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Rethinking crop diversification under changing climate, hydrology and food habit in Bangladesh

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Abstract: Extreme temperature, frequent and intensive flood, cyclone and other natural disasters due to climate change became acute in Bangladesh and would be severe in future. Besides, water crisis due to shortage of upstream flow and very little rainfall in dry season would affect in a same way. Gradual higher dependency on groundwater irrigation during last few decades created pressure on groundwater even after a huge discharge during rainy season. Using secondary data, this research analyzed the changes in cropping pattern along with a forecast of area to be distributed among various crops in 2029-30 and proposed a re-distribution considering probable crop failure, water crisis and change in food habit. Inherit rice-dominated food habit and government incentive policy encouraged farmers to be concentrated highly on water-intensive rice farming. However, a recent tendency of less rice consumption would encourage crop diversification in future. An incentive policy for farming of diversified crops and their intensification in all crop seasons would be effective to reduce pressure on groundwater and to persuade a balanced food basket in Bangladesh.

Keywords: Climate change, water crisis, food security, crop diversification

Introduction

Bangladesh is blessed with alluvial soils and huge water resources of upstream flow, rainfall and groundwater. However, imbalance in availability of water in different seasons is a barrier for its proper utilization in crop farming. Enormous amount of water from upstream through 57 trans-boundary rivers along with i) high internal rainfall, ii) general low level of the country and iii) inadequate drainage use to create a widespread inundation during wet (May - October) season (WARPO, 2001). With an expansion of groundwater irrigation system, a huge amount of food grain production in dry (November – April) season has promoted the country to reach at a level of its self-sufficiency under favorable climate (Akanda, 2008). The climate often becomes unfavorable and Bangladesh is widely recognized as one of the most climate vulnerable countries in the world (MOEF, 2008).

Bangladesh has an advantage of growing diversified crops in summer (April - July), monsoon (August – November) and winter (December - April) seasons. The crop farming became intensified with expansion of groundwater irrigation and the cropping pattern (sequential arrangement of crops on a piece of land) remarkably changed after adoption of HYV (high yielding variety) rice in winter season. The main pattern changed form Local summer rice /Jute (during summer) - Local monsoon rice (during monsoon) - Wheat /pulses /mustard /vegetables (during winter) to Fallow (summer) - Local /HYV monsoon rice (monsoon) - HYV winter rice (winter). The water-intensive farming of winter rice replaced many crops grown in winter season (Akanda, 2008). Gradual rising pressure on groundwater became an issue for food security of ever growing population in the country. Moreover, this lower riparian country of Ganges-Brahmaputra-Meghna basin faced a paradoxical situation of too much and too little water in different seasons.

Many researches in the past analyzed the possible impacts of climate change, water crisis and water dispute of trans-boundary rivers in Bangladesh. Rahman and Alam (2003) identified the impacts of climate change in terms of adaptations and vulnerabilities to poverty, health, infrastructures and food security in Bangladesh. They made an estimation of probable yield-loss through experiments on sensitivity to temperature, moisture, salinity and fertilization in HYV rice and wheat farming. In a subsequent research, Rashid and Islam, (2007) evaluated the impacts of climate change on soil salinity, draught, irrigation, water availability, etc. and suggested agricultural operations to be quick in seedling, intercultural operations, irrigation management and harvest.

Ahmed and Roy (2007) in their research addressed some problems with water management in Bangladesh. They suggested regional cooperation among co-basin countries to minimize water gap of dry and wet seasons to create a sustainable agro-environment. In an earlier research, Mahtab and Karim (1992) assessed the carrying capacity of agricultural resources and technological breakthroughs towards a sustainable food production system in Bangladesh. They identified depletion of agricultural land as a key barrier for sustainable agricultural environment. Meanwhile, the country reached at a level of self-sufficiency in food grain production that was assumed difficult to be achieved. Subsequently, Yusuf and Islam (2005) explored the means of achieving a balanced food basket by limiting a standard of cereal intake and recommended for diversified crop farming. Regarding the possibility of crop diversification, Ateng (1998) analyzed its feasibility comparing financial returns of almost all crops and suggested diversification with vegetables, potato and soybean.

