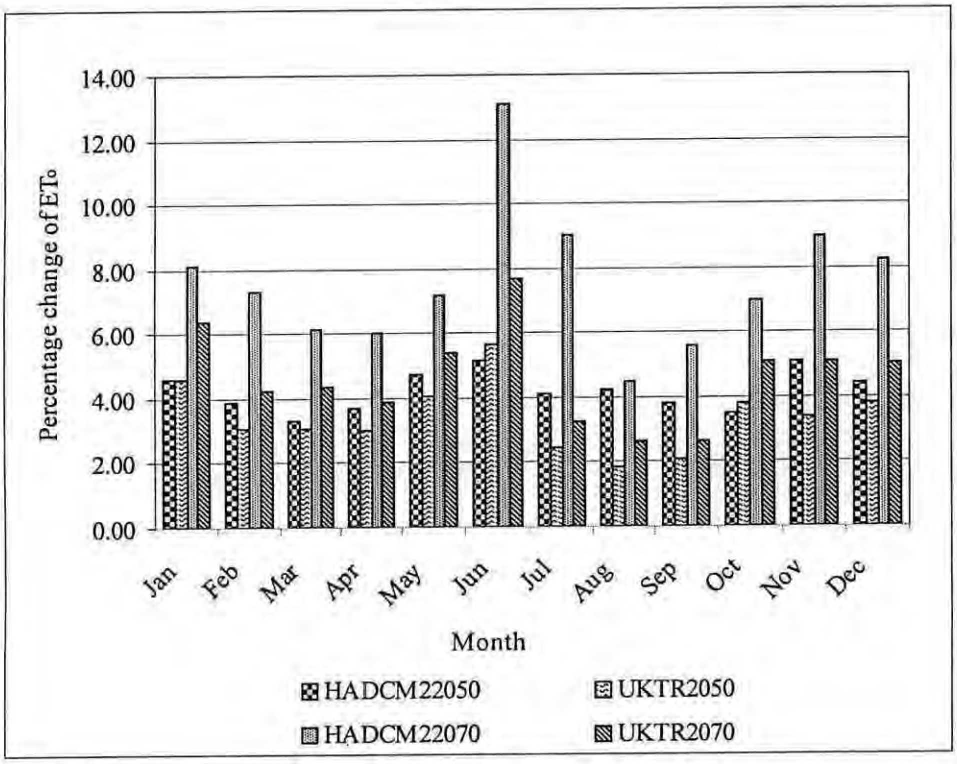
In case of UKTR model, the average reference evapotranspiration (ET_0) climbed up to 3.37 mm /day in 2050 and 3.41 mm/day in 2070 which indicates that average reference evapotranspiration (ET_0) will be 3.41 % more in 2050 and 4.65% higher in 2070 than that of base climate conditions as a result of increasing Temp, Vapor Pressure, Wind Spd., shown in Figure 5.7 (a) & (b) and Table A 5.5 .a and A 5.5.b.

From Figure 5.7 (c), it is greatly seen that reference evapotranspiration value of pre-monsoon season and monsoon are higher than that of post-monsoon and winter season.



(a)

Figure 5.7 (a) Evapootranspiration in study area



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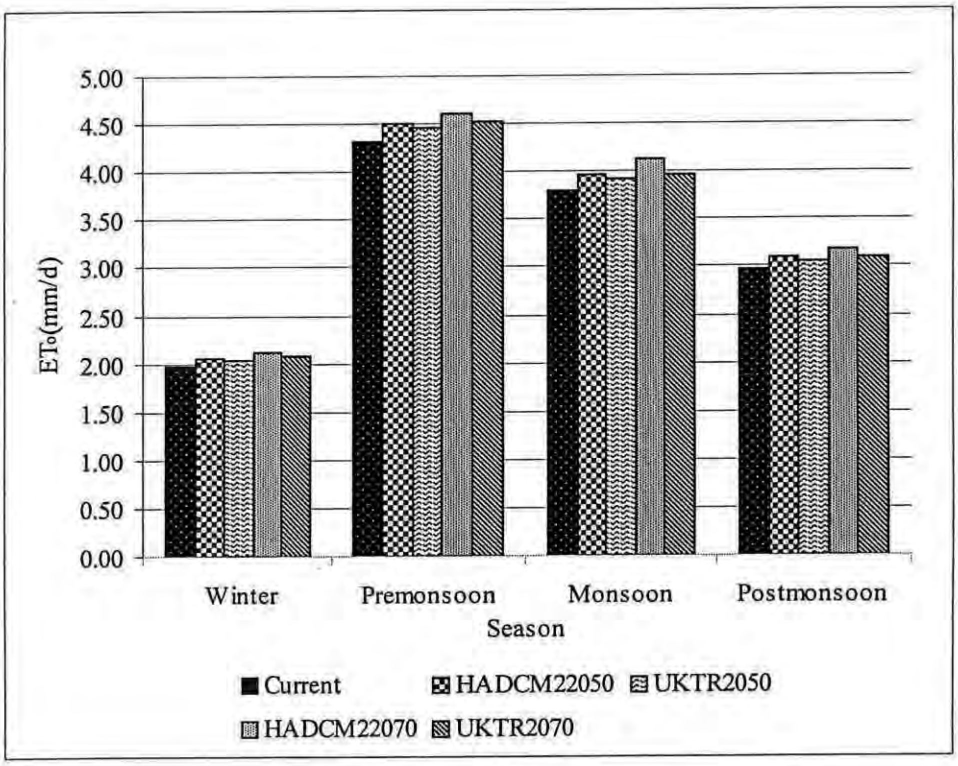


(c)

Figure 5.7 (b) Percentage change of ETo (c) Season wise variation of ETo

5.4 Assessment of the Impact of Climate Change on Crop Water Requirement of Major Crops in Dinajpur

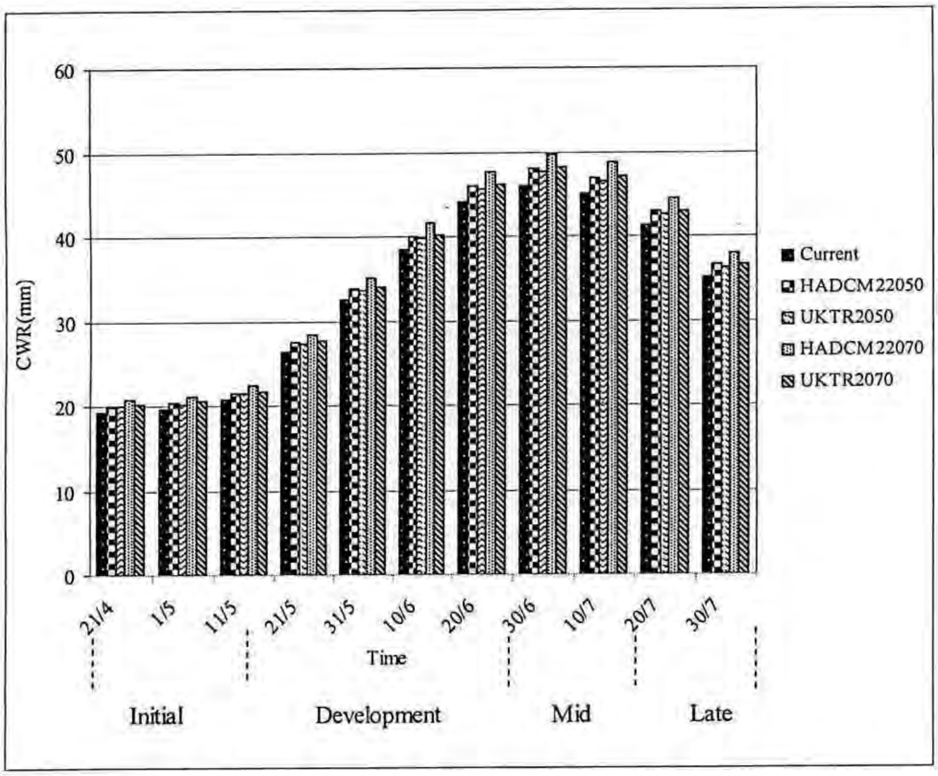
The climate data under current and climate change conditions were incorporated into the CROPWAT model and used to evaluate the potential impact of climate change on water needs of major crops at various seasons .The results show that climate change increases the crop water use. An increase in temperature increases the percentage change in crop water use. T.Aman, B.Aus and Boro were selected for the study since they represent different growing seasons and water needs.

(a) B.Aus:

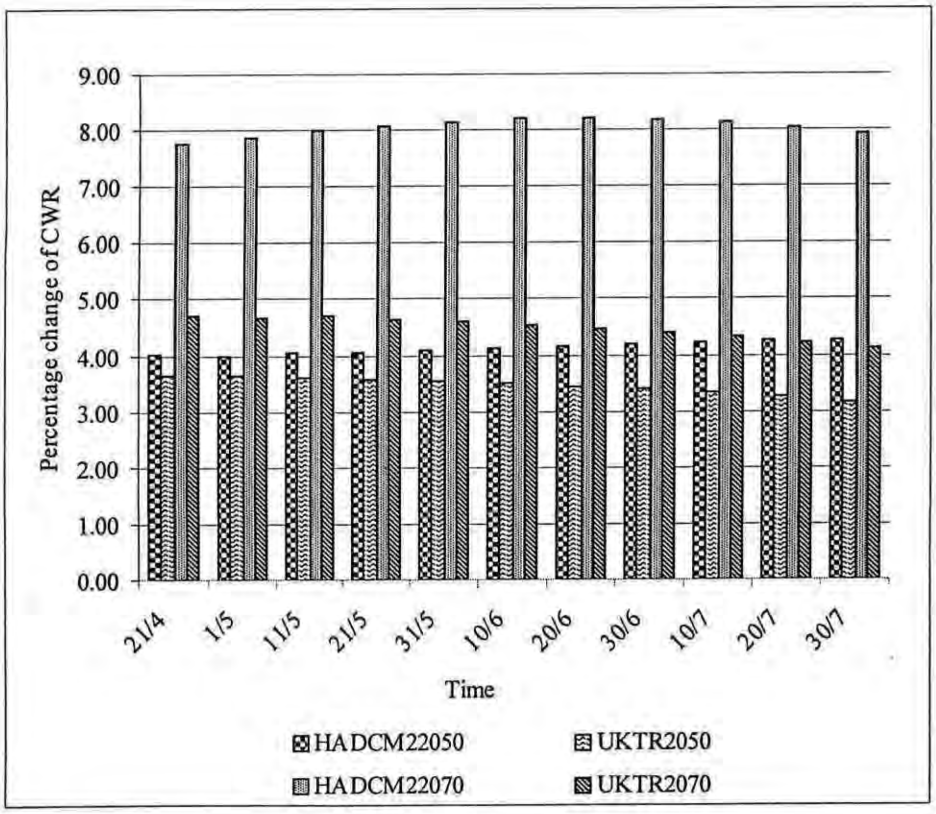
B.Aus is the major crop in the study area. This crop is grown under rainfed conditions in the Kharif I season. Crop water demand is not uniform throughout the growing season.

