Climate Change and the Boro Rice Phenology in Rajshahi

Scenarios of future crop water demand for Boro rice due to climate change in Rajshahi, north-western district of Bangladesh

MSc. Major Thesis by Md Shariot-Ullah

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Water Resources Management group

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Front page image: Drought affected field of north-western part of Bangladesh (Source: http://www.thedailystar.net/news-detail-135551; Taken by: Iqbal Ahmed / Driknews).

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Scenarios of future crop water demand for Boro rice due to climate change in Rajshahi, north-western district of Bangladesh

Major Master thesis Water Resources Management submitted in partial fulfillment of the degree of Master of Science in International Land and Water Management at Wageningen University, the Netherlands

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Abstract

Global climate is changing and affecting agriculture by influencing crop phenology and the water requirement. The valuable water resource is under threat for the increasing global warming phenomena. In this research the effects of climate change on Boro rice phenology and the influence on crop water requirement has been assessed in the drought prone north-western area, Rajshahi district, Bangladesh. The effects of change in temperature, solar radiation, humidity, wind speed, drought stress and the growing degree days (GDD) on rice phenology and the crop water requirement parameters has been observed in the case study.

Temperature has the main influence on rice phenology and crop water requirement. In future, it has been predicted that the average daily temperature will be increased by 1 and 1.4°C by 2030 and 2050 respectively. The individual growing stages will be short for this increased temperature (initial stage 2 days, vegetative stage 4 days, flowering stage 2 days and maturity stage 1 day) by 2050. The daily evapotranspiration will be increased by 31.3 mm in 2100 for dry season Boro rice but the total seasonal evapotranspiration will be decreased by 32 mm or 4% of total evapotranspiration for 1°C temperature rise. Increased solar radiation will accelerate the maturity and ripening stage (leaf senescence); thus less ET, and less biomass loss due to respiration, and thus higher yields. For the low light during flowering period may causes severe spikelet sterility about 30-50%. The relative humidity increases at the rate of 0.287% each year during Boro rice growing season in the case study area. There are no significant changes observed by the year 2035 and 2050. The maximum increased humidity found to be 10.16% in March by 2050. The transpiration rate has possibility to decrease by 1.5 to 2 folds for the increased humidity and the spikelet sterility also has possibility to increase. Beside this, the increase of wind speed by 30% might influence the evapotranspiration by 20% each year. The projected growing degree days will also increase by 2035, 2050 and 2065 that will influence to shorten the growth stages. Severe water stress condition will enhance the vegetative stage and flowering stage to be lengthy. Severe water stress also responsible for delayed maturity stage and will cause delayed panicle initiation. Beside this the reference crop evapotranspiration will be increased during rice developmental stage and the crop evapotranspiration will increase throughout the growing period by 2050 (maximum increased by 1.66 mm/day in April, during maturity stage) for the changing climatic parameters and growth stages. This will influence the irrigation water requirement to be increased during crop developmental stage. The maximum irrigation water has been observed in April (17.2 mm/decade) during maturity stage.

One of the important finding of this study is that the projected temperature and the humidity percentage both are increasing over time and has possibility to increase in future as well in the case study area. That will lead to decrease in total crop water requirement but might hamper the proper grain development for spikelet sterility due to increased humidity with high temperature. As a result yield might reduce considerably.

Acknowledgement

At the very first, I would like to show my gratitude to my supervisor Dr. Ir. Gerardo E. van Halsema for his continuous encouragement and constructive instructions that inspired me to do the research and to think critically.

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Chapter 1

Introduction

1.1 Background

Global climate is changing. This climate change makes meteorological parameters more variable and affects production of crops biophysically by increasing the temperature and carbon di-oxide levels and changing the pattern of rainfall (Parry, 2004). Climate change is affecting agricultural production in tropical region by increasing temperature and changing variable nature of monsoon. Climate change is influencing the food security by changing agro-ecology, land suitability and thus the yield of crop (Schmidhuber & Tubiello, 2007). Already many Asian countries have started to show the decreasing trend of rainfall during last few decades (Sivakumar et al, 2005).

Irrigation is an important input in agriculture for better crop production by reducing dependency on the pattern of rainfall. Globally, irrigation area has expanded and the main water user sector agriculture reached about 70% of total withdrawal of water (Fischer et al, 2007). It is said that future climate change will influence mostly the irrigation sector (Döll, 2002). Climate change has the possibility to affect the sources of agriculture water source by changing rainfall event, evaporative water demand and exacerbating the occurrence of extreme events such as drought and flood. It is decreasing precipitation and leading to the water scarcity by increasing the severity and frequency of drought in arid and semi-arid regions (Kahil et al, 2014; Kundzewicz et al, 2007). Increased temperature due to climate change is also influencing the rate of evaporation and irrigation water demand to increase (Bates et al, 2008; Frederick and Major, 1997; Fischer et al, 2007).

Bangladesh is a vulnerable country to climate change and already has started to show the effects of climate change during last few years. In the global climate risk index, Bangladesh ranked 5th among 170 climate change vulnerable countries ((Kreft and Eckstein, 2013). She experiences several extreme climate events such as floods, droughts, cyclones, erosion every year (Dastagir, 2015). Bangladesh is suffering from flood severity due to heavy monsoon precipitation every year (Yu, 2010). Beside this, drought is also an important issue in Bangladesh that is recurrent in nature (Shahid & Behrawan, 2008) and becoming worse due to climate change. The drought frequency is increasing due to low rainfall from November to April every year. Mostly, north-western part of Bangladesh is facing drought due to rainfall variability (World Bank, 2013; NDMC, 2006; Shahid and Behrawan, 2008). The temperature has also increased during the monsoon season over the last three decades. The daily average temperature has been predicted to increase 1.0 °C by 2030 and 1.4 °C by 2050 and the rainfall pattern will be more variable (MOEF, 2005; GOB, 2009; FAO, 2006).

There is a close connection among the effects of climate change, drought and the desertification (Stringer, 2009). Drought is the remarkable shortage of precipitation that causes the hydrological imbalance (Trenberth et al, 2014). It has serious effects on the production system of resources based on land (ICCD, 1994). Many studies have been carried out to observe the severity of drought in agriculture of Bangladesh by giving emphasis on the north-western region of Bangladesh (Mazid et al, 2005, Saleh et al, 2000). During the summer, most of the surface water sources dries up and irrigation (about 79%) becomes dependent on groundwater source to satisfy extra water demand (FAO, 2012). As a result of dependency on only one source and unplanned extraction during the driest period, groundwater is depleting beyond pumping level for most of the shallow tube wells.

Beside this, Bangladesh is a densely populated country. There is a need to increase production to ensure food security. Rice is the main crop grown in Bangladesh. About 80% of the cropped area is used for rice cultivation that contributes to around 90% of the total grain production (BBS, 2009). Boro rice is the main cultivating crop in the northern part of Bangladesh and grown under irrigation. The growing period of Boro rice is the driest period from November-January to April-May (Riches, 2008; Shahid, 2011) and depends on irrigation water that leads to pressure on groundwater. During dry period, overexploitation of groundwater for the irrigation purpose of Boro cultivation is leading continuous declination of groundwater source in Bangladesh. Unplanned management system of groundwater extraction is also influencing the decline of groundwater (NMIDP, 1996; BADC, 2005). So, to continue the irrigation in a sustainable way and to save the valuable groundwater sources, it is essential to observe the probable scenarios of plausible crop water demand in future for the specific crop and plan the water extraction from groundwater source by avoiding overexploitation.

According to Hulme & Viner (1998), climate scenarios resemble the future climate. This scenario explained probable climate change in future accordingly and in a systematic way and helped to assess climate change impact. Development of climate change scenarios is also important to know how climate change affects crop water requirements and proper management of water resources by reducing pressure on a single source.

1.2 Problem Analysis

The case study area, Rajshahi district situated under Barind tract (an uplifted area that has a comparatively higher elevation than other floodplains in Bangladesh). This region situated at north-western part of Bangladesh consisting nine upazilas (sub-district) covering an area of 2407 km^2 with 2.4 million people which is the largest part of Barind tract (33%). Characteristics of this area is having comparatively low and variable rainfall (1400–1600 mm annually) than other areas. The temperature is also comparatively higher in this area and in warmest month, the average range of temperature varies from 25° to 35°. Sometimes temperature exceeds 40°. This region is characterized by a semi-arid and drought-prone area (Alam, 2015; Riches, 2008; Banglapedia, 2003).

Groundwater is the main source for irrigation in Rajshahi district and about 75% irrigation water depends on groundwater (Bari and Anwar, 2000). This area becomes fully dependent on groundwater for irrigation during the dry season because the surface water sources dry up. Rajshahi district is a relatively drought prone area (Shahid, 2008). Overexploitation of groundwater leading groundwater mining and 10% of the irrigated lands already become critical to irrigate with shallow tube-wells (BADC, 2005). Recently, during the dry seasons this problem is becoming more severe.

The prolonged absence of groundwater sources due to drought is leading water levels fall below the range of shallow tube-wells. In Bangladesh, population is increasing and agriculture sector is expanding to meet the extra need of food for overpopulation that causing pressure on water sector as well. This extra demand for water is increasing water scarcity problem and thus making this problem crucial to address (Shahid & Hazarika, 2010). Agricultural production at the case study area is under great threat of water scarcity due to frequent drought and has the possibility to affect the livelihood and economy of rural people as they depend on agriculture.

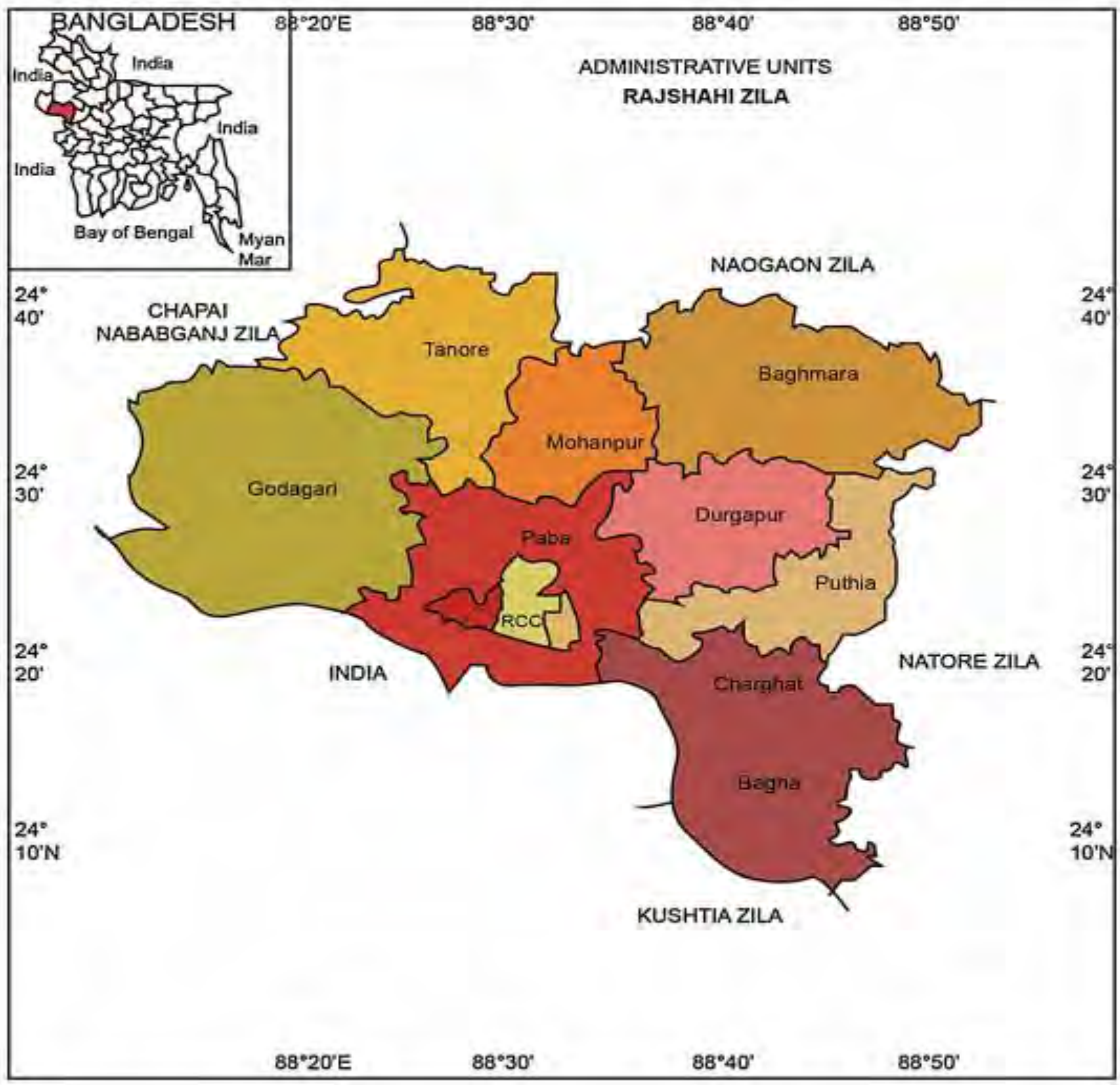


Figure 1 Rajshahi district map (Alam, 2015)

Aus[1], Aman[2] and Boro[3] are the general types of rice varieties grown in Bangladesh and Boro is completely irrigation-dependent variety that grown during the dry season (Alam, 2015). Shahid (2011) carried out an experiment on climate change impact on Boro rice at north-western region of the country and showed that the daily irrigation water requirement will be increased by influencing crop evapotranspiration, crop phenology, water balance and changing the precipitation and that might affect the groundwater source. Boro rice is one of

[1] Aus is rainfed rice variety and can be both upland (broadcasted) and lowland rice (transplanted) (March/April- July /August)
[2] Aman is also lowland rice variety grown in monsoon (July to December)
[3] Boro is cold tolerant and irrigation dependent variety and grown where sufficient water retains throughout the growing season (November/January to April/May,) (Parsons et al, 1999 and Sattar, 2000)

the high yielding varieties that contribute the highest percentage of the total rice production of Bangladesh. Boro rice alone contributes about 55% of the total grain production in Bangladesh. Yield of Boro rice per unit area (3.84 metric ton) is also higher than the production of Aus and Amon. During last 20 years, Boro rice growing area has been increased substantially (BBS, 2010; Akter and Jaim 2002). It is the main cultivars in the north-western part of Bangladesh that grown during the dry period under irrigation. So, there is no way to avoid cultivation of this variety in the north-western district as well as other parts of Bangladesh. Basak et al (2010) carried out an experiment by taking 12 districts of Bangladesh under consideration including Rajshahi to observe the impact of climate change on Boro rice production. They predicted the Boro rice production for 2050 and 2070 that the production will be reduced by 20 and 50% respectively. The increased solar radiation and temperature for climate change will reduce the maturity period by influencing crop physiology. On the other hand increased carbon-dioxide and solar radiation will help to increase crop production.

As there is no way to avoid growing irrigation water dependent Boro rice and there is also possibility of increasing water scarcity for climate change at the case study area, so it is important to predict the crop water demand of Boro rice for the future. These will help to understand the future water demand in Boro rice for proper rescheduling irrigation water. This might reduce pressure on groundwater source that occurs due to drought and overexploitation for the excess need for aggravated climate change. So, it is also important to assess how Boro rice responses for water during growing period for climate change in the case study area.

This prediction will help to develop improve water requirement scenarios at the case study area and will be helpful to schedule the irrigation perfectly. This scenario will also assist policy makers to take necessary steps in respect to climate change at the case study area of Bangladesh. By considering above context the research question has been drawn as follows:

1.3 Main Research Question

What are the phenological responses of Boro rice for climate change and how it affects crop water requirements?

Sub Research Questions

1) Which climatic parameters are influencing rice phenology?

2) What are the effects of projected climate change on rice phenology due to climate change?
3) What are the effects of climate change on crop water requirement parameters?

Chapter 2

Methodologies

2.1 Conceptual Framework

In this research work climate change is the main issue. Due to climate change the case study area Rajshahi district, Bangladesh is becoming drought prone day by day. To develop a better crop water requirement scenario due to climate change at the research area is the main aim of this research. To attain this aim, the main research question has been subdivided into three sub questions. One is to assess the crop sensitivity due to climate change and other two is related to the present and future crop water requirement.

Concepts used to understand the case

The growth of crop depends on photosynthesis that depends on the amount of radiation captured by the crop canopy and the use of the photosynthates to convert in to biomass (Monteith, 1977). Beside this there are also effects of temperature, wind speed, humidity at different crop phases from initial to grain production by influencing evapotranspiration process (Peng et al, 2004, Allen et al, 1998). Climate parameters influence evapotranspiration (ET). The crop coefficient (K_c) influenced by crop phenology and physiology. Beside this climate change, crops are also affected by raising CO_2 level. In this research it has been assessed that how the climatic parameters specially temperature, solar radiation and humidity affects different growth stages (initial, vegetative, flowering and maturing) of rice crop during growing period by affecting crop evapotranspiration. Specially the literature review on relation between rice crop growth stage and the climatic parameters has been done and assessed how and what extent the different growth stages of rice might be influenced by the changed climatic parameters.

The crop phenology and the physiology are greatly influenced by the climatic parameters. To continue rice physiological process properly it needs water for photosynthesis. Crop uses the water for photosynthesis and later transpiration happen after satisfying plants needs for proper physiological process. Only small amount (around 0.1%) of total water uptake by root is use for the development of the plant tissue. And the rest of the water are transpires by leaves (Colorado Climate Centre, 2010). Photosynthesis equation is as follows:

$$6CO_2 + 6H_2O \xrightarrow[\text{Sunlight}]{} C_6H_{12}O_6 + 6O_2$$

$$\text{Carbon dioxide + Water} \xrightarrow[\text{Sunlight}]{} \text{Sugar + Oxygen}$$

Sunlight has influence on photosynthesis process. Temperature, humidity and wind speed influence the transpiration process.

