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Temperature, precipitation and net irrigation requirement scenario for major winter crops in the south-eastern Bangladesh

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ABSTRACT

Bangladesh ranked top among the climate vulnerable countries in the world. Climate change is evident since few decades. Changing climate affects the life, property and economy of the country. Among them, agricultural is the most affected sector. Literature suggests that the future climatic condition might affect the agriculture even more adversely. Therefore, considering the economic strength, agriculture based economy and population density, the country needs much effort to adjust with the changing circumstances. A clear and specific understanding of the apprehending changes would certainly assist in preparation to fight against the adverse impact. Aiming to provide updated knowledge about the climate change scenario and future irrigation water demand, this study simulated the temperature, precipitation and net irrigation requirement (NIR) scenario for Boro, Potato and Wheat crop for the south-eastern part of Bangladesh.

MAGICC/SCENGENE model was used to simulate local scale temperature and precipitation scenario considering Special Report on Emission and Radiation (SRES) A1B-AIM emission scenario and thereafter simulated NIR based on the temperature and precipitation scenario using the AquqCrop model. The MAGICC/SCENGEN model was calibrated and validated using the observed datasets collected from 12 weather stations of Bangladesh Meteorological Station (BMD). The changes in temperature, precipitation and NIR are estimated based on the 11 year mean values extending from the year 2000 to 2010 (as the base data).

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The analysis reveals that the south-eastern part of Bangladesh is likely to experience diverse trends of climatic change. The temperature showed a linear trend of increment ranging from 1.4°C to 2.4°C by the year 2100. The changes would not be the same for all season. Winter temperature showed maximum changes as compared to that of base period. On the other hand, the changes in precipitation showed two trends. Precipitation scenarios showed initial increase until 2040 and thereafter decline in 2050. After 2050 the total precipitation is likely continue to increase. However, it showed substantial variability throughout the seasons. The area would receive less rainfall during pre-monsoon, while the precipitation is likely to increase in the post-monsoon. NIR scenario suggests a steady increase for all three winter crops. The NIR might be increased by 10 to 25% depending on the crop types.

AquaCrop model estimates the irrigation water requirement based only on soil moisture stress level and carbon-di-oxide (CO_2) fertilization. It does not include organic matter depletion, initial moisture stress, impact of salinity etc. Despite this simplicity, the study outcome provides important implications for the policy practitioners to ensure future food security and water management challenges.

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I. Introduction

Changing climate is likely to have significant impacts on the hydrological cycle (IPCC, 1996). Literature suggests that the hydrological cycle would be altered with unequally distributed extensive evaporation and precipitation. Few areas might experience substantial increase or decrease of precipitation, or changes in the timing and duration of wet or dry seasons (Arnell, 1999). Bangladesh is ranked top among the most climate vulnerable countries in the world (Ali, 1999; Ahmed, 2006; IPCC, 2007). In and around Bangladesh, hydro-meteorological changes would induce the most effects to her society and economy under future climatic conditions (OECD, 2003).

The economy and society of Bangladesh is highly dependent on agriculture. This, in fact makes her more vulnerable to climate change. Several studies reported that climate change will have significant impact on crop yields (Gitay et al., 2001; Easterling et al., 2007). IPCC (2007) predicted a steady increase of temperature and a clear change of rainfall pattern in Bangladesh. A contradictory phenomenon was explained by Shahid (2011) regarding the impacts of temperature increase on irrigation water requirement. Increased temperature would escalate evapotranspiration, and thus requires more water to meet the irrigation requirement. Simultaneously, an increase in temperature could potentially change the crop physiology and shorten the crop lifecycle, and thus reduces the total irrigation requirement. However, agriculture in Bangladesh remains the most important sector to be considered for climate change adaptations due to its highly valuable contribution to her society.