The crop diversification program started in the early 1990s was not successful in Bangladesh (Akanda, 2008). Earlier government policies and researches supported to intensify rice farming or diversify crops considering water as available and abundant. The researches did not analyze the food security issue taking all the factors together like forecasting of water supply, crop area, productivity, food habit and threats from climate change. This research attempted to simulate an allocation of crop area for sustainable crop farming. The objectives of this research are to 1) evaluate the existing and possible threats with climate change and hydrological imbalance, 2) analyze the past and future trends of crop farming and 3) evaluate the impacts of upcoming changes in climate, water and food habit on crop farming, and 4) recommend for an allocation of crop area to attain a sustainable food production system in Bangladesh.

This research analyzed secondary data on natural disasters, water resources, cropping pattern, food production and consumption behaviors for last 50 years. The data was collected from statistical books, journal articles and reports of many institutions. This research made a projection of distributing crop area for the year 2029-30 considering 20 years as a sufficient time for long-term adjustment. Simple arithmetic tools were used to observe changes in previous years. Moreover, forecasting was made in some cases using linear, logarithmic and exponential functions based on their explanatory values. The share of crop area was used in analyzing the changes in cropping pattern just to avoid an obvious positive trend of total crop area. The food security scenario was evaluated considering population growth, loss-adjusted crop area and self-sufficiency ratio. The self-sufficiency ratio was calculated as the percentage of domestic production to consumption. In addition, regional concentration of specific crop was observed by crop concentration co-efficient as a ratio measure of the share of crop area in a region to the share of crop area in the country. Finally, a calculation was done on re-distribution of crop area for diversification considering possible challenges from climate, water supply and food habit.

Problems created for Climate and Hydrological Changes in Bangladesh

Agricultural activities in Bangladesh is expected to suffer much from upcoming problems like extreme temperature, frequent natural disasters, saline water intrusion, etc. due to climate change and also problems like prolonged floods, shortage of surface water, higher pressure on groundwater, etc. due to hydrological imbalance. The problems are discussed below in two broad aspects.

Problem with natural disasters and sea level rise

Surface temperature was estimated an increase up to 1.3°C by the year 2030 with a seasonal variation of 1.4°C in winter and 0.7°C in monsoon months in Bangladesh (Rahman and Alam, 2003). This disaster prone country was identified as the most vulnerable to tropical cyclones and sixth most vulnerable to floods in the world (MOEF, 2008). The number of natural disasters including cyclones and floods during 1975 to 2006 in Bangladesh is shown in Figure 1. It is observed that the incidences of natural disasters maintained an increasing trend.

Flood is considered as the major disaster and incidences of flood along with area inundated during 1972 to 2008 is shown in Figure 2. The figure depicts a more frequent appearance of major floods (more than average inundation of 20% of total area) over time. Moreover, a factual overview of major cyclones with wind speeds and floods with percentages of area inundated during 1963 to 2007 along with their forecasts is presented in Table 1. It is observed that wind speeds and percentages of area inundated to total area gradually increased and would follow an increasing trend in future.