The climate change has impact on rice phenology and physiology as the climatic parameters directly impacts on the growth and development process. The responses of rice phenology for the changed climatic parameters has been assessed through past research that has been done. It has been assumed that the temperature might increase and the solar radiation might decrease in near future for the climate change that will greatly influence the rice phenology. The rice evapotranspiration might increase for the increased temperature. The aspects of Boro rice that might change for the climate change are as follows:

-Phenological development and growing degree days
-Biomass accumulation might be influenced
-Spikelet sterility and flowering of Boro rice
-Finally that might influence the harvesting index and the rice yield

The crop evapotranspiration concept has been used to calculate the crop water requirement. The reference evapotranspiration is an important factor to calculate the actual crop evapotranspiration. Crop needs water for its proper growth. But the applied water evaporated from the soil surface, leaves and the surface of plant stems, and most of water transpires through the leaves of the plant after fulfilling the need for proper development of plant physiology. It is really difficult to separate them and for the reason of that, they are referred together as evapotranspiration (ET). Actually the crop water requirement is the amount of water needs to meet the loss of water that happen due to evapotranspiration process. Evapotranspiration is divided into reference crop evapotranspiration, crop evapotranspiration at standard condition (Where no limitation imposed on evapotranspiration or crop growth) and the adjusted evapotranspiration at non-standard condition (environmental and water stressed condition) (Brouwer and Heibloem, 1986; Allen, 1998). In this research the first two types are analysed to assess crop water requirement.

Panman Monteith Equation was used for the calculation of Evapotranspiration (Allen et al, 1998). There are numerous methods developed to calculate the reference crop evapotranspiration but most of them are limited due to climate data variability, validity and availability. Later, FAO recommended four methods to calculate reference evapotranspiration namely Blaney-Criddle method, radiation method, modified Penman method and pan evaporation methods depending on available data at the study area. The modified Penman method found to be the best resulted method but sometimes overestimate the crop evapotranspiration. Later, FAO Penman-Monteith method developed and consider as the standard one that also have provision for data shortage condition. Penman derived the equation to calculate reference crop evapotranspiration that use the climatological data such as temperature, sunshine hours, wind speed and humidity. The FAO Panman Monteith equation for calculating reference crop evapotranspiration is as follows:

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

Where,

ETo	=	Reference evapotranspiration, mm day^{-1}
R_n	=	Net radiation, MJ m^{-2} day^{-1}
G	=	Soil heat flux density, MJ m^{-2} day^{-1}
(e_s -e_a)	=	Saturation vapour pressure deficit of the air, kPa
T	=	Mean daily air temperature at 2 m height, °C
u_2	=	Wind speed at 2 m height, m s^{-1}
Δ	=	Slope of the saturation vapour pressure curve
γ	=	Psychometric constant, kPa °C^{-1}

Then, the evapotranspiration (ET_c) of crop (to distinguish with reference crop evapotranspiration by integrating crop characteristics) at standard condition has been calculated by multiplying the reference crop evapotranspiration (ET_0) with a factor called crop coefficient (k_c). Crop coefficient is the ratio of evapotranspiration at standard condition and reference evapotranspiration. The crop evapotranspiration at standard condition was calculated from the following equation:

$$ET_c = K_c \, ET_o \, .$$

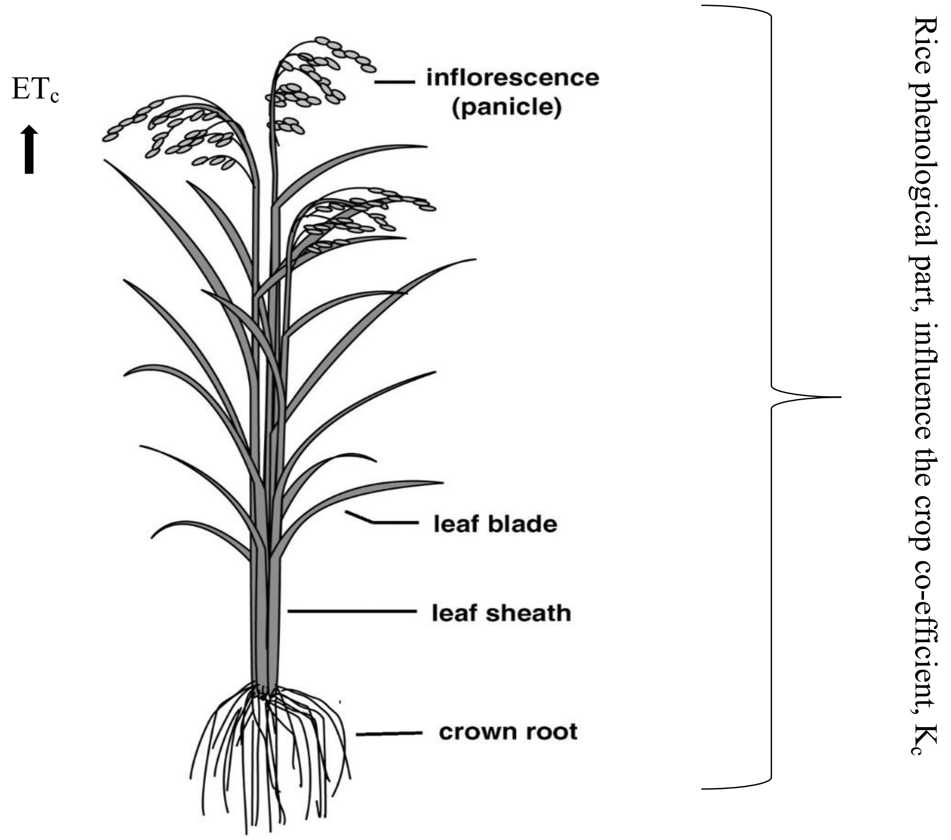


Figure 2 Schematic picture describing rice phenology, Itoh et al (2005)

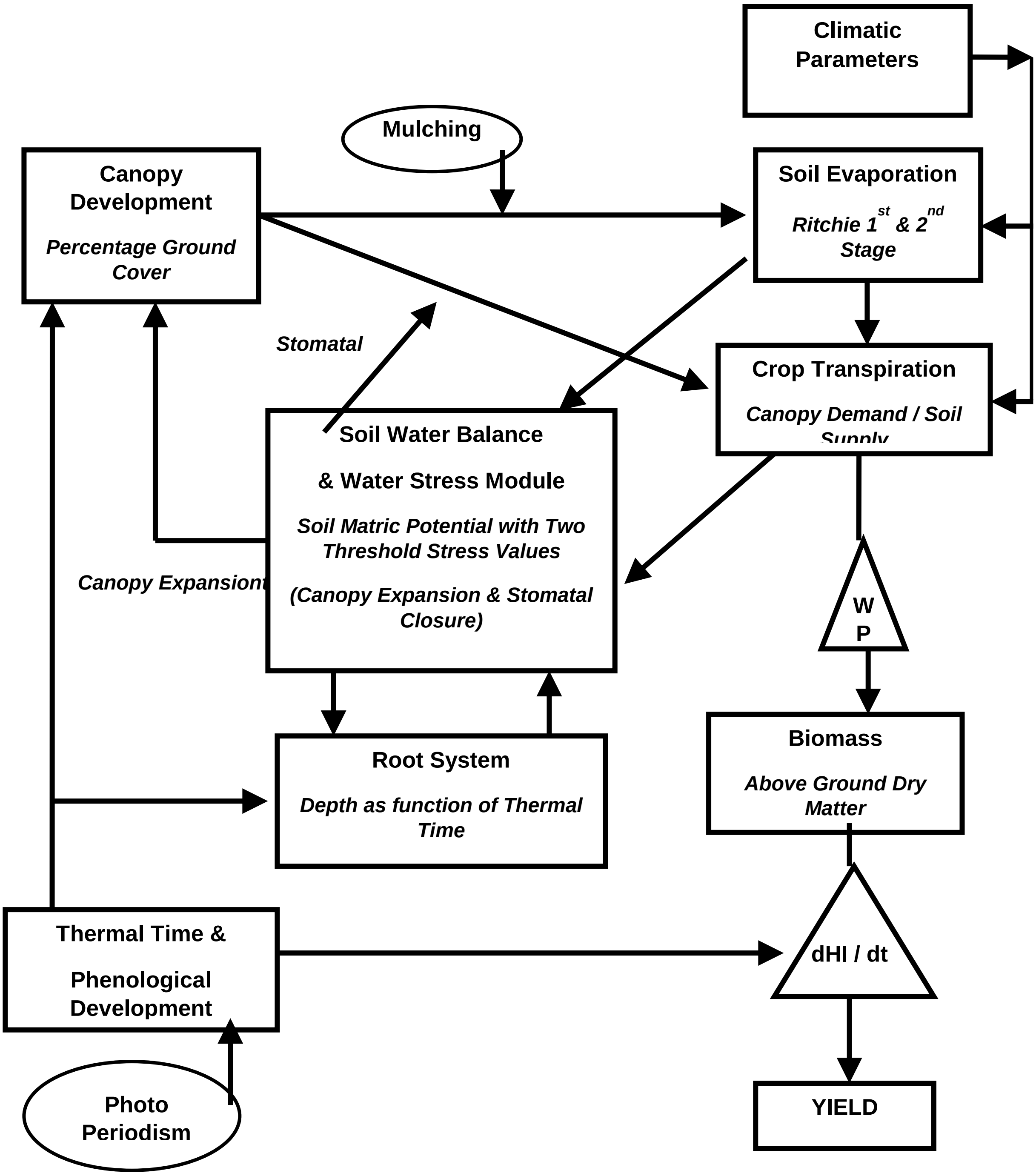


Figure 3 Schematic outline of crop transpiration relation with crop phenology and yield (Source: Presentation, Halsema, 2015)

The relationship among climatic parameters, photosynthesis, biomass accumulation and the evapotranspiration has also been assessed in this research. Figure 3 is representing the relationship. For the change in climatic parameters, the crop evapotranspiration and the photosynthesis also influenced. The higher day temperature influence to increase crop transpiration and make the growing period to be shorter. As a consequence, the crop-water requirement also become reduced. The higher solar radiation influence to increase photosynthesis within a range of temperature up to 30 degree. This increase leads to higher biomass accumulation of the crop. Higher humidity has negative impact on biomass accumulation as this process leads to higher canopy temperature and imbalance physiological process that leads to negative impacts in grain production by causing spikelet sterility.

The future crop water requirement has been forecasted by using bias corrected climate data generated by Global Climate Change Models (GCMs). The Global Climate Change Models is a prominent mathematical model that used in the researches related to climate change. GCMs are used to simulate the future changes in climatic parameters for the increased CO_2 due to climate change (Shackley, 1998). The HadGem2 model, RCP 4.5 has been used in this research.
The main theme was to assess the change in rice phenological responses and in water requirement calculation parameters of Boro rice in the study area. From the changed climatic parameters, the shortening or lengthening of growth stages has also been assessed and the crop water requirement in the changed environment will be assessed by calculating evapotranspiration in the changed condition. The present water requirement for Boro rice was also calculated to look the trend of changed evapotranspiration in respect to changed climatic parameters. The responses of growth stage for climate change was analysed.

2.2 Assessment of crop response for climate change

The assessment of the response of Boro rice for water due to climate change was done by scientific literature review and analysing historical climate data. The changes in climatic parameters and the impact of those changes on crop phenology was assessed. This impact analysis has been used to assess the response of crop for the future climate change as well.

Crop phenology in response to climatic parameters

It has been assumed that there is influence of climatic parameters specially temperature, solar radiation, wind speed and humidity on rice phenology to affect the crop water requirement by changing different growth stages and overall growing period as well. Growth of rice depends on the ambient temperature of the surrounding air, relative humidity and the wind speed that influence the rate of transpiration from the rice crop and control the crop water requirement. The lowland rice verity that grown in dry period and depend on irrigation for fulfilling the crop water requirement was considered to be analysed. The response of different growing stages of rice such as panicle initiation, vegetative growth stage flowering and maturity stages has been analysed critically by using past scientific literature review and drawing conclusion how the climatic parameters influencing to lengthen or shortening the growth stages of rice.

Growing degree days and water stress condition

The growing degree days (GDD) is the measure of the amount of time of thermal days that needed to enter from one growing stage to another stage. This is the limit up to which the rice shows a specific growth stage. The growing degree days depends on mainly the temperature and the heat absorbs. The growing degree days also influence the rice phenology to lengthen or shorten the growing stages. The effect of climate change that might influence the growing degree days was analysed by scientific literature review.

Influence of water stress on rice phenology

Water stress also influences to shorten or lengthen the various growth stages of rice over its growing period and thus influence the total crop water requirement. Water stress leads to an increase in temperature and thus shortening the growing period. Influence of water stress condition at different level such as irrigated condition, mild and severe drought stress condition was also analysed on the basis of scientific literature review that carried out by researchers in this field. This might also be helpful to observe how the growth stages vary over the growing period of rice. Mainly the literature on lowland rice variety was considered to be analysed to observe the changed phenological aspects.

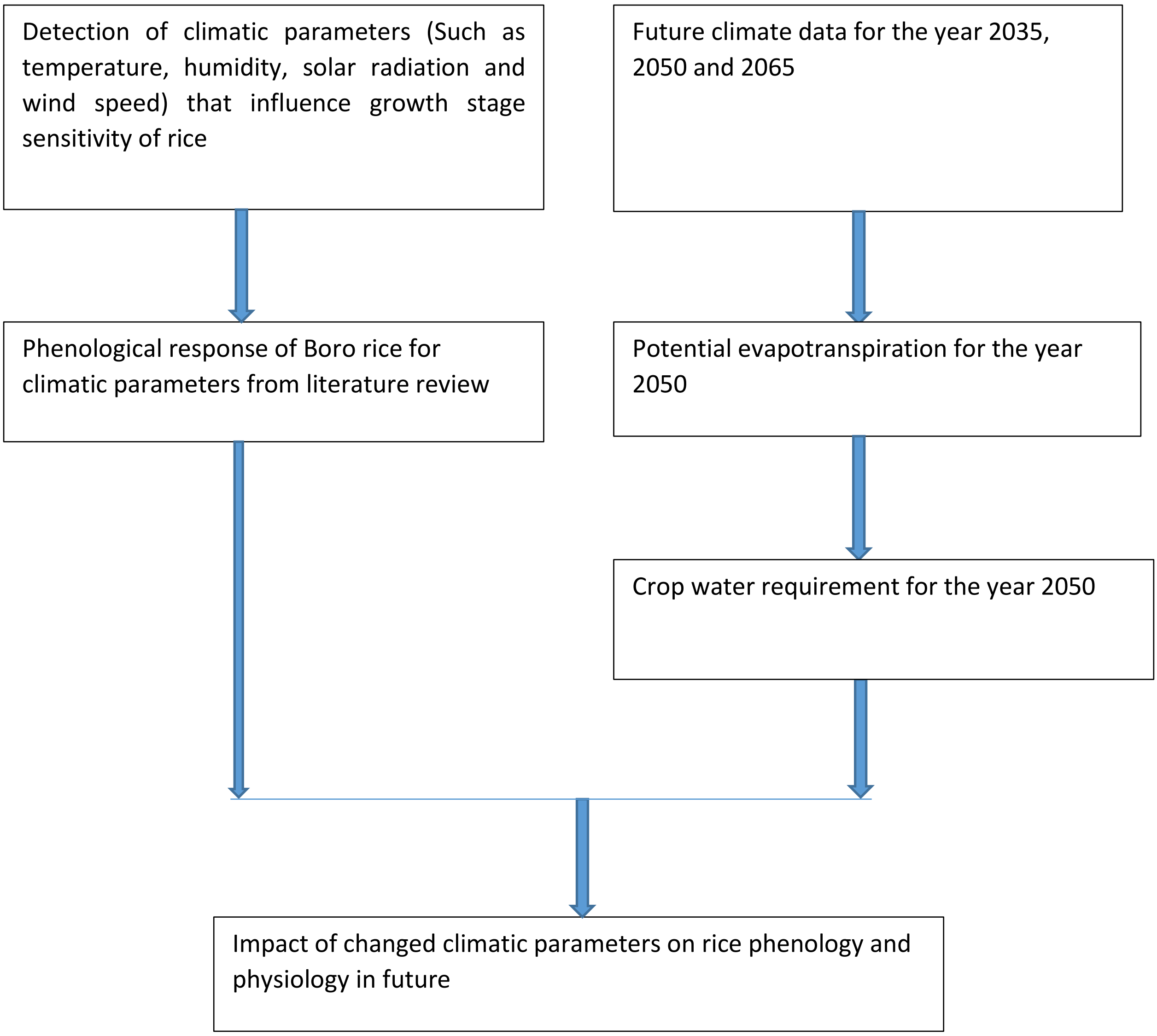


Figure 4 Impact of climate change on phenology and physiology of Boro rice at Rajshahi district, Bangladesh

Crop water requirement

Present and future crop water requirement was calculated by using climate data, soil data and crop data as input in CROPWAT 8 model.

The data to be given as input in CROPWAT 8 Model

Climate data:

Daily maximum and minimum temperature in degree Celsius, average daily relative humidity in percentage, wind speed in km per hour and the sunshine hours per day were considered. The recent climate data was collected from Bangladesh Meteorological Department and the future data was generated from Global Circulation Model (GCM).

Soil data:

Generally total available water, maximum rooting depth (m), maximum rate of infiltration and initial depletion of available soil moisture content data is required. In addition for rice, some other data such as drainable porosity, critical depletion for puddle cracking, water availability at planting and maximum water depth is also required for the calculation. Optimized soil data has been used after collecting from different agricultural research organizations of Bangladesh such as Bangladesh Agricultural Research Institute (BARI) (Annex1).

Crop data:

The rice growing season divided into different stages and the data were collected from past literature. As an example Mahmood (1997) modelled the length of the different growing stage of Boro cultivation for the north-western region of Bangladesh. They are initial (25 days), vegetative (60 days), flowering (40 days) and maturing (20 days) stages. The initial stage was defined from the plantation to 10% of vegetation cover, 10% ground cover to full effective full ground cover, mid stage selected from the effective full cover to maturity stage and the late season defined from the maturity to harvest period. The experimental crop name, plantation date, length of the stage, rooting depth, crop coefficient both dry and wet (K_c), yield response factor (K_y), critical depletion factor and the maximum height of crop were collected to give input in the CROPWAT 8 model to produce crop water requirement. The optimized crop co-efficient data has been used for the calculation. Crop data were collected from various research organization of Bangladesh (Annex 1).