Figure 5.8(a) and Table A 5.6.a shows that the CWR value was low (19.21mm/period) in the initial stage of crop growth. The CWR value increases during the crop development stage and reaches its maximum value (46.04 mm) at the mid-season stage. During the late season stage, CWR value begins to decrease. In general, the evapotranspiration (CWR) ranged from (19.21 to 46.04) and the total actual CWR was 368.37 mm at the experimental site under current climate condition (shown in Appendix B).

From Figure 5.8(b) it is greatly seen that Crop Water Requirement increases by an average of 4.13% in 2050 and 8.06% in 2070 using forecasted value from HADCM2 model and average 3.46% in 2050 and 4.5% in 2070 using forecasted value from UKTR model as compared with the base line climate period as a result of increasing Temp, Vapor Pressure and Wind Speed.



(a)



(b)

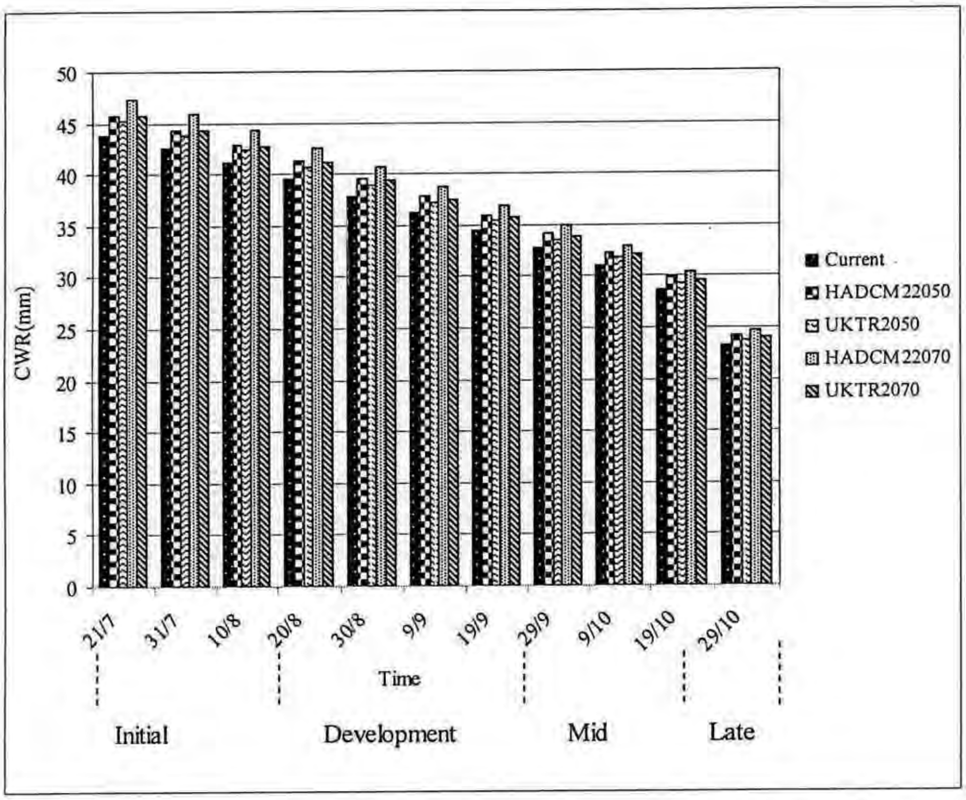
Figure 5.8(a) Crop Water Requirement of B.Aus crop (b) and percentage of change of CWR

(b) T.Aman:

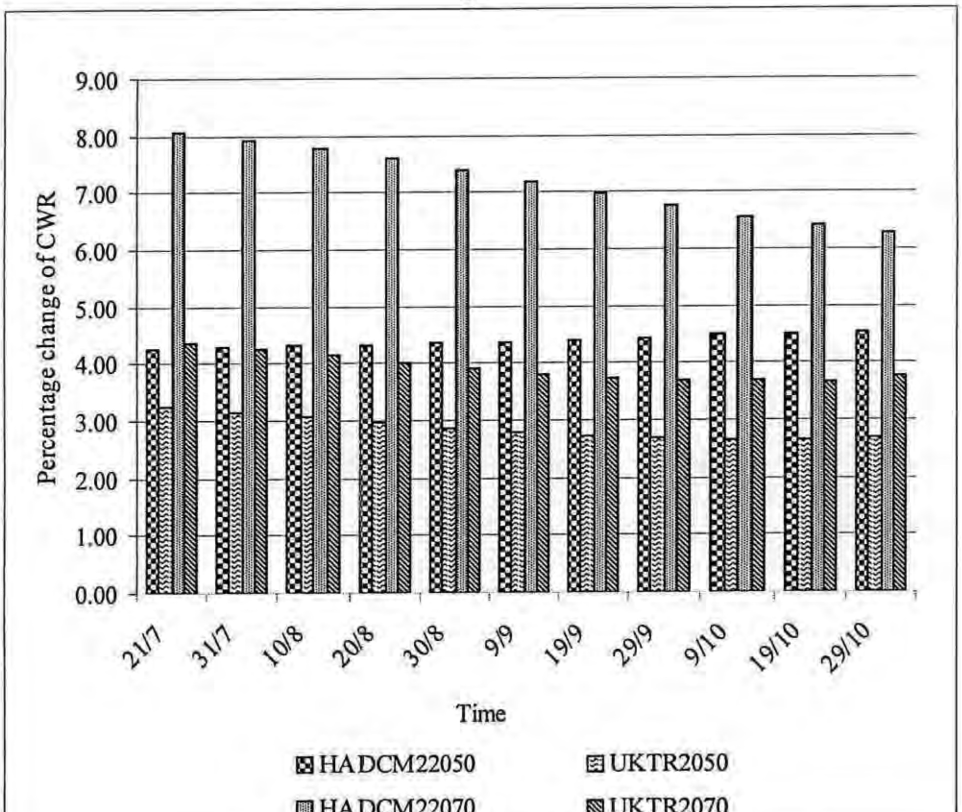
T.Aman is the major crop in the study area. This crop is grown under rainfed conditions in the Kharif II season. Crop water demand is not uniform throughout the growing season. Demand is high during the development stage shown in Table A 5.7.a.

The Figure 5.9(a) represents the changes of CWR value over the growing stages. It is clear that the CWR values are highest (43.83 mm) in the initial stage of crop growth. The CWR value begins to decline over the remaining growth stage. The simulated Etc value ranged from (23.19 mm to 43.83 mm) in base year. The total actual CWR at the experimental site under current climate condition was 390.88 mm.

From Figure 5.9(b) it is found that increasing temperature causes CWR to increase by an average of 4.39% in 2050 and 7.17% in 2070 compared with the CWR under current climate condition analyzing forecasted value of climatic parameters from HADCM2 model .By analyzing UKTR it is found that CWR will increase by an average of 2.86% in 2050 3.91% in 2070. Generally, the effect of climate change on the T.Aman crop is to further increase Crop water Requirement.



(a)



(b)

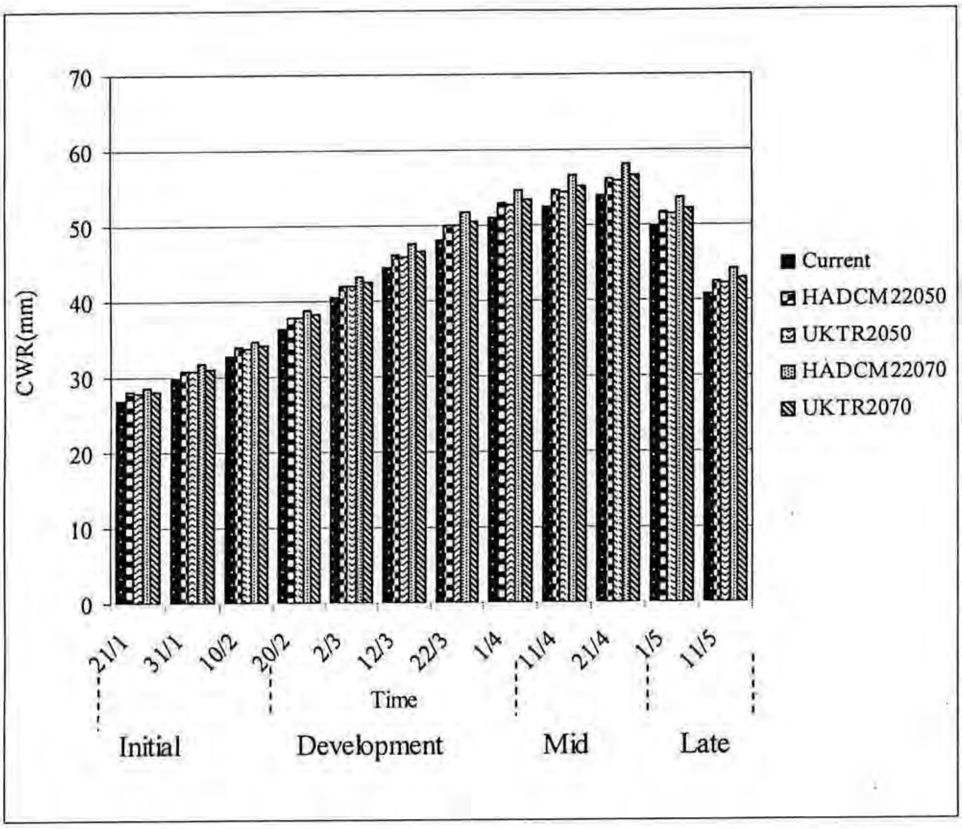
Figure 5.9 (a) Crop Water Requirement of T.Aman crop and (b) percentage of change of CWR

