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CLIMATE CHANGE AND FOOD SECURITY IN BANGLADESH: AN APPLICATION OF DSSAT MODEL

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A historical analysis of two climatic parameters- temperature and rainfall during 1976-2008- in 34 meteorological stations in Bangladesh has been carried out. The yearly and monthly average maximum and minimum temperatures in the majority of the stations have been on the increase. The study identifies that the average annual maximum and minimum temperature have increased by about 0.019^{0}C and 0.015^{0}C per year respectively during the period mentioned. The rainfall for the same period also has an increasing trend in majority of the stations during monsoon and post-monsoon periods, while total rainfall during winter suggests a decreasing trend. The analysis also reveals that the changing pattern of temperature and rainfall in the selected 34 stations are significantly higher compared to the IPCC estimates of 100-year period ending in 2005. The research employs a DSSAT (Decision Support System for Agrotechnology Transfer) model and points out that rice yield might reduce in the range of 3.2 to 18.7 percent for an increased temperature by 2^{0}C and in the range of 5.33 to 36.0 percent for a surge by 4^{0}C, affecting food security of the country. Therefore, location-wise participative, appropriate and sustainable adaptation measures in terms of management of seed, crop, irrigation and fertiliser are necessary.

Keywords: Climate change, DSSAT model, Rice yield, Rainfall, Temperature.

INTRODUCTION

Climate change primarily includes changes in norms and patterns of temperature and consequently rainfall. These changes have significantly wide-ranging geographical, economic, social and political impacts (Nair, 2010). Often these impacts are not isolated but intricately linked to one another with ripple effects.

Global temperatures have been rising at an increasing rate as evidenced by data from IPCC (2007). The causes of climate change, variability and impacts one of the most widely discussed topics in the world for the last couple

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of decades. A number of researches have been carried out on trends of change in climate parameters in the context of Bangladesh (Chowdhury and Debsarma, 1992; Warrick et al., 1994; Karmakar and Nessa, 1997; World Bank, 2000; Debsarma, 2003). Warrick et al., (1994) and Debsarma (2003) provided general assessments of changes in temperature and precipitation in Bangladesh, while Chowdhury and Debsarma (1992) identified trends that are based on the analysis of historical data of some selected weather stations in Bangladesh. Karmakar and Nessa (1997) projected changes in the frequency and intensity of natural disasters resulting from climate change.

The changing climatic conditions have a significantly negative impact on agricultural production and food security. Agriculture in many countries needs to undergo significant reforms in order to meet the challenges of achieving food security and responding to climate change. Estimates show that world population will grow from the current 6.7 billion to 9 billion by 2050 with most of the increase taking place in South Asia and Sub-Saharan Africa. Taking into account the changes in the composition and level of consumption associated with growing household incomes, FAO estimates that feeding the world population will require a 70 percent increase in total agricultural production (Bruinsma, 2009).

At the same time, climate change threatens production's stability and productivity. In many areas of the world where agricultural productivity is already low and the means of coping with adverse events are limited, climate change is supposed to reduce productivity to even lower levels and make production more erratic (Stern Review, 2006; Cline, 2007; Fisher et al., 2002; IPCC, 2007). For instance, rice plant has nine growth stages with its three distinct growth phases and every stage has an optimum temperature range for its proper development. However, the critical temperatures differ with the variety and physiological status of the plant (Yoshida, 1981). Extreme temperatures, whether low and high, cause injury to the rice plant. High temperature is a constraint to rice production and can cause a significant yield reduction. Crops often respond negatively with a steep decline in net growth and yield, if temperatures exceed the optimal level of biological processes (Rosenzweig and Hillel, 1995).

Food security of Bangladesh significantly depends on rice production, contributing to over 63 percent of the caloric intake for urban consumers and over 71 percent for the rural population based on 2005 household survey data of BBS (BBS, 2007). The percentages are much higher for the poor. The per capita consumption of rice in Bangladesh is 162.30 kg per person per year and it is the highest among all South Asian countries (Titumir and Basak, 2010). Therefore, it is imperative to assess the future rice demands in advance so that necessary actions could be taken to overcome the food security challenge considering climate change impact along with population growth.

