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Future Climate Change and Moisture Stress: Impact on Crop Agriculture in South-Western Bangladesh

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Abstract

Scenario of Moisture Stress in soils and its effects on major crops in South-western region of Bangladesh (grid cell: 22.5^{0}N - 25.0^{0}N, 87.5^{0}E - 90.0^{0}E) has been assessed based on climate scenarios for two projection years 2030 and 2075 compared to the 1990 baseline. The climate scenarios were developed using an ensemble of 15 GCM outputs by using MAGICC/SCENGEN version 5.3 model of the IPCC. Then CROPWAT model developed by the FAO was used to predict the soil moisture deficit (SMD) for the projected climate scenarios to assess crop water requirement (CWR) and variation in yield of the main rainfed crops in the said region.

The model predicted 1.49°C and 4.12°C increase of temperature in winter (DJF) and 0.87°C and 3.16°C increase of temperature in monsoon (JJA) in projection year 2030 and 2075 respectively compared to the 1990 baseline assuming A1 BAIM scenario. It was also found that winter (DJF) rainfall is likely to increase by 3.8 and 10.4 percent by the year 2030 and 2075. The pre-monsoon (MAM) rain likely to be less varying over the projected years, though post-monsoon (SON) rainfall show a huge increase of 6.2 and 17 percent by the year 2030 and 2075 respectively. Monsoon rainfall was also found to increase 7.8 percent by the year 2075. Using the projected scenarios as input for CROPWAT model, it was found that due to soil moisture stress, rainfed HYV *Boro* rice and potato are likely to face increased yield reduction by 2075, which are 4% and 8.7% respectively in addition to the 1990 baseline. To cope with the situation even up to 22 percent more irrigation would be required in worst cases like potato production. Despite of increase in projected rainfall over every season, unavailability of rainfall in planting periods and different growing periods would hamper crop production a big. As a result food security is likely to be threatened under climate change. Development of irrigation system, temperature tolerant variety adoption, adjustment in present farmers' practice in irrigation and planting etc are urgent to adapt with the potential threat in agriculture posed by climate change. More in-depth researches are therefore required for future planning of the poverty ridden country.

1. Introduction

Despite outputs of many models for estimating the impacts of climate change on crop production vary widely due to multidimensional complications (Karim *et al*., 1999; Reilly, 1996; Reilly *et al*., 1996), generally the simulation results support the statement that global agricultural production might not suffer much, though regional effects will vary widely (Reilly *et al*., 1996a). The effects will be more acute in the subtropical and tropical (Karim *et al*., 1999) developing countries (Walker and Steffen, 1997) such as Bangladesh. The country is already a victim of hydro-meteorological variability, as it suffers from moisture stress during the pre-monsoon and post-monsoon periods, when the Potential Evapo-transpiration (PET) stays lower than the available moisture in soil due to uncertainty of rainfall for the first period and insufficient rainfall for the second period (Karim *et al*., 1990). In both periods, rising temperature coupled with unavailability of rainfall hike up the moisture stress in soil leading the condition to an agricultural drought which eventually affects the major crops (e.g., HYV *Boro*, *Aus*, Wheat, Pulses, Sugarcane and potato) and cause significant damage in production where irrigation is limited

(Ahmed, 2006). Such phenomena in Bangladesh normally occur in pre-*Kharif* months, affecting *Boro,* wheat and potato cultivation in the north-eastern part of Bangladesh and in *Kharif* season, affecting mainly transplanted *Aman* cultivation. On the other hand, the south-western part of the country faces the same vulnerabilities with a dissimilar fashion as presence of high salinity in both surface and ground water restrict irrigation and crop growth. It is expected that, with the changing climatic conditions over Bangladesh, eventually the country has to face these vulnerabilities in crop agriculture in future.

This paper studies 15 AOGCM outputs appropriate for south-western quarter of Bangladesh following the IPCC 2007 guidelines to project possible changes in climatic condition until 2075 and analyze how this change would impact crop agriculture in the region in terms of soil moisture deficiency.

2. Climate and Crop agriculture vulnerabilities in South-West Bangladesh

Generally crop agriculture is vulnerable in Bangladesh and is observed in many different ways (Karim *et al*., 1999). As a whole, Bangladesh is highly susceptible to climate induced geo-physical events like floods and droughts (eg. Karim, 1996; Huq *et al*., 1996). Paddy is the most important agricultural crop in Bangladesh followed by Wheat in terms of cereal production (Karim *et al*., 1999) though this crop faces the threats of both drought and flood in different regions of the country. Along with paddy wheat, maize and many vegetables face the same threats. Figure 1 presents a map of pre-*kharif* prone areas of Bangladesh.