(c) Boro:

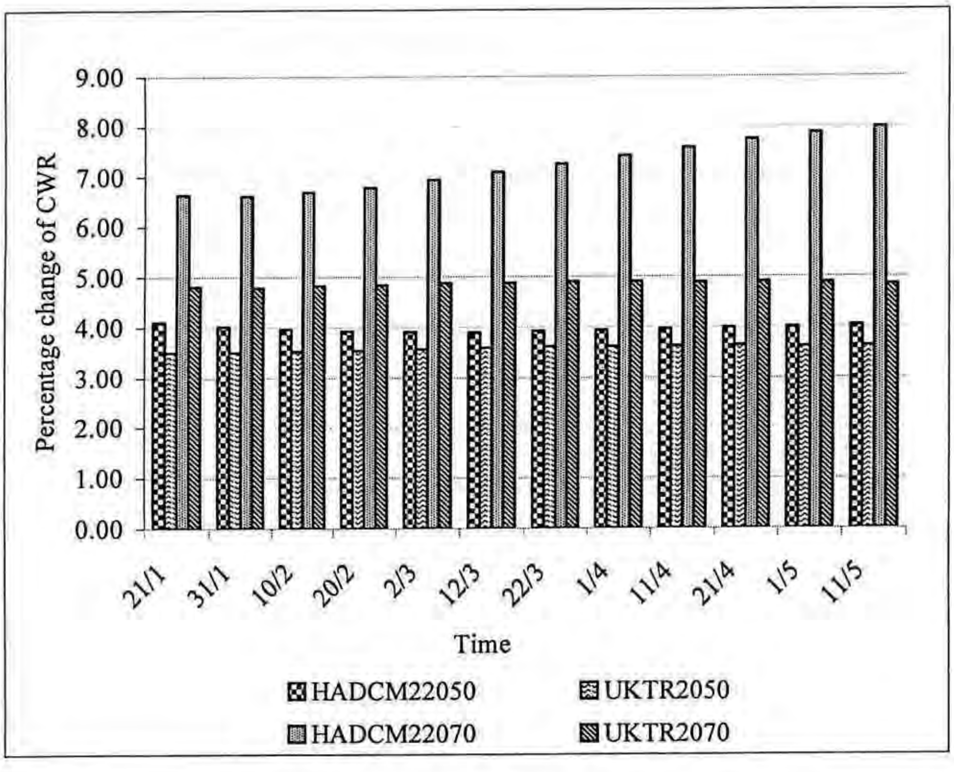
Boro is a dry season rice crop. This crop has the highest record of water demand among all other crops, since evapotranspiration of this crop is high. The demand of this crop mainly depends on evapotranspiration. The actual evapotranspiration was predicted in the study as a function of weather data and stage crop development. The simulated CWR value ranged from (26.83 mm to 53.88 mm) in base year.

Figure 5.10(a) shows that under current climatic condition the CWR value was low (26.83 mm) in the initial stage of crop growth. The CWR value increases during the crop development stage and reaches its maximum value (53.88 mm) at the mid-season stage. During the late season stage, CWR value begins to decrease.

From Figure 5.10(b) and Table A 5.8.b, it is found that increasing temperature causes increment of CWR value by an average of 3.96% in 2050 and 7.27% in 2070 compared with the CWR under current climate condition analyzing forecasted value of climatic parameters from HADCM2 model. By analyzing UKTR it is found that CWR will increase by an average of 3.59% in 2050 and 4.87% in 2070.



(a)



(b)

Figure 5.10: (a) Crop Water Requirement of Boro crop and (b) percentage of change of CWR

CHAPTER 6

CONCLUSION AND RECOMMENDATIONS

6.1 Conclusion

This study re-echoes the relative importance of climate in Dinajpur, whose agriculture depends entirely on climatic parameters and is at the mercy of unpredictable weather and climatic instability. A comprehensive approach for assessment of water demand of major crops in study area has been developed based on some future climate scenarios. There will be significant changes in climate variables (Temp, Vapor Pressure and wind Spd, Relative humidity) in future year which are important to agriculture. The future water demand scenario was quantified and was found to be significantly changed. The results of the HADCM2 and UKTR transient experiment climate models and CROPWAT irrigation management model were used for study area to find reasonable answers to designed question. From the research outputs following concluding comments can be made:

I. It was found from HADCM2 that the average increment of maximum temperature and minimum temperature would be 1.59° C and 1.78° C for the forecasted year of 2050 and average increment of maximum and minimum temperature would be 2.77° C and 2.93° C in forecasted year of 2070. Highest increment of maximum temperature found in June is 2.1 ° C in 2050 which climbed up to 4.9 ° C in 2070 and minimum temperature in November is 2.3 ° C in 2050 which would be increased to 3.7 ° C in 2070. From UKTR model it is found that increment of average maximum temperature and average minimum temperature would be 1. 11° C and 1.74° C for the forecasted year of 2050 and 1.48° C and 2.43° C for the forecasted year of 2070. Highest increment of average maximum temperature found in June is 2.1 ° C in 2050 which climbed up to 2.8 ° C in 2070 and highest increment of average minimum temperature found in January is 2.3 ° C in 2050 would be increased to 3.2 ° C in 2070.

There will be significant changes in climate variables (Temperature, Vapor Pressure and wind Speed, Relative, humidity) in future year which are important to agriculture. Average maximum temperature of monsoon and post-monsoon shows higher value than that of winter and pre-monsoon. On the other hand average minimum temperature of winter and pre-monsoon shows higher values compared to values for the monsoon and post monsoon. It was found from HADCM2 model that, highest average maximum temperature change of 1.73° C found in the monsoon (June, July and August) months and minimum temperature 1.83° C change found in the winter (Dec, Jan and Feb) in 2050. For 2070 the highest increment value for maximum temperature and minimum temperature would be 3.37° C & 3.23° C for monsoon and winter respectively. It was found from UKTR model that highest increment of average maximum temperature found 1.37 ^{0}C in pre-monsoon and minimum temperature found 1.97 ^{0}C in winter for the year of 2050 and highest increment of average maximum and average minimum temperature found 1.87 ^{0}C in pre-monsoon & 2.73 ^{0}C in the winter in 2070 respectively.

II. The CROPWAT model simulated results show that Reference crop evapotranspiration (ET_0) value will increase in 2050 and 2070. ET_0 value found from HADCM2 is higher than that of UKTR. Under current climate conditions the avg reference evapotranspiration (ET_0) is 3.26 which climbed up to 3.39 mm /day in 2050 and 3.5 mm/day in 2070 which indicates that avg reference evapotranspiration (ET_0) will be 4.17 % more in 2050 and 7.49% higher in 2070 than that of base climate conditions. Highest average value of ETo under current climate condition was found 4.32 mm/d in pre-monsoon season which increased to 4.49 mm/d in 2050 and 4.6 mm/d in 2070 using HADCM2 model and in case of UKTR model ETo climbed to 4.47 mm/d and 4.52 mm/d in 2050 and 2070 respectively.

III. Results found using HADCM2 shows higher value of CWR than that of UKTR.The CROPWAT model simulated result using HADCM2 model demonstrates, in case of B. Aus cropping pattern the annual agricultural water in base year demand amounted to 368.37 mm will increase 383.66 mm in 2050 and 398.17 mm in the year 2070.For T. Aman, this amounted to 390.88 mm in base yr will climb up to 407.99 mm & 419.31 mm, in forecasted year 2050 & 2070 respectively. Total water demand of Boro is 506.17 in base year and this amount will rise to 526.25 mm and 543.08 in 2050 and 2070 year respectively. The crop water requirement of Boro which is rabi crop is highest among the major crops in Dinajpur District. It is found that CWR may increase by an average of 4% in 2050 and 8 % in 2070 as compared with the baseline climate period.

IV. This study hence shows a more important hint that the CROPWAT irrigation management model could be used to effectively and efficiently to estimate the agricultural water requirements with different cropping patterns. The information obtained from this research enhances understanding of crop water requirements, which will consequently help improve the productivity of food.

6.2 Recommendations

6.2.1 Limitations of study

I. The results of this project are a reflection of the available data. Limitations in number of years of weather data available and the quality of these data affected the final calculations.

II. The crop coefficient integrates the effect of characteristics that distinguish a typical field crop from the grass reference, which has a constant appearance and a complete ground cover. Consequently, different crops will have different Kc coefficients. The changing characteristics of the crop over the growing season also affect the Kc coefficient. Kc value depends on climate. For example, variation of wind alter the aerodynamic resistance of the crops and hence crop co-efficient. Because aerodynamic properties are greater for many agricultural crops as compared to the grass reference, the ratio of ETc to ETo (i.e., Kc) for many crops increases as wind speed increases and as relative humidity decreases. More arid climates and conditions of greater wind speed will have higher values for Kc. More humid climates and conditions of lower wind speed will have lower values for Kc. But the effects of climate change on Kc value have been ignored, as there is no phytotron chamber in our country.

6.2.2 Recommendations for further studies

The following recommendations are made for further study in the relevant field:

I. The present study cannot be considered as perfect one covering effects of climate change on all crop characteristics .However within limitations and scope this study has certainly provided a basis and focused on various important issues, which should be considered for detailed study in future. More effort has to focus in the collection of high quality information. Further detailed study in future in this field is required.

II. In this study only major crops have been considered to be analyzed. Other growing crops can be analyzed to find out impact of climate change. Using these findings one may also help achieve the potential for increased agricultural production in selected areas of the country.