In quantitative terms, IPPC (2007) estimated that, by 2050, changing rainfall patterns with increasing temperatures, flooding, droughts and salinity (in coastal belts) could result in decline in rice production in Bangladesh by 8 percent and wheat by 32 percent against 1990 as the base year (MoEF, 2009). At the country level, studies using crop models with various assumptions about temperature and CO_2 level predicted a general decline in yield and output of rice crop in all seasons in 2050, compared to base year 1990. The rate of reduction varying between crops and models is also used (Karim et al., 1996).

The recent estimates using different models with changed assumptions predicted that the production of *aus* and *aman* rice might be reduced by 1.5-25.8 percent and 0.4-5.3 percent (*aus* and *aman* rice both are cultivated during the monsoon season in Bangladesh), respectively in 2050, due to the effect of high temperature (Hussain, 2008). Basak et al. (2010) predicted significant reduction in yield of some varieties of *boro* rice (which is cultivated in winter season) due to climate change. Yield reductions of over 20 percent and 50 percent have been predicted for the years 2050 and 2070, respectively (Basak et al., 2010). Besides this, climatic eventualities (believed to be increased in frequency due to climate change) like prolonged drought spell, floods, changes in rainfall pattern, cyclones, and salinity intrusion pose serious threats to the overall food production. FAO/GIEWS Global Watch (2007) reported at the time of the passage of cyclone SIDR, about 70 percent of the annual production of *aman* rice in most of the affected areas were partially or sometimes fully damaged. Salinity also decreases the terminative energy and germination rate of some plants (Rashid, 2004; Ashraf, 2002). Due to salinity effect, rice yield reduced about 23 percent during the period of 1985 to 2005 and 69 percent for shrimp culture in the country (Ali, 2005).

Several model-based simulation studies have been conducted to assess the impacts of climate change and variability on rice productivity in Bangladesh using the CERES-Rice model (e.g., Basak et al., 2009; Mahmood, 1998; Karim et al., 1996). These studies mainly focused on the effects of higher air temperature and atmospheric CO_2 concentration on rice yield.

The present study has three main tenets. Firstly, the paper has analysed the trends of changing climatic parameters, mainly temperature and rainfall pattern, for the period of 1976 to 2008 in Bangladesh. Secondly, it has explored the effects of climate change through increasing temperature and CO_2 concentration using DSSAT model on rice yield. Thirdly, it provides implications of climatic change on food security situation in Bangladesh, due to adverse impact on rice yield.

MATERIALS AND METHODOLOGY

Study Sites

The study was conducted in six major rice-growing locations (Rajshahi, Mymensingh, Satkhira, Barisal, Comilla and Sylhet) among six divisional areas in Bangladesh under different climatic scenarios (mentioned in *Table-7*). These locations covered High Ganges River Floodplain Agro-Ecological Zones (AEZ-11) for Rajshahi, Eastern Surma-Kushyara Floodplain (AEZ-20) for Sylhet, Young Meghna Estuarine Floodplain (AEZ-18) for Barisal, Ganges Tidal Flood Plain (AEZ-13) for Satkhira, Old Brahmaputra Flood Plain (AEZ-9) for Mymensingh and Old Meghna Estuarine Floodplain (AEZ-19) for Comilla region (*Figure-1*).

Data Collection and Analysis

To understand the changing pattern of temperature and rainfall, data on temperature and rainfall of 34 meteorological stations in Bangladesh were collected from the Bangladesh Meteorological Department (BMD) for the period of 1976 to 2008. These data were used to assess the trends for both maximum and minimum temperature and rainfall. Rainfall pattern has been assessed by analyzing changes in total rainfall during four seasons i.e., pre-monsoon (March-May), monsoon (June-September), post-monsoon (October-November) and winter (December- February) for the same period. In each case, only linear trend was assessed for the period of 1976-2008 and the nature (increasing or decreasing) and the level of significance of the trend was estimated from the R^2 value of the fit. It should also be noted that there are some missing data for some months at some stations, which have been excluded for the trend analysis.