Prediction of future crop water demand

The prediction of future crop water demand was made by using future downscaled climate data generated by GCMs. CROPWAT 8 was used further to find out crop water demand for future. Global climate models (GCMs) is a useful mathematical model to simulate the future climatic parameters such as rainfall, the temperature for a specific region.

Climate change scenarios of crop water requirement

Climate change scenario on crop water requirement has been focused in this research. The perfect GCMs were selected by considering multi-model analysis and correcting errors to simulate climate data for the future prediction. In this research, mainly the HadGem2 model, RCP 4.5 was used to predict the future changes. Though two scenarios RCP[4] (Representative Concentration Pathways), 4.5[5] and RCP 8.5[6] have been used in simulating climatic parameters in the future but only the climate data related to scenario 4.5 was used to calculate evapotranspiration and the crop water requirement (IPCC, 2014). The simulated future climate data for 2035, 2050 and 2065 were used to calculate water requirement for Boro rice. Finally, a conceptualization of crop water requirement scenario was made for the case study area.

The assessment of future crop water requirement was made on the basis of the analysis that done for the phenological response in respect to climate change. The conclusion for the future crop water requirement was drawn from the information that has been presented for the response of Boro rice in regards to various climatic parameters that change over time for global climate change. Specially the phenological and physiological responses of Boro rice that might influence the crop water requirement were considered to contribute the water requirement scenario building process.

[4] RCP (Representative Concentration Pathway) is defined and select on the basis of their radiative forcing amount and represented up to a level of 2100 (cumulative amount of emission of GHG's from all sources and represented by W/m^2)
[5] RCP 4.5-Stabilization without overshoot pathway to 4.5 W/m2 at stabilization after 2100
[6] RCP 8.5-Stabilization without overshoot pathway to 8.5 W/m2 at stabilization after 2100

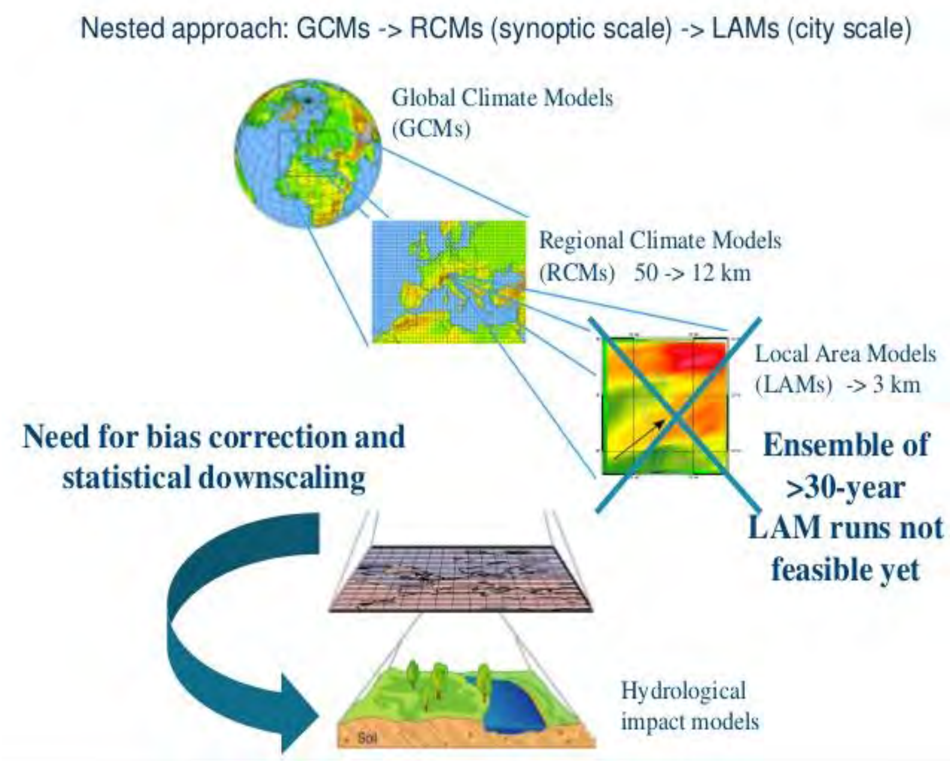


Figure 5 Global Climate Change Model (Source: Presentation of Patrick Willems (KU Leuven) on 'Climate change and impacts on hydrological, 2015)

Chapter 3

Results and Discussion

Climate Change and Responses of Rice (Boro) Phenology and Physiology

Growth stages and the development of rice crop depend on climatic parameters, mainly on temperature, solar radiation, wind speed, and humidity. Important climatic features of Bangladesh during growing period of rice are presented below in the table:

Table 1The important climatic features during growing season of rice in Bangladesh

Seasons	Mean maximum air temperature T_{min} (°C)	Mean Minimum Air temperature, T_{max} (°C)	Solar Radiation, Q ($MJm^{-2}day^{-1}$)	Precipitation (mm)
Aus (Mar-Aug)	34-31	16-26	14-23	1200-3100
Aman(June-Nov)	34-28	26-16	14-19	1250-3000
Boro(Dec-May)	24-34	10-26	14-23	250-550

Source: Partly modified and adapted from Mahmood (1997).

3.1 Responses of rice phenology and physiology for climatic parameter

Temperature

Optimum temperature range is an important factor for the proper growth and development of rice. Considerable numbers of researches has been carried out in past to observe the optimum temperature range for the proper growth and development of growing Boro rice. In Bangladesh, the temperature range for growing Boro rice has been estimated as 15°C and 35°C as base and highest threshold temperatures respectively (BRRI, 1991, Mahmood, 1993 and Hussain, 2008).

Surrounding air temperature has significant influence on rice phenology by influencing the growth of rice at different growth stages (Mahmood, 1997). A numbers of case studies have been conducted and they show that the air temperature has a vital role on the physiology of rice. Germination, the growth of seedlings, vegetative growth and reproductive stages respond to temperature change. The higher temperature reduces and the lower temperature increases the length of different growth stages and thus influences to increase or decrease the length of total growth period of rice (Munakata, 1976; Nishiyama, 1976, Yoshida, 1981, Haque, 1987 and Oldeman et al, 1987). Basak et al (2010) also mentioned for the Boro rice that the physiological maturity shortens with the increase of temperature. Mahmood (1997) also presented in his research that the length of the growth stages of crop depends on variability of surroundings air temperature. He carried out his study on Boro rice in Bangladesh using YIELD model. The model was validated for the agro ecological parameters and the crop characteristics of Bangladesh. He tried to estimate the changes in evapotranspiration and the changes in the length of different growth stages of rice that take place in response to temperature change for global warming.

Temperature also influences the photosynthesis process of rice. Maximum photosynthesis occurs when the temperature range is between 25-30°C. So, the increased maximum and minimum temperature (significantly when the temperature increased about 4°C) might affect rice phenology. Higher photosynthesis rates explains quicker growth of rice plant and thus shorten the growing periods. The high ambient temperature makes the flowering and maturity period quicker, that shorten the growing period and the total crop evapotranspiration as well. Biomass accumulation also accelerate for the higher photosynthesis rate due to high temperature.

For higher temperature the biomass accumulation increases significantly and happens faster than lower temperature. Baker et al (1992) in an experiment showed that the increase of CO_2 in interaction with increased temperature accelerate the biomass accumulation. When the temperature increased the biomass accumulation also become higher.

High night temperatures and elevated CO_2 influence growing period of rice. Cheng et al (2009) mentioned that due to high night temperature the vegetative growth increased and the spikelet fertility decreased due to uneven distribution of dry matter in grains. The high night temperature also slightly increases the respiration at night. The consequence of higher night time respiration leads to increases in biomass consumption, so a reduction of biomass accumulation and yield.

Solar radiation

Solar radiation is also a determining factor for the proper growth and development of rice. Rice is grown under the solar radiation range of 300 to 600 MWh cm^2 day^{-1}

(Swaminathan, 2000). Equal amount of solar radiation is required for both reproductive and ripening stages of rice. In tropical countries, for high solar radiation the temperature also become higher and that influence to increase the respiration rate. Higher respiration rate is responsible to make grain filling period shorter.

The incident solar radiation influences the rice evapotranspiration. Evapotranspiration is proportional to the daily solar radiation and the numbers of days the rice withstand in the field (Yoshida, 1978). Increased solar radiation reduces physical maturity and different growth stages of rice thus influence the evapotranspiration process by making growing period shorter (Karim et al, 2012).

Due to cloud cover the solar radiation incident reduces considerably and slowed down the photosynthesis and biomass accumulation. This consequence leads to lower temperature as a result lengthening the growing periods. There is an evident that the cloud cover causes the grain filling period to be long. Beside this, reduced incident of radiation also has impact to make the ripening period to be longer (Mahmood, 1998). During wet season , the cloud cover increases and the incident solar radiation become low. This low solar radiation impacts on rice growth stages. This influence depends on the variety of rice and the duration of maturity period. Especially, for rain fed rice, low solar radiation is responsible for low photosynthesis during growing period (IRRI, 1987). But the reduced solar radiation with higher temperature might have different effects on rice physiology. Karim et al (2012) mentioned that this phenomena might encourage the continuous shortening of individual growth stages of rice. In general, cloud cover reduced the ambient temperature of the rice and that lengthen different growing stages and ultimately affect the total crop water requirement to be higher.

This reduced solar radiation also causes reduced numbers of grains per panicles, high spikelet sterility and reduced numbers of panicles for short, medium and long duration varieties of rice. The low light at flowering stage, causes spikelet sterility high and leads the harvesting index to be low. Low incident light make the dry matter production less (Janardhan et al, 1980). The rice grown in dry period gets sufficient solar radiation during growing period. Thirty days before harvesting, it is urgent to have 200 h bright solar radiation to get the optimum yield. Photosynthesis and the photorespiration also influenced by the change in solar radiation. For reduced incident solar radiation, the photosynthesis and photorespiration also reduced significantly(Nayak et al, 1979).

Humidity

For the increased relative humidity, the crop evapotranspiration reduces considerably. This reduced evapotranspiration is responsible to increase the canopy temperature slightly and affects the panicle initiation. This effect thus leads to spikelet sterility. This sterility ultimately affects the grain production of rice. Increased relative humidity with increased temperature has negative effects on sterility of spikes (Weerakoon et al, 2008). The increased relative humidity reduces the temperature and the biomass accumulation and thus make the growing periods to be longer.

The evapotranspiration rate depends on humidity of the surrounding air. The lower the relative humidity in the air is the favourable condition for the further evapotranspiration from the rice plant. The low humidity in the air increases its capacity to accept more evaporative water from the plant by continuing physiological processes perfectly (Yoshida, 1981). Humidity also has influence on the rate of transpiration of rice plant. Kuwagata et al, (2012) mentioned that the transpiration rate increases for low humidity than high humidity. Relative humidity also plays a vital role in spikelet sterility.

The uppermost leaves of the plant become expanded in low humidity and get more water stress as the gas exchange capacity in stomata reduces considerable amount for having lower humidity (Kuwagata et al, 2012) but the rice panicle specially the spikelet achieves more temperature in humid condition (Julia and Dingkuhn, 2012).

Wind speed

The crop evpotranspiration mainly influenced by wind speed. Though, another literature revealed that the rice reference evapotranspiration does not change considerable amount for increasing wind speed in humid and tropical climate (Batchelor and Robert, 1983). The crop evapotranspiration greatly influenced by wind speed. The wind blown away the driest mass from one place to another and by means of which carry the evaporated water Rahman (2002)

Figure 6 is depicting that the ratio of evapotranspiration and pan evaporation is high at flowering stage. Increased transpiration and reduced evaporation can increase the ratio and thus the length of the individual growth stage can be fluctuated due increased transpiration rate and can be co-relate with the response of growth stage of rice in respect to wind speed.

From the experiment of Rahman (2002), it can be observed for the case study area, the wind speed increases up to May and then it starts to decline. So for the Boro cultivation at the driest period might be influenced by this phenomena as the crop evapotranspiration influenced by the wind speed. In the rest of the period, this reduced wind speed might influence the humidity to be high and thus the proper physiological growth as well.

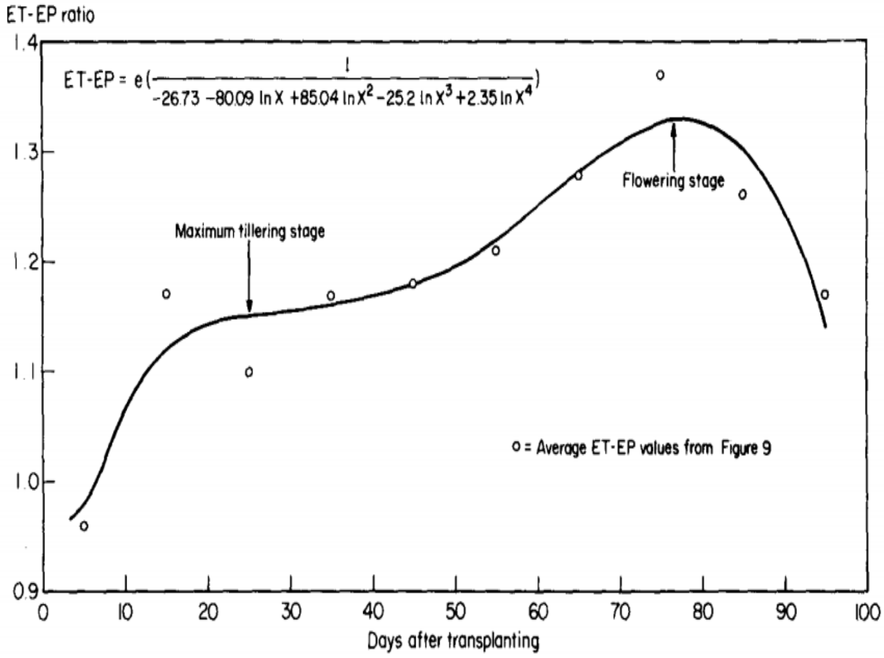


Figure 6 General trend of growth stages versus ratio of ET (Evapotranspiration) and PE (Pan Evaporation) for wetland rice in Asian countries (Source: Tomar & O'Toole, 1980)

Except in humid and tropical climate the crop evapotranspiration increases with the increased wind speed as the wind take the evaporated water droplets away from the field and encourages the air mass surroundings of the rice field capable to accept more water.

Growing Degree Days (GDD)

Development of plant from one stage to another depends on the amount of heat receiving by the plant in its whole life cycle. This amount of heat varies in each of the stages from seeding to maturity. So, temperature is a vital parameter to influence the duration of growth stage of plant. And an essential term Growing Degree Days (GDD) arise to co-operate in understanding the influence of temperature for the development of the stages of plant and the way the growth stages become long or short (Miller et al, 2001). GDD is a means to give an estimation of the seasonal growth by adding the heat that the plant is accumulating in each day. The GDD can be finding out by the equation given bellow.

$$GDD = \frac{T_{max} + T_{min}}{2} - T_b$$

Where,

GDD= Growing degree days

T_{max}= Daily maximum temperature (°C)

T_{min}= Daily minimum temperature (°C)

T_b= Base temperature for the specific plant (the critical limit below this the plant growth ceased, for rice this value is 10°C)

The growing degree day method is a temperature based method. `This method helps to build a rice growth and development model that can represents the changes that might happen in the growth stages in response to temperature change or the heat accumulated. The crop phenology is an important term that is included in this model to look for the increased temperature on rice growth stages. The growth stage model shows two threshold values of accumulating certain amount of heat to shift from one growth stage to another growth stage. The highest one is the limit at which, the growth and development of the crop might seem to be ceased (Miller et al, 2001). In this model, it has been assumed that the growth and development of any crop is the function of the thermal accumulation time from planting stage to harvesting stage. The growth stage for a specific crop shifted from one stage to another if the thermal accumulation time reach the minimum amount that required to enter the next consecutive stage (Shahid, 2011). The growth stage period of Boro rice was modelled by Mahmood (1997) for the case study area based on the growing degree days. The estimated growth stage duration are mentioned in the next section.

Growth stages of Boro Rice

The length of different growth stages of Boro rice in Bangladesh varies at different region depending on the specific climatic condition of that region and the cultivars that use to grow at that specific area. The length of different growth stages of Boro rice has been estimated by Mahmood (1997) for different parts of Bangladesh including the north-western part that is the case study area of Bangladesh considering the types of cultivars and the climatic parameters. He determined the length of different growth stages of Boro rice for north-western part of Bangladesh as initial stage, 25 days; vegetative stage, 60 days; flowering stage, 40 days and the maturity stage, 20 days. Irrigation water is required for the first three stages (About 125 days) that are for initial, vegetative and for the flowering stages mainly.