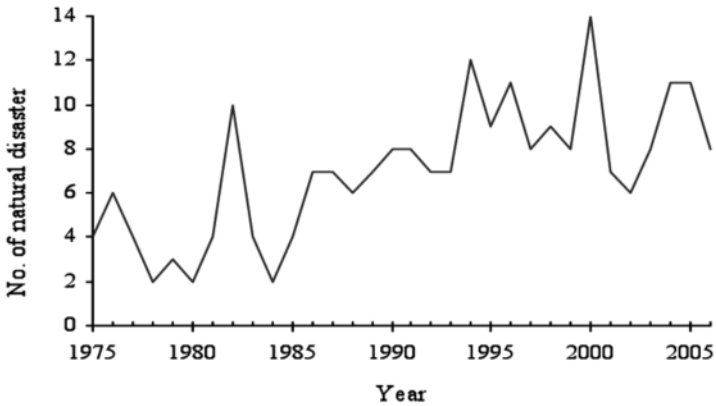

Figure 1 - Number of natural disasters in Bangladesh during 1975 to 2006

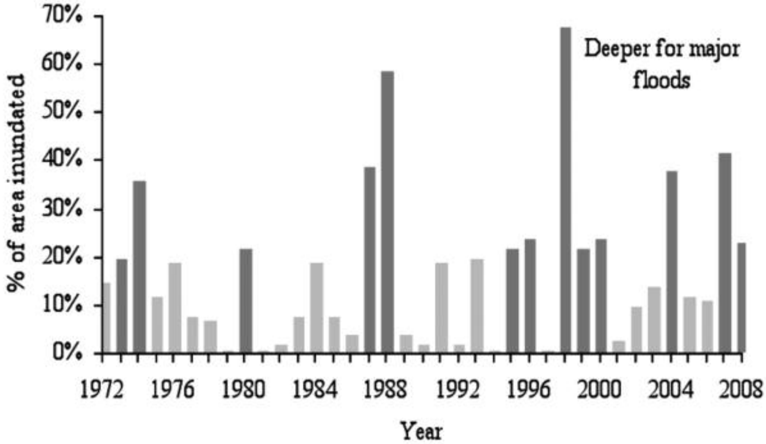

Figure 2 - Percentages of area inundated to total area during 1972 to 2008

Table 1 - Trend and forecast of wind speeds of major cyclones and percentages of area inundated during major floods in Bangladesh

Disasters	Intensity parameters	Years							
		1963	1970	1974	1988	1991	1998	2007	2030
Cyclone	Speed (Kilometer/ hour)	200	222	-	-	225	-	240	280
Flood	% of area inundated to total area	29	29	36	59	19	68	42	75

Source: BWDB 2008 and BWDB website

Besides cyclones, sea level rise would affect the southern part, about 47,000 square kilometers coastal areas of the country, which is equivalent to 32% of total landmass (CEDR, 2009). The losses of total land and agricultural land from possible rises in sea level are presented in Table 2.

It is apparent from the table that a maximum sea level rise of 0.50 meter by the year 2030 might lead to 11% loss of total landmass, which would submerge 395,000 ha (hectare) agricultural land of the country. The situation might be worse in 2100 for a continuous rise in sea level. Moreover, saline water intrusion already appeared as a natural disaster in coastal area. The saline water followed an increasing trend of inundation and raised soil salinity (MOEF, 2008).

Table 2 - Losses of total land and agricultural land from probable sea level rise in Bangladesh

Characters	Year 2030		Year 2100	
	Minimum	Maximum	Minimum	Maximum
Sea level rise (meter)	0.30	0.50	1.00	1.50
Share of area inundated (in %)	6	11	17	22
Loss of agricultural land (in '000 hectare)	215	395	610	790

Source: Rashid and Islam 2007, CEDR 2008 and author's calculation

The submerging of low lying coastal land together with saline water intrusion was identified as a crucial issue for agriculture in this land-scarce country.

Problem with crisis of surface and ground water

Surface water resources are comprised of water from rainfall, upstream flow, in-stream storage and storage in other water bodies. Rainfall and upper stream flows in Bangladesh accounted for 24% and 74% of total water resources, respectively (Ahmed and Roy, 2007). Average annual rainfall was approximately 470 mm (millimeter) during 2000s among which only 19% occurred in dry season (BBS, 2009). Greater precipitation extremes associated with climate change induced for less rainfall with a wide yearly variation in dry season, would gradually raise the water stress in the country.

Even with high annual contribution of upstream flows, water supply was found vulnerable to meet its demand. It is remarkable to note that upstream flows accounted for only 1% of total flows in the critical month of February or March during dry season (Ahmed and Roy, 2007). This situation could be observed in three major rivers. The minimum water flow in dry or lean period came to only 0.40% of maximum flow in wet or peak period for Meghna river at Sylhet point and 1.27% for Ganges river at Hardinge bridge point in 2007. However, the situation was satisfactory with 17.55% of lean to peak flow for Brahmaputra river at Bahadurabad point (BBS, 2009). The country used to suffer from prolonged floods in wet or peak period because of lowering the water conveyance capacity of rivers due to upper river bed created through deposits of sediments.

The south-west part of Bangladesh under Ganges basin is under a threat of its viability of surface water irrigation system. The upstream water flow situation of Ganges river at Hardinge bridge point is presented in Table 3. The comparison was made for one peak and one lean month each from respective period. Average water flow at the Hardinge bridge point decreased after the construction of

Table 3 - Changes in average water flow of Ganges river at Hardinge bridge point during 1934 to 2004

Period	Month	Pre-Farakka flow	Post-Farakka flow		
		During 1934-1974	During 1975-1988 (with agreement)	During 1989-1992 (without agreement)	Year 2004 (with agreement)
Annual		11,685	11,295	9,663	10,120
Peak	August	38,348	40,183	32,596	32,825
Lean	March	2031	1155	576	947
% of lean to peak		5.30 %	2.87 %	1.77 %	2.88 %

Source: FPCO 1993 and BBS 2005

Farakka barrage on Ganges river. The ratio of water flow in lean to peak month was found declining, which attained a better situation after the water sharing agreement in 1996.