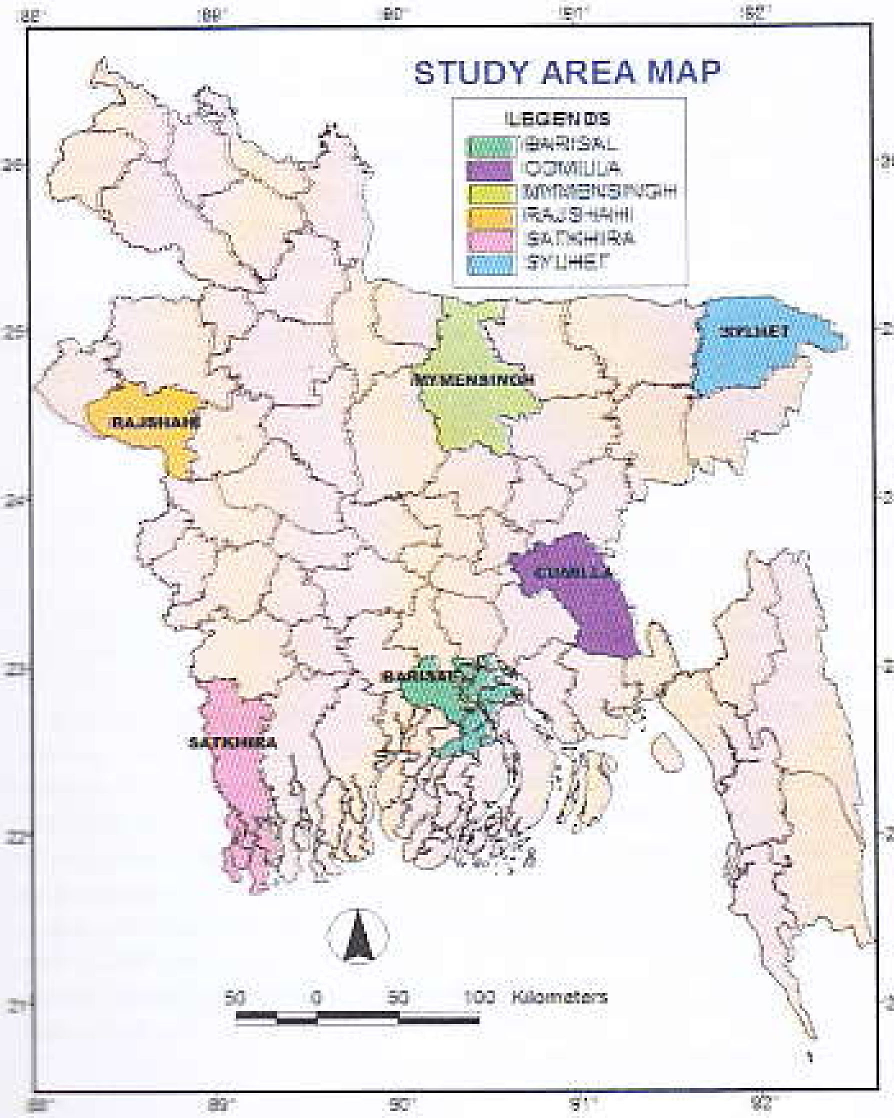
A simulation exercise has been conducted to estimate the rice demand future and per capita rice consumption data was collected from Household Income and Expenditure Survey 2010 (BBS, 2010). The projection of future population was estimated on the basis of exponential population growth model.

$$P_t = P_0 e^{rt}$$

Where, P_0= Population of the previous year, P_t = Population of the present year, t = Time interval between previous and present years, r = Annual growth rate of the population.

The demand of rice was calculated by multiplying the population and consumption data for those specified years. Rice consumption rate was calculated from HIES, 1995-96 and 2010. Average value of rice consumption is used in this study to calculate rice demand for the targeted years. Future production of rice has been estimated from the data reflecting the trend of rice production in 47 years (1961-2007).