III. The information obtained from this research enhances understanding of crop water requirements, which will consequently help for further study on irrigation scheduling of major growing crops and other crops comparing water supply with water demand. The much longed-for attainment of stability in food security, reduction in poverty and general enhancement of agro-ecosystem productivity, may be achieved through policies based on these findings.

IV. Crop water demand must be met as this strongly determines crop emergence, development and survival in the tropical regions. However, more accurate knowledge about crop response to water is essential in a range of crops for further study on water stress of different crops.

V. More studies related to crop production and water use by crops are needed. The factors affecting the quality of the soil have to be studied. Erosion, salinity, drainage, and soil and water pollution have to be considered in future work. The use of water for aquaculture, especially shrimp farms, has to be measured.

6.2.3 Recommended interventions to minimize impacts

Following Adaptation Measures can be taken

I. Integrating the water availability with soils use-to develop scientific support for crop sector

II. Implying the private sector-to allow technology transfer in the crops field and soils exploitation.

III. Reinforcing the research and scientific cooperation specially in the genetic field

IV. Providing opportunities for transferring water among competing uses in response to changing conditions

V. Re-evaluating the operations of the existing infrastructure to address climate and non-climate changes.

VI. Geospatial, and weather network data and GIS-based planning are needed to refine agricultural planning, particularly for new permutations of crop type, rotation, irrigation efficiency, and water-distribution policies.

VII. There has been a growing need to quantify water use by various consumers with a view to apportioning the available water resources for use by the competing socio-economic sectors of the country: agricultural, industrial and domestic. This calls for the formulation of appropriate policies to guide the use of the available water resources.

VIII. There is need to improve the irrigation efficiency by changing traditional irrigation system to more efficient systems such as drip irrigation and pipe irrigation. There is need to mount an effort to integrate small farms into big units to increase the irrigation efficiency.

IX. To ease water constraints and enhance productivity, there is need to consider improving crop patterns and cultivate crops with less water requirements. Various aspects of water resource management should be considered, such as supply, demand and construction management.

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APPENDIX A

Table A 5.1.a: Output value of climatic parameters found from HADCM2 model and UKTR model for the forecasted year of 2050

Model	HADCM2				UKTR			
Month	Max Temp(degree C)	Min Temp(degree C)	Vapour Pressure(hpa)	Wind Speed (%)	Max Temp(degree C)	Min Temp(degree	Vapour Pressure(hpa)	Wind Speed (%)
Jan	1.5	1.8	0.9	1.2	1.4	2.3	1.10	-2.00
Feb	1.3	1.9	1.1	-0.1	1.3	1.7	0.90	-2.90
Mar	1.2	1.8	1.3	1.2	1.30	1.8	1.30	-0.80
Apr	1.3	1.7	1.2	2.3	1.30	1.3	0.90	0.00
May	1.9	1.9	1.5	4.2	1.50	1.7	1.10	3.20
Jun	2.1	1.7	1.8	1	2.10	1.8	1.30	3.60
Jul	1.5	1.8	2	0.7	0.80	1.7	2.10	-0.90
Aug	1.6	1.7	1.8	1.4	0.40	1.6	2.20	1.00
Sep	1.5	1.6	1.6	-0.9	0.20	1.5	1.90	1.00
Oct	1.7	1.4	1.3	-1.3	1.10	1.8	1.80	0.00
Nov	2	2.3	1.4	1.7	1.00	1.8	1.30	-2.00
Dec	1.5	1.8	0.9	2	0.90	1.9	1.10	1.10

Table A 5.1.b: Output value of climatic parameters found from HADCM2 model and UKTR model for the forecasted year of 2070

Model	HADCM2				UKTR			
Month	Max Temp(degree C)	Min Temp(degree C)	Vapour Press	Wind Speed (%)	Max Temp(degree C)	Min Temp(degree C)	Vapour Pressure (hpa)	Wind Speed (%)
Jan	2.5	3.3	2.6	2.2	1.9	3.2	1.60	-2.80
Feb	2.3	3.2	2.7	3.1	1.7	2.4	1.30	-4.00
Mar	2.3	2.9	2.5	3.5	1.8	2.5	1.70	-1.10
Apr	2.3	2.7	2.2	.7	1.8	1.7	1.20	0.00
May	3	2.9	2.4	3.5	2.00	2.4	1.60	4.40
Jun	4.9	3.7	1.5	5.6	2.80	2.5	1.80	4.90
Jul	3.4	2.9	3.1	7	1.00	2.4	2.90	-1.20
Aug	1.8	2	3.6	5	0.50	2.3	3.10	1.40
Sep	2.2	2.1	3.4	0.1	0.20	2.1	2.60	1.40
Oct	2.9	2.7	3	1.2	1.50	2.5	2.50	0.00
Nov	3.2	3.6	3	4	1.30	2.5	1.80	-2.80
Dec	2.4	3.2	2.7	2.1	1.20	2.6	1.50	1.50

Table A 5.2.a: Changing value of average maximum and average minimum temperature of different seasons in 2050 & 2070 respectively found from HADCM2 model

HADCM2				Season
2050	**2050**	**2070**	**2070**	
Max	**Min**	**Max**	**Min**	
1.43	1.83	2.40	3.23	Winter(DJF)
1.47	1.80	2.53	2.83	Premonsoon(MAM)
1.73	1.73	3.37	2.87	Monsoon(JJA)
1.73	1.77	2.77	2.80	Post monsoon(SON)

Table A 5.2.b: Changing value of average maximum and average minimum of different seasons in 2050 & 2070 respectively found from UKTR model

UKTR				Season
2050	**2050**	**2070**	**2070**	
Max	**Min**	**Max**	**Min**	
1.2	1.97	1.6	2.73	Winter(DJF)
1.37	1.6	1.87	2.2	Premonsoon(MAM)
1.1	1.7	1.43	2.4	Monsoon(JJA)
0.77	1.7	1	2.37	Post monsoon(SON)

Table A 5.2.c: Percentage change of average maximum and minimum temperature in 2050 & 2070 respectively found from HADCM2 and UKTR model

Month	**HADCM2**				**UKTR**			
	Max Temp (%)	Min Temp (%)	Max Temp (%)	Min Temp (%)	Max Temp (%)	Min Temp (%)	Max Temp (%)	Min Temp (%)
	2050	**2050**	**2070**	**2070**	**2050**	**2050**	**2070**	**2070**
Jan	6.25	17.32	10.37	31.86	5.83	22.14	7.91	30.80
Feb	4.82	15.10	8.60	25.60	4.82	13.51	6.30	19.08
Mar	3.83	10.63	7.43	16.88	4.14	10.63	5.74	14.76
Apr	3.86	8.10	6.95	12.86	3.86	6.19	5.35	8.10
May	5.81	8.18	9.24	12.35	4.59	7.32	6.12	10.33
Jun	6.46	6.76	15.01	14.86	6.46	7.15	8.61	9.94
Jul	4.73	7.01	10.76	11.37	2.52	6.62	3.16	9.35
Aug	5.01	6.53	5.61	7.61	1.25	6.15	1.57	8.84
Sep	4.75	6.34	7.03	8.25	0.63	5.95	0.63	8.33
Oct	5.49	6.28	9.39	12.11	3.55	8.07	4.84	11.21
Nov	6.93	14.08	10.96	21.79	3.47	11.02	4.51	15.30
Dec	5.85	15.14	9.20	27.00	3.51	15.98	4.68	21.87

Table A 5.3.a: Climatic Parameters i.e. Maximum temperature $[^0C]$; Minimum temperature $[^0C]$, Relative humidity [%]; Wind speed (Km/d), Vapour Pressure Deficit (Kpa); for the base year

Month	Max Temp(degree C)	Min Temp(degree C)	Saturated vapour pressure(Kpa)	Actual vapour pressure(Kpa)	Relative Humidity (%)	Vapour pressure deficit(Kpa)	Wind speed(Km/d)
Jan	24.01	10.39	2.12	1.54	72.34	0.59	25.9
Feb	26.98	12.58	2.51	1.51	60.36	0.99	33.6
Mar	31.37	16.94	3.26	1.64	50.33	1.62	56.2
Apr	33.66	21	3.85	2.08	53.94	1.77	65.6
May	32.68	23.23	3.9	2.7	69.25	1.2	54
Jun	32.52	25.16	4.05	3.18	78.57	0.87	55
Jul	31.69	25.68	3.99	3.29	82.65	0.69	51
Aug	31.91	26.02	4.05	3.33	82.33	0.72	46.1
Sep	31.58	25.22	3.93	3.25	82.77	0.68	34.4
Oct	30.99	22.3	3.59	2.78	77.5	0.81	20.4
Nov	28.84	16.34	2.91	2.16	74.17	0.75	17.8
Dec	25.64	11.89	2.34	1.75	74.58	0.6	17.6

Table A 5.3.b: Climatic Parameters i.e. Maximum temperature$\left[{}^{0}C\right]$; Minimum temperature$\left[{}^{0}C\right]$, Relative humidity [%]; Wind speed (Km/d), Vapour Pressure Deficit (Kpa); for 2050 (HADCM2)

Month	Max Temp(degree C)	Min Temp(degree C)	Saturated vapour pressure(Kpa)	Actual vapour pressure(Kpa)	Relative Humidity (%)	Vapour pressure deficit(Kpa)	Wind speed(Km/d)
Jan	25.51	12.19	2.34	1.63	69.4	0.72	26.24
Feb	28.28	14.48	2.75	1.62	59.17	1.12	33.52
Mar	32.57	18.74	3.54	1.77	50.07	1.77	56.84
Apr	34.96	22.7	4.18	2.2	52.53	1.99	67.12
May	34.58	25.13	4.34	2.85	65.56	1.5	56.27
Jun	34.62	26.86	4.52	3.36	74.32	1.16	55.54
Jul	33.19	27.48	4.38	3.49	79.85	0.88	51.37
Aug	33.51	27.72	4.45	3.51	78.98	0.93	46.72
Sep	33.08	26.82	4.29	3.41	79.47	0.88	34.06
Oct	32.69	23.7	3.94	2.91	74	1.02	20.17
Nov	30.84	18.64	3.3	2.3	69.72	1	18.1
Dec	27.14	13.69	2.58	1.84	71.16	0.74	17.92