Agriculture accommodates more than 75% of the country's total labor force and produces about 25% of her gross domestic product (Rahman, 2004). Rice is the main food of her people (over 160 million in an area of 147,570 km2, most density in the world). The population is projected to increase by approximately 30% by 2050 (Rahman, 2007). This will inevitably increase food demand in Bangladesh. A probable way to meet this extra food demand by expanding irrigation demanding boro rice (winter rice) cultivation (Shahid, 2011). On the flipside, Karim et al. (1996) predicted a decline of rice production by 3.9% due to cumulative impact of climate change over a period from 2005 to 2050. Moreover, several studies predicted that crop production during the rabi season (November to March) season will be impacted most and reported a loss of gross production from 18 to 62% with no clear consensus (Karim et al., 1998). Boro rice is mainly produced in rabi season. Wheat and potatoes are other two main rabi crops in Bangladesh. Considering the precipitation pattern over Bangladesh (nearly 80 percent of the country's annual precipitation occurs during the summer monsoon season) and the irrigation requirement for three main crops, a prediction of seasonal irrigation water requirement under future climate scenarios would be very valuable for planning food security of the country.

Several studies have been carried out to analyze the impact of climate change on irrigation water requirement for different parts of the world (Brumbelow and Georgakakos, 2001; Doll, 2002; Izaurralde et al., 2003; Rosenzweig et al., 2004; Fischer et al. 2006; Elgaali et al., 2007; Yano et al., 2007; Rodriguez et al., 2007; de Silva et al., 2007; Shahid, 2011). Almost all the studies ignored the climate change impact on crop phenology and predicted an increase of irrigation water demand. This study also estimates the changes in irrigation water requirement for three main rabi crops for the south-eastern parts of Bangladesh under SRES (Special Report on Emission Scenarios) A1B-AIM climate scenarios (see IPCC, 2001 for more details about SRES A1B-AIM emission scenarios).

II. Materials and Methods

Study area: This study analyzes the climate change impacts on net irrigation requirement for three major crops in the south-east region of Bangladesh. The study area is shown in Figure 01. The study area is about 34418.44 km^2 and covers nearly 25 percentage of the total land area of Bangladesh. The study area encompasses 11 administrative districts (Chittagong, Cox's bazar, Rangamati, Bandarban, Khagrachhari, Feni, Lakshmipur, Comilla, Noakhali, Brahmanbaria and Chandpur) of Bangladesh. The area is inhabited by over 27 million people with a density of 795 person/km^2. (Bangladesh National Portal; http://www.bangladesh.gov.bd/; accessed on July 4, 2016). Study area receives about 3028 mm of precipitation annually and experiences three distinct seasons (pre-monsoon, monsoon and winter (BMD, 2012). The pre-monsoon season (March-May) is characterizes with hot summer and sporadic rains and hails. The monsoon season extends from June to October associated with 80% of the total annual rainfall. The winter season (December-February) usually offers the best growing season with relatively low temperature, little rain and extended cultivable land. Since winter season receives little or no rain, it demands irrigation for agriculture. The irrigation within the study area mainly comes from surface and ground water sources.

Data: Analysis was done based on 64 year (1948-2011) meteorological data collected from 12 weather stations of Bangladesh Meteorological Department (BMD) located within the study area. Station-wise monthly mean temperature, rainfall, relative humidity, sunshine hour and wind speed data were collected from BMD. The weather stations are listed in Table 01 and shown in Figure 01.

Generation of future climate scenario: To generate the future climate scenario for the study area, a reputed regional climate scenario generator software package namely MAGICC/SCENGEN (Model for the Assessment of Greenhouse-gas Induced Climate Change a regional climate SCENnario GENerator) version 5.3.v2 was used (available at http://www.cgd.ucar.edu/cas/wigley/magicc/) (MAGICC and SCENGEN, 2000). MAGICC/SCENGEN is user friendly interactive software suites that allow users to examine future climate change and its uncertainties at both the global-mean and regional levels based on the scenarios of General Circulation Models (GCM). MAGICC calculations consider the same global mean value that has been employed by Intergovernmental Panel on Climate Change (IPCC). SCENGEN uses MAGICC results, together with spatially detailed results from the CMIP3/AR4 archive of Atmosphere-Ocean Global Circulation Models (AOGCM), to produce spatially detailed information on future changes in temperature, precipitation and MSLP, changes in their variability, and a range of other statistics (Wigley, 2008). MAGICC/SCENGEN has been one of the primary tools used by IPCC since 1990 (Meehl et al., 2007). The detail working principle of MAGICC/SCENGEN can be found at Wigley (2008).