Figure 1: Study Area Map



Crop Model and Soil and Crop Management Inputs

DSSAT modeling system is an advanced physiologically-based rice crop growth simulation model that has been widely applied to understand the relationship between rice yield, development phases and its environment. DSSAT uses a detailed set of crop specific genetic coefficients, which allow the model to respond to diverse weather and management conditions (Ritchie et al., 1987; Hoogenboom et al., 2003). The *boro* rice variety BR3 has been selected in the present study because genetic coefficients for this variety are available in the DSSAT modeling system. Although these varieties are not widely used at present, the effects of climate change and variability on these varieties provide insights into possible impact of climate change on yield of rice. Moreover, the model requires a quite detailed set of input data on soil and hydrologic characteristics (i.e., pedological and hydrological data) and crop management. Input data related to soil characteristics, including soil texture, number of layers in soil profile, soil layer depth, pH of soil for each depth, clay, silt and sand contents and organic matter were collected from Soil Resources Development Institute (SRDI), Dhaka and Bangladesh Rice Research Institute (BRRI). Moreover, crop management data required by the model, including planting method, transplanting date, planting distribution, plant population at seedling, plant population at emergence, row spacing, plant per hill, fertiliser application dose and irrigation application and frequency, were collected from BRRI.

Weather Data for Model Simulation

The simulation study was conducted to predict the average rice yield by using DSSAT model for the year 2008. Then five different climatic scenarios were set up to find out the rice yield to assess the food security situation for the target years (*Table-1*). These scenarios were considered on the basis of the IPCC and SRSE assumptions. IPCC (2007) considers four families representing socio-economic development and associated emission scenarios, A2, B2, A1, and B1. On the other hand, SRES emission scenario, the atmospheric CO_2 concentration is projected to increase from 379 ppm to >550 ppm by 2100 in SRES B1 to >800 ppm in SRES A1FI. Increasing of CO_2 at a level of 50 ppm, 100 ppm and 200 ppm with 379 ppm (the value reported for the year 2005 in the fourth assessment report of the IPCC) was taken into account. The average yield reduction predicted by DSSAT model has been used to find out the impacts of climate change on rice production as well as on food security in the future.

Table -1: Different climatic scenarios

Assumptions	Predicted year	Scenario
Increased Tmax 2⁰C+ Tmin 2⁰C+50 ppm CO_2	2050	A
Increased Tmax 2⁰C+ Tmin 2⁰C+100 ppm CO_2	2050	B
Increased Tmax 4⁰C+ Tmin 4⁰C+50 ppm CO_2	2070 & 2100	C
Increased Tmax 4⁰C+ Tmin 4⁰C+100 ppm CO_2	2070 & 2100	D
Increased Tmax 4⁰C+ Tmin 4⁰C+200 ppm CO_2	2070 & 2100	E

Source: Assumptions based on the IPCC and SRSE assumptions, 2008

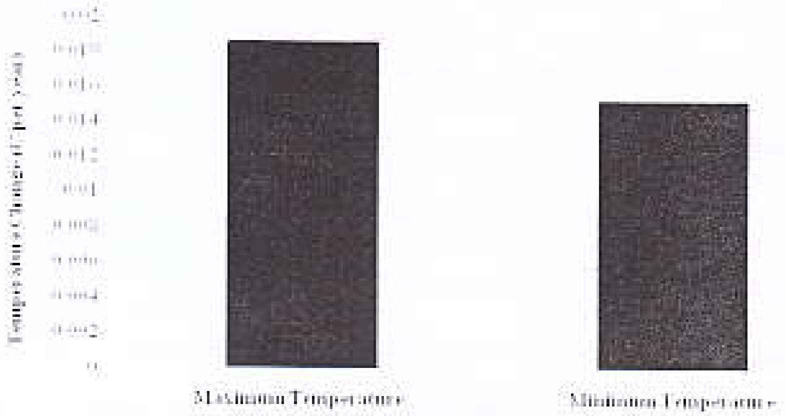
RESULTS AND DISCUSSION

Changes of Maximum and Minimum Temperature and Rainfall

The variation trend of yearly average maximum temperature has been analysed for each of the 34 stations and the results are summarized in *Table-2*, which show that in 28 out of the 34 stations, yearly average maximum temperatures exhibit increasing trends. Of these, the increasing trends in 13 stations were significant at 99 percent confidence level. On an average (i.e., average value of 34 stations) yearly average maximum temperature of Bangladesh has been found to be increasing at a rate of 0.0186⁰C per year.