Non-availability of surface water made agriculture more dependent on groundwater and about 73% of total water was withdrawn from groundwater source in 2005 (MOA, 2007). The use of groundwater increased mostly due to gradual higher concentration on HYV rice farming in dry season. Meanwhile, groundwater irrigation expanded at a higher rate than expected (WARPO, 2001). The trend of expansion of both surface and ground water irrigation for crop farming during 1979 to 2030 is presented in Table 4.

The share of groundwater to total irrigation increased remarkably from 15% to 73% during 1979 to 2005, which was estimated to increase up to 87% in 2029-30. It is noted that gradual pressure on groundwater would be a burden for irrigation system to be sustainable, because it occupied only 2% of total water resources (Ahmed and Roy, 2007). A higher withdrawal of groundwater would be more dangerous for arsenic contamination (natural occurring high concentration of arsenic in deeper levels of groundwater) in some south-central part of the country (WARPO, 2001). Moreover, salinity in coastal area was found increasing because of gradual intrusion of saline water due to lower upstream flow in dry season (MOEF, 2008). It is apparent from the above discussion that all natural irregularities coming from climate and hydrology would be a severe issue for future crop-farming in Bangladesh.

Table 4 - Trend of using surface and ground water irrigation for crop farming during 1979 to 2030

Type of irrigation	Years				
	1979-80	1989-90	1999-00	2004-05	2029-30
Ground water (%)	15	50	71	73	87
Surface water (%)	85	50	29	27	13

Source: MOA, 2007 and author's calculation

Trend of Changes in Crop Farming and Food Production in Bangladesh

Agricultural policies in Bangladesh were highly devoted to increase the production of rice since early 1960s. Consequently, rice production increased from 9.6 to 26.5 million MT (metric ton) during 1960-01 to 2005-06. However, the expansions of vegetables and potato among non-cereals (pulse, oilseed, spices, potato, vegetables, etc.) during 1974-05 to 2005-06 was possible for the development of widespread irrigation coverage throughout the country (MOA, 2007). Meanwhile, agricultural policies started demand-led supports to all types of farmers, which inspired them to expand commercially important crop farming in Bangladesh (Akanda, 2008).

Trend of land utilization and its forecasting for crop farming

It is revealed from literatures that net crop area (net amount of area in crop farming) of the country was found declining because of land-loss from river and coastal erosions and agricultural land being used for urbanization. The net crop area for the year 2029-30 was estimated at 7,430,000 ha excluding a significant loss from coastal erosion. The distribution of total crop area (aggregate areas under various crops farming on same land in a year) among various crops since 1970s along with a forecasting for the year 2029-30 is presented in Table 5. It is observed that the cereal crops (rice, wheat, maize, etc.) occupied more than 80% of total crop area during 1970 to 2007, which would not vary much in 2029-30. The share of area under rice decreased during 1970s and 1990s, and increased thereafter. On the contrary, the shares of areas under pulses, oilseeds and spices increased during 1970s and 1990s, and decreased thereafter. However, the area under rice was estimated a relative decrease in 2029-30, which was estimated an increase for pulses and oilseeds.

On the other hand, the cropping intensity (percentage of total crop area to net crop area) increased from 154 to 177 during 1980-01 to 2005-06 (MOA, 2007), which was estimated to reach at 184 in 2029-30. The distribution of area under specific food crop was calculated using the shares of area under respective crop forecasted for the year 2029-30. The area under food crops in 2005-06 and its forecast for the year 2029-30 are presented in Table 6. The areas under rice, spices and potato were estimated a decrease in 2029-30, which would increase for other food crops. The major increase would take place on areas under pulses, oilseeds and other cereals those were presently concentrated in winter season. It is noted that the expansion of winter crops other than rice might face an obstacle because of their substitute production of winter rice (Akanda, 2008).