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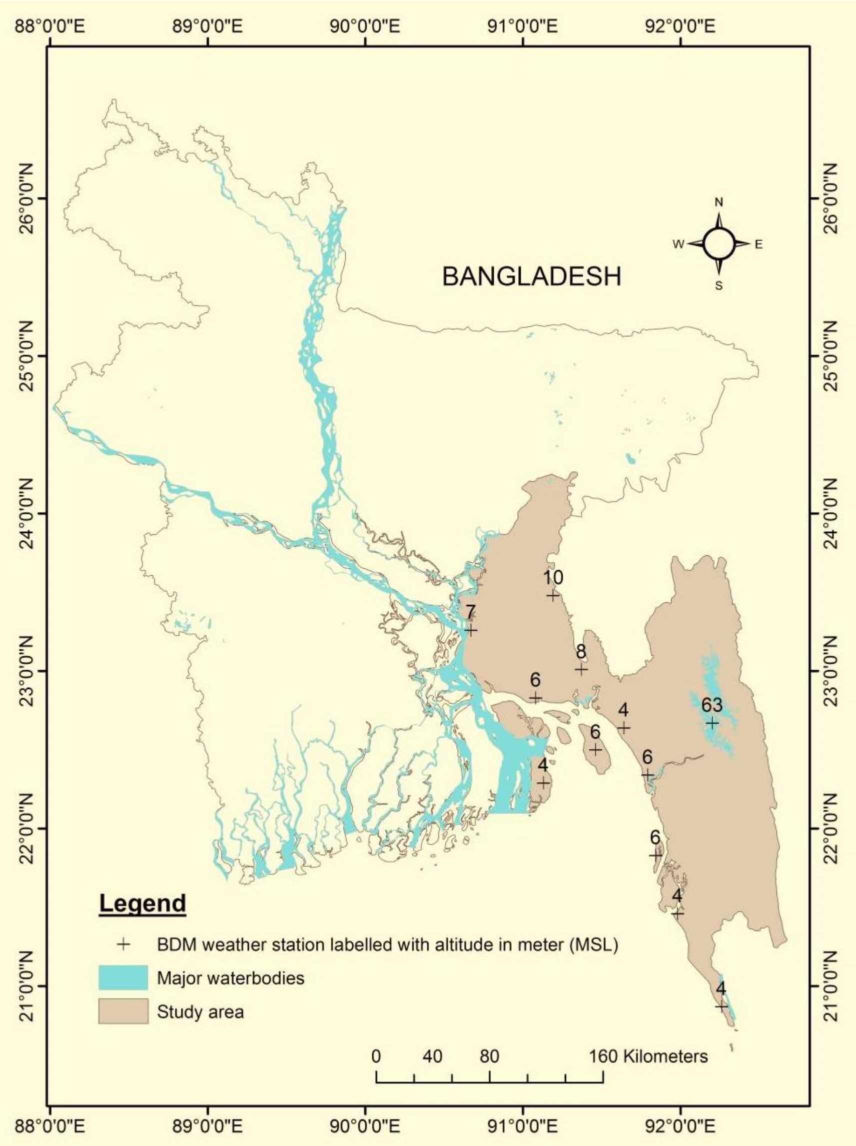

Figure 01. Location map of study area and BMD weather stations.

Table 01. Description of weather stations

Station Name	Latitude (⁰N)	Longitude (⁰E)	Altitude (m)	Mean precipitation (mm/year)	Mean temperature (°C)
Chandpur	23.26	90.67	7	2191	25.81
Chittagong	22.34	91.79	6	2951	25.70
Comilla	23.48	91.19	10	2068	25.35
Cox's Bazar	21.46	91.98	4	3732	25.77
Feni	23.01	91.37	8	2974	25.35
Hatiya	22.29	91.13	4	3235	25.77
Kutubdia	21.83	91.84	6	2835	25.80
Maizdi	22.83	91.08	6	3120	25.74
Rangamati	22.67	92.20	63	2495	25.29
Sandwip	22.50	91.46	6	3583	26.00
Sitakunda	22.64	91.64	4	3052	25.53
Teknaf	20.87	92.26	4	4100	26.28