Like the yearly average maximum temperature, yearly average minimum temperature has also increased at a rate of 0.0152⁰C per year during the period of 1976 to 2008. Among the 34 stations, 27 showed an increasing trend, with significance level of 11 stations above 99 percent. On the other hand, only 7 stations followed decreasing trend during the same period.

Figure-2: Total changes in yearly average temperature in Bangladesh during 1976-2008



Source: Authors' calculation based on BMD data, 2012

Table-2: Summary of change in annual temperature pattern for the period of 1976-2008

Climate Change Phenomena (annual)	No. of stations showing increasing trend	No. of stations showing decreasing trend	Average temp. changes per year °C /year	Increasing trend (No. of stations)			Decreasing trend (No. of stations)		
				95% LOS	99% LOS	NS	95% LOS	99% LOS	NS
Maximum Temperature	28	5	0.0158	1	13	14	0	0	5
Minimum Temperature	27	7	0.0152	3	11	13	2	1	4

Note: LOS: Level of significance; NS: Not significant

Source: Authors' calculation based on BMD data, 2012

Changes in monthly average maximum temperatures, calculated from trend lines, show the increasing trends for all months except for January (*Table-3*). Significant increase was observed for the months of May through September and also for February and December. An average increase in temperature for each of these months was about 1°C for the 33-year period. However, it decreased by 0.647°C for the month of January.

Except for January and November, monthly average minimum temperatures reveal increasing trends for the majority of the weather stations (*Table-4*). These were significant, especially for the months of April through August and February, October and December. For the 10 months (February-October and

December), the average (i.e., average of 34 stations) total increase was about 0.7°C, while for January and November, it was about 0.2°C.

Table-5 shows the season-wise trends in total rainfall for the 34 meteorological stations in Bangladesh for the period of 1976-2008. It was found that the observed trends are not statistically significant in most cases. Nevertheless, majority of the stations witnessed increasing trends during the monsoon and post-monsoon seasons, while a significant number of stations saw decreasing trends during winter. These results are consistent with the generic understanding on climate change indicating that wet periods would become wetter and dry more drier.

Table-3: Magnitude and significance of changes in monthly-average maximum temperature

Month	No. of stations observing increasing trend	No. of stations witnessing decreasing trend	Total temp change (°C) in 33 years (1976 – 2008)	Average temp. changes per year °C /year	Increasing trend (No. of stations)			Decreasing trend (No. of stations)		
					95% LOS	99% LOS	NS	95% LOS	99% LOS	NS
January	11	23	-0.6488	-0.0196	4	0	7	8	3	12
February	32	2	1.1583	0.0351	4	3	25	1	0	1
March	17	17	0.0792	0.0024	1	0	16	1	1	15
April	18	16	0.3300	0.0100	7	0	11	2	1	13
May	32	2	0.9042	0.0274	3	2	27	0	0	2
June	33	1	1.1154	0.0338	7	8	18	0	0	1
July	34	0	1.1121	0.0337	8	19	8	0	0	0
August	34	0	1.2309	0.0373	7	19	8	0	0	0
September	33	1	0.8504	0.0258	2	15	16	0	0	1
October	24	10	0.5544	0.0168	1	7	16	0	0	10
November	22	12	0.4686	0.0142	4	4	14	1	0	11
December	31	3	1.1616	0.0352	1	13	17	0	0	3

Note: LOS: Level of significance; NS: Not significant

Source: Authors' calculation based on BMD data, 2012

Table-4: Magnitude and significance of changes in monthly-average minimum temperature