Table 5 - Trend of land use pattern for crop farming since 1970s along with a forecast for the year 2029-30

Crop category	Name of crops	Years				
	(share of crop area)	1970s	1980s	1990s	2000s	2029-30
Cereals (%)		82.7	81.7	80.9	83.0	81.5
	Rice (%)	80.2	76.7	74.9	78.1	74.8
	Other cereals (%)	2.5	5.0	6.0	4.9	6.7
Non-cereal (%)		17.3	18.3	19.1	17.0	18.5
	Cash crop (%)	8.0	7.0	6.1	5.2	5.0
	Pulses (%)	3.2	4.5	5.0	3.0	4.5
	Oilseeds (%)	2.5	3.3	4.1	2.8	3.9
	Spices (%)	1.3	1.1	1.1	2.0	1.5
	Potato (%)	1.3	1.3	1.4	2.3	1.9
	Vegetables (%)	1.0	1.1	1.4	1.7	1.7

Source: MOA 2007 and author's calculation

Table 6 - Distribution of area under food crops in 2005-06 and its forecast for the year 2029-30

Characters	Crop area in 2005-06 (in '000 ha)	Crop area in 2029-30 (in '000 ha)
Net crop area	7,930	7,035
Cropping intensity	177	184
Total crop area	14,060	12,945
Rice	10,529 (74.7)	9,690 (74.8)
Other cereals	604 (4.3)	826 (6.7)
Pulses	337 (2.4)	579 (4.5)
Oilseeds	301 (2.1)	429 (3.9)
Spices	321 (2.3)	189 (1.5)
Potato	335 (2.4)	242 (1.9)
Vegetables	193 (1.4)	216 (1.7)

Note: Net crop area for 2029-30 was calculated by deducting 395,000 ha land loss due to sea level rise from forecasted net crop area of 7,430,000 ha; Figures in the parentheses indicated the percentage of crop area to total crop area.
Source: MOA 2007 and author's calculation

Trend of food production and its forecasting

Food production in Bangladesh gradually increased due to technological progress in crop farming. The changes in yield (MT/ha) of food crops since 1970s along with their forecasts for the year 2029-30 is presented in Table 7. The yield of rice and potato was higher compared to other food crops, which was estimated

Table 7 - Changes in yield (MT/ha) of food crops since 1970s and forecast for the year 2029-30

Food crops	Years				
	1970s	1980s	1990s	2000s	2029-30
Rice (MT/ha)	1.17	1.44	1.84	2.39	4.50
Other cereals (MT/ha)	0.87	0.99	1.47	1.89	3.92
Pulses (MT/ha)	0.63	0.69	0.75	0.80	1.08
Oilseeds (MT/ha)	0.78	0.88	0.85	1.08	1.24
Spices (MT/ha)	1.96	2.01	2.12	2.36	2.70
Potato (MT/ha)	9.37	9.98	11.11	14.19	18.30
Vegetables (MT/ha)	6.36	6.35	6.46	6.62	6.80

Source: MOA 2007 and author's calculation

higher in 2029-30. Higher yield of rice could easily be achieved in 2029-30 even with on-going efforts. The projected yields for pulses and oilseeds were, however, lower, which could be increased through higher involvement in research. Subsequent to that, a question might arise on how much food requirement could be achieved from domestic production.

Food requirement of the country was calculated multiplying per capita domestic production of 2005-06 by an estimated population of 2029-30. This was based on an assumption of hardly possible increase in calorie intake under huge pressure of population. Meanwhile, food consumption statistics showed that food intake increased from 914 to 948 gram / capita / day and calorie intake even decreased from 2,244 to 2,239 kilocalorie / capita / day, reflected no remarkable change during 1995 to 2005 (BBS, 2009). A projection of production of food crops including their surplus / deficit in 2029-30 is presented in Table 8.

Under continuous trend of changes in both area and yield, the country would produce a surplus amount of rice, wheat, pulses and oilseeds and a deficit of spices, potato and vegetables in 2029-30. Over production of rice would be achieved at the cost of scarce water because of its higher water requirement compared to other crops. On the other hand, vegetable farming used to require lesser water (Pimentel *et. al.* 1997) and provided higher financial return compared to HYV rice (Ateng, 1998). The expansion of rice-led crop farming would create a severe water crisis and raise damage-risk from natural disasters. Meanwhile, higher demands for vegetables, potato and other food crops were created whereas their production was found decreasing since 1990s. It is apparent from the above discussion that food production in the country might face many challenges.