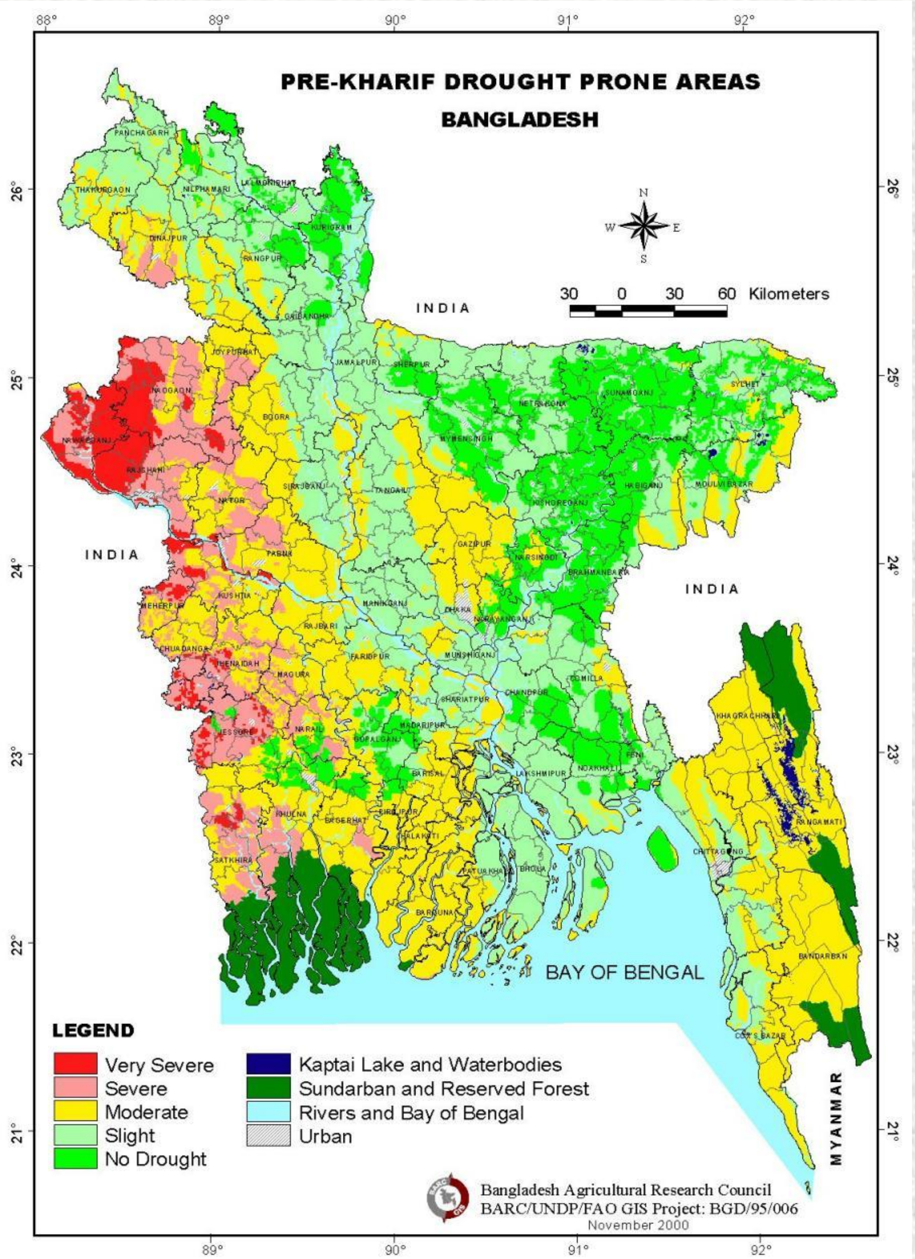

Figure I: Map Pre-*Kharif* drought prone areas of Bangladesh (Source: BARC/UNDP/FAO GIS Project: BGD/95/006)