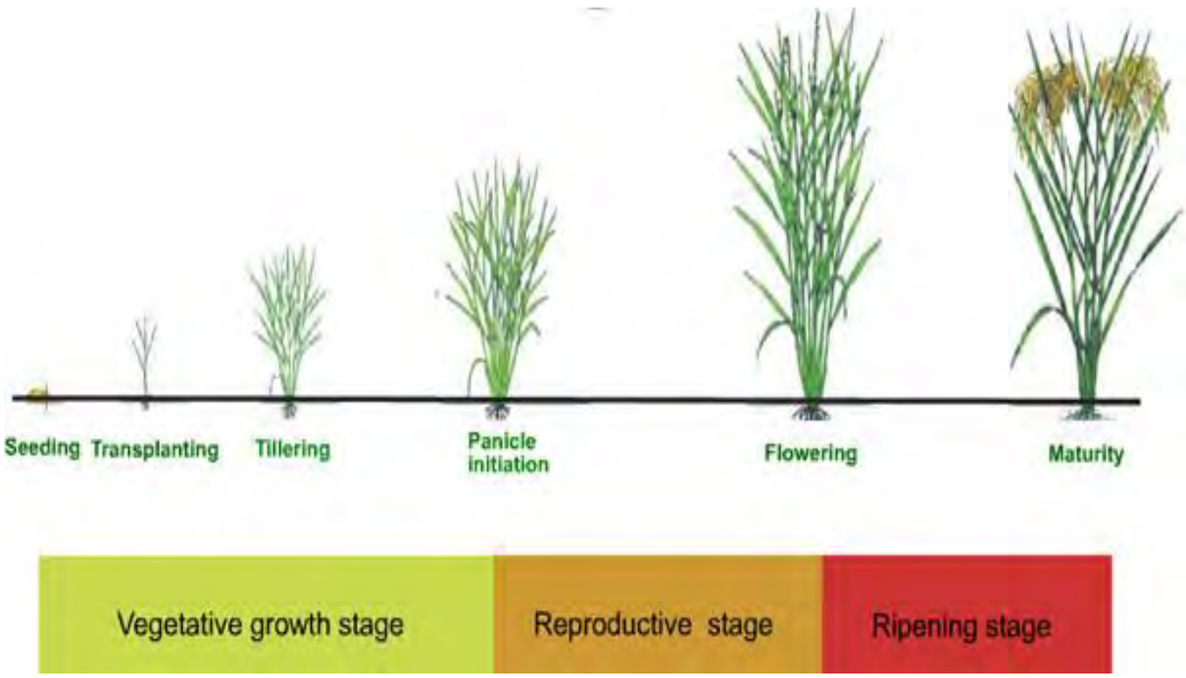


Figure 7 Growth stages of rice (Source: IRRI (International Rice Research Institute) knowledge bank)

Water stress condition

Proper growth and development of rice also depends on the water management aspects. Water stress is the term that affects rice plant from proper development and normal growth for the lack of water to the plant. Rice is sensitive to water stress during growth stage that ultimately affects the grain production. Water stress mainly affects rice production at its developmental stage from flowering to grain filling period (Pandey et al, 2014).

There is also a possibility of water stress condition to influence the rice phenology by influencing different growth stages. The growth rate of rice varied with the soil water availability and some sorts on incident solar radiation as well. But this variation become prominent when the environmental stress suppose the water stress or the drought problem become severe (Boonjung and Fukai, 1996).

For the water stress condition, the crop evapotranspiration reduces and the increase the canopy temperature. As a result the proper growth and the biomass accumulation hampered that negatively affects the grain production. Beside this, the vegetative stage become longer that leads to delayed maturity period.

3.2 Climate change scenarios

Temperature

For global warming, the climate is changing for increased greenhouse gas emission by human activities. The climatic parameter such as temperature is becoming variable in climate change vulnerable countries like Bangladesh. Agricultural sector is becoming more vulnerable for climate change. For last three decades, the temperature at monsoon in Bangladesh is increasing and it has been predicted that the average daily temperature will be increased by 1 and 1.4 degree Celsius by 2030 and 2050.This increased temperature has effects on crop production by affecting different stages of growing period of rice. In an example, maximum temperature has negative effect on the production of Boro rice though this temperature has positive impact on other varieties of rice in Bangladesh such as Aus and Aman rice (FAO, 2006; IPCC, 2007; GOB and UNDP, 2009). So, for the temperature change, there might be some changes happen in next upcoming years in growth stages of rice as well as in the yield of rice. This sensitivity of Boro rice in response to temperature change is explained in this section.

Basak et al (2010) conducted research on Boro in north-western district, Rajshahi, Bangladesh. They used DSSAT model to observe the changes in growth stages of rice and reported that the projected maturity period will be shorten for the increased temperature. They presented in their research that the projected maturity period will be reduced significantly from 88 to 83 day by 2100 for BR3 variety of Boro rice.

Shahid (2010) carried out an experiment in the north-western part of Bangladesh considering 82 sub-districts. He used the model MAGICC, SCENGEN and some GCM models to get the climate change scenario at the study area. The baseline was drawn in the research by considering the climate data of 1961 to 1990 from seven different stations of the North-Western part of Bangladesh. He presented in his research findings that the temperature will be increased in next century. The projected changes in temperature have been showed in the table given below (Table 2).

Table 2The projected daily average temperature during growing period of rice in 2025, 2050, 2075 and 2100 years

Daily average projected temperature (◦C)	January	February	March	April	May
2025	16.9	20.2	24.7	28.2	29.8
2050	17.7	21.2	25.5	29.0	30.3
2075	18.5	22.1	26.3	29.7	30.9
2100	19.2	23.0	27.0	30.4	31.4

Source: Partly modified from Shahid (2011)

The table 2 is depicting that the daily average projected temperature will increase in considerable amount during the growing period of Boro rice by next centuries. The model provided a projection that the temperature will increase by 0.8, 1.4, 1.9 and 2.4°C in 2025, 2050, 2075 and 2100 respectively.

The projected temperature is increasing in upcoming next centuries. This increasing temperature has influence to change the duration of different growth stages of Boro rice and ultimately affect the total growing period. The climate data from HadGem2 earth system model and 4.5 climate scenario based on 1960 to 1999 is also showing the same kind of increasing trend of temperature in the coming next few decades (Table 3).

Table 3Projected average monthly temperature for next few decades in the case study area, Rajshahi, Bangladesh (HadGem2 model, RCP 4.5)

Projected years	Jan	Feb	Mar	Apr	May	June	July	Aug	Sep	Oct	Nov	Dec
2013	16.3	20.7	26.1	29.5	29.3	30.9	30.5	29.9	30.4	27.4	22.9	19.1
2035	21.1	24.3	27.8	31.0	30.5	29.7	29.4	29.6	29.4	30.0	27.9	23.8
2050	20.45	23.99	27.27	33.37	32.72	32.61	30.26	30.39	30.29	29.95	27.75	22.30
2065	21.25	24.29	29.25	32.53	31.61	31.32	30.80	30.13	30.87	29.89	27.27	24.41

The temperature change has significant influence in changing growth stages of Boro rice. The projected changes in growth stages are explained by Shahid (2010) that provided below in the table (Table 4). The table showing that the days required for the growth stages are reducing and thus the total growing period and the Irrigation required days are also reducing in response to the increased temperature.

Table 4Estimated changed in days of growth stage during the growing period of rice for next centuries

Growing Years	Initial stage (Days)	Vegetative stage (Days)	Flowering stage (Days)	Maturing stage (Days)	Growing period (Days)	Irrigation required (Days)
Base period average	25	60	40	20	145	125
2025	24	58	39	19	140	121
2050	23	56	38	19	136	117
2075	22	55	37	19	133	114
2100	21	54	37	18	130	112

Source: Shahid (2011)

Mahmood (1997) also used YIELD model to analyse how the growth stage responses for changing air temperature and mentioned that for the temperature lower than the normal temperature leads the transplanting dates to start a bit later such as 2-7 weeks. In his experiment, for -5°C scenario might leads to quicker accumulation of thermal heat as the rice growing season forwarding towards summer and makes the initial growing stage quicker. Vegetative, flowering and maturity stage showed decreasing trend for the high air temperature but there was no clear evidence found about the initial growth stage. For high air temperature, the growing season will be short and the model predicted that the maturity stage will move backwards about six weeks that might be favourable and will provide stable thermal condition for Boro rice in Bangladesh. Figure 5 is representing the amount of projected growth stage change happen by next 2100 centuries.

The average total seasonal evapotranspiration increases for the decreased air temperature as the growing period become longer. Mahmood (1997) mentioned in his research that the average total seasonal evapotranspiration increases (37 mm or 5% per 1°C decreased temperature) for the decreased temperature. The model also predicted that on an average seasonal total evapotranspiration will decrease in response to increased temperature and having short growing period. This reduced evapotranspiration is around 32 mm or 4% for 1°C temperature rise. Beside decreasing evapotranspiration this increased air temperature gives a stable thermal condition during maturity stage of Boro rice.

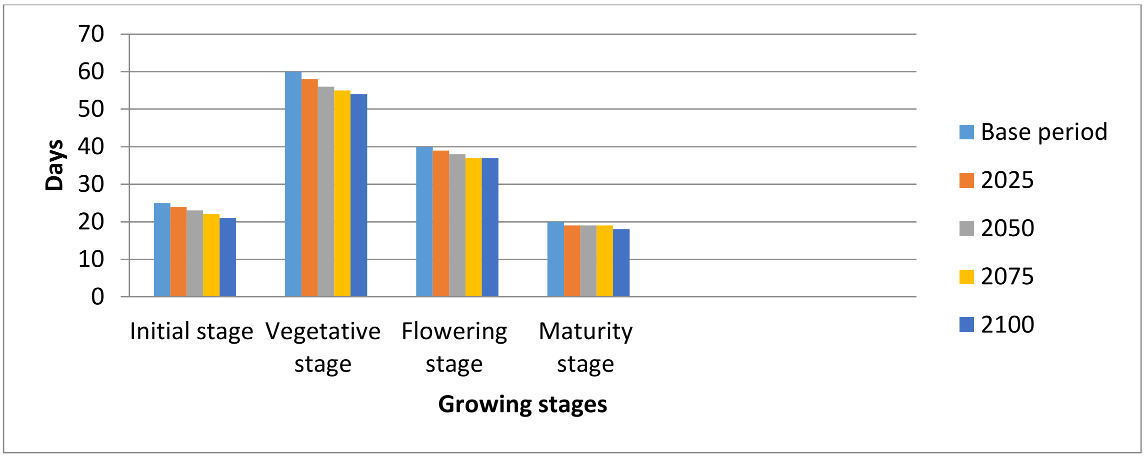


Figure 8 Changed in days of growth stage during the growing period of rice for next centuries (Shahid, 2011)

The projected result is also showing that for the increase of temperature the number of days of total growing period shortens. Beside this the irrigation required days are also becoming less for the projected temperature change (Figure 9).

Due to increased temperature the daily evapotranspiration increased but the total seasonal evapotranspiration decreased as the total growing period shorten for the increasing air temperature. Shahid (2010) also showed that the soil moisture deficiency will increase and the daily evapotranspiration will also increase by 31.3 mm in 2100 for dry season Boro rice but the study presents there will no significant changes happen on total water requirement for the short growing period and for the possibility of increasing effective rainfall (48.5 mm) in the north-western part of Bangladesh.

The increased temperature increases the respiration rate and affect spikelet sterility and thus reduce the yield of rice by 6-16% for 2-4°C though the increased CO_2 due to increased temperature helped to increase the rice yield slightly. This increase of CO_2 is not sufficient to balance the reduction of yield (Basak, 2013).

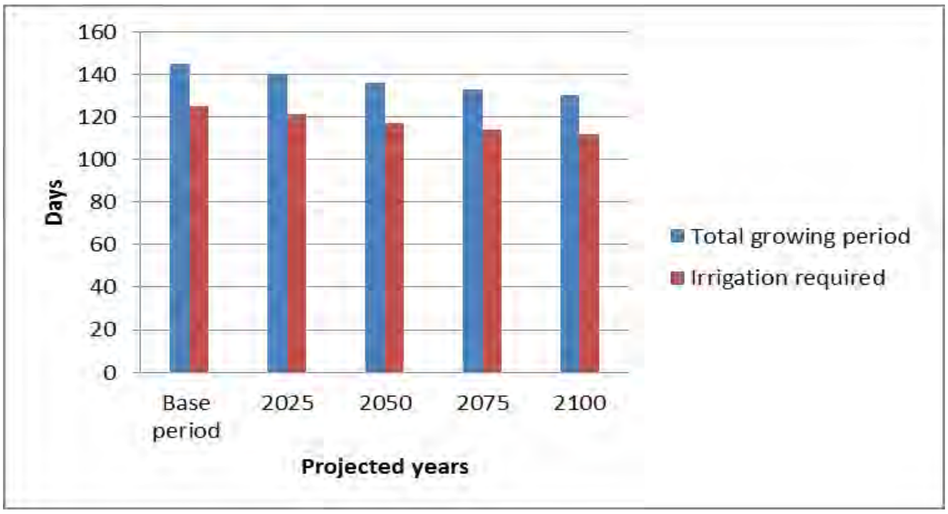


Figure 9Change in future total growing days and irrigation required days in projected future years (Shahid, 2011)

Biomass accumulation also alter by the change in temperature and with the change in concentration of CO_2 . Baker et al (1992) showed that the biomass accumulation increased by 8% and 52% for temperature change from 28/21/25°C to 40/33/37°C respectively. In that research the concentration of CO_2 maintained as 330 μmol mol^{-1} and 600 μmol mol^{-1}. High temperature has some adverse effect on rice with different concentration of CO_2 and even rice plant died for the low CO_2. But the intermediate temperature 34/27/31°C showed the increased biomass accumulation than that of the lowest temperature without any hazards. Increased temperature also has influence to increase the tillering rate. Another experiment also showed almost same phenomena about higher biomass accumulation for the high temperature in combination with enriched CO_2 concentration Idso et al (1987).

The increased temperature has great impact at early growth stages of rice. Yoshida (1987) carried out an experiment in controlled environment by keeping the temperature range from 18°C to 35°C to match with the growing season temperature of Los Banos, Philippines to observe how temperature change influences at different growth stages of rice and he found that the early growth stage become faster when the temperature increased to 31 from 22°C. He also found that the growth rate increased as well as increasing the number of panicle. At high temperature the tillers also become more healthy and vigorous. Saseendran (2000) conducted another experiment to see the climate change impacts on rice production in Kerala, a tropical humid place of India and found that the maturity period reduced by 8% for high temperature.

At the end this can be concluded that, the projected temperature will increased due to global warming in next 2025, 2050, 2075 and 2100. This projected increased temperature will shorten the growing period of rice that will increase the evapotranspiration but the total seasonal evapotranspiration will be decreased. The increased evapotranspiration will influence to enhance the growth rate of rice and thus will impact to increase the accumulation of biomass as well by increasing photosynthesis. The maturity period will decreased considerable amount such as in example 8% in India for temperature rise. Beside this the increased night temperature slightly increase the transpiration rate. Increased temperature with increased CO_2 speed up the respiration and influence the biomass accumulation to be faster.

Solar radiation

The Table 5 and Figure 10 representing the change in sun hours by 2050 in respect to base period sun hours. The sun hours in the dry period are increasing considerably and the sun hours reducing during wet seasons. This reduction might be happen due to increasing cloud cover. The increased sun hours may leads to short individual growth stages in dry periods and comparatively longer growth stages during wet seasons. For the case study area, this research is done for the dry period Boro rice. So, there is possibility to shorten the individual growth stages for the increased sun hours in upcoming future.

Table 5Projected average monthly sun hours for future in the case study area, Rajshahi, Bangladesh (HadGem2 model, RCP 4.5)

Projected Years	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
2013	5.31	7.88	8.32	7.61	4.33	5.94	5.67	4.17	6.24	5.19	8.02	4.72
2050	6.98	8.64	9.34	10.03	6.06	5.05	7.57	3.06	4.86	6.94	6.59	8.24

Basak et al (2010) presented in their research that the projected solar radiation will be increased from 15.37 to 16.71 MJ/m2 /day by 2008 and 2070 respectively that has influence to increase the yield of Boro rice by 11%. In the case study area, the projected solar radiation has possibility to influence rice phenology from plantation to stage of maturity (Zhao et al, 2016). Tao et al (2013) also showed the same phenomenon that the maturity stage may change by reduced solar radiation for climate change though Zhaoa et al (2016) have not find any significant effect of solar radiation on rice maturity stage. So, it is important to investigate how the solar radiation associated with changing different growth stages during rice growing period. In this section, the phenological responses of rice for solar radiation have been explained.

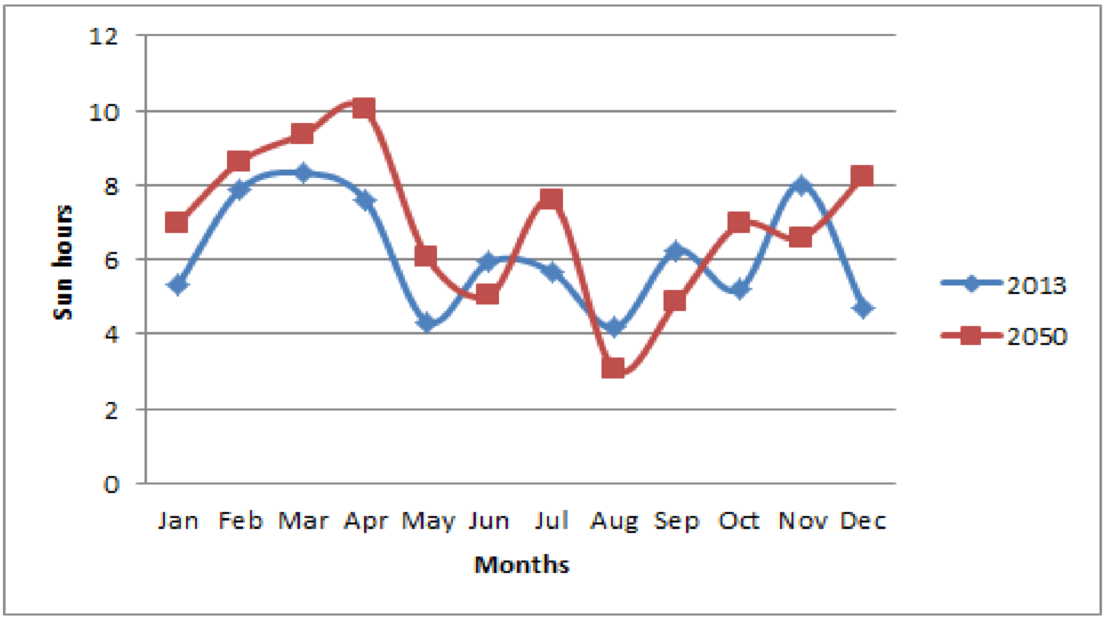


Figure 10The trend of average monthly sun hours in coming next decades in Rajshahi, Bangladesh (HadGem2 model, RCP 4.5)

Basak et al (2010) also showed that the solar radiation does not have significant effects on increasing yield but it has influence on shortening the physiological maturity period of Boro rice. Higher solar radiation in accompanied with high temperature makes the reduced physiological maturity that influences the evapotranspiration to be higher. Karim et al (2012) also mentioned the same phenomena that evapotranspiration increases for the higher solar radiation with high temperature. Though the projected evapotranspiration was high but for the shortened physiological maturity, the total water requirement will be lower as the author explained in their article focusing specially the year 2070. Beside this, solar radiation with CO_2 will help to sooth the adverse effect of temperature on yield though that is not enough to neutralize the temperature effects completely.