Table A 5.3.c: Climatic Parameters i.e. Maximum temperature $[^0C]$; Minimum temperature $[^0C]$, Relative humidity [%]; Wind speed (Km/d), Vapour Pressure Deficit (Kpa); for 2070 (HADCM2)

Month	Max Temp(degree C)	Min Temp(degree C)	Saturated vapour pressure(Kpa)	Actual vapour pressure(Kpa)	Relative Humidity (%)	Vapour pressure deficit(Kpa)	Wind speed(Km/d)
Jan	26.5	13.7	2.51	1.8	71.4	0.72	26.47
Feb	29.3	15.8	2.94	1.78	60.79	1.15	34.64
Mar	33.7	19.8	3.77	1.89	50.13	1.88	58.17
Apr	36	23.7	4.44	2.3	51.8	2.14	68.03
May	35.7	26.1	4.61	2.94	63.69	1.68	55.89
Jun	37.4	28.9	5.2	3.33	64.07	1.87	58.08
Jul	35.1	28.6	4.78	3.6	75.35	1.18	54.57
Aug	33.7	28	4.51	3.69	81.95	0.81	48.41
Sep	33.8	27.3	4.44	3.59	80.75	0.86	34.43
Oct	33.9	25	4.23	3.08	72.92	1.15	20.64
Nov	32	19.9	3.54	2.46	69.54	1.08	18.51
Dec	28	15.1	2.75	2.02	73.37	0.73	17.97

Table A 5.4.a: Climatic Parameters i.e. Maximum temperature $[^0C]$; Minimum temperature $[^0C]$, Relative humidity [%]; Wind speed (Km/d), Vapour Pressure deficit (Kpa); for 2050 (UKTR)

Month	Max Temp(degree C)	Min Temp(degree C)	Saturated vapour pressure(Kpa)	Actual vapour pressure(Kpa)	Relative Humidity (%)	Vapour pressure deficit(Kpa)	Wind speed(Km/d)
Jan	25.41	12.69	2.36	1.65	69.83	0.71	25.38
Feb	28.28	14.28	2.73	1.6	58.67	1.13	32.63
Mar	32.67	18.74	3.55	1.77	49.87	1.78	55.75
Apr	34.96	22.3	4.15	2.17	52.23	1.98	65.6
May	34.18	24.93	4.26	2.81	65.84	1.46	55.73
Jun	34.62	26.96	4.53	3.31	73.04	1.22	56.98
Jul	32.49	27.38	4.27	3.5	82.12	0.76	50.54
Aug	32.31	27.62	4.27	3.55	83.24	0.72	46.56
Sep	31.78	26.72	4.1	3.44	83.87	0.66	34.74
Oct	32.09	24.1	3.89	2.96	76.17	0.93	20.4
Nov	29.84	18.14	3.14	2.29	72.88	0.85	17.44
Dec	26.54	13.79	2.52	1.86	73.56	0.67	17.79

Table A 5.4.b: Climatic Parameters i.e. Maximum temperature $[^0C]$; Minimum temperature $[^0C]$, Relative humidity [%]; Wind speed (Km/d), Vapour Pressure deficit (Kpa); for 2070. (UKTR)

Month	Max Temp(degree C)	Min Temp(degree C)	Saturated vapour pressure(Kpa)	Actual vapour pressure(Kpa)	Relative Humidity (%)	Vapour pressure deficit(Kpa)	Wind speed(Km/d)
Jan	25.91	13.59	2.45	1.7	69.22	0.75	25.17
Feb	28.68	14.98	2.82	1.64	58.36	1.17	32.26
Mar	33.17	19.44	3.67	1.81	49.35	1.86	55.58
Apr	35.46	22.7	4.26	2.2	51.57	2.06	65.6
May	34.68	25.63	4.41	2.86	64.84	1.55	56.38
Jun	35.32	27.66	4.71	3.36	71.27	1.35	57.7
Jul	32.69	28.08	4.37	3.58	82	0.79	50.39
Aug	32.41	28.32	4.36	3.64	83.58	0.72	46.75
Sep	31.78	27.32	4.16	3.51	84.28	0.65	34.88
Oct	32.49	24.8	4.01	3.03	75.66	0.98	20.4
Nov	30.14	18.84	3.23	2.34	72.56	0.89	17.3
Dec	26.84	14.49	2.59	1.9	73.19	0.69	17.86

Table A 5.5.a Assessment of the impact of climate change on evapotranspiration (mm/d) in Dinajpur using CROPWAT model

Model		**HadCM2**		**UKTR**	
Month	Current	2050	2070	2050	2070
	ET_0 (mm/d)	ET_0 (mm/d)	ET_0 (mm/d)	ET_0 (mm/d)	ET_0 (mm/d)
Jan	1.73	1.81	1.87	1.81	1.84
Feb	2.59	2.69	2.78	2.67	2.7
Mar	3.89	4.02	4.13	4.01	4.06
Apr	4.64	4.81	4.92	4.78	4.82
May	4.44	4.65	4.76	4.62	4.68
Jun	3.9	4.1	4.41	4.12	4.2
Jul	3.66	3.81	3.99	3.75	3.78
Aug	3.8	3.96	3.97	3.87	3.9
Sep	3.4	3.53	3.59	3.47	3.49
Oct	3.14	3.25	3.36	3.26	3.3
Nov	2.35	2.47	2.56	2.43	2.47
Dec	1.58	1.65	1.71	1.64	1.66

Table A 5.5.b Assessment of the impact of climate change on season wise variation of evapotranspiration in Dinajpur using CROPWAT model

Model		**HadCM2**		**UKTR**	
Season	**Current**	**2050**	**2070**	**2050**	**2070**
	ET_0 (mm/d)	ET_0 (mm/d)	ET_0 (mm/d)	ET_0 (mm/d)	ET_0 (mm/d)
Winter	1.97	2.05	2.12	2.04	2.07
Premonsoon	4.32	4.49	4.60	4.47	4.52
Monsoon	3.79	3.96	4.12	3.91	3.96
Postmonsoon	2.96	3.08	3.17	3.05	3.09

Table A 5.5.c Assessment of the impact of climate change on percentage change of evapotranspiration in Dinajpur using CROPWAT model

Model	**HadCM2**	**UKTR**	**HadCM2**	**UKTR**
Month	ETo(%change) 2050	ETo(%change) 2050	ETo(%change) 2070	ETo(%change) 2070
Jan	4.62	4.62	8.09	6.36
Feb	3.86	3.09	7.34	4.25
Mar	3.34	3.08	6.17	4.37
Apr	3.66	3.02	6.03	3.88
May	4.73	4.05	7.21	5.41
Jun	5.13	5.64	13.08	7.69
Jul	4.10	2.46	9.02	3.28
Aug	4.21	1.84	4.47	2.63
Sep	3.82	2.06	5.59	2.65
Oct	3.50	3.82	7.01	5.10
Nov	5.11	3.40	8.94	5.11
Dec	4.43	3.80	8.23	5.06

Table A 5.6.a: Assessment of the impact of climate change on crop water requirement (mm) of B.Aus in Dinajpur using climate scenarios of HADCM2 and UKTR in CROPWAT model

B.Aus	HADCM2			UKTR	
	current	2050	2070	2050	2070
Date	CWR	CWR	CWR	CWR	CWR
21/4	19.21	19.98	20.7	19.91	20.15
1/5	19.57	20.35	21.11	20.28	20.52
11/5	20.71	21.55	22.37	21.46	21.72
21/5	26.37	27.44	28.5	27.31	27.64
31/5	32.51	33.84	35.16	33.66	34.06
10/6	38.43	40.02	41.59	39.78	40.24
20/6	44.06	45.89	47.68	45.58	46.1
30/6	46.04	47.97	49.81	47.6	48.14
10/7	45.09	46.99	48.76	46.59	47.1
20/7	41.22	42.97	44.54	42.56	43.02
30/7	35.16	36.66	37.95	36.27	36.65

Table A 5.6.b: Assessment of the impact of climate change on percentage change of crop water requirement of B.Aus in Dinajpur using climate scenarios of HADCM2 and UKTR in CROPWAT model

B.Aus	HADCM2		UKTR	
	2050	2070	2050	2070
Date	% Change of CWR	% Change of CWR	% Change of CWR	% Change of CWR
21/4	4.01	7.76	3.64	4.72
1/5	3.99	7.87	3.63	4.68
11/5	4.06	8.02	3.62	4.71
21/5	4.06	8.08	3.56	4.65
31/5	4.09	8.15	3.54	4.60
10/6	4.14	8.22	3.51	4.55
20/6	4.15	8.22	3.45	4.48
30/6	4.19	8.19	3.39	4.41
10/7	4.21	8.14	3.33	4.31
20/7	4.25	8.05	3.25	4.23
30/7	4.27	7.94	3.16	4.11

Table A 5.7.a: Assessment of the impact of climate change on crop water requirement (mm) of T.Aman in Dinajpur using climate scenarios of HADCM2 and UKTR in CROPWAT model

T.Aman		HADCM2		UKTR	
Date	current CWR	2050 CWR	2070 CWR	2050 CWR	2070 CWR
21/7	43.83	45.7	47.36	45.25	45.74
31/7	42.52	44.34	45.89	43.86	44.33
10/8	41.08	42.85	44.28	42.34	42.78
20/8	39.53	41.24	42.53	40.7	41.11
30/8	37.89	39.54	40.69	38.98	39.37
9/9	36.19	37.77	38.79	37.2	37.57
19/9	34.45	35.97	36.85	35.39	35.73
29/9	32.69	34.14	34.9	33.57	33.9
9/10	30.94	32.33	32.97	31.76	32.08
19/10	28.57	29.86	30.4	29.33	29.62
29/10	23.19	24.24	24.65	23.81	24.06

Table A 5.7.b: Assessment of the impact of climate change on percentage change of crop water requirement of T.Aman in Dinajpur using climate scenarios of HADCM2 and UKTR in CROPWAT model