In South-Western part of Bangladesh, coupled with climatic conditions, salinity plays an important role in crop agriculture. The SRDI (2000) survey states that about 1.02 million hectares out of 1.459 hectares of cultivable land of the total coastal area of the country is affected by soil salinity for various degrees, of which about 58 percent (computed from SRDI soil salinity data) lie in the south-western part. Due to soil salinity, irrigation in the dry season (locally known *Rabi* season) is restricted in this part of the country, which leads to dependency on rainfed crops. Drainage congestion and resultant waterlogging also is another important factor hindering crop agriculture in the region (Roy, 2004). According to WB (2000), together with salinity and waterlogging, a possible reduction of *Aman* and *Boro* paddy area due to longer duration of flooding and restriction in irrigation respectively would lead country's rice production to a possible decline in future. CEGIS (2006) has already reported that due to Sea Level Rise the High Yielding Verities of *Aman* paddy would start losing increasing amount of suitable land for cropping in the south-western coastal region.

In the lower Ganges floodplains, low flow conditions are observed during drier months which make irrigation severely restricted. Low pressure on the upstream gives space to uprise of saline tidal water further north and make surface water irrigation more unsuitable for crop agriculture. Under such conditions farmers are forced to exploit ground water for irrigation purposes, which also in most cases become saline. In addition to saline water, organic matter in the soils of the coastal zone is low to high, ranging from 1.72% to 4.93% (SRDI, 2000). Presence of nitrogen in soils in coastal areas is also very low, varies from 0.058% to 0.109%, which might be caused by high decomposition rates or organic matter in the region (SRDI, 2000). Lack of organic matter and nitrogen in soil hinders crop agriculture in the region.

3. Climate change and crop vulnerability: Previous modeling exercises

Karim *et al*., (1998) attempted a GCM coupled crop model called DSSAT version 3.0 (for details of the model see Tsuji *et al*., 1994) to see crop vulnerability under climate change in Bangladesh. They reported, *Aus* production would suffer by 27% while wheat would suffer a 61% reduction under moderate climate change scenario in Bangladesh. The finding also indicate that, the CO_2 fertilization would be able to prevent crop loss to a certain level, but again rising of temperature well over 4^0C would not be able to completely offset the possible yield loss despite of elevated level of CO_2 . The modeling effort considered variety of soils and many edaphic and agronomic parameters into account. Given the possibility of increased salinity in the coastal areas of Bangladesh under climate scenarios, crop production is expected to be further vulnerable. Habibullah *et al* (1998) reported that, the effects of soil salinity on *Aus* production would be detrimental as grain production would be reduced up to 15 percent compared to the baseline conditions under moderate climate change scenario while *Aman* production would see a reduction of more than four folds under severe climate change scenario.

4. Climate Change in Bangladesh: GCM projections

Since early 1990s a number of General Circulation Models (GCMs) have been exercised for projecting possible future temperature and precipitation pattern in Bangladesh. The BUP-CEARS-CRU (1994) attempted first on GCM model in Bangladesh where it reported 0.5 to 2.0^0C rise in temperature in Bangladesh by the year 2030 under 'business as usual' scenario. It also projected an increase of 10-15% in precipitation by the motioned projected year. The ADB (1994) study used 4 GCMs to project climate change: CSIRO9, CCC, GFDLH and UKMOH. There are many outputs in this study following the IPCC scenarios, however, a summary of the results of this study show an increase in monsoon rainfall and decrease in dry season rainfall for 2010 and 2070 projection years. The study indicated 0.3^0C increase in temperature by the year 2010 and for 2070 the corresponding increase would be 1.5^0C. Ahmed and Alam (1998) reported an increase in temperature by 1.3^0C and 2.6^0C by the projection years 2030 and 2075 respectively. They projected a negligible amount of rainfall in dry seasons in the projection years while monsoon rain were projected to increase about 12 and 27 percent for the two projection years, respectively. The WB (2000) used outputs of Mirza (1997) in their study which developed climate change scenarios using a number of GCMs. The results show similarities with Ahmed and Alam (1998). Mirza (2005) again exercised an ensemble of GCMs instead of any particular model and its validation analysis for Bangladesh Climate Change case. The study suggests that the mean rainfall over Bangladesh would be increasing with global warming.