Solar radiation increases in the dry season during maturity (ripening) have a double advantage, as it accelerates the maturity or ripening stage (leaf senescence); thus less ET, and less biomass loss due to respiration, and thus higher yields. Beside this the sun hours is reducing during wet season due to increasing cloud covers. For the low light during flowering period may causes severe spikelet sterility about 30-50% (Murty and Murty, 1982). And the dry matter production also reduced for this low incident of solar radiation. In low light incident at wet season has influence to reduce the dry matter production to be low. Janardhan et al (1980) presented in their research that the dry matter production reduces by 20-30%.

Summarising, it has been predicted that the projected solar radiation will be increased during dry period but will be reduced during wet period. The solar radiation mainly impacts on flowering to grain production and development. This increased solar radiation will shorten the maturity period and beside this in combined with high temperature it influences the evapotranspiration to be high. The total water requirement will be lower for the increased solar radiation as for the similar reason of temperature rise. During grain filling time there have possibility of cloud cover that reduces the incident solar radiation and make grain filling and ripening period to be longer though this event has impact on shortening other growing period. In wet period there is possibility to reduce the in the incident solar radiation that might impact to reduce the photorespiration and the photosynthesis that can reduce the dry matter production.

Humidity

From the past literature, it has been seen that the relative humidity is increasing for the case study area. Mamun et al (2015) carried out a study at Rajshahi by analysing past historical data from 1972 to 2010 and they found that the relative humidity increases at the rate of 0.194% each year at the study area. The rate of increasing relative humidity at the Boro rice growing season is comparatively higher as they shown in their study as 0.287% each year (Figure 12).

The projected humidity percentages at the case study is showing almost no changes happen. The trend of humidity is showing in the driest period that the humidity is increasing slightly by 2035 and 2050. And for the rest of the period there is almost no changes happen for the case study area (Table 6 and Figure 11).

Table 6Projected average monthly humidity percentages for future in the case study area, Rajshahi, Bangladesh (HadGem2 model, RCP 4.5)

Projected year	Jan	Feb	Mar	April	May	June	July	Aug	Sep	Oct	Nov	Dec
2013	81.19	70.5	62.84	67.07	77.45	81.37	84.81	86.54	86.63	83.26	79.5	81.1
2035	74	72	73	75	80	85	86	87	85	85	81	74
2050	72	73	73	73	78	80	84	87	86	82	78	72

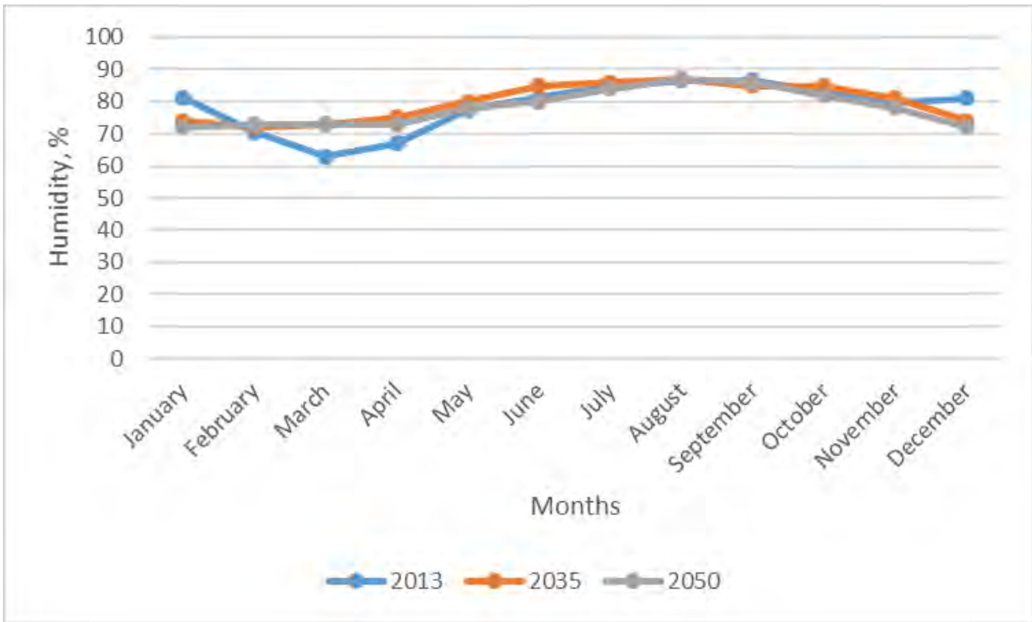


Figure 11The trend of average monthly humidity percentages in coming next decades in Rajshahi, Bangladesh (HadGem2 model, RCP 4.5)

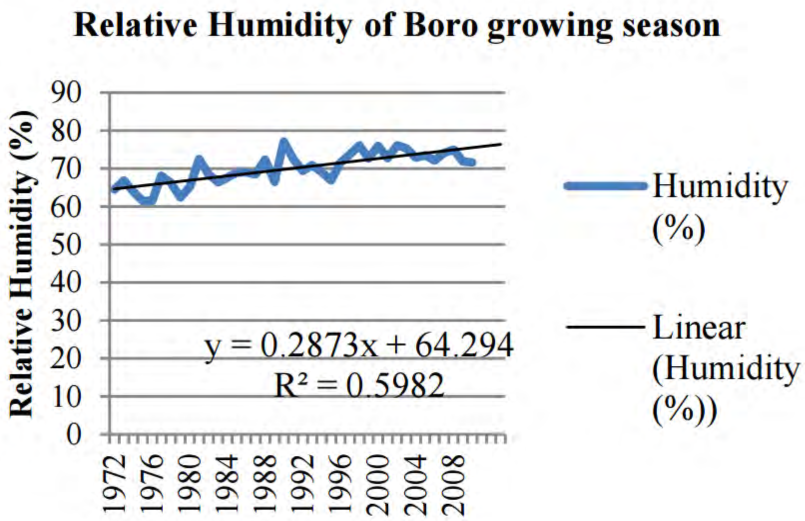


Figure 12 The trend of relative humidity for Boro rice growing season in Rajshahi (Source: Mamun et al, 2015)

Kuwagata et al, (2012) carried out an experiment and presented that the transpiration rate increases 1.5 to 2 folds greater for low humidity than higher one. The experiment also revealed that the daily transpiration rate of rice plant is slowly increasing during plant growing period though the total transpiration decreased per unit leaf area.

Weerakoon et al (2008) carried out an experiment on Japonica and Indica rice varieties under 85% and 60% relative humidity at different night and day temperatures and reported that the spikelet sterility increases when the relative humidity increases with increased temperature though the effect of relative humidity is more on reducing or increasing spikelet sterility.

Beside this, at the case study area the projected temperature is increasing and there is also possibility to increase the relative humidity as well. The increased relative humidity has positive impact to reduce the excess evaporative demand that happen for the increased temperature. Though this phenomena might affect proper physiological growth of rice as the higher humidity reduces the transpiration rate.

The response of rice in respect to the relative humidity at the case study area can be concluded as, the relative humidity is increasing slightly for the climate change. To balance the excess evapotranspiration for the increased temperature, increased humidity has positive impacts on reducing evapotranspiration but proper growth might be hampered and the spikelet sterility might be severe as the transpiration rate become lower for the higher humidity condition.

Wind speed

The table 7 and the figure 13 is showing the trend of wind speed by the year 2050. It has been predicted that the wind speed will increase considerably throughout the year by 2050 in Rajshahi district, Bangladesh.

Table 7Projected average monthly wind speed (km/day) for future in the case study area, Rajshahi, Bangladesh (HadGem2 model, RCP 4.5)

Projected year	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
2013	77.57	98.26	95.78	100.30	123.45	90.97	114.27	103.09	72.15	107.11	103.42	82.16
2050	80.094	117.74	129.73	155.25	253.51	206.51	215.97	156.68	175.22	140.74	106.89	91.97

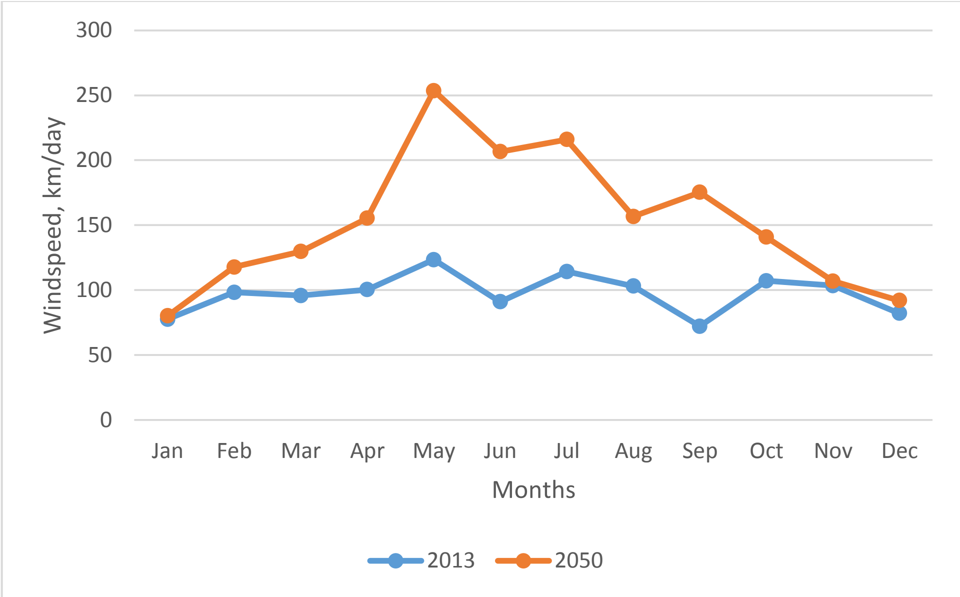


Figure 13 The trend of average monthly wind speed (km/day) in coming next decades in Rajshahi, Bangladesh (HadGem2 model, RCP 4.5)

Rahman (2002) carried out an experiment on agro climatic parameters in Bangladesh by taking the historical climate data from 1961 to 1996 from 31 different stations and shown for the study area Rajshahi that the wind speed increased slowly from January to May and declined afterwards rest of the months. Rice evapotranspiration has sensitive response for the changing wind speed. So, there is possibility that the reference evapotranspiration might increase in the case study area for the increased wind speed. Shah and Edling (2000) showed that the rice evapotranspiration increases considerable amount to 63.5% when the change in wind speed happen 84.5% but the condition is that all other weather parameters should be almost same. Lage et al (2003) also showed the same increasing trend of higher rice evapotranspiration with the increasing wind speed. They showed that when the wind speed increased by 30%, the rice evapotranspiration increased by 20%.

3.3 Growing Degree Days (GDD)

The projected growing degree days are calculated from the temperature data and the base temperature of rice (10) using HadGem2 model with climate scenario 4.5 and has been presented for the case study area Rajshahi district, Bangladesh for the years 2035, 2050 and 2065 in table 8 and figure 14.

The projected growing degree days increases in future that indicates that the growing periods will attain earlier and the growth stages will be short. The projected future temperature is rising in next few decades and the growing degree days are becoming higher. The growing degree days for the years 2035, 2050 and 2065 are showing almost same trends over time. The growing degree days changing considerably from January to March and from September to December that is during dry periods. It resembles that the growth stages will attain quicker during dry period in future (Table 8 and Figure 14).

Table 8The projected average monthly growing degree days for the next few decades in Rajshahi, Bangladesh (HadGem2 model, RCP 4.5)

Projected year	Jan	Feb	Mar	Apr	May	June	July	Aug	Sep	Oct	Nov	Dec
2013	6.32	10.74	16.07	19.51	19.31	20.85	20.50	19.87	20.35	17.40	12.87	9.12
2035	11.08	14.34	17.82	21.00	20.54	19.67	19.38	19.62	19.39	20.02	17.94	13.82
2050	10.45	14.00	17.27	23.37	22.72	22.61	20.26	20.39	20.29	19.95	17.75	12.30
2065	11.25	14.29	19.25	22.53	21.61	21.32	20.80	20.13	20.87	19.89	17.27	14.41

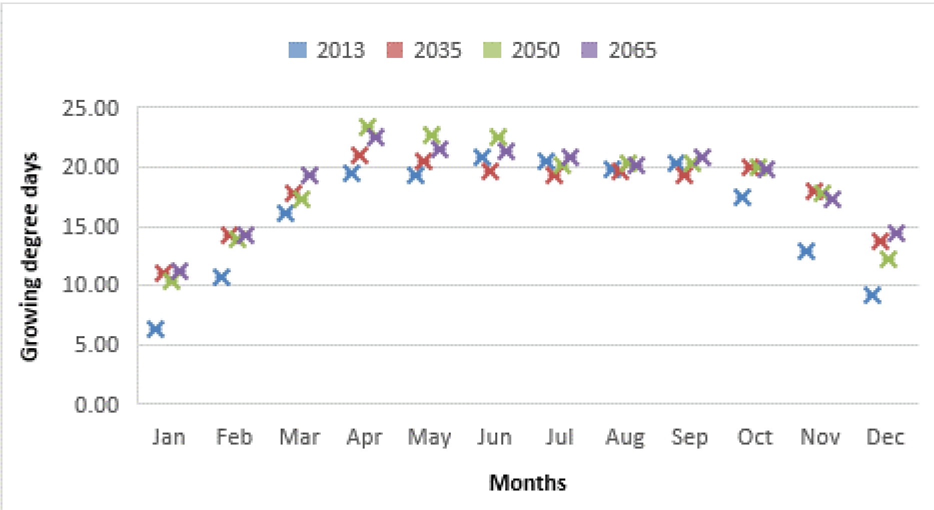


Figure 14 Projected average monthly growing degree days in Rajshahi, Bangladesh

3.4 Impact of water stress condition on growth stages of rice

Water stress condition has influence on growth stage periods of rice. In this section, the influence of water stress to change growth stage period will be described briefly.

Boonjung and Fukai (1996) carried out an study to observe the effect of drought stress at different stages of growing period of two different varieties of rice sown at three week intervals. There were three experiment among them first two were related to the drought stress condition on rice phenology and growth stages. They applied three treatments namely irrigated, mild stressed and severe stress and gave trials of different duration of water stress condition at different growth stages rice growing period and they observed the days after that a specific phenological stage achieved. Mainly they observed the period when the vegetative, panicle initiation and maturity stages of rice achieved.

According to their experiment (Annex 2), the growth stages and the other phenological development of rice showed no significant changes during sowing time over the 40 days period for irrigation treatment. The same kind of result also found from the experiment of Lilley and Fukai (1994). The panicle initiation was found to be delayed for the severe water stress condition but for the less stress condition, the effect was reported as lower. The vegetative stage become lengthy and the maturity stage delayed for the severe stress condition (Novero et al. 1985; Lilley and Fukai 1994). Boonjung and Fukai (1996) carried out their experiment in three sowings of rice in three week interval and they reported that the longest delay for the flowering or anthesis period. This delay was for the drought stress during panicle initiation period to the period of anthesis. The number of days delayed by 18 days for 23 day drought during first sowing, 22, 28 days for 34 days drought during second and third sowing respectively. Turner et al. (1986), Inthapan and Fukai (1988) and Lilley and Fukai (1994) also reported the same kind of delaying in flowering for the drought stress condition.

So, there was no significant change on sowing period for drought stress but the panicle initiation and the maturity stage delayed for the severe drought stress. Beside this the vegetative stage also becomes longer for the severe water stress condition. The flowering stage also has been affected and the flowering stage also becomes lengthy.

3.5 Prediction of future crop water requirement of Boro rice

The climate data that is temperature, humidity, solar radiation, winds peed and precipitation has been analysed to explain the crop water requirement parameters in this section. The future climate data has been generated by global circulation model and analysed by CROPWAT 8 model by giving those climate data as input. One set data from HadGem2 model, RCP 4.5 that has been generated by using global circulation model and the climate data of 2013 that has been collected from Bangladesh meteorological department were used to observe the plausible scenario of crop water requirement in near future for the changed climatic condition.

Reference Crop Evapotranspiration (ET_0)

The projected reference evapotranspiration might increase considerably for the climate change by the year 2050. The greatest change is shown in the months April and May (increased by 1.09 and 1.47 mm/day). The reference crop evapotranspiration also showing the increasing trend from the month September to December by the year 2050. Table 9 and the figure 16 are presenting the evapotranspiration trend at base period and by the year 2050. The figure is showing the increasing trend op reference crop evapotranspiration by the year 2050.