Month	No. of station witnessing increasing trend	No. of station observing decreasing trend	Total temp. change (°C) in 30 years from 1976 to 2008	Average temp. changes per year °C/year	Increasing trend (No. of stations)			Decreasing trend (No. of stations)		
					95% LOS	99% LOS	NS	95% LOS	99% LOS	NS
January	16	18	-0.2175	-0.0066	1	3	12	2	4	12
February	29	5	0.5207	0.0279	5	9	15	0	1	4
March	24	10	0.5511	0.0167	4	3	17	1	1	8
April	28	6	0.5808	0.0176	4	0	24	0	0	6
May	29	5	0.9009	0.0273	9	3	17	0	0	5
June	31	3	0.5379	0.0163	3	5	23	1	0	2
July	30	4	0.6336	0.0192	7	8	15	0	0	4
August	28	6	0.5148	0.0156	6	5	14	0	0	6
September	23	11	0.2871	0.0087	1	5	17	0	1	10
October	30	4	0.7788	0.0236	3	7	20	1	0	3
November	14	20	-0.1683	-0.0051	1	1	12	0	1	19
December	25	8	0.6501	0.0197	10	2	14	2	1	5

Note: LOS: Level of significance; NS: Not significant

Source: Author's calculation based on BMD data, 2012

Table-5: Season-wise changes in total amount of rainfall during 1976-2008

Seasons	No. of station showing increasing trend	No. of station showing decreasing trend	Increasing trend (No. of station)				Decreasing trend (No. of station)			
			90% LOS	95% LOS	99% LOS	NS	90% LOS	95% LOS	99% LOS	NS
Winter (Dec. to Feb.)	16	18	1	0	1	14	2	0	1	15
Pre-monsoon (Mar. to May)	20	14	2	2	1	15	1	0	0	13
Monsoon (June to Sept.)	31	3	2	1	3	25	0	0	0	3
Post-monsoon (Oct.-Nov.)	30	4	3	3	3	21	3	0	1	3

Note: LOS: Level of significance; NS: Not significant

Source: Authors' calculation based on BMD data, 2012

Impacts of Climate Change on Rice Yield

These predictions have been made using a fixed concentration of atmospheric CO_2 of 379 ppm (the value reported for the year 2005 in the Fourth Assessment Report of the IPCC), irrigation application (860 mm in 14 applications), fertiliser dose (125 kg/ha in 3 applications of nitrogen) with the planting date on 15 January. Soil data and climate data have been varied on location basis.

DSSAT model predicts that maximum rice yield was 5427 kg/ha at Comilla and minimum 3102 kg/ha at Rajshahi in 2008. Moreover, yield of rice was above 5000 kg/ha for the locations of Barisal, Comilla and Sylhet, whereas it was below 4000 kg/ha for Rajshahi and Satkhira. Therefore, significant amount of *boro* rice yield varied in different locations for different climatic and hydrological properties of soil. The average yield of *boro* for these six locations was found to be 4564 kg/ha in 2008.

Table 6: Location-wise prediction of rice yield

Location	Rajshahi	Mymensingh	Satkhira	Barisal	Comilla	Sylhet
Rice yield (Kg ha^{-1})	3102	4468	3934	5096	5427	5359

Source: DSSAT model prediction

Maximum temperature had significant negative impact on *boro* rice yield, reducing by about 2.6 to 13.5 percent due to the increase of maximum temperature by 2^0C from the base year temperature and 0.11 to 28.7 percent for a change of 4^0C. The average value (average percentage change of rice yield for 6 locations) of yield reduction as regards to maximum temperature was found to be above 6 percent for 2^0C and 16 percent for 4^0C (*Table-7*). The rice plant follows nine stages in three distinct growth phases and every stage requires an optimum temperature for its proper development. Extreme temperatures, whether low and high, cause injury to the rice plant. Daily average maximum and minimum temperatures exceed the optimal level and cause a significant yield reduction through a steep decline in net growth of rice plant.

Like maximum temperature, minimum temperature also had negative impact on *boro* yield, reduction of about 0.40 to 13.1 percent due to increase of 2^0C from base point minimum temperature in 2008 and 0.11 to 15.5 percent for 4^0C. The averages (average percentage change of rice yield for 6 locations) of yield reduction for minimum temperature were above 4 percent for 2^0C and above 8.5 percent for 4°C. Therefore, maximum temperature had the most significant negative effect on rice yield compared to the minimum temperature.

Combined effects of maximum and minimum temperatures are enormously significant compared to their individual effect on rice yield. Rice yield was found to be drastically reduced due to rise of the maximum and minimum temperatures for the period under study. *Boro* rice yield was found to have reduced by 3.2 to 18.7 percent for 2°C and about 5.33 to 36.0 percent in case of a rise by 4°C. The average (average percentage change of rice yield for 6 locations) yields reduction of the two temperature parameters were above 10.4 percent in case of the rise of temperature by 2°C and above 22.87 percent for 4°C.