Agrawala *et al.* (2003) used the MAGICC driven SCENGEN database to produce a best estimating ensemble of 11 GCMs for projecting Climate Change Scenario in Bangladesh. The results were obtained using IPCC B2 SRES scenario and suggests that annual temperature would increase up to 1.4^0C and 2.4^0C by the projection year 2050 and 2100. Dry season precipitation was projected as 1.7% and 3.0% reduced for the projected years, respectively. An increase in monsoon precipitation up to 6.8 and 11.8 percent by the year 2050 and 2100 was also found in the study. However, unlike other GCM out puts, Choudhury *et al.* (2005) obtained results using HadCM2 regional model suggesting an high increase in pre-monsoon and winter precipitation.

5. Objective and Methodology

The objective of the study was to use the CROPWAT model (FAO 1979, 1998) to predict soil moisture deficit (SMD) with climate change scenario and assess crop water requirement (CWR) and the variation in yield of the main rainfed crops in southwestern part of Bangladesh under the changing climatic conditions. Climate change scenarios were assessed by coupled MAGICC (**M**odel for the **A**ssessment of **G**reenhouse-gas **I**nduced **C**limate **C**hange)-SENGEN (SCEnario GENerator) model version 5.3 which is consistent with the IPCC Fourth Assessment Report (FAR).

5.1 Choosing of GCMs

The idea of averaging more than one GCM experiment and constructing a composite pattern for future climate change was first introduced by Santer *et al.* (1990), as later Hulme *et al*. (2000) reported the clear supremacy of the technique over just only one GCM. As it is observed that most GCMs are consistent in producing future temperature projection under climate change scenarios, in this study all 20 GCMs provided by the MAGICC/SCENGEN software were validated using the precipitation dataset provided by the software itself. Validation analysis was performed on the region 18.8^0 to 28.8^0 N latitudes and 86.3^0 to 93.8^0 E longitudes for 4 seasons, winter (December, January and February-denoted by DJF), pre-monsoon (March, April and May-denoted by MAM), monsoon (June, July and August-denoted by JJA) and post-monsoon (September, October and November-denoted by SON) and best 4 GCMs projecting future precipitation change for each season were selected by future climate change projection for the region. Using the selected GCMs for each of the 4 seasons, temperature and precipitation change for the year 2030 and 2075 were projected. A list of the best 4 GCMs identified by validation analysis for each season is provided in Table I. From the monthly global projections of future temperature and rainfall provided by the MAGICC/SCENGEN software using corresponding best estimating 4 GCMs, data for south-western Bangladesh was extracted from latitudes 22.5^0 to 25.0^0 and longitude 87.5^0 to 90.0^0. Projections were done using A1-BIM scenario.

TABLE I: BEST 4 GCMS PROJECTING FUTURE PRECIPITATION FOR EACH OF THE 4 SEASONS FOUND IN VALIDATION ANALYSIS BY MAGICC/SCENGEN

GCM rank	Winter (DJF)	Pre-monsoon (MAM)	Monsoon (JJA)	Post-monsoon (SON)	Annual
1	ECHO-G	ECHO-G	INMCM-3.0	UKHADGEM	UKHAD-CM3
2	GISS-ER	CCCMA-3.1	UKHAD-CM3	UKHAD-CM3	INMCM-3.0
3	GISS-EH	MRI-232A	GFDLCM2.0	CNRMCM3	CCSM-3.0
4	CSIRO-3.0	INMCM-3.0	CSIRO-3.0	GFDLCM2.1	CCCMA-3.1
Total 15 GCMs used in analysis					

5.2 Observed data set

Long term observed data set for precipitation, temperature, humidity, sunshine hour and wind speed was obtained from Bangladesh Water Development Board (BWDB) data set available for 1954-2002. Data from 6 stations representing south-western zone of Bangladesh were selected to extract observed data. These six meteorological stations are Khulna, Satkhira, Madaripur, Barisal, Faridpur and Jessore. Also 32 stations data provided by the BWDB data set was also analyzed to observe the trend of rainfall and temperature in Bangladesh.

5.3 Simulation of CROPWAT model

The CROPWAT model version 4.3 for windows was used to analyze climate and crop data to project future crop water requirement (CWR) and Soil Moisture Deficiency (SMD). Crop data was obtained from Allen *et al.* (undated). At this step of its development, the MAGICC/SCENGEN can only give temperature and rainfall for 2030 and 2075. Therefore other required parameters like humidity, sunshine hour and wind speed were estimated using the current trend analyzed from the BWDB data set. Five and ten percent reduction in sunshine hour was estimated for 2030 and 2075 while a corresponding increase by 5% and 10% of humidity was projected. Wind speed was kept unchanged from the 1990-2002 average. The other required parameters for 2030 and 2075 were used as defined in the CROPWAT model.