T.Aman	HADCM2		UKTR	
Date	2050 % Change of CWR	2070 % Change of CWR	2050 % Change of CWR	2070 % Change of CWR
21/7	4.27	8.05	3.24	4.22
31/7	4.28	7.93	3.15	4.13
10/8	4.31	7.79	3.07	4.02
20/8	4.33	7.59	2.96	3.88
30/8	4.35	7.39	2.88	3.80
9/9	4.37	7.18	2.79	3.71
19/9	4.41	6.97	2.73	3.62
29/9	4.44	6.76	2.69	3.60
9/10	4.49	6.56	2.65	3.59
19/10	4.52	6.41	2.66	3.58
29/10	4.53	6.30	2.67	3.65

Table A 5.8.a: Assessment of the impact of climate change on Crop Water Requirement (mm) of Boro in Dinajpur using climate scenarios of HADCM2 and UKTR in CROPWAT model

Boro	HADCM2			UKTR	
	current	2050	2070	2050	2070
Date	CWR	CWR	CWR	CWR	CWR
21/1	26.83	27.93	28.61	27.77	28.12
31/1	29.64	30.83	31.6	30.68	31.06
10/2	32.57	33.86	34.75	33.72	34.14
20/2	36.42	37.85	38.89	37.71	38.18
2/3	40.4	41.98	43.2	41.84	42.37
12/3	44.33	46.06	47.47	45.92	46.49
22/3	48.14	50.03	51.63	49.88	50.5
1/4	50.87	52.87	54.64	52.71	53.36
11/4	52.55	54.63	56.53	54.46	55.12
21/4	53.88	56.03	58.05	55.84	56.52
1/5	49.71	51.7	53.62	51.51	52.14
11/5	40.83	42.48	44.09	42.31	42.81

Table A 5.8.b: Assessment of the impact of climate change on percentage change of Crop Water Requirement of Boro in Dinajpur using climate scenarios of HADCM2 and UKTR in CROPWAT model

Boro	HADCM2		UKTR	
	2050	2070	2050	2070
Date	% Change of CWR	% Change of CWR	% Change of CWR	% Change of CWR
21/1	4.10	6.63	3.50	4.65
31/1	4.01	6.61	3.51	4.63
10/2	3.96	6.69	3.53	4.66
20/2	3.93	6.78	3.54	4.67
2/3	3.91	6.93	3.56	4.71
12/3	3.90	7.08	3.59	4.70
22/3	3.93	7.25	3.61	4.73
1/4	3.93	7.41	3.62	4.72
11/4	3.96	7.57	3.63	4.72
21/4	3.99	7.74	3.64	4.73
1/5	4.00	7.87	3.62	4.72
11/5	4.04	7.98	3.62	4.68

Table A 5.9: Length of growing stages of rice crops

Crop	Initial	Development	Mid	Late	Total	Planting Date
B.Aus	25	45	20	20	110	21-Apr
T.Aman	30	40	25	15	110	21-Jul
Boro	30	45	25	20	120	21-Jan

Table A 5.10: Crop coefficient of major crops

Crop	Decades starting from transplanting date of crop											
	1	2	3	4	5	6	7	8	9	10	11	12
B.Aus	046	0.57	0.74	0.94	1.07	1.10	1.10	1.1	1.05	0.95	0.85	
T. Aus	1.1	1.10	1.10	1.10	1.10	1.10	1.05	0.95	.85			
T.Aman	1.1	1.10	1.10	1.10	1.10	1.10	1.10	1.1	1.05	0.95	0.85	
Boro	1.1	1.10	1.10	1.10	1.11	1.15	1.22	1.29	1.29	1.22	1.10	0.85
Wheat	0.45	0.57	0.74	0.94	1.07	1.13	1.15	1.12	1.03	0.88	0.50	
Pulses	0.46	0.61	0.85	1.04	1.10	1.10	1.10	1.00	.8	0.60	0.40	
Mustard	0.46	0.61	0.85	1.04	1.10	1.10	1.10	1.00	.8			
Potato	0.40	0.50	0.85	1.09	1.15	1.12	1.12	1.05	.8			
Onion	0.40	0.45	0.65	0.85	0.90	0.95	0.95	0.90	.85	0.80		
Jute	0.40	0.45	0.50	0.60	0.75	1.08	1.08	1.14	1.15	1.15	1.10	1.00
Til	0.40	0.55	0.75	0.95	1.00	1.00	1.00	0.85	0.6			

Source: MPO, 1987

Table A 5.11: Rooting depth of full grown crops and soil water availability of different crops

Crop	Rooting depth(m)	Fraction of available soil water
Wheat	1.0	0.55
Pulses	1.0	0.60
Mustard	1.0	0.50
Potato	0.6	0.25
Onion	0.5	0.25
B.Aus	0.4	0.30
Jute	1.0	0.35
Til	1.0	0.65
Sugarcane	1.5	0.65
Banana	0.9	0.35
Transplanted rice	0.2	0.20

Source: UNDP/FAO, 1988

Table A 5.12: Yield response factors for different crops

Crop	Yield response factors			
	Initial	Development	Mid	Late
Wheat	0.20	0.20	0.65	0.35
Pulses	0.20	0.40	0.30	0.15
Mustard	0.20	0.30	0.40	0.20
Potato	0.40	0.70	0.60	0.20
Onion	0.45	0.40	0.70	0.20
B.Aus	0.60	0.80	1.00	0.40
Jute	0.70	0.80	1.00	0.50
Til	0.20	0.30	0.40	0.15
Sugarcane	0.75	0.65	0.45	0.20
Banana	1.30	1.00	1.00	0.81
	Vegetative	Flowering	Yield	Ripening
Transplanted	0.9	1.6	0.5	-

Source: FAO, 1986

Appendix B (Samples of CROPWAT model output)

3/25/2008 CropWat 4 Windows Ver 4.3

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Climate and ETo (grass) Data

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Data Source: C:\CROPWATW\CLIMATE\current ET.PEM

Country : Bangladesh Station : Dinajpur

Latitude: 25.63 Deg. (North) Longitude: 88.65 Deg. (East)

Month	MaxTemp (deg.C)	MiniTemp (deg.C)	Humidity (%)	Wind Spd. (Km/d)	SunShine (Hours)	Solar Rad. (MJ/m2/d)	ETo (mm/d)
January	24	10.4	72.3	25.9	5.4	12	1.73
February	27	12.6	60.4	33.6	7.6	16.5	2.59
March	31.4	16.9	50.3	56.2	8.5	20.1	3.89
April	33.7	21	53.9	65.6	7.9	21.1	4.64
May	32.7	23.2	69.3	54	6.8	20.2	4.44
June	32.5	25.2	78.6	55	4.6	17	3.9
July	31.7	25.7	82.7	51	4.1	16.1	3.66
August	31.9	26	82.3	46.1	5.1	17.1	3.8
September	31.6	25.2	82.8	34.4	5.1	15.9	3.4
October	31	22.3	77.5	20.4	7.2	16.7	3.14
November	28.8	16.3	74.2	17.8	8.1	15.4	2.35
December	25.6	11.9	74.6	17.6	5.1	11.1	1.58

Average 30.2 19.7 71.6 39.8 6.3 16.6 3.26

Pen-Mon equation was used in ETo calculations with the following values for Angstrom's Coefficients:

a = 0.25 b = 0.5

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C:\CROPWATW\REPORTS\REPORT\Current ET.TXT

3/29/2008 CropWat 4 Windows Ver 4.3

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Climate and ETo (grass) Data

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Data Source: [Keyboard]

Country : Bangladesh Station : Dinajpur

Latitude: 25.63 Deg. (North) Longitude: 88.65 Deg. (East)

Month	MaxTemp (deg.C)	MiniTemp (deg.C)	Humidity (%)	Wind Spd. (Km/d)	SunShine (Hours)	Solar Rad. (MJ/m2/d)	ETo (mm/d)
January	25.5	12.2	69.4	26.2	5.4	12	1.81
February	28.3	14.5	59.2	33.6	7.6	16.5	2.69
March	32.6	18.7	50.1	56.9	8.5	20.1	4.02
April	35	22.7	52.5	67.1	7.9	21.1	4.81
May	34.6	25.1	65.6	56.3	6.8	20.2	4.65
June	34.6	26.9	74.3	55.5	4.6	17	4.1
July	33.2	27.5	79.8	51.3	4.1	16.1	3.81
August	33.5	27.7	79	46.7	5.1	17.1	3.96
September	33.1	26.8	79.5	34.1	5.1	15.9	3.53
October	32.7	23.7	74	20.1	7.2	16.7	3.25
November	30.8	18.6	69.7	18.1	8.1	15.4	2.47
December	27.1	13.7	71.2	18	5.1	11.1	1.65
Average	31.8	21.5	68.7	40.3	6.3	16.6	3.4

Pen-Mon equation was used in ETo calculations with the following values for Angstrom's Coefficients:

a = 0.25 b = 0.5

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C:\CROPWATW\REPORTS\ET2050(HADCM2).TXT

3/30/2008 CropWat 4 Windows Ver 4.3

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Climate and ETo (grass) Data

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Data Source: [Keyboard]

Country : Bangladesh Station : Dinajpur

Latitude: 25.63 Deg. (North) Longitude: 88.65 Deg. (East)

Month	MaxTemp (deg.C)	MiniTemp (deg.C)	Humidity (%)	Wind Spd. (Km/d)	SunShine (Hours)	Solar Rad. (MJ/m2/d)	ETo (mm/d)
January	26.5	13.7	71.4	26.5	5.4	12	1.87
February	29.3	15.8	60.8	34.6	7.6	16.5	2.78
March	33.7	19.8	50.1	58.2	8.5	20.1	4.13
April	36	23.7	51.8	68	7.9	21.1	4.92
May	35.7	26.1	63.7	55.9	6.8	20.2	4.76
June	37.4	28.9	64.1	58.1	4.6	17	4.41
July	35.1	28.6	75.3	54.6	4.1	16.1	3.99
August	33.7	28	81.9	48.4	5.1	17.1	3.97
September	33.8	27.3	80.8	34.4	5.1	15.9	3.59
October	33.9	25	72.9	20.6	7.2	16.7	3.36
November	32	19.9	69.5	18.5	8.1	15.4	2.56
December	28	15.1	73.4	18	5.1	11.1	1.71
Average	32.9	22.7	68	41.3	6.3	16.6	3.5