Table 9The projected reference crop evapotranspiration (ET_0) in Rajshahi, Bangladesh (HadGem2 model, RCP 4.5)

Projected Year	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sept	Oct	Nov	Dec
2013	1.93	3.01	4.26	4.93	4.08	4.48	4.35	3.67	4	3.27	3.05	2.05
2050	2.46	3.39	4.16	6.02	5.55	5.35	4.48	3.65	3.59	3.85	3.43	2.86

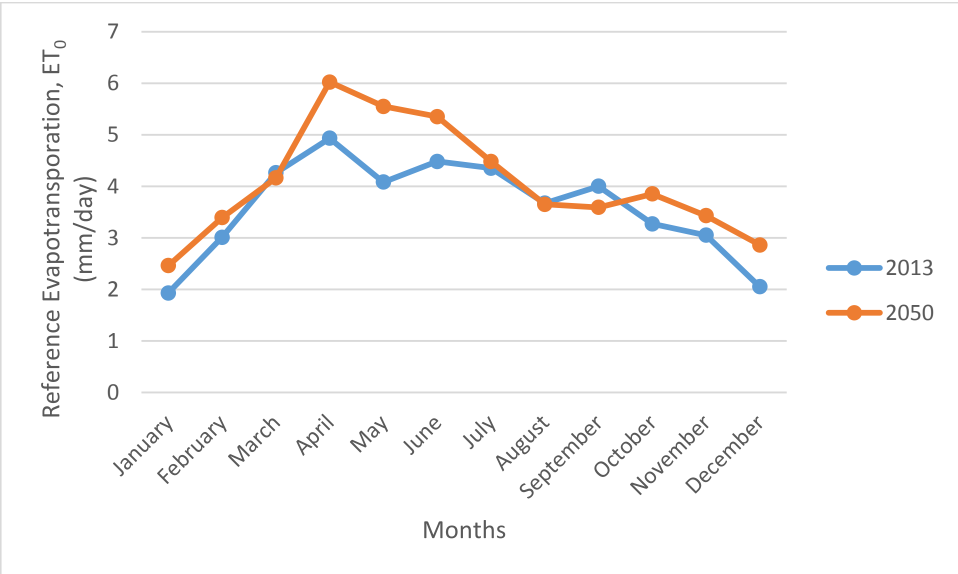


Figure 15 Trends of Reference Evapotranspiration by the year 2050

Crop coefficient (K_c) and the crop evapotranspiration (ET_c)

Almost no changes happen in the projected crop coefficient over the growing period. The trend declines during maturity period from April to May. The crop coefficient increased by 0.1 in November that is during nursery period by the projected year 2050 (Figure 16 and Annex 5).

The projected crop evapotranspiration increases from December to March and then again from end of March to May that is during throughout the growing period crop evapotranspiration increases by 2050. The maximum increase happen in April that is during maturity stage by 1.66 mm/day (Figure 17 and Annex 5).

Irrigation water requirement

Irrigation water requirement for Boro rice at the case study area has been predicted for the year 2050. There is no significant change observed in irrigation water requirement until development stage of rice. After the development stage the irrigation water requirement started to increase by 2050 and the maximum irrigation requirement observed in April (17.2 mm/decade) that is at the end of maturity stage and then started to decline for the rest of growing period (Figure 18 and Annex 6).

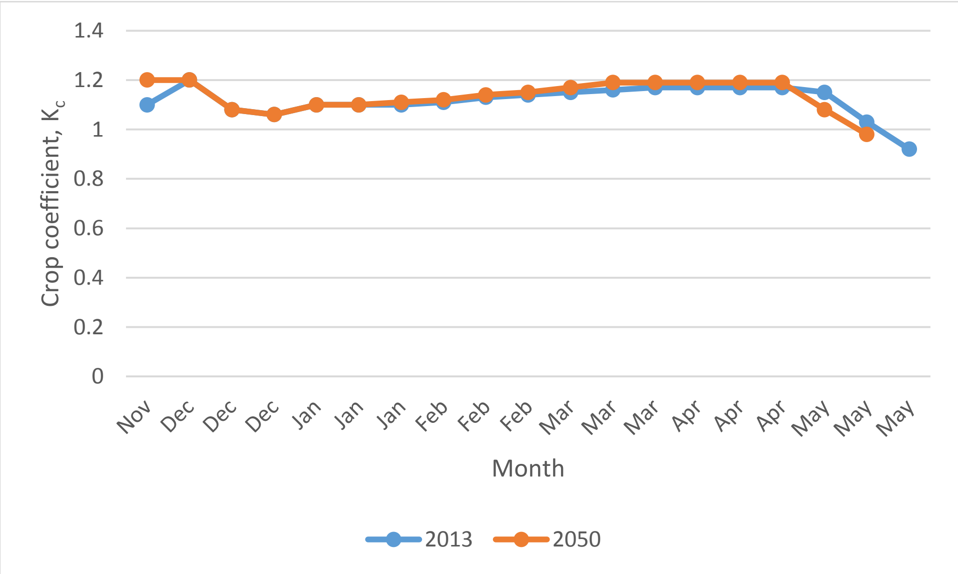


Figure 16 Trends of future crop coefficient (Kc) by the year 2050

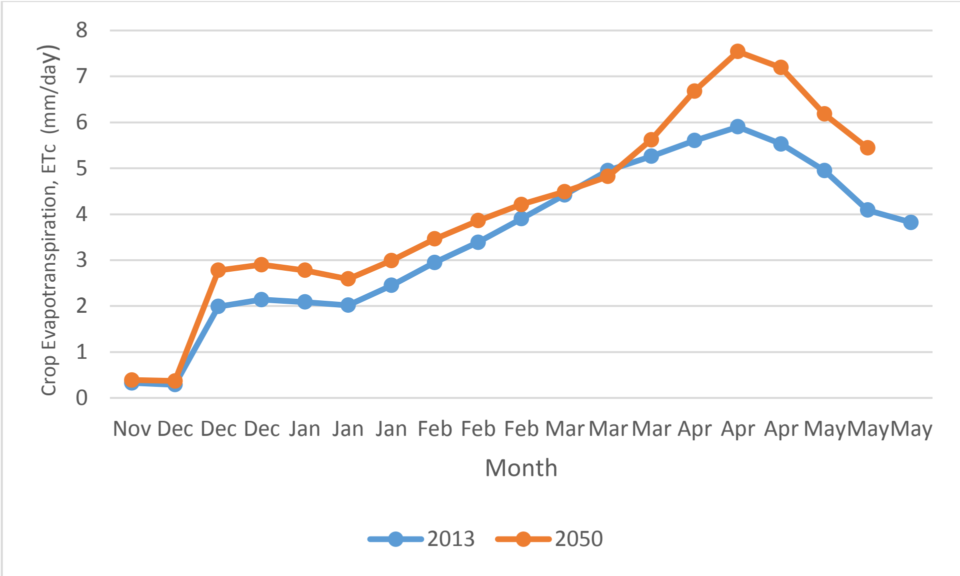


Figure 17 Trends of crop evapotranspiration by the year 2050

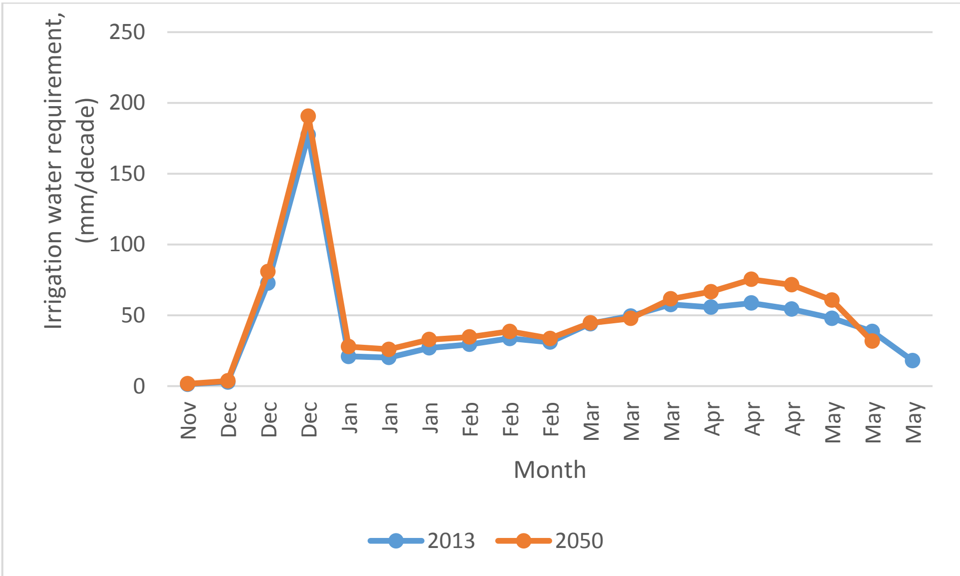


Figure 18 Trends of Irrigation Water Requirement

Chapter 4

Conclusion and Discussion

Though it is not easy to formulate the result directly that can be explain directly the impact of climate change on rice phenology and on crop water requirement but some interesting findings that can be presented here by considering all of kinds of limitations in the research work:

4.1 Effects of climate change on rice phenology and water requirement parameters

1. The projected average daily temperature will be increased by 1 and 1.4°C by 2030 and 2050 respectively. The growth stages will be short for this increased temperature (initial stage 2 days, vegetative stage 4 days, flowering stage 2 days and maturity stage 1 day) by 2050. The soil moisture deficiency will be increased and the daily evapotranspiration will also be increased by 31.3 mm in 2100 for dry season Boro rice. But the predicted average seasonal total evapotranspiration will be decreased in response to increased temperature and due to having short growing period. This reduced evapotranspiration is around 32 mm or 4% of total evapotranspiration for 1°C temperature rise. The biomass accumulation increased by 8% and 52% for temperature change from 28/21/25°C to 40/33/37°C respectively and the respiration rate will also increase that might decrease the yield by 6-16% for 2-4°C temperature rise.
2. During the driest period the sun shine hours are showing the increasing trend but during wet season there is decreasing trend of sun shine hours. Increased solar radiation accelerates the maturity and ripening stage (leaf senescence); thus less ET, and less biomass loss due to respiration, and thus higher yields. The projected solar radiation will be increased from 15.37 to 16.71 MJ/m2 /day by 2008 and 2070 respectively that has influence to increase the yield of Boro rice by 11%. For the low light during flowering period may causes severe spikelet sterility about 30-50%.
3. Past research has been revealed that the relative humidity increases at the rate of 0.287% each year during Boro rice growing season in the case study area. There are no significant changes observed in the projected future trend of humidity except slightly increasing trend during the driest period by 2035 and 2050. The maximum increased humidity found to be 10.16% in March by 2050. The transpiration rate has

possibility to decrease by 1.5 to 2 folds for the increased humidity and the spikelet sterility also has possibility to increase.

4. In the case study area, it has been predicted that the wind speed will increase considerably throughout the year by 2050 and that will increase the evapotranspiration. The past scientific literature revealed that for the increase of wind speed by 30% might influence the evapotranspiration by 20% each year.
5. The projected growing degree days is increasing during dry period by the year 2035, 2050 and 2065 and the growth stages becoming short. The highest increased GDD observed in November by 4.88 and the second highest in January by 4.13.
6. Severe water stress causes delayed panicle initiation. This phenomenon also influences the vegetative stage and flowering stage to be lengthy and, delayed maturity stage.
7. The reference crop evapotranspiration might increase greatly during rice developmental stage by the year 2050 and the highest change has been observed in April and May (increased by 1.09 and 1.47 mm/day).
8. Almost no changes observed for the the projected crop coefficient over the growing period. The trend declines during maturity period from April to May and increased by 0.1 in November that is during nursery period by the projected year 2050.
9. The projected crop evapotranspiration increases throughout the growing period by 2050. The maximum increase observed by 1.66 mm/day in April that is during maturity stage.
10. There is no significant change observed in irrigation water requirement until development stage of rice. The irrigation water requirement started to increase after development stage and the maximum irrigation requirement observed in April (17.2 mm/decade) that is at the end of maturity stage by 2050.

This is a bit difficult to summarize the research work in a sentence as the research work based on many scientific literature review and the calculation of field data as well. Even then, the overall conclusion can be drawn on the basis of all of the results obtained from the research work as, the future climate change has influence in altering the Boro rice phenology and the crop water requirement parameters. The climate change has positive impacts on Boro rice production with having some negative impacts as well for the case study area, Rajshahi district, Bangladesh. The important finding is that the future temperature and the humidity percentage has possibility to increase in future. The increased temperature will reduced individual growth stages and the total growing period. This will influence in reduction of total water requirement of rice. The increased humidity will also reduce the crop water requirement by reducing transpiration but this phenomena might increase the canopy temperature in some extent. The increased humidity percentage with high temperature thus may hamper the proper grain development by severe spikelet sterility. This will lead to yield reduction considerably.

4.2 Discussion

Choosing appropriate methods and models to analyse climate data was complex as the climatic parameters are uncertain in nature. All generated data from the global circulation model is not directly ready to use and they need correction before use for further analysis. As an example, the predicted future sun shine hour and the wind speed data are more uncertain in nature and could not be use directly in further interpretation without bias correction. Beside this, it is not possible to get humidity data direct from the global circulation model. So, the future humidity data was generated by CROPWAT 8 model from other climate data.

It was difficult to represent the exact climate change impact on rice phenology because the used model was more static type. In the model, only climate change parameters and the individual growing period has been varied for the estimation. The estimation could be more worthy if some dynamic model could be used in the research work to simulate the changes in phenological part as well . To assess the influence of climatic parameters on rice phenological and physiological changes that might influence the crop-water-requirement and yield is not that much straight forward. There might have influence of environmental factors, the soil characteristics and the crop factors as well. These factors made the research work more challenging to forecast for the future.

The growing degree days has been calculated only from maximum and minimum temperature of the case study area, and the base temperature of rice. But it would be more appropriate if the water stress part could be considered during calculation of growing degree days. There was also difficulties to calculate the changes of Boro rice phenology for per unit changes in climatic parameters and represent them numerically. So, the conclusion mainly has been drawn and explain by comparing the calculated value with past scientific literatures. Beside this the biomass accumulation, harvesting index and the rice yield are mostly interpreted in a broad range in the research for the lack of time and availability of detail field work.

There was problem to validate the results as there was no enough sufficient field research data available to validate the model output properly. There need a detail field work to get the crop and soil data to incorporate the this type of research work properly at the case study area. The time frame of the research work made the research more challenging to analysis all available and possible data.

Insufficient past scientific literature on lowland rice phenology and physiological responses of rice for the variable climatic parameters in the case study area made the case study more convoluted to observe. Beside this, specifically, there were less research work has been done on Boro rice in the case study area. So, this was another drawback to observe the case study perfectly. Over all the climatic parameters are so uncertain that prediction is more or less difficult and not so straight forward like other kind of research. So need more and more critical researches for the case study area so that the real scenarios can be attain from the studies in future.

4.3 Recommendations

1. Detail field research can be done to introduce the exact effect of climate change on Boro rice phenology. There is scope to quantify the growth stages, biomass accumulation, harvesting index and the yield responses for the change in climatic parameters in the case study area.

2. The growing degree days can be calculated by taking water stress part in account. The water stress function can also be assessed to get real growing degree days.

3. There is also scope to work with other dynamic model to compare the results with the present findings that has been interpreted in this research work.

Annexes

Annex 1 Crop and soil data (Bangladesh Agricultural Research Institute, BARI)

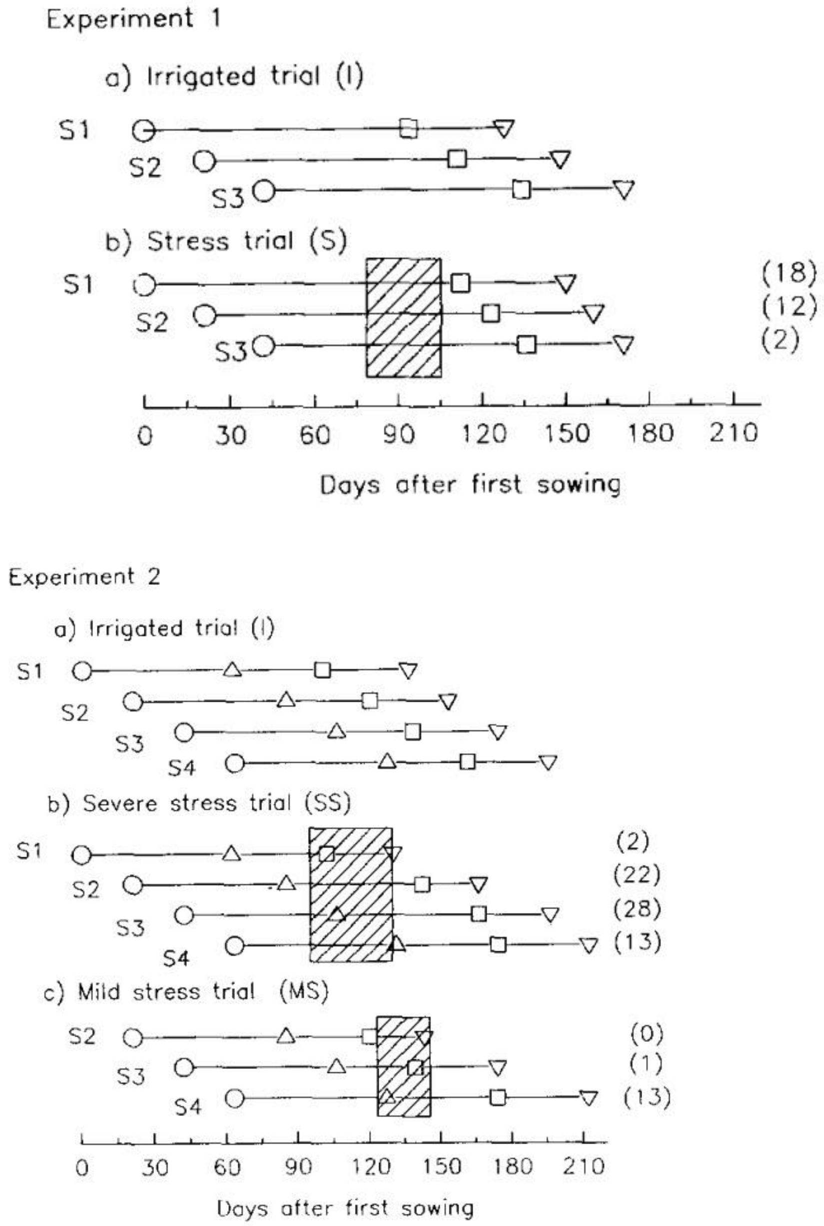
Crop Data:

Kc dry	**0.7**	**0.3**	**0.5**	**1.05**	**0.65**			
Kc wet	**1.2**	**1.05**	**1.1**	**1.2**	**0.95**			
Stage (days)-2013	**35**	**20**	**5**	**25**	**60**	**40**	**20**	**180**
2050	**35**	**20**	**5**	**23**	**56**	**38**	**19**	**171**
Rooting depth	**0.1**	**0.5**						
Puddling depth	**0.4**							
Nursery area	**10**							
Critical depletion	**0.2**		**0.8**		**0.8**		**0.75**	
Yield response f.			**1**	**1.09**	**1.32**	**0.5**	**1.1**	
Crop height					**0.94**			

Soil Data:

FC-WP	**200**	**mm/m**
Max rain infiltration rate	**40**	**mm/day**
Max rooting depth	**900**	**cm**
Initial soil moisture depletion	**0**	**%**
Initial available soil moisture	**200**	**mm/m**
Drainable porosity	**13**	**%**
CD for puddle cracking	**0.5**	**fraction**
Max percolation rate after puddling	**3.4**	**mm/day**
Water availability at planting	**50**	**% depl.**
Max water depth	**400**	**mm**

Annex 2 Phenological development of rice for different water stress condition



Where, sowing-O, panicle initiation-Δ and flower initiation- □ and maturity period-∇. Within the brackets showing the days that will be delayed.