6. Results

6.1 GCM outputs: Temperature

The GCM outputs provided by MAGICC/SCENGEN for the south-western region of Bangladesh shows that the average increase of temperature would be 0.88^0C and 2.42^0C for the year 2030 and 2075, respectively. The results also show that the highest increase in temperature would occur in the winter months (DJF) which is as high as 1.49^{0}C and 4.12^{0}C for the year 2030 and 2075, respectively. The monsoon season shows lowest hike of temperature in the region (0.87^{0}C increase by 2030 and 2.52^{0}C increase by 2075) while pre-monsoon and post-monsoon are persistent with medium hike in temperature. A summary of the seasonal differences of temperature projected for 2030 and 2075 are presented in Table II.

TABLE II: EXTENT OF FUTURE CHANGES IN TEMPERATURE IN SOUTH-WESTERN BANGLADESH

Year	Average Temperature (Temperature Increase) ^{0}C				
	DJF	MAM	JJA	SON	Annual
2030	20.70 (1.49)	29.34 (1.05)	29.78 (0.87)	27.01 (1.14)	26.45 (0.88)
2075	23.33 (4.12)	31.20 (2.91)	31.44 (2.53)	29.03 (3.14)	27.99 (2.42)

The results also reveal that there is a general increasing trend in temperature which is consistent over seasons. Projection year 2030 shows an annual increase of 0.88^{0}C in temperature while year 2075^{0}C shows an annual increase of 2.42^{0}C. The monthly average temperature obtained from the GCM exercises are presented in Figure II.

However, these GCM results to some extent entirely concur with the observed trend of increasing rate of temperature in different seasons. The observed BWDB 1958-2002 dataset suggests a rapid increase of winter (DJF) and post monsoon (SON) temperature over 1998-2002 average in comparison to 1958-1990 average. The 1991-2002 average and 1998-2002 average was compared to the 1958-2002 average. It has been found that in last 5 years in the dataset (1998-2002) winter temperature has increased about 0.4^{0}C in compare to the 1958-2002 average while even 1991-2002 average suggest no change in temperature in compare to 1958-2002 average. The temperature of

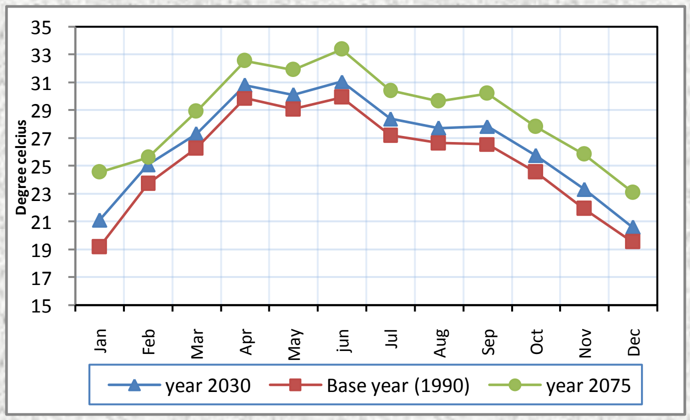

FIGURE II: FUTURE CHANGES IN TEMPERATURE OVER SOUTH-WESTERN BANGLADESH

monsoon and post-monsoon also show a significant increase while pre-monsoon still shows a little change. Table III summarizes the observed trend of temperature over Bangladesh.

6.2 Changes in precipitation

Like temperature, increasing trend for precipitation in all seasons was found. An annual increase of 2% and 10.1% by the year 2030 and 2075, respectively show an increasing trend in the rate of increase of annual precipitation over the south-western region. Results suggest the highest hike in precipitation in post monsoon followed by winter as post-monsoon rainfall would increase by 6.2% and 17.0% by 2030 and 2075, respectively while winter rainfall would show a corresponding increase of 3.8% and 10.4%. Table IV presents a summary of the GCM results for precipitation over the region.