Table 8 - Projection of food requirement and production in 2029-30 at 2005-06 level domestic availability

FOOD CROPS	PER CAPITA production in 2005-06 (kg / person)	REQUIRED production for 2029-30 (000' MT)	REQUIRED yield (MT / ha)	PROJECTED yield (MT / ha)	PROJECTED production in 2029-30 (000' MT)	PRODUCTION Surplus (+) or deficit (-) (000' MT)
Rice	190.73	36,429	3.76	4.50	43,605	(+) 7,176
Other cereal	9.17	1,751	2.12	3.92	3,238	(+) 1,487
Pulses	1.95	372	0.64	1.08	625	(+) 253
Oilseeds	1.94	371	0.74	1.24	617	(+) 247
Spices	8.50	1,623	8.59	2.70	510	(-) 1,113
Potato	44.21	8,445	34.90	18.30	4,428	(-) 4,016
Vegetables	17.89	3,416	15.81	6.80	1,469	(-) 1,947

Note: Projected productions were calculated as projected area multiplied by projected yield in 2029-30
Source: MOA 2007 and author's calculation

Challenges for Crop Farming in Bangladesh

Damages of crop productions for climate change, non-availability water for attaining expected production and imbalances of demand-supply for food habit change would emerge as challenges for crop farming in Bangladesh. Keeping this under consideration, subsequent discussions are carried out to explore a coherent cropping pattern to cope up with upcoming challenges.

Challenges from production loss due to climate change

Land loss, soil degradation, cyclone, flood, draught and other natural hazards reduce livelihood opportunities in crop farming. Moreover, artificial intrusion of saline water for salt and shrimp production raised salinity in coastal area. Among all disasters, flood and cyclone destroy more and rice farming was found to be affected the most. However, total rice loss was not increased even after gradual increase in total production. The average loss of rice among crop seasons during two periods of 1986 to 1995 and 1996 to 2005 is presented in Table 9.

It is found that the shares of rice loss in their respective seasons decreased from 1986-1995 to 1996-2005 periods, might be because of using disaster tolerant varieties and farmers' adaptive measures. However, the share of loss of winter rice increased from 11.24% to 27.19% of total rice loss and the relative loss was higher than relative increase in production during 1986 - 1995 and 1996 - 2005 periods. A higher damage in winter rice indicated relatively higher incidences of cyclones

Table 9 - Loss of rice production due to cyclones and floods during 1986 to 2005

Crop season	Duration 1986-1995			Duration 1996-2005		
	Relative share of production (%)	Loss in respective season (%)	Seasonal loss to total rice loss (%)	Relative share of production (%)	Loss in respective season (%)	Seasonal loss to total rice loss (%)
Summer	14.5	3.80	15.09	7.9	3.30	14.00
Monsoon	51.5	5.70	73.67	44.5	2.61	58.81
Winter	34.0	1.27	11.24	47.6	1.00	27.19
Total	100	3.91	100	100	1.93	100

Source: BBS (Agricultural statistics), 1993 - 2008

and storms during winter season. Moreover, damages of vegetables and other crops were insignificant even in early 1980s, which gradually increased because of expansion of their farming in risk-natural seasons of summer and monsoon (BBS, 1993 - 2008: Agricultural statistics).

In case of production loss due to temperature extreme, 4°C increase in temperature would result in 28% and 68% reduction of rice and wheat production, respectively, in the country. The salinity would reduce rice yield by 0.2 MT/ha, which would increase to 0.56 MT/ha under severe scenario (Rahman and Alam, 2003). It is notable that rice researchers in Bangladesh already released disaster and salinity tolerant rice varieties yielding up to 6.43 MT/ha (Sattar and Moniruzzaman, 2008). However, innovation of resilient varieties of other crops was negligible, effort for which was found necessary. The Bangladesh Climate Change Strategy and Action Plan 2008 put emphasis on development of climate resilient cropping systems (e.g., research to develop varieties tolerant to flood, drought and salinity) to ensure local and national food security (MOEF, 2008).

Challenges for higher production due to water crisis

Higher crop production was achieved through utilization of surface, rain and ground water and more water to be used for further higher production in Bangladesh. The water requirement in 2005-06 and excess requirement for projected production of food crops in 2029-30 are presented in Table 10. The calculation shows that food production required 57,707 million m^3 (cubic meter) water in 2005-06 and an additional 33,745 million m^3 to be required to attain the projected production in 2029-30.