The spatial resolution of MAGICC/SCENGEN is 2.5^0 and whole Bangladesh is covered by only six pixels. This study analyzed only one pixel that covers the south-eastern part of the country. The analysis assumes a uniform change of climate over the whole study area. The scenario generation for the study area using MAGICC/SCENGEN comprises two main steps. In the first step, MAGICC model was run to generate ensemble scenarios. This involves choosing a pair of emission scenarios, termed as the Reference and Policy scenario. This study considers SRES A1B-AIM emission scenario (balance across all sources). Default options for carbon cycle, carbon cycle climatic feedbacks, aerosol forcing, climate sensitivity, thermohaline circulation, vertical diffusivity and ice melt were opted for this study. In the second step, options were chosen to acquire the actual projections for the selected climate variable, the set of GCMs to be averaged and the future date of interest to run SCENGEN. Chosen options for the MAGICC/SCENGEN model are listed in Table 02.

Table 02. Options chosen for modelling climate scenario and net irrigation requirement

Model name	Modelling option	Option chosen
MAGICC	SRES scenario	A1B-AIM emission scenario
	Carbon cycle model	"mid" level forcing control for carbon cycle model
	Carbon-cycle climatic feedbacks	Left "on"
	Aerosol forcing	"mid" level
	Climate sensitivity	3.0^{0}C
	Thermohaline circulation	The default case responds to a moderate slow-down of the THC as the globe warms
	Vertical diffusivity (Kz)	The default value 2.3 cm2/s.
	Ice melt	"mid" level
SCENGEN	Options for analysis	"Mod. + Change" was chosen to acquire the actual projections for temperature and precipitation extended up to the year 2100 averaged from 6 GCMs (GFDLCM20, UKHADCM3, NCARPCM1, CSIRO-30, CCSM-30, MRI-232A) over the south-east part of Bangladesh
	Selection of models	This study required multi-model ensemble of the full suite of GCMs. Hence all of available models were chosen.
	Selection of definitions of changes	"Def. 2" was chosen. Def. 2 determines the differences between the start and end of a perturbation experiment and removes spatial drifts among the models
	Scaling	Linear scaling
	Smoothing	Spatial smoothing
	Warming	Scenario for the year 2010, 2025, 2050, 2075 and 2100 was set to have a "best guess" configuration for the MAGICC model
Aqua Crop 3.1 Plus	Climate	Base year climatic parameters, temperature and rainfall, were retrieved from the 11 year (2000-2010) averaged observed dataset of BMD and inputs for CO_2 concentration was assumed as of SRES A1B scenario
	Crop	Paddy Rice CRO (Default Paddy Rice, Calendar; Los Banos 15 Jan 04). Aman and Boro paddy growing cycle starts from July 1 and December 1 respectively
	Soil	Heavy clay kind "PADDY.SOL"
	Management	Irrigation requirement for Aman paddy was simulated with "Rainfed" as the management option. For Boro determination of net irrigation requirement was opted for

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Base year data generation and validation: The changes of temperature and precipitation for the year 2025, 2050, 2075 and 2100 were estimated based on the base year. This study considers the mean values of 11 years (2000-2010) temperature and precipitation data as the base year. MAGICC/SCENGEN generated temperature and precipitation datasets were validated against those of observed dataset of BMD. Observed values were calculated from the mean of 12 BDM stations within the study area. The root mean square error (RMSE) in a monthly scale for the base year (2000-2010) simulated precipitation and temperature data was calculated by Eq. (1).

$$RMSE = \sqrt{\frac{\sum_{i=1}^{n}(y_{sim,i}-y_{obs,i})^2}{n}} \quad (1)$$

Where, *RMSE* is the root mean square error, $y_{sim,i}$ is the simulated monthly mean value for the i^{th} month, $y_{obs,i}$ is the observed monthly mean value for the i^{th} month and n is the number of data sets.