TABLE III: OBSERVED CHANGES IN TEMPERATURE OVER SOUTH-WESTERN BANGLADESH

	Temperature (change) ^{0}C				
	DJF	MAM	JJA	SON	Annual
1958-1990 average	26.57	32.65	31.25	30.56	30.26
1991-2002 average	26.59 (+0.02)	32.66 (+0.02)	31.67 (+0.43)	31.08 (+0.51)	30.50 (+0.24)
1998-2002 average	26.97 (+0.40)	32.54 (-0.10)	31.76 (+0.51)	31.32 (+0.76)	30.65 (+0.39)

TABLE IV: EXTENT OF FUTURE CHANGES IN PRECIPIATION IN SOUTH-WESTERN BANGLADESH

Year	Precipitation Increase (%)				
	DJF	MAM	JJA	SON	Annual
2030	3.8	1.3	2.8	6.2	2.0
2075	10.4	3.7	7.8	17.0	10.1

The results of monthly precipitation projection show from late winter to mid monsoon rainfall would demonstrate considerable consistency with the 1990 baseline. But over the period of late monsoon to early winter rainfall would increase at a huge rate. Figure III presents the monthly precipitation pattern over the projection years.

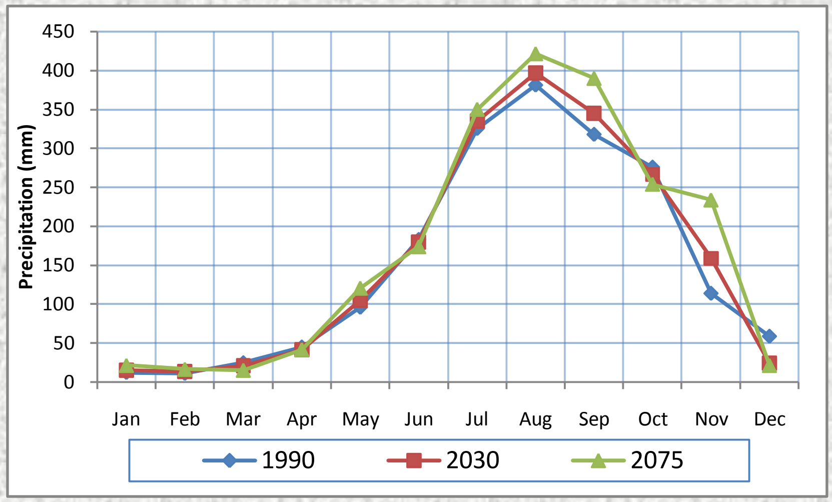

FIGURE III: FUTURE CHANGES IN PRECIPITATION OVER SOUTH-WESTERN BANGLADESH

The results obtained from the GCMs concur with the observed trend of precipitation over Bangladesh. Observed precipitation data over Bangladesh from 1954 to 2002 show an increasing trend in annual precipitation. Analysis reveals, winter precipitation gave the highest hike as 50.37% increase in 1991-2002 average in compare to 1954-1990 average have been observed. A summary of the observed change in precipitation over Bangladesh is given in Table V.

TABLE V: FUTURE CHANGES IN TEMPERATURE OVER SOUTH-WESTERN BANGLADESH

Year	Precipitation (mm)				
	DJF	MAM	JJA	SON	Annual
1954-1990 average	32.6	412.6	1382.4	503.1	2330.6
1991-2002 average	48.9	464.5	1426.1	542.8	2482.3
% change	+50.4	+12.6	+3.16	+7.9	+6.5

6.3 CROPWAT outputs: Soil Moisture Deficit (SMD) Scenario

As observed from the CROPWAT outputs, many of Bangladesh's rainfed crops suffer more or less vulnerability due to Soil Moisture Deficit (SMD) and resultant yield loss. Results show potato and *Boro* paddy is the worst vulnerable to SMD in current days. Under the prevailing climatic conditions Local *Boro*, HYV *Boro* and Potato suffer a yield loss of 53.2%, 44.1% and 61.9%, respectively due to only moisture stress. Given the projected climatic scenario for 2030 and 2075, CROPWAT outputs suggest SMD would increase negligibly in the local *Boro* period leaving the crop no added vulnerability while HYV *Boro* would show a climb in yield loss (from current 44.1% to by 2030, 46.1% and by 2075, 48.1%) though SMD won't show any increase. This might be caused by moisture stress at initial growing period. The same scenario would make potato the most vulnerable crop grown in the south-western part of the country. Due to moisture stress at initial growth stage potato yield reduction would jump from 64.1% to 75.8 % by 2030, but then would be reduced down to 72.9% by 2075. A summary of the SMD scenario and associated yield loss of main rainfed crops in South-Western region of Bangladesh is presented in Table VI.