Figure: Representation of phenological development of rice at different sowing time (S1-S4) in respect to three different water stress condition. Source: Boonjung and Fukai (1996)

Annex 3 Average daily temperature data in the case study area, Rajshahi district, Bangladesh

Average daily temperature data collected from meteorological department of Bangladesh by the year 2013 in the case study area, Rajshahi district, Bangladesh

Year	2013											
Months	Jan	Feb	Mar	Apr	May	June	July	Aug	Sep	Oct	Nov	Dec
	16.4	18.55	22.5	28.85	34.25	28	30.1	29.9	31.15	26.9	24.45	22.35
	17.75	18.75	20.75	28.95	34	30.75	30.7	31.3	27.5	29.15	25.7	21.05
	19.6	21.15	22.1	30.45	33	31.75	30.2	31.1	29.6	27.75	25.4	21.85
	18	20.5	22.7	31.15	32.3	31.3	30	32.05	30.3	28.1	25.6	22.6
	16.65	21	24.25	28.8	26.25	31.9	31.1	31.2	30.4	29.45	24.2	22.25
	15.35	21.15	24.45	27.45	26.5	31.75	31.1	29.65	31.1	26.9	24.1	21.3
	14.65	22.8	25.05	29.05	27.15	29.9	31.6	28.45	30.85	27.35	24.55	21.5
	11.7	19.9	24	29.3	28.7	31.1	30.6	27.7	30.4	28.1	24.15	22.05
	10.95	18.2	25.3	31.15	28.75	32.1	31	29.05	28.7	27.85	23.9	22.25
	11.6	19.6	25.5	32.35	31.2	31.2	32.05	30.6	30.5	29	23.65	21.5
	12.7	18.95	26.15	31.45	31.7	31.85	30.7	29.7	30.5	29.35	22.95	20.55
	14.1	19.4	27.2	31.25	29.05	32.35	29.85	29.3	30.9	29.5	21.05	18.55
	16	21.35	27.3	33.1	29.9	31.5	30.9	30.3	31.85	29.2	21.65	18.6
	16.75	20.6	27.9	31.65	28.55	30.15	30.35	31.6	30.95	27.95	21.55	19
	17.9	21.1	28.25	29	29.7	31.3	31.1	28.6	30.1	26.25	24.1	19.05
	18.45	20.6	27.55	28.35	28.95	31.8	30.9	28.35	31.2	28	23.55	18.25
	18.75	17.65	25.5	24.9	28.4	32.1	31.45	29.4	31.05	28.2	22.9	18.1
	19.6	20.35	24.65	29.2	29.1	32.4	31.25	30.2	29.25	28.5	23.4	18.55
	19.9	18.9	25.65	29.9	29.45	31.2	30	28.7	30.45	28.7	22	18.15
	19.55	19.85	26.65	26.2	28.85	29.9	30.65	28.4	30.8	28.6	21.6	16.6
	16.6	20.5	27.2	26.75	29.6	30.7	31.1	27.6	31.1	28.3	20.5	19.6
	17.2	21.7	26.05	25.6	28.75	31	31	29.95	31.5	27.45	21.35	19.5
	17.15	22.75	26.9	26.65	28.1	31.75	31.65	30.05	31.75	25.7	21.1	20.7
	15.8	22.5	28.95	27.25	26.25	31.45	30.45	31.55	32.65	27	20.35	19.85
	14.1	23.25	28.7	29.25	27.3	30.25	30.9	32.2	31.9	23.7	21	16.9
	13	22.65	28.2	30.55	30.75	28.65	29.6	31.35	30.5	24.05	21.8	15.75
	15	23.4	26.65	31.3	31.25	30	28	28.85	30.4	25.7	22.5	14.95
	18.4	23.55	26.6	31.2	30.05	29.45	28.6	28.6	29.9	26.05	22.25	13.6
	16.85		28.25	31.8	29.4	29	29.3	30.1	26.95	27.05	22.75	14.8
	17.2		29.25	32.5	26.5	28.9	29.75	30.1	26.25	24.5	21.9	15.95
	18.25		28.1		25.05		29.55	30		25		16.9

Average daily future temperature data from HadGEM2 model and 4.5 scenarios in the case study area, Rajshahi district, Bangladesh

Year	2035											
Months	Jan	Feb	Mar	Apr	May	June	July	Aug	Sep	Oct	Nov	Dec
	23.15	18.9	26.6	28.25	29.85	31	30.15	31.2	28.3	29.3	27.6	25.45
	24.15	17.35	28.2	29.15	31.3	28.75	29.85	30.4	29.3	30.7	28.15	26.5
	23.25	19.3	28.4	30.85	30.5	31.55	29.1	29.7	28.85	29.75	28.6	28
	23.95	21.5	29.85	31.5	32.2	32.15	29.4	29.2	29.35	29.4	27.8	25.8
	22.25	21.75	28.3	30.7	32.15	29.75	29.25	28.9	29.1	29.35	32.35	25.4
	20.2	21.8	27.6	28.05	34.4	30.95	28.9	29.8	29.25	29.7	28.05	24.7
	21.4	22.05	30.7	29.6	31.15	30.8	28.85	29.7	29.35	31.8	29.8	23.3
	21.75	22.75	27.95	31	30.85	28.7	28.9	29	29.45	31.35	28.35	26.5
	21.3	23.8	27.5	28.8	32.05	28.45	29.75	29.75	30	31.45	28.05	23.45
	19.5	24.7	27.95	31.45	34.1	28.1	29.65	29	29.85	30.85	27.3	23.25
	23.25	23.75	29.25	30.15	29.7	28.45	28.6	29.65	29.65	31.05	27	24.1
	23	24.8	30.1	31.15	30.8	27.7	28.8	30.8	30.25	29.95	26.5	25.15
	23.05	21.95	29.1	33	30.25	28.8	30.3	29.8	30.55	31.2	27.75	24.5
	20.3	20.65	30.75	34.2	30.5	28.3	29.9	29.8	25.55	31.1	27.15	23.3
	23.35	21.55	29.6	33.65	33	29.25	28.8	30	27	31.65	26.15	24.35
	21.45	24.2	26.1	31.5	31.55	28.35	30.8	27.5	27.4	31.15	26.6	24.45
	21.95	27.1	26.5	30.05	28.2	27.85	28.7	29.4	27.3	31.8	27.5	24.55
	18.5	27.9	25.8	32.25	32.05	28.15	27.55	30.45	28.6	31.6	27.55	23.7
	18.35	25.8	27.9	31.95	29.4	31.3	28.6	29.2	30.25	32	27.8	22.15
	22	24.9	27.4	29.25	25.75	29.3	27.7	29.35	29.2	31.4	26.4	23.4
	19.25	26.45	26.9	34.1	27.2	32.1	30.25	29.4	29.1	30.55	29.05	22.6
	19.4	28.5	23.35	33.55	27.8	31.15	29.15	28.85	29.5	30.05	30.7	20.45
	19.45	28.8	28.7	32.75	27.7	32.25	29.75	30	29.45	29.7	29.6	22.9
	22.35	29.35	27.85	30.4	29	31.5	30.25	30.45	30.75	27.7	29.95	23.2
	21.2	28.7	26.85	29.3	28.8	28.8	30.3	30.05	32.1	26.65	27.35	23.2
	20.9	27.35	26.85	30.1	32.6	33.4	30.75	27.85	30.95	29.3	27.2	21.7
	22.7	27.35	26.6	31.3	29.45	28.95	28.75	28.35	29.4	28.75	27.9	21.85
	19.3	28.6	27.85	30.7	29.45	27.3	29.3	29.2	30.9	29.4	26.55	22.55
	18.55		26.75	29.95	31.7	28.3	30	30.15	30.6	28.2	27.05	22
	17.1		27.65	31.35	31.75	28.6	29.4	30.6	30.4	26.85	26.25	23
	17.1		27.55		31.6		29.4	30.6		26.95		23

Year	2050											
Months	Jan	Feb	Mar	Apr	May	June	July	Aug	Sep	Oct	Nov	Dec
	19.5	20.9	22.15	32.3	36.55	34.15	30.9	30.5	29.85	30.1	29.8	27.9
	18.6	21.85	24	30.2	36.85	34.6	30.25	29.85	30.3	29.85	30.95	27.65
	17.4	23.85	22.15	31.8	38.85	34.9	30.8	30.05	30.15	29.5	30.35	25.9
	17.75	22.45	24.55	31.3	38.55	35.05	29.6	30.25	30.2	30.45	30.7	26.25
	19.75	19.15	25.9	31.9	35.85	35.05	28.1	31.35	30.55	32.45	29.9	26.3
	19.45	21.9	26	34.4	37.2	32.45	29.05	29.8	30.85	29.85	29.15	25.15
	21.1	20.15	22.4	33.25	33.2	33.4	28.55	30.25	31.45	30.55	28.45	26.25
	19.6	21.9	25.95	28.75	29.25	34.05	26.55	31.2	28.25	30.1	26.3	26.1
	20.3	24.6	26.8	29.4	30.4	33.75	28.65	29.35	29.25	29.3	26.55	25.55
	20.85	22.1	27.9	29.5	29.5	34.7	29.95	29.95	30.5	29.15	24.75	24
	20.6	24.55	28.6	31.45	29.75	34	31.25	31.3	30.6	30.65	23.95	20.6
	20.1	23.25	28.1	34.9	33.3	33.8	28.15	30.9	30.1	30.2	28.25	22.4
	20.55	23.15	27.65	37.45	28.7	30.85	28.05	29.85	31	29.55	26.5	19.55
	20.15	23.2	29.05	28.8	30.5	29.5	31.05	30.65	30.05	30.85	26.95	21.55
	22.2	25.55	31.3	30.95	29.8	31.15	29.7	32.25	30.7	30.5	28.7	21.55
	20.95	24.45	30.4	29.65	29.95	30.55	30.55	31.25	29.4	30.05	28.05	20.45
	19.9	23.9	23.3	33.35	30.25	30.7	31	30.15	30.5	30.9	28.95	22.2
	22.05	23.85	24.35	34.9	29.9	31.55	30.1	29.25	30.8	29.15	25.7	18.8
	20.4	26.55	23.95	34.85	28.4	30	29.2	30.9	29.35	30.65	26.1	21.2
	20.6	24.45	25.9	36.9	27.9	30.5	30.6	30.75	28.55	29.4	25.5	19.7
	20.3	28.4	25.95	36.05	32.15	32.7	32.9	30.55	31	31.9	28.3	22.65
	21.3	26.8	26.45	36.65	32.2	31.7	31.85	31.4	30.75	30.75	27.35	18.35
	19.95	26.45	28.3	37.9	34.9	32.3	33.4	31	30.25	28.85	27	20.8
	20	27.25	29	36.05	33.05	33.2	31.8	30.4	30.4	29.3	27.05	18.3
	22.7	23.75	28.8	35.5	35.45	33.6	32.3	29.1	30.75	27.9	27.3	22.1
	22.75	26.2	29.25	30.6	33.6	31.95	30.6	30.65	30.45	30.9	28.75	20
	21.4	25.3	29.3	33.15	33.85	32.6	29.75	32.55	30.55	30.65	28.25	20.05
	20.85	26.05	30.9	34.4	34.85	31.5	30.55	29.05	31.75	30.2	28.25	19.9
	23.45		31.95	37.05	34.3	30.65	31.1	29.1	30.35	28.6	27.6	21.25
	19.7		32.55	37.75	32.75	33.5	30.9	29.15	29.9	28.15	27.15	19.35
	19.7		32.5		32.6		30.95	29.25		28.2		19.35

Year	2065											
Months	Jan	Feb	Mar	Apr	May	June	July	Aug	Sep	Oct	Nov	Dec
	20.25	22.4	28.55	34.8	31.85	35.4	30.25	28.4	29.55	30.3	29.7	27.75
	20.65	23.35	27.25	30.95	32.75	33.8	32	26.9	30.4	31.15	28.65	27.25
	20.5	23.45	25.7	33.35	32.35	33.1	30.15	28.05	30.35	31.5	28.4	29.55
	21.9	25.05	28.4	32.95	32.9	30.75	32.55	29.4	30.85	31.05	26.1	29.45
	22.9	26.15	27.7	30.9	33.35	32	32.9	30.95	30.15	30.45	26.9	29.45
	21.05	24.95	27.8	31.75	31.4	30.85	30.65	30.65	31.15	30.3	25	28.65
	20.55	23.45	28.9	29.25	30.25	31.8	31.7	30.45	30.45	30.3	29.2	27.7
	21.7	23.25	26.95	30.8	31.05	32.8	29.65	31.35	31.85	31.65	27.55	27
	21.3	24.4	30.05	29.1	31.65	31.55	30.25	31.05	31.35	31.65	28.45	27.35
	23.6	22.15	30.15	32.2	33.9	31.1	31.25	32.75	31.7	31.4	26.85	24.85
	22.25	24.9	29	32.25	30.95	30.25	33.8	31.5	31.75	31.9	27.7	25.7
	22.2	25	28.2	33.9	29.9	30.2	28.5	30.7	30.6	30.7	26.45	25.5
	22.8	25.2	26.5	33.4	32.6	28.9	30.2	31.5	31.25	30.4	27.6	25.9
	22.85	24	26.8	35.15	30.15	29.15	30.35	31.75	32.7	31.65	27.55	25.7
	20.85	26.55	26.7	34.5	27.1	28.75	31.5	30.7	32	30.75	26.9	22.4
	21.85	26.65	27.85	35.4	32	29.6	32.1	31.75	31.65	29.95	28.4	23.45
	19.65	25.45	24.55	38.15	30.5	31.35	30.15	31.85	30.95	30.05	26.85	21.55
	20.05	23.45	28.6	34	32.2	33.15	31.3	31.35	30.15	30.4	28.7	20
	20.05	23.45	26.1	32.05	33.2	32.6	30.7	31.35	30.05	30.1	28	21.65
	18.9	22.1	30.15	32.45	29.1	32.2	29.2	31.1	31.8	28	26.85	21.5
	19.05	22.8	30.35	32.7	31.35	31.35	30	28.3	32.45	26.9	28.45	20.3
	20	25.1	29.8	34.5	29.85	30.9	30.05	28.65	32.75	29.05	27.45	22.05
	20.8	20.95	29.65	33.25	30.6	32.25	30.45	30.6	30.5	28.15	26.9	22.15
	20.45	25.75	30.2	31.9	30.9	31.8	29.55	28.4	31	29.75	27.8	21.25
	21.1	26.25	30.25	33.25	31.9	29.75	31.1	28.45	28.95	29.8	27.5	24.15
	20.5	26.65	31.3	32.65	29.8	31.75	31.15	29.3	29.2	30.2	26.1	23.85
	21.25	25.85	31.7	32.05	30.6	30.1	31.4	27.65	30.4	27.9	26.85	21.15
	21.3	21.3	33.25	28.95	31.8	30.3	30.45	28.4	29.7	29.2	25.05	22.35
	23.5		36.25	29.1	34	31.2	31.3	31.15	30.6	27.35	24.25	21.75
	22.45		34.15	30.3	35.05	30.75	30.1	29.75	29.8	27.35	25.8	22.7
	22.5		34.1		34.9		30.2	29.75		27.4		22.7

Annex 4 Growing Degree Days (GDD) in the case study area, Rajshahi district, Bangladesh

Year	2013											
Months	Jan	Feb	Mar	Apr	May	June	July	Aug	Sep	Oct	Nov	Dec
	6.4	8.55	12.5	18.85	24.25	18	20.1	19.9	21.15	16.9	14.45	12.35
	7.75	8.75	10.75	18.95	24	20.75	20.7	21.3	17.5	19.15	15.7	11.05
	9.6	11.15	12.1	20.45	23	21.75	20.2	21.1	19.6	17.75	15.4	11.85
	8	10.5	12.7	21.15	22.3	21.3	20	22.05	20.3	18.1	15.6	12.6
	6.65	11	14.25	18.8	16.25	21.9	21.1	21.2	20.4	19.45	14.2	12.25
	5.35	11.15	14.45	17.45	16.5	21.75	21.1	19.65	21.1	16.9	14.1	11.3
	4.65	12.8	15.05	19.05	17.15	19.9	21.6	18.45	20.85	17.35	14.55	11.5
	1.7	9.9	14	19.3	18.7	21.1	20.6	17.7	20.4	18.1	14.15	12.05
	0.95	8.2	15.3	21.15	18.75	22.1	21	19.05	18.7	17.85	13.9	12.25
	1.6	9.6	15.5	22.35	21.2	21.2	22.05	20.6	20.5	19	13.65	11.5
	2.7	8.95	16.15	21.45	21.7	21.85	20.7	19.7	20.5	19.35	12.95	10.55
	4.1	9.4	17.2	21.25	19.05	22.35	19.85	19.3	20.9	19.5	11.05	8.55
	6	11.35	17.3	23.1	19.9	21.5	20.9	20.3	21.85	19.2	11.65	8.6
	6.75	10.6	17.9	21.65	18.55	20.15	20.35	21.6	20.95	17.95	11.55	9
	7.9	11.1	18.25	19	19.7	21.3	21.1	18.6	20.1	16.25	14.1	9.05
	8.45	10.6	17.55	18.35	18.95	21.8	20.9	18.35	21.2	18	13.55	8.25
	8.75	7.65	15.5	14.9	18.4	22.1	21.45	19.4	21.05	18.2	12.9	8.1
	9.6	10.35	14.65	19.2	19.1	22.4	21.25	20.2	19.25	18.5	13.4	8.55
	9.9	8.9	15.65	19.9	19.45	21.2	20	18.7	20.45	18.7	12	8.15
	9.55	9.85	16.65	16.2	18.85	19.9	20.65	18.4	20.8	18.6	11.6	6.6
	6.6	10.5	17.2	16.75	19.6	20.7	21.1	17.6	21.1	18.3	10.5	9.6
	7.2	11.7	16.05	15.6	18.75	21	21	19.95	21.5	17.45	11.35	9.5
	7.15	12.75	16.9	16.65	18.1	21.75	21.65	20.05	21.75	15.7	11.1	10.7
	5.8	12.5	18.95	17.25	16.25	21.45	20.45	21.55	22.65	17	10.35	9.85
	4.1	13.25	18.7	19.25	17.3	20.25	20.9	22.2	21.9	13.7	11	6.9
	3	12.65	18.2	20.55	20.75	18.65	19.6	21.35	20.5	14.05	11.8	5.75
	5	13.4	16.65	21.3	21.25	20	18	18.85	20.4	15.7	12.5	4.95
	8.4	13.55	16.6	21.2	20.05	19.45	18.6	18.6	19.9	16.05	12.25	3.6
	6.85		18.25	21.8	19.4	19	19.3	20.1	16.95	17.05	12.75	4.8
	7.2		19.25	22.5	16.5	18.9	19.75	20.1	16.25	14.5	11.9	5.95
	8.25		18.1		15.05		19.55	20		15		6.9