Modeling net irrigation requirement: To model future net irrigation requirement under climate scenarios generated by MAGICC/SCENGEN a separate model as suggested and developed by Food and Agricultural Organization (FAO) namely AquaCrop (version 3.1 Plus) was used. The ET_0 calculator (Raes et al., 2009) uses Penman-Monteith equation for calculation of evapotranspiration. The inputs for the calculator are maximum air temperature, minimum air temperature, relative humidity, sunshine hours and wind speed at a height of 2 *m*. In this study, the inputs for ET_0 calculator was determined based on the 11 year long (1990-2000) average apart from maximum and minimum air temperature. ET_0 was calculated for each of the projected climatic scenario of 2025, 2050 and 2075. Other options chosen for AquaCrop model is given in Table 02.

III. Results and Discussion

Base year data and validation

MAGICC generated base year precipitation and temperature data showed relatively good agreement with those of observed data with a *RMSE* of 18.73 and 0.65 respectively. Figure 02 shows the validated precipitation and temperature data for the base year.

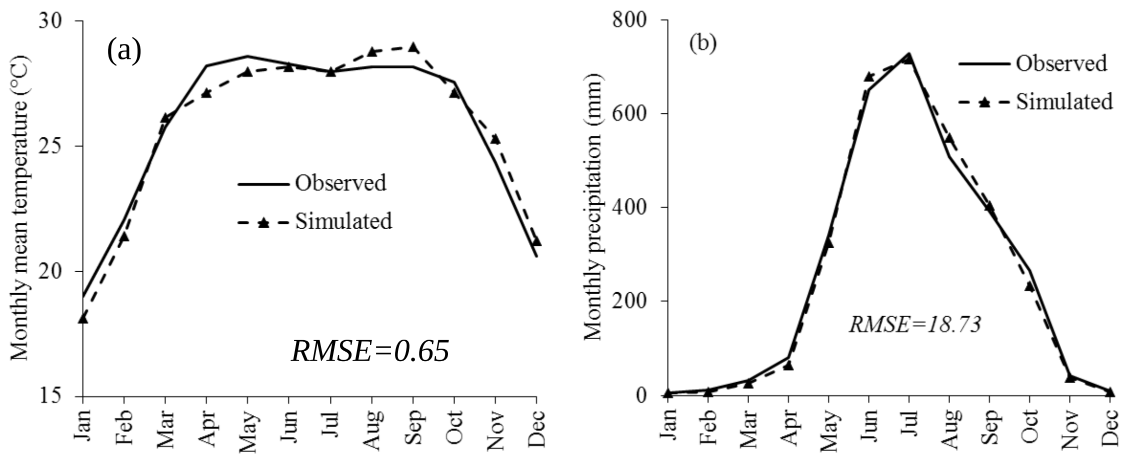

Figure 02. Validated precipitation and temperature scenario (mean from 2000 to 2010).

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Future temperature scenario

The future temperature scenario for the study area obtained from the MAGICC/SCENGEN model suggest that the annual mean temperature will be increased by 0.46°, 1.49°, 2.33° and 2.92° C by the year 2025, 2250, 2075 and 2100, respectively as compared with that of base year (yearly mean temperature from the year 2001 to 2010). Applying the same methodology and considering IPCC B2 SRES scenario Agarwala et al. (2003) predicted a change of yearly mean temperature by 1.4° and 2.4°C degree by the year 2050 and 2100. In other study, Ahmed and Alam (1998) reported a probable increase of average temperature by 1.3°C and 2.6°C for the two projected years, 2030 and 2075, respectively. Figure 03 displayed the future temperature scenarios for the study area.