As understood from Table VI, overall future SMD scenarios won't be significantly worse in any case, though if planting time is not shifted according to the shifts of the rainy days over the years, rainfed crops would suffer hiked yield loss in future, especially in case of potato and *Boro*. Table VII gives a present and future scenario of irrigation requirement by

TABLE VI: CROPWAT OUTPUTS OF SMD SCENARIO AND ASSOCIATED YIELD LOSS OF MAIN RAINFED CROPS IN THE SOUTH-WESTERN REGION OF BANGLADESH OVER DIFFERENT YEARS

Crop Name	Planting Date	Total SMD (mm) over crop life			Yield loss due to moisture stress (%)		
		1990	2030	2075	1990	2030	2075
Local *Boro*	Mid December	196	198	201	53.2	56.0	54.4
HYV *Boro*	Late January	159	157	155	44.1	46.1	48.1
T-*Aman*	Early August	10	18	19	00	00	00
Wheat	Late December	227	229	231	20.2	22.1	21.6
Pulses	Early November	173	172	169	26.0	31.0	25.6
Potato	Mid November	96	93	95.4	64.1	75.8	72.9

different crops which show, although rainfall would increase appreciably over all seasons on average, inadequate rainfall during growing stages would require more irrigation. Table VII reveals, irrigation requirement for potato would increase the most followed by *Boro*.

TABLE VII: FUTURE IRRIGATION REQUIREMENT FOR SOME MAJOR CROPS IN SOUTH-WEST BANGLADESH

Crop Name	Irrigation required over crop life (mm)		
	1990	2030	2075
HYV *Boro*	456	471	489
Local *Boro*	506	535	535
T-*Aman*	12	17	17
Pulses	282	314	289
Potato	350	435	429
Wheat	388	410	405

7. Conclusion

The results obtained from CROPWAT coupled by MAGICC/SCENGEN clearly make a statement that, although in future the south-western region of Bangladesh is going to face higher temperature and rainfall during all the seasons, due to unappreciable rainfall at the start of the planting season in winter would severely affect most of the rainfed crops because of moisture stress. Also higher temperature in the winters is expected to increase evapotranspiration effect, and thus will lead increased yield loss. As understood, rainfed crops would suffer more acutely than that of irrigated crops. These calculations are based on only soil moisture stress. They do not include organic matter depletion, initial moisture stress, level of CO_2 fertilization etc. Despite of these, the results indicate that increase in irrigation is a must to protect yield loss.

Development of a good irrigation system to adapt with such climatic conditions and associated crop production loss due to moisture stress is a matter of long time, may be even 50-100 years (e.g., James and Lee, 1971; Howe, 1971). An effective land and waterbodies management system would be able to enhancement the growth of the irrigation system, as the GCM outputs indicate a considerable amount rainfall in future years might supplement the flow of water in the country. In the mean time adaptation measures like development of temperature tolerant varieties of crops, shifts in planting season, changes in irrigation practice etc should become handy for short term measure. The process is progressive and possesses potential future in the long run. A summary of varieties of adaptation measures in agriculture and it's time to adapt with have been presented in Table VIII.

In order to meet the growing demand of food grains in Bangladesh beyond 2015 there is an urgent need to expand area of irrigation and increase its efficiency. Along with this, temperature tolerant variety development, adjustment in fertilizer and irrigation practices among farmers is of highest importance. Farmers are required to be equipped with more knowledge and understanding while the total agricultural system should be developed with a specific strategic plan emphasizing future climatic changes. Research initiatives should act as a catalyst character in this development.

TABLE VIII: SUMMARY TABLE OF VARIOUS ADAPTATION PROCESSES AND TIME REQUIRED FOR POSSIBLE ADAPTATION

Adaptation Process	Time (yrs)	References
Variety adoption	3-14	Dalrymple, 1986; Griliches, 1957; Plucknett *et al.*, 1987; CIMMYT, 1991
Dams and irrigation	50-100	James and Lee, 1971; Howe, 1971
Variety development	8-15	Plucknett *et al.*, 1987; Knudson, 1988
Tillage systems	10-12	Hill *et al.*, 1994; Dickey *et al.*, 1987; Schertz, 1988
Fertilizer adoption	10	Pieri, 1992; Thompson and Wan, 1992

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