Pen-Mon equation was used in ETo calculations with the following values
for Angstrom's Coefficients:
a = 0.25 b = 0.5

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Climate and ETo (grass) Data

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Data Source: C:\CROPWATW\CLIMATE\2050UKTR.PEM

Country : Bangladesh Station : Dinajpur

Latitude: 25.63 Deg. (North) Longitude: 88.65 Deg. (East)

Month	MaxTemp (deg.C)	MiniTemp (deg.C)	Humidity (%)	Wind Spd. (Km/d)	SunShine (Hours)	Solar Rad. (MJ/m2/d)	ETo (mm/d)
January	25.4	12.7	69.8	25.4	5.4	12	1.81
February	28.3	14.3	58.7	32.6	7.6	16.5	2.67
March	32.7	18.7	49.9	55.8	8.5	20.1	4.01
April	35	22.3	52.2	65.6	7.9	21.1	4.78
May	34.2	24.9	65.8	55.7	6.8	20.2	4.62
June	34.6	27	73	57	4.6	17	4.12
July	32.5	27.4	82.1	50.5	4.1	16.1	3.75
August	32.3	27.6	83.2	46.6	5.1	17.1	3.87
September	31.8	26.7	83.9	34.7	5.1	15.9	3.47
October	32.1	24.1	76.2	20.4	7.2	16.7	3.26
November	29.8	18.1	72.9	17.4	8.1	15.4	2.43
December	26.5	13.7	73.6	17.8	5.1	11.1	1.64
Average	31.3	21.5	70.1	40.0	6.3	16.6	3.37

Pen-Mon equation was used in ETo calculations with the following values
for Angstrom's Coefficients:
a = 0.25 b = 0.5
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Climate and ETo (grass) Data

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Data Source: C:\CROPWATW\CLIMATE\2070UKTR.PEM

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Country : Bangladesh Station : Dinajpur

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Latitude: 25.63 Deg. (North) Longitude: 88.65 Deg. (East)

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Month	MaxTemp (deg.C)	MiniTemp (deg.C)	Humidity (%)	Wind Spd. (Km/d)	SunShine (Hours)	Solar Rad. (MJ/m2/d)	ETo (mm/d)
January	25.9	13.6	69.2	25.2	5.4	12	1.84
February	28.7	15	58.4	32.3	7.6	16.5	2.7
March	33.2	19.4	49.3	55.6	8.5	20.1	4.06
April	35.5	22.7	51.6	65.6	7.9	21.1	4.82
May	34.7	25.6	64.8	56.3	6.8	20.2	4.68
June	35.3	27.7	71.3	57.7	4.6	17	4.2
July	32.6	28.1	82	50.4	4.1	16.1	3.78
August	32.4	28.3	83.6	46.8	5.1	17.1	3.9
September	31.8	27.3	84.3	34.9	5.1	15.9	3.49
October	32.5	24.8	75.7	20	7.2	16.7	3.3
November	30.1	18.8	72.6	17.3	8.1	15.4	2.47
December	26.8	14.5	73.2	17.9	5.1	11.1	1.66
Average	31.6	22.1	69.7	40.0	6.3	16.6	3.41

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Pen-Mon equation was used in ETo calculations with the following values
for Angstrom's Coefficients:

a = 0.25 b = 0.5

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Crop Water Requirements Report

****

- Crop # 1 : BAus
- Block # : [All blocks]
- Planting date : 21/4
- Calculation time step = 10 Day(s)

#NAME?

Date	ETo (mm/period)	Planted Area (%)	Crop Kc	CWR (ETm)
21/4	41.77	100	0.46	19.21
1/5	42.53	100	0.46	19.57
11/5	43.03	100	0.48	20.71
21/5	43.27	100	0.61	26.37
31/5	43.26	100	0.75	32.51
10/6	43.01	100	0.89	38.43
20/6	42.53	100	1.04	44.06
30/6	41.85	100	1.1	46.04
10/7	40.99	100	1.1	45.09
20/7	39.96	100	1.03	41.22
30/7	38.78	100	0.91	35.16
Total	460.98			368.37

* ETo data is distributed using polynomial curve fitting.
* Rainfall data is distributed using polynomial curve fitting.

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Crop Water Requirements Report

****

- Crop # 1 : BAus
- Block # : [All blocks]
- Planting date : 21/4
- Calculation time step = 10 Day(s)

#NAME?

Date	ETo (mm/period)	Planted Area (%)	Crop Kc	CWR (ETm)
21/4	43.43	100	0.46	19.98
1/5	44.24	100	0.46	20.35
11/5	44.77	100	0.48	21.55
21/5	45.03	100	0.61	27.44
31/5	45.03	100	0.75	33.84
10/6	44.78	100	0.89	40.02
20/6	44.31	100	1.04	45.89
30/6	43.61	100	1.1	47.97
10/7	42.72	100	1.1	46.99
20/7	41.66	100	1.03	42.97
30/7	40.44	100	0.91	36.66
Total	480.03			383.68

* ETo data is distributed using polynomial curve fitting.
* Rainfall data is distributed using polynomial curve fitting.

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Crop Water Requirements Report

****

- Crop # 1 : BAus
- Block # : [All blocks]
- Planting date : 21/4
- Calculation time step = 10 Day(s)

#NAME?

Date	ETo (mm/period)	Planted Area (%)	Crop Kc	CWR (ETm)
21/4	45	100	0.46	20.7
1/5	45.88	100	0.46	21.11
11/5	46.47	100	0.48	22.37
21/5	46.77	100	0.61	28.5
31/5	46.79	100	0.75	35.16
10/6	46.53	100	0.89	41.59
20/6	46.03	100	1.04	47.68
30/6	45.29	100	1.1	49.81
10/7	44.33	100	1.1	48.76
20/7	43.18	100	1.03	44.54
30/7	41.86	100	0.91	37.95
Total	498.13			398.17

* ETo data is distributed using polynomial curve fitting.
* Rainfall data is distributed using polynomial curve fitting.

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Crop Water Requirements Report

****

- Crop # 1 : BAus
- Block # : [All blocks]
- Planting date : 21/4
- Calculation time step = 10 Day(s)

#NAME?

Date	ETo (mm/period	Planted Area) (%)	Crop Kc	CWR (ETm)
21/4	43.29	100	0.46	19.91
1/5	44.08	100	0.46	20.28
11/5	44.59	100	0.48	21.46
21/5	44.82	100	0.61	27.31
31/5	44.79	100	0.75	33.66
10/6	44.52	100	0.89	39.78
20/6	44	100	1.04	45.58
30/6	43.28	100	1.1	47.6
10/7	42.35	100	1.1	46.59
20/7	41.26	100	1.03	42.56
30/7	40.01	100	0.91	36.27
Total	476.98			381.01

* ETo data is distributed using polynomial curve fitting.
* Rainfall data is distributed using polynomial curve fitting.

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Crop Water Requirements Report

****

- Crop # 1 : BAus
- Block # : [All blocks]
- Planting date : 21/4
- Calculation time step = 10 Day(s)

#NAME?

Date	ETo (mm/period	Planted Area) (%)	Crop Kc	CWR (ETm)
21/4	43.81	100	0.46	20.15
1/5	44.61	100	0.46	20.52
11/5	45.12	100	0.48	21.72
21/5	45.35	100	0.61	27.64
31/5	45.32	100	0.75	34.06
10/6	45.03	100	0.89	40.24
20/6	44.5	100	1.04	46.1
30/6	43.76	100	1.1	48.14
10/7	42.82	100	1.1	47.1
20/7	41.7	100	1.03	43.02
30/7	40.43	100	0.91	36.65
Total	482.46			385.34

* ETo data is distributed using polynomial curve fitting.
* Rainfall data is distributed using polynomial curve fitting.

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Crop Water Requirements Report

****

- Crop # 1 : T.Aman
- Block # : [All blocks]
- Planting date : 21/7
- Calculation time step = 10 Day(s)

#NAME?

Date	ETo (mm/period	Planted Area) (%)	Crop Kc	CWR (ETm)
21/7	39.85	100	1.1	43.83
31/7	38.66	100	1.1	42.52
10/8	37.35	100	1.1	41.08
20/8	35.93	100	1.1	39.53
30/8	34.44	100	1.1	37.89
9/9	32.9	100	1.1	36.19
19/9	31.32	100	1.1	34.45
29/9	29.72	100	1.1	32.69
9/10	28.13	100	1.1	30.94
19/10	26.57	100	1.08	28.57
29/10	25.04	100	0.93	23.19
Total	359.91			390.88

* ETo data is distributed using polynomial curve fitting.
* Rainfall data is distributed using polynomial curve fitting.

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Crop Water Requirements Report

****

- Crop # 1 : T.Aman
- Block # : [All blocks]
- Planting date : 21/7
- Calculation time step = 10 Day(s)

#NAME?

Date	ETo (mm/period	Planted Area) (%)	Crop Kc	CWR (ETm)
21/7	41.54	100	1.1	45.7
31/7	40.31	100	1.1	44.34
10/8	38.95	100	1.1	42.85
20/8	37.49	100	1.1	41.24
30/8	35.95	100	1.1	39.54
9/9	34.34	100	1.1	37.77
19/9	32.7	100	1.1	35.97
29/9	31.04	100	1.1	34.14
9/10	29.39	100	1.1	32.33
19/10	27.76	100	1.08	29.86
29/10	26.19	100	0.93	24.24
Total	375.67			407.99

* ETo data is distributed using polynomial curve fitting.
* Rainfall data is distributed using polynomial curve fitting.

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Crop Water Requirements Report

****

- Crop # 1 : T.Aman
- Block # : [All blocks]
- Planting date : 21/7
- Calculation time step = 10 Day(s)

#NAME?