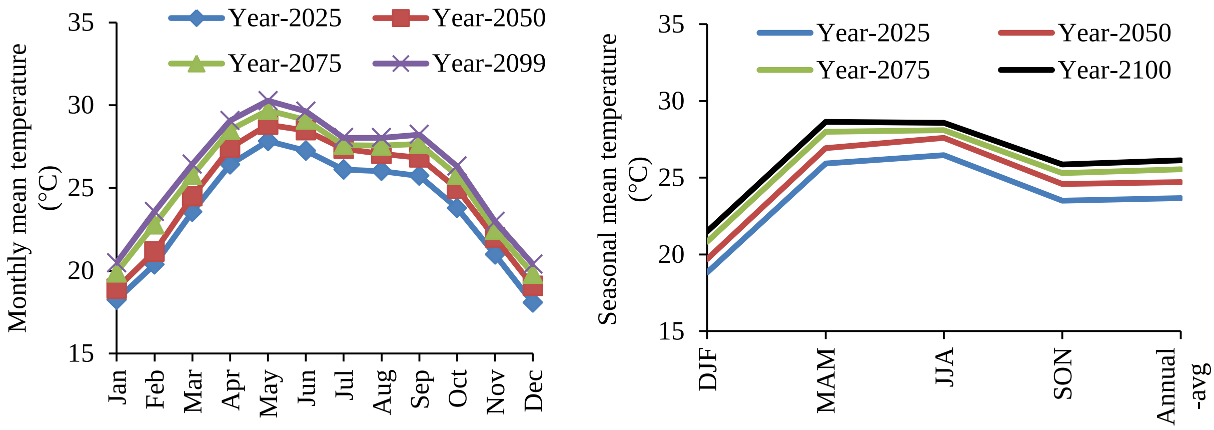

Figure 03. Future temperature scenario for the south-eastern part of Bangladesh.

The increase of temperature seems to be quite uniform throughout the year with little variations. The changes of mean temperature is highest during the winter season (December-February) and lowest during the summer season (June-August) corresponding those of base year. Climate scenario documented by Ahmed and Alam (1998) and Agarwala et al. (2003) also suggests a seasonal variation in changed temperature, where the maximum difference would be during the winter and smallest during the monsoon.

Future precipitation scenario

The future precipitation scenarios for the study area are presented in Figure 04 and Table 03. The projected precipitation scenario exhibits a decrease of winter (DJF) precipitation except for 2050. On the flipside, the post monsoon (SON) season likely to receive more precipitation for all projected year.

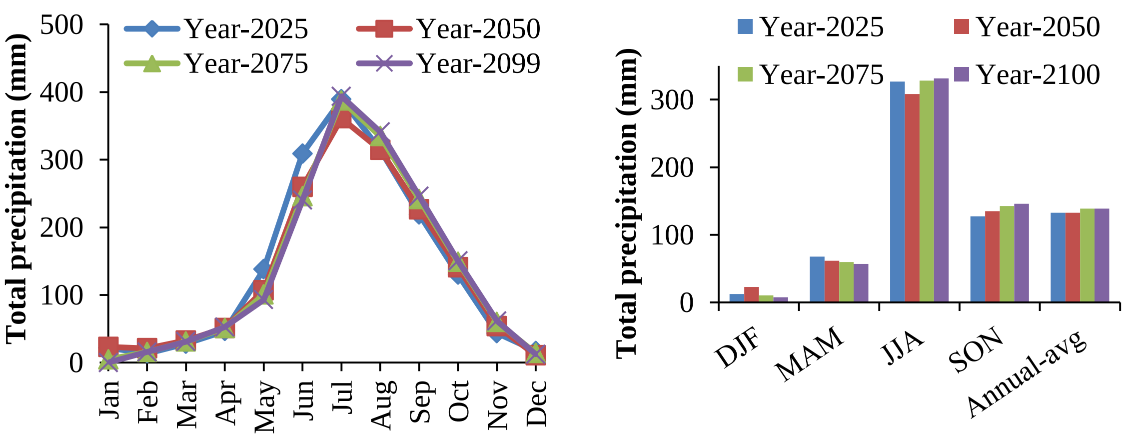

Figure 04. Future precipitation scenario for the south-eastern part of Bangladesh.

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During the pre-monsoon period, the study area might also experience with less precipitation. Overall, the area would receive more rainfall as compared that of base period. Ahmed and Alam (1998) also recorded an increase of monsoon precipitation by 12 percent and 27 percent by the year 2030 and 2075 respectively.

Table 03. Precipitation scenario over south-eastern part of Bangladesh. Changes with respect to the base period are presented in parentheses.