The results of rice yield under different concentrations of CO_2 are shown in *Table-7*. These have been reached with the use of a fixed concentration of atmospheric CO_2 of 379 ppm and then were increased by levels of 50 ppm,

Table 7: Average percentage change of *Boro* rice yield under various

Climate change phenomena	% change in rice yield
a) Temperature Effect	
Increased Maximum Temperature 2°C	-6.09
Increased Maximum Temperature 4°C	-16.0
Increased Minimum Temperature 2°C	-4.17
Increased Minimum Temperature 4°C	-8.9
Increased Tmax 2°C+ Tmin 2°C	-10.41
Increased Tmax 4°C+ Tmin 4°C	-22.87
b) Carbon dioxide Effect	
Increased 50 ppm CO_2	+3.47
Increased 100 ppm CO_2	+6.47
Increased 200 ppm CO_2	+11.97
c) Temperature and Carbon dioxide Effect	
Increased Tmax 2°C+ Tmin 2°C+50 ppm CO_2	-8.28
Increased Tmax 2°C+ Tmin 2°C+100 ppm CO_2	-4.95
Increased Tmax 2°C+ Tmin 2°C+200 ppm CO_2	+1.37
Increased Tmax 4°C+ Tmin 4°C+50 ppm CO_2	-24.66
Increased Tmax 4°C+ Tmin 4°C+100 ppm CO_2	-21.79
Increased Tmax 4°C+ Tmin 4°C+200 ppm CO_2	-14

Source: DSSAT model prediction, 2009

100 ppm and 200 ppm. Increased atmospheric CO_2 concentration was likely to have some positive effects on rice yield. If the level of atmospheric CO_2 concentration increased by 50 ppm from the year 2005 (IPCC reported value 379 ppm), *boro* rice yield was found to be increased by about 2.1 to 4.4 percent, while it was 4.0 to 9.6 percent in case of an increase by 100 ppm and 5.2 to 18.2 percent under the 200 ppm scenario. Simulations have also been conducted under different climatic scenarios of temperature and carbon dioxide concentration (*Table-7*).

Future Population and Food Demand in Bangladesh

As the population continues to grow in Bangladesh, a huge pressure is being built to ensure the provision of an adequate supply of food. If the annual population growth rate of 1.34 percent per year (BBS, 2011) continues at the business as usual rate based on the year of 2011 (152.518 million), estimates suggest that the total population might stand at 172.53 million in 2020, 260.23 million in 2050, 342.26 million in 2070 and 516.24 million in 2100 in Bangladesh. In 2100, under the business as usual scenario, the population could be more than half a billion. Therefore, a huge amount of food will be required for the future generations to meet their demands.

The per capita current consumption of rice in Bangladesh is 162.30 kg per person per year. An exponential population growth model predicts that if the production goes at the business as usual rate, Bangladesh might face food shortage. Rice shortage has been estimated to be 2.46 million tons and as a result, more than 10 million populations may face rice shortage in 2050, which is equivalent to 3.85 percent of the projected population of that particular point of time. Therefore, a considerable level of population might face a remarkable amount of rice shortage in years to come (*Table-8* and *9*).

Table-8: Paddy rice demand and production (million ton)

Year	Demand	Production*
2020	42.30	44.10
2050	63.76	61.30
2070	83.85	72.30
2100	126.48	90.80

Note *: Level of significance below 90 percent

Source: Authors' calculation based on FAOSTAT and World Bank data

Future Food Security Conditions under Different Scenarios in Bangladesh

The study has found a significant production gap of rice during 2050, 2070 and 2100 under five different scenarios of IPCC (A, B, C, D and E, earlier discussed in Materials and Methodology section), which may cause food security situation more vulnerable in those years in Bangladesh.

DSSAT model predicts that rice yield may be reduced (on an average for the selected six regions in Bangladesh) by 8.28 percent in case of scenario A, 4.95 percent for B, 24.66 percent for C, 21.79 percent for D and 14 percent for E (*Table-7*). These amounts of yield reductions might have significant negative impact on food security situation for the country.