Date	ETo (mm/period	Planted Area) (%)	Crop Kc	CWR (ETm)
21/7	43.05	100	1.1	47.36
31/7	41.72	100	1.1	45.89
10/8	40.25	100	1.1	44.28
20/8	38.66	100	1.1	42.53
30/8	36.99	100	1.1	40.69
9/9	35.26	100	1.1	38.79
19/9	33.5	100	1.1	36.85
29/9	31.73	100	1.1	34.9
9/10	29.97	100	1.1	32.97
19/10	28.26	100	1.08	30.4
29/10	26.62	100	0.93	24.65
Total	386.01			419.31

* ETo data is distributed using polynomial curve fitting.
* Rainfall data is distributed using polynomial curve fitting.

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Crop Water Requirements Report

****

- Crop # 1 : T.Aman
- Block # : [All blocks]
- Planting date : 21/7
- Calculation time step = 10 Day(s)

#NAME?

Date	ETo (mm/period)	Planted Area (%)	Crop Kc	CWR (ETm)
21/7	41.14	100	1.1	45.25
31/7	39.88	100	1.1	43.86
10/8	38.49	100	1.1	42.34
20/8	37	100	1.1	40.7
30/8	35.44	100	1.1	38.98
9/9	33.82	100	1.1	37.2
19/9	32.17	100	1.1	35.39
29/9	30.52	100	1.1	33.57
9/10	28.87	100	1.1	31.76
19/10	27.27	100	1.08	29.33
29/10	25.72	100	0.93	23.81
Total	370.31			402.19

* ETo data is distributed using polynomial curve fitting.
* Rainfall data is distributed using polynomial curve fitting.

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Crop Water Requirements Report

****

- Crop # 1 : T.Aman
- Block # : [All blocks]
- Planting date : 21/7
- Calculation time step = 10 Day(s)

#NAME?

Date	ETo (mm/period	Planted Area) (%)	Crop Kc	CWR (ETm)
21/7	41.58	100	1.1	45.74
31/7	40.3	100	1.1	44.33
10/8	38.89	100	1.1	42.78
20/8	37.38	100	1.1	41.11
30/8	35.79	100	1.1	39.37
9/9	34.15	100	1.1	37.57
19/9	32.49	100	1.1	35.73
29/9	30.81	100	1.1	33.9
9/10	29.16	100	1.1	32.08
19/10	27.54	100	1.08	29.62
29/10	25.99	100	0.93	24.06
Total	374.08			406.28

* ETo data is distributed using polynomial curve fitting.

* Rainfall data is distributed using polynomial curve fitting.

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Crop Water Requirements Report

****

- Crop # 1 : Boro
- Block # : [All blocks]
- Planting date : 21/1
- Calculation time step = 10 Day(s)

#NAME?

Date	ETo (mm/period	Planted Area) (%)	Crop Kc	CWR (ETm)
21/1	24.39	100	1.1	26.83
31/1	26.95	100	1.1	29.64
10/2	29.44	100	1.11	32.57
20/2	31.82	100	1.14	36.42
2/3	34.04	100	1.19	40.4
12/3	36.07	100	1.23	44.33
22/3	37.87	100	1.27	48.14
1/4	39.43	100	1.29	50.87
11/4	40.73	100	1.29	52.55
21/4	41.77	100	1.29	53.88
1/5	42.53	100	1.17	49.71
11/5	43.03	100	0.95	40.83
Total	428.09			506.18

* ETo data is distributed using polynomial curve fitting.
* Rainfall data is distributed using polynomial curve fitting.

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Crop Water Requirements Report

****

- Crop # 1 : Boro
- Block # : [All blocks]
- Planting date : 21/1
- Calculation time step = 10 Day(s)

#NAME?

Date	ETo (mm/period	Planted Area) (%)	Crop Kc	CWR (ETm) ------
-----	-----------	----------	------	---------
21/1	25.39	100	1.1	27.93
31/1	28.03	100	1.1	30.83
10/2	30.6	100	1.11	33.86
20/2	33.07	100	1.14	37.85
2/3	35.38	100	1.19	41.98
12/3	37.48	100	1.23	46.06
22/3	39.36	100	1.27	50.03
1/4	40.99	100	1.29	52.87
11/4	42.35	100	1.29	54.63
21/4	43.43	100	1.29	56.03
1/5	44.24	100	1.17	51.7
11/5	44.77	100	0.95	42.48
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Total	445.08			526.26

* ETo data is distributed using polynomial curve fitting.
* Rainfall data is distributed using polynomial curve fitting.

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****

Crop Water Requirements Report

****

- Crop # 1 : Boro
- Block # : [All blocks]
- Planting date : 21/1
- Calculation time step = 10 Day(s)

#NAME?

Date	ETo (mm/period	Planted Area) (%)	Crop Kc	CWR (ETm)
-----	-----------	----------	------	---------
21/1	26.01	100	1.1	28.61
31/1	28.73	100	1.1	31.6
10/2	31.41	100	1.11	34.75
20/2	33.98	100	1.14	38.89
2/3	36.4	100	1.19	43.2
12/3	38.63	100	1.23	47.47
22/3	40.62	100	1.27	51.63
1/4	42.36	100	1.29	54.64
11/4	43.82	100	1.29	56.53
21/4	45	100	1.29	58.05
1/5	45.88	100	1.17	53.62
11/5	46.47	100	0.95	44.09
-----	-----------	----------	------	---------
Total	459.3			543.1

* ETo data is distributed using polynomial curve fitting.
* Rainfall data is distributed using polynomial curve fitting.

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Crop Water Requirements Report

****

- Crop # 1 : Boro
- Block # : [All blocks]
- Planting date : 21/1
- Calculation time step = 10 Day(s)

#NAME?

Date	ETo (mm/period	Planted Area d) (%)	Crop Kc	CWR (ETm)
-----	----------	-----------	------	-----------
21/1	25.25	100	1.1	27.77
31/1	27.89	100	1.1	30.68
10/2	30.48	100	1.11	33.72
20/2	32.95	100	1.14	37.71
2/3	35.26	100	1.19	41.84
12/3	37.37	100	1.23	45.92
22/3	39.24	100	1.27	49.88
1/4	40.86	100	1.29	52.71
11/4	42.21	100	1.29	54.46
21/4	43.29	100	1.29	55.84
1/5	44.08	100	1.17	51.51
11/5	44.59	100	0.95	42.31
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Total	443.46			524.37

* ETo data is distributed using polynomial curve fitting.
* Rainfall data is distributed using polynomial curve fitting.

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Crop Water Requirements Report

****

- Crop # 1 : Boro
- Block # : [All blocks]
- Planting date : 21/1
- Calculation time step = 10 Day(s)

#NAME?

Date	ETo (mm/period	Planted Area) (%)	Crop Kc	CWR (ETm) -----
-----	-----------	----------	------	--------
21/1	25.56	100	1.1	28.12
31/1	28.24	100	1.1	31.06
10/2	30.86	100	1.11	34.14
20/2	33.36	100	1.14	38.18
2/3	35.7	100	1.19	42.37
12/3	37.83	100	1.23	46.49
22/3	39.73	100	1.27	50.5
1/4	41.37	100	1.29	53.36
11/4	42.73	100	1.29	55.12
21/4	43.81	100	1.29	56.52
1/5	44.61	100	1.17	52.14
11/5	45.12	100	0.95	42.81
-----	-----------	----------	------	--------
Total	448.92			530.8

* ETo data is distributed using polynomial curve fitting.
* Rainfall data is distributed using polynomial curve fitting.

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Indicator Cluster	Socio-economic indicator					Environmental Indicator								Final Ranking
	Gross value added of Agriculture(crops)(Million Taka)	Major Gross Cropped Area(acre)	Literacy Rate	Population Density/ SqKm	SUM W	Net cultivated area(%)	Temporary cropped area(%)	Irrigated area(%)	Land Type				SUM W	
									High Land (%)	Medium High Land (%)	Medium Low Land (%)	Lowland (%)		
	0.35	**0.30**	**0.15**	**0.2**	**1.00**	**0.20**	**0.15**	**0.25**	**0.10**	**0.10**	**0.10**	**0.10**	**1.00**	
District	**99-2000**	**1996**	**1991**	**1991**		**1996**	**1996**	**1996**	**1996**	**1996**	**1996**	**1996**		
DINAJPUR	8225	1034040	28.7	657.4	9	11.2	11	12	38.27	59.93	9.15	0.64	9	9
NAOGAON	9199	899818	27.9	625.2	9	10.9	11	12	8.13	69.17	8.12	1.56	9	9
BOGRA	8909	892664	27.2	914.2	9	8.4	9	12	15.00	74.55	9.58	0.86	8	8
SIRAJGANJ	5093	595055	26.1	906.2	6	6.1	6	7	20.96	36.63	25.95	15.92	9	8
PABNA	4922	570392	26.3	809.6	6	6.2	6	4	17.80	26.60	25.01	23.57	9	8
NATORE	5236	496166	26.8	731.9	6	5.9	6	5	6.70	53.32	19.74	20.25	8	7
RANGPUR	6946	748044	25.1	936.1	8	7.4	7	8	19.26	80.33	0.40	0.00	6	7
GAIBANDHA	5729	615080	23.6	894.5	7	6.1	6	7	2.71	86.86	7.62	2.81	6	6
RAJSHAHI	4465	427804	28.6	784.4	6	5.6	5	6	14.56	67.93	13.56	3.95	6	6
THAKURGAON	4316	522918	25.7	558.7	5	6.0	6	5	62.22	36.49	0.67	0.63	6	6
KURIGRAM	5392	535281	21.9	698.2	6	5.2	5	4	4.88	84.25	8.96	1.90	5	5
NILPHAMARI	4857	526504	26.2	822.0	6	5.2	5	5	23.56	76.03	0.41	0.00	5	5
NAWABGANJ	3801	350154	24.2	688.1	5	4.7	5	4	9.78	74.74	9.62	5.87	5	5
JOYPURHAT	3498	344548	30.2	855.2	5	3.2	3	4	11.80	84.09	4.11	0.00	4	4
PANCHAGARH	2767	351501	30.4	506.9	4	4.1	4	1	59.77	39.67	0.33	0.23	4	4
LALMONIRHAT	3170	330552	23.4	768.0	4	3.6	4	3	21.67	76.32	2.00	0.00	4	4