Year	Average precipitation (mm)				
	DJF	MAM	JJA	SON	ANNUAL
Base data	17.69	65.24	312.24	128.92	130.98
2025	12.07 (-46.56)	67.47 (+3.31)	326.6 (+4.39)	127.40 (+1.19)	132.49 (+1.14)
2050	22.63 (+21.83)	61.33 (-6.38)	308.2 (-1.31)	134.98 (+4.49)	132.49 (+1.14)
2075	10.56 (-66.57)	59.80 (-9.09)	328.13 (+4.84)	142.57 (+9.58)	138.59 (+5.49)
2100	7.54 (-134.00)	56.73 (-15.00)	331.20 (+5.73)	145.6 (+11.46)	138.59 (+5.49)

Projected net irrigation requirement

Boro rice

Cultivation of Boro rice suggests a steady increase of net irrigation requirement (NIR). The simulated data base reveals an increment of NIR by 6.2%, 3.7%, 11.4% and 15.5% corresponding to the year 2025, 2050, 2075, and 2099 respectively as compared that of the base year. This outcome provides important insight for the future food security of the country. On the basis of a GCM-coupled crop modeling exercise outcomes, Karim et al. (1998) claimed a decline of Boro yield by 7-10% under a moderate climate change scenarios. Elevated emissions of CO2 could have offset the loss of Boro yield due to positive affect on crop physiology. However, literature argues that the potential yield loss could not be completely offset by increase in CO2 concentration in the atmosphere (CCC, 2009). On the other hand, consistently with the prediction of a probable increase of precipitation in the year 2050 as compared that of 2025, the model suggests a little decrease of NIR by 2.4%. However, it would be consider the model uncertainty. A finer scale simulation might improve the understanding about the actual cause of the decline of NIR in 2050. The NIR scenarios for the projected year in presented in Figure 05.

Figure 05. Net irrigation requirement scenario for the south-eastern part of Bangladesh.

Potato

The changes of NIR for potato seem to be unchanged until the year 2025 and tend to decline by 0.8% by the year 2050. Simulated scenario suggests a sharp increase of NIR for potato by the year 2075 (16.9%) and 2099 (20.8%). Hijmans (2003) in a modeling study reported a decline of potato yield over Bangladesh by 25% by the year 2060 without adopting and adaptation measures.

Wheat

The NIR for wheat showed similar trends as compared that of Boro rice. It suggests a drop of NIR by only 2.03% in 2050 as compared that of 2025, while it is likely to be increased by 13.7% and 16.8% by the year 2075, and 2099 respectively in comparison to that of the base year.

IV. Conclusion

Bangladesh is considered as the most vulnerable country of the world to climate change impacts due to a number of hydro-geological and socio-economic factors. The international community also recognizes that Bangladesh ranks high in the list of most vulnerable countries on earth for climate change impacts. The South-East region of Bangladesh has already faced the worst look of climate change impacts. The increasing temperature, erratic precipitation and other natural disaster are seen in this region of at a high magnitude and increasing frequency. This research practices can help us with additional information for adopting better options to face the problem of apprehending climate change.

This modeling effort was done with a view to projecting the future climate scenario and to find out the climate change impact on crop production in the south east region of Bangladesh using the MAGICC/SCENGENE-Aqua Crop model. The research outcome suggests that this region would face the increase of temperature and rainfall variability. Increasing temperature and variable rainfall would affect the future crop production. Although it can be argued that the increasing trends of atmospheric carbon-di-oxide (CO_2) could afford to increase in production, simultaneously, it is likely to require higher amount of irrigation water due to the increase of temperature and subsequent evapotranspiration.

Irrigation intensive crops like Boro, Potato and Wheat would be affected severely because of increasing temperature and uncertain precipitation in winter. Diminishing rainfall in winter and erratic rainfall variability over time and space would consequently, increase the severity of moisture stress which in turn will lead to drought conditions. The net irrigation water requirement for the irrigation feed crops will increase for the future years.

It is to note that, AquaCrop model estimates the irrigation water requirement based only on soil moisture stress level and carbon-di-oxide (CO_2) fertilization. It does not include organic matter depletion, initial moisture stress, impact of salinity etc. Despite this simplicity, the study outcome provides important implications for the policy makers to ensure future food security and water management challenges.

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Publication Ethics

Authors are responsible for the contents of this article. This article or part of it is not published elsewhere neither is under consideration for publication. All the authors contributed, developed and approved this manuscript for submission and publication. There are no conflicts of interest to declare by the authors.

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