It is estimated that if the current trend of production persists, on an average about 7.54 and 5.49 million tons of rice shortage would be there compared to the demand in 2050 under the scenario A and B, respectively. As a result, more than 30 and 22 million people may face rice shortage, which is equivalent to 11.80 percent and 8.80 percent of the projected population in 2050, for the respective scenarios.

Similarly, the amount of shortage of rice in 2070 might be 29.38, 27.30 and 21.67 million tons on an average under the C, D and E scenario, respectively. The number of population might face such rice shortage amounts more than 119; 111 and 88 million, equivalent to 35.04, 32.56 and 25.96 percent respectively, of the projected population under the above-mentioned three scenarios.

The gap between demand and production of rice might also increase further in 2100. Continuation of the prevailing trend might witness a demand and production gap of rice by 58.07; 55.47 and 48.39 million tons under the scenarios of C, D and E, respectively. Consequently, 45.90 (273.02 million), 43.85 (226.40 million) and 38.25 percent (197.50 million) of the projected population might also face difficulty in the quantity of rice in 2100.

Table-9: Percentage of deprived population from rice under different climate scenarios

2050			2070				2100			
P	A	B	P	C	D	E	P	C	D	E
3.65	11.80	8.80	13.75	35.04	32.56	25.96	28.20	45.90	43.85	38.25

Note: P: Demand-production gap due to huge population pressure on rice

Source: Authors' calculation based on different climatic scenarios using DSSAT model based on FAOSTAT and World Bank data

CONCLUSION

Long term changes in the patterns of temperatures and rainfall, which are part of climate change, are expected to shift production seasons, pest and diseases patterns and modify the set of feasible crops affecting production, prices, income and ultimately lives and livelihoods of people. In Bangladesh, different climate change induced events, such as recurring floods, riverbank erosion, drought in dry season, salinity intuition, among others, have been leaving impacts on the yields of crops and augmenting vulnerability in many areas. Contextual analysis suggests that unless urgent actions are taken, climate change may undermine the efforts to ensure food security for the country in near future.

The findings indicate that changing the pattern of temperature and rainfall for the selected 34 meteorological stations of Bangladesh is significantly higher compared to the IPCC projection on a world scale for 100-year period ending in 2005, meaning considerable negative impact on rice yield. The DSSAT model also predicts a reduction in rice yield at significant rate due to increased maximum and minimum temperature for the country. The current study finds that rice yield may be reduced by 3.2 to 18.7 percent due to an increase of temperature by 2^{0}C from the base-year-temperature and 5.33 to 36.0 percent for a rise by 4^{0}C.

The application of DSSAT model also suggests that increasing CO_2 concentrations are likely to offset only slightly the adverse effects of other climatic parameters on rice yield, but it is comparatively lower than that of temperature effect for Bangladesh. Boro rice yields are found to be increased by 2.1 to 4.4 percent for a rise of the atmospheric CO_2 concentration by 50 ppm from the year 2005; it is 4.0 to 9.6 percent in case of an escalation by 100 ppm and 5.2 to 18.2 percent under the 200 ppm scenario.

However, most scenarios indicate that climate change is likely to reduce rice yield severely that might cause high degree of food insecurity in the country. The study shows that rice shortage would be about 6 million tons (average) and consequentially 10 percent of the projected population may face difficulty in procuring rice in 2050.

There is, thus, a need to devise a long-term strategy for Bangladesh to achieve food security for all. Food security could be strengthened by increased production of food, augmented diversification of its economy, enlarged employment and income generating opportunities and larger investment in this sector. In addition, due to changes of climatic conditions, this dependence may further increase and create more pressure on stability of food for the country. It is also necessary to develop high temperature-resistant rice varieties and modify management practices to off-set adverse effects of climate change. Moreover, participative, location-wise and scientifically appropriate sustainable adaptation practices are essential to cope with the changing climatic conditions; otherwise, it would be extremely difficult to make communities more resilient towards adverse impacts of climate change and to ensure food security for Bangladesh in near future.

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