Year	2035											
Months	Jan	Feb	Mar	Apr	May	June	July	Aug	Sep	Oct	Nov	Dec
	13.15	8.9	16.6	18.25	19.85	21	20.15	21.2	18.3	19.3	17.6	15.45
	14.15	7.35	18.2	19.15	21.3	18.75	19.85	20.4	19.3	20.7	18.15	16.5
	13.25	9.3	18.4	20.85	20.5	21.55	19.1	19.7	18.85	19.75	18.6	18
	13.95	11.5	19.85	21.5	22.2	22.15	19.4	19.2	19.35	19.4	17.8	15.8
	12.25	11.75	18.3	20.7	22.15	19.75	19.25	18.9	19.1	19.35	22.35	15.4
	10.2	11.8	17.6	18.05	24.4	20.95	18.9	19.8	19.25	19.7	18.05	14.7
	11.4	12.05	20.7	19.6	21.15	20.8	18.85	19.7	19.35	21.8	19.8	13.3
	11.75	12.75	17.95	21	20.85	18.7	18.9	19	19.45	21.35	18.35	16.5
	11.3	13.8	17.5	18.8	22.05	18.45	19.75	19.75	20	21.45	18.05	13.45
	9.5	14.7	17.95	21.45	24.1	18.1	19.65	19	19.85	20.85	17.3	13.25
	13.25	13.75	19.25	20.15	19.7	18.45	18.6	19.65	19.65	21.05	17	14.1
	13	14.8	20.1	21.15	20.8	17.7	18.8	20.8	20.25	19.95	16.5	15.15
	13.05	11.95	19.1	23	20.25	18.8	20.3	19.8	20.55	21.2	17.75	14.5
	10.3	10.65	20.75	24.2	20.5	18.3	19.9	19.8	15.55	21.1	17.15	13.3
	13.35	11.55	19.6	23.65	23	19.25	18.8	20	17	21.65	16.15	14.35
	11.45	14.2	16.1	21.5	21.55	18.35	20.8	17.5	17.4	21.15	16.6	14.45
	11.95	17.1	16.5	20.05	18.2	17.85	18.7	19.4	17.3	21.8	17.5	14.55
	8.5	17.9	15.8	22.25	22.05	18.15	17.55	20.45	18.6	21.6	17.55	13.7
	8.35	15.8	17.9	21.95	19.4	21.3	18.6	19.2	20.25	22	17.8	12.15
	12	14.9	17.4	19.25	15.75	19.3	17.7	19.35	19.2	21.4	16.4	13.4
	9.25	16.45	16.9	24.1	17.2	22.1	20.25	19.4	19.1	20.55	19.05	12.6
	9.4	18.5	13.35	23.55	17.8	21.15	19.15	18.85	19.5	20.05	20.7	10.45
	9.45	18.8	18.7	22.75	17.7	22.25	19.75	20	19.45	19.7	19.6	12.9
	12.35	19.35	17.85	20.4	19	21.5	20.25	20.45	20.75	17.7	19.95	13.2
	11.2	18.7	16.85	19.3	18.8	18.8	20.3	20.05	22.1	16.65	17.35	13.2
	10.9	17.35	16.85	20.1	22.6	23.4	20.75	17.85	20.95	19.3	17.2	11.7
	12.7	17.35	16.6	21.3	19.45	18.95	18.75	18.35	19.4	18.75	17.9	11.85
	9.3	18.6	17.85	20.7	19.45	17.3	19.3	19.2	20.9	19.4	16.55	12.55
	8.55		16.75	19.95	21.7	18.3	20	20.15	20.6	18.2	17.05	12
	7.1		17.65	21.35	21.75	18.6	19.4	20.6	20.4	16.85	16.25	13
	7.1		17.55		21.6		19.4	20.6		16.95		13

Year	2050											
Months	Jan	Feb	Mar	Apr	May	June	July	Aug	Sep	Oct	Nov	Dec
	9.5	10.9	12.15	22.3	26.55	24.15	20.9	20.5	19.85	20.1	19.8	17.9
	8.6	11.85	14	20.2	26.85	24.6	20.25	19.85	20.3	19.85	20.95	17.65
	7.4	13.85	12.15	21.8	28.85	24.9	20.8	20.05	20.15	19.5	20.35	15.9
	7.75	12.45	14.55	21.3	28.55	25.05	19.6	20.25	20.2	20.45	20.7	16.25
	9.75	9.15	15.9	21.9	25.85	25.05	18.1	21.35	20.55	22.45	19.9	16.3
	9.45	11.9	16	24.4	27.2	22.45	19.05	19.8	20.85	19.85	19.15	15.15
	11.1	10.15	12.4	23.25	23.2	23.4	18.55	20.25	21.45	20.55	18.45	16.25
	9.6	11.9	15.95	18.75	19.25	24.05	16.55	21.2	18.25	20.1	16.3	16.1
	10.3	14.6	16.8	19.4	20.4	23.75	18.65	19.35	19.25	19.3	16.55	15.55
	10.85	12.1	17.9	19.5	19.5	24.7	19.95	19.95	20.5	19.15	14.75	14
	10.6	14.55	18.6	21.45	19.75	24	21.25	21.3	20.6	20.65	13.95	10.6
	10.1	13.25	18.1	24.9	23.3	23.8	18.15	20.9	20.1	20.2	18.25	12.4
	10.55	13.15	17.65	27.45	18.7	20.85	18.05	19.85	21	19.55	16.5	9.55
	10.15	13.2	19.05	18.8	20.5	19.5	21.05	20.65	20.05	20.85	16.95	11.55
	12.2	15.55	21.3	20.95	19.8	21.15	19.7	22.25	20.7	20.5	18.7	11.55
	10.95	14.45	20.4	19.65	19.95	20.55	20.55	21.25	19.4	20.05	18.05	10.45
	9.9	13.9	13.3	23.35	20.25	20.7	21	20.15	20.5	20.9	18.95	12.2
	12.05	13.85	14.35	24.9	19.9	21.55	20.1	19.25	20.8	19.15	15.7	8.8
	10.4	16.55	13.95	24.85	18.4	20	19.2	20.9	19.35	20.65	16.1	11.2
	10.6	14.45	15.9	26.9	17.9	20.5	20.6	20.75	18.55	19.4	15.5	9.7
	10.3	18.4	15.95	26.05	22.15	22.7	22.9	20.55	21	21.9	18.3	12.65
	11.3	16.8	16.45	26.65	22.2	21.7	21.85	21.4	20.75	20.75	17.35	8.35
	9.95	16.45	18.3	27.9	24.9	22.3	23.4	21	20.25	18.85	17	10.8
	10	17.25	19	26.05	23.05	23.2	21.8	20.4	20.4	19.3	17.05	8.3
	12.7	13.75	18.8	25.5	25.45	23.6	22.3	19.1	20.75	17.9	17.3	12.1
	12.75	16.2	19.25	20.6	23.6	21.95	20.6	20.65	20.45	20.9	18.75	10
	11.4	15.3	19.3	23.15	23.85	22.6	19.75	22.55	20.55	20.65	18.25	10.05
	10.85	16.05	20.9	24.4	24.85	21.5	20.55	19.05	21.75	20.2	18.25	9.9
	13.45		21.95	27.05	24.3	20.65	21.1	19.1	20.35	18.6	17.6	11.25
	9.7		22.55	27.75	22.75	23.5	20.9	19.15	19.9	18.15	17.15	9.35
	9.7		22.5		22.6		20.95	19.25		18.2		9.35

Year	2065											
Months	Jan	Feb	Mar	Apr	May	June	July	Aug	Sep	Oct	Nov	Dec
	10.25	12.4	18.55	24.8	21.85	25.4	20.25	18.4	19.55	20.3	19.7	17.75
	10.65	13.35	17.25	20.95	22.75	23.8	22	16.9	20.4	21.15	18.65	17.25
	10.5	13.45	15.7	23.35	22.35	23.1	20.15	18.05	20.35	21.5	18.4	19.55
	11.9	15.05	18.4	22.95	22.9	20.75	22.55	19.4	20.85	21.05	16.1	19.45
	12.9	16.15	17.7	20.9	23.35	22	22.9	20.95	20.15	20.45	16.9	19.45
	11.05	14.95	17.8	21.75	21.4	20.85	20.65	20.65	21.15	20.3	15	18.65
	10.55	13.45	18.9	19.25	20.25	21.8	21.7	20.45	20.45	20.3	19.2	17.7
	11.7	13.25	16.95	20.8	21.05	22.8	19.65	21.35	21.85	21.65	17.55	17
	11.3	14.4	20.05	19.1	21.65	21.55	20.25	21.05	21.35	21.65	18.45	17.35
	13.6	12.15	20.15	22.2	23.9	21.1	21.25	22.75	21.7	21.4	16.85	14.85
	12.25	14.9	19	22.25	20.95	20.25	23.8	21.5	21.75	21.9	17.7	15.7
	12.2	15	18.2	23.9	19.9	20.2	18.5	20.7	20.6	20.7	16.45	15.5
	12.8	15.2	16.5	23.4	22.6	18.9	20.2	21.5	21.25	20.4	17.6	15.9
	12.85	14	16.8	25.15	20.15	19.15	20.35	21.75	22.7	21.65	17.55	15.7
	10.85	16.55	16.7	24.5	17.1	18.75	21.5	20.7	22	20.75	16.9	12.4
	11.85	16.65	17.85	25.4	22	19.6	22.1	21.75	21.65	19.95	18.4	13.45
	9.65	15.45	14.55	28.15	20.5	21.35	20.15	21.85	20.95	20.05	16.85	11.55
	10.05	13.45	18.6	24	22.2	23.15	21.3	21.35	20.15	20.4	18.7	10
	10.05	13.45	16.1	22.05	23.2	22.6	20.7	21.35	20.05	20.1	18	11.65
	8.9	12.1	20.15	22.45	19.1	22.2	19.2	21.1	21.8	18	16.85	11.5
	9.05	12.8	20.35	22.7	21.35	21.35	20	18.3	22.45	16.9	18.45	10.3
	10	15.1	19.8	24.5	19.85	20.9	20.05	18.65	22.75	19.05	17.45	12.05
	10.8	10.95	19.65	23.25	20.6	22.25	20.45	20.6	20.5	18.15	16.9	12.15
	10.45	15.75	20.2	21.9	20.9	21.8	19.55	18.4	21	19.75	17.8	11.25
	11.1	16.25	20.25	23.25	21.9	19.75	21.1	18.45	18.95	19.8	17.5	14.15
	10.5	16.65	21.3	22.65	19.8	21.75	21.15	19.3	19.2	20.2	16.1	13.85
	11.25	15.85	21.7	22.05	20.6	20.1	21.4	17.65	20.4	17.9	16.85	11.15
	11.3	11.3	23.25	18.95	21.8	20.3	20.45	18.4	19.7	19.2	15.05	12.35
	13.5		26.25	19.1	24	21.2	21.3	21.15	20.6	17.35	14.25	11.75
	12.45		24.15	20.3	25.05	20.75	20.1	19.75	19.8	17.35	15.8	12.7
	12.5		24.1		24.9		20.2	19.75		17.4		12.7

Annex 5 Calculation of reference evapotranspiration parameters

Calculation of reference evapotranspiration for the year 2013

Month	Min Temp	Max Temp	Humidity	Wind	Sun	Rad	ETo
	°C	°C	%	km/day	hours	MJ/m²/day	mm/day
January	9.3	23.4	81	78	5.3	12.2	1.93
February	13.6	27.9	71	98	7.9	17.2	3.01
March	18.2	33.9	63	96	8.3	20.1	4.26
April	22.6	36.4	67	100	7.6	20.7	4.93
May	24.8	33.9	77	123	4.3	16.4	4.08
June	26.5	35.1	81	91	5.9	18.9	4.48
July	26.7	34.3	85	114	5.7	18.5	4.35
August	26.3	33.4	87	103	4.2	15.8	3.67
September	26.3	34.4	87	72	6.2	17.5	4
October	23.4	31.4	83	107	5.2	14.3	3.27
November	16.2	29.6	80	103	8	15.7	3.05
December	12.7	25.5	81	82	4.7	11	2.05
Average	20.6	31.6	79	97	6.1	16.5	3.59

Calculation of reference evapotranspiration for the year 2050

Month	Min Temp	Max Temp	Humidity	Wind	Sun	Rad	ETo
	°C	°C	%	km/day	hours	$MJ/m^2/day$	mm/day
January	13.6	27.3	71	80	6.8	14	2.46
February	17	30.9	72	118	7.6	16.8	3.39
March	20.5	34	73	130	7.3	18.7	4.16
April	26.1	40.7	72	155	8.9	22.7	6.02
May	27.4	38	77	254	6.2	19.3	5.55
June	27.9	37.4	79	207	6.4	19.7	5.35
July	26.8	33.7	84	216	5.5	18.2	4.48
August	27.7	33.1	87	157	3.8	15.2	3.65
September	27.4	33.1	86	175	4.3	14.8	3.59
October	26	33.9	82	141	6.8	16.4	3.85
November	22.5	33	77	107	7.6	15.2	3.43
December	15.4	29.2	72	92	8.6	15.3	2.86
Average	23.2	33.7	78	153	6.7	17.2	4.07

Annex 6 Calculation of crop water requirement

Calculation of crop water requirement for the year 2013

Month	Decade	Stage	Kc	ETc	ETc	Eff rain	Irr. Req.
			coeff	mm/day	mm/dec	mm/dec	mm/dec
Nov	3	Nurs	1.2	0.33	1.3	0	1.3
Dec	1	Nurs	1.2	0.29	2.9	0	2.9
Dec	2	Nurs/LPr	1.08	1.99	19.9	0	72.7
Dec	3	Nurs/LPr	1.06	2.14	23.5	0	177.4
Jan	1	Init	1.1	2.09	20.9	0	20.9
Jan	2	Init	1.1	2.02	20.2	0	20.2
Jan	3	Deve	1.1	2.45	27	0.1	26.9
Feb	1	Deve	1.11	2.95	29.5	0.2	29.4
Feb	2	Deve	1.13	3.39	33.9	0.3	33.6
Feb	3	Deve	1.14	3.9	31.2	0.2	31
Mar	1	Deve	1.15	4.42	44.2	0.1	44
Mar	2	Deve	1.16	4.95	49.5	0.1	49.4
Mar	3	Mid	1.17	5.26	57.8	0.2	57.6
Apr	1	Mid	1.17	5.6	56	0.4	55.7
Apr	2	Mid	1.17	5.9	59	0.5	58.6
Apr	3	Mid	1.17	5.53	55.3	1	54.3
May	1	Late	1.15	4.95	49.5	1.7	47.9
May	2	Late	1.03	4.09	40.9	2.2	38.6
May	3	Late	0.92	3.82	19.1	1	18
					641.5	7.9	840.3

Calculation of crop water requirement for the year 2050

Month	Decade	Stage	Kc	ETc	ETc	Eff rain	Irr. Req.
			coeff	mm/day	mm/dec	mm/dec	mm/dec
Nov	3	Nurs	1.2	0.39	1.6	0	1.6
Dec	1	Nurs	1.2	0.37	3.7	0	3.6
Dec	2	Nurs/LPr	1.08	2.78	27.8	0.1	80.8
Dec	3	Nurs/LPr	1.06	2.9	32	0	190.6
Jan	1	Init	1.1	2.78	27.8	0	27.8
Jan	2	Init	1.1	2.59	25.9	0	25.9
Jan	3	Deve	1.11	2.99	32.8	0	32.8
Feb	1	Deve	1.12	3.46	34.6	0	34.6
Feb	2	Deve	1.14	3.86	38.6	0	38.6
Feb	3	Deve	1.15	4.21	33.7	0.1	33.6
Mar	1	Deve	1.17	4.49	44.9	0.3	44.6
Mar	2	Deve	1.19	4.82	48.2	0.4	47.8
Mar	3	Mid	1.19	5.62	61.9	0.3	61.6
Apr	1	Mid	1.19	6.68	66.8	0.1	66.7
Apr	2	Mid	1.19	7.54	75.4	0	75.4
Apr	3	Late	1.19	7.19	71.9	0.3	71.5
May	1	Late	1.08	6.18	61.8	1.3	60.6
May	2	Late	0.98	5.44	32.7	1.1	31.7
					721.8	4	929.8

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