Table 10 - Requirements of water and excess water for attaining the projected food production in 2029-30

Food crops	Production in 2005-06 (000' ha)	Water requirement (m^3 / kg)	Water requirement in 2005-06 (million m^3)	Projected surplus production in 2029-30 (000' ha)	Required Excess water for production projected in 2029-30 (million m^3)
Rice	26,530	1.9	50,725	17,075	32,647
Other cereals	1,275	0.9	1,148	1,963	11,767
Pulses	271	1.5	407	354	531
Oilseeds	270	1.4	378	348	487
Spices	1,182	1.1	1,300	-672	-739
Potato	6,150	0.5	3,075	-1,721	-861
Vegetables	1,687	0.4	675	-218	- 87
Total			57,707		33,745

Source: Dutta 1993, Pimentel *et al.* 1997 and MOA 2007

Groundwater is mostly used to supplement soil moisture in winter season. Meanwhile, the pressure on groundwater increased because of gradual less availability of surface water in Bangladesh. Water requirement in winter season was expected to increase potentially by at least a quarter over the next 25 years (WARPO, 2001). The trend of changes in irrigated area in winter season during 1979 to 2030 is presented in Table 11.

It is estimated that about 94% of net crop area would come under irrigation in 2029-30. The contribution of surface water to irrigation continued decreasing and groundwater would provide 91% of irrigation during winter season in 2029-30. However, the National Water Management Plan emphasized on comprehensive and integrated utilization of surface water by increasing availability of water at farm boundary (WARPO, 2001).

Irrigation requirements differ among regions of the country due to variations in rainfall, evaporation and soil moistures. The deficit balance of evaporation and rainfall was accounted from 432 to 536 mm in different regions (Ahmed and Roy, 2007). Due to widespread variation in future, more irrigation would be required

Table 11 - Trend of irrigated area to total irrigated and net crop area in winter season during 1979 to 2030

Irrigated area in winter	Years				
	1979-80	1989-90	1999-00	2009-10	2029-30
% of net crop area irrigated	15	30	45	62	94
% irrigated to total irrigated area	79	84	86	89	91

Source: MOA 2007 and author's calculation for cultivation of HYV winter rice and other winter crops. Meanwhile, a higher concentration on winter rice and wheat farming was found in northern region of the country. The crop concentration co-efficient in northern districts lied between 1.06 to 1.69 for winter rice and 1.29 to 3.05 for wheat in 2005-06, indicated a higher regional concentration for their values greater than 1.00 (BBS, 2008: Agricultural statistics). Besides very low upstream flow, gradual lower rainfall and higher evaporation during winter season would create a severe problem for rice-intensive farming in some regions of Bangladesh.

Challenges for adopting alternative food habit

The consumption of vegetables including potato increased from 140.5 to 157.0 grams /capita /day in the country whereas consumption of rice decreased from 459 to 440 grams /capita /day during 2000 to 2005 (BBS, 2007). The change towards lower rice intake was identified as a good symptom of minimizing water utilization for its higher water requirement in production. Because of a higher rate of migration, urban population of Bangladesh was estimated to be more than 50% in 2049-50 from 25% in 2005-06 (WARPO, 2001). The urban people have a higher tendency to come out of rice-dominated dish and move towards a balanced food basket. The existing and desired consumptions of food crops along with their self-sufficiency ratio are presented in Table 12.

The productions of rice, spices, potato and vegetables reached near to their self-sufficiency in 2005-06 and it was very far in case of pulses, oilseeds and other cereals. The country would be required to expand production of other cereals at 2 times, pulses at 4.6 times, oilseeds at 2.4 times and vegetables at 2 times to reach

Table 12 - Self-sufficiency ratio and food consumption in 2005 and expansion requirement of production for a balanced food basket in Bangladesh

Food crops	Self-sufficiency ratio in 2005-06 (%)	Consumption in 2005-06 (gram /capita/day)	Desirable consumption (Yusuf & Islam, 2005) (gram /capita/day)	Expansion requirement (times)
Rice	95	440.0	312	No
Other cereals	46	29.2	60	2.0
Pulses	49	14.2	66	4.6
Oilseeds	30	6.6	16	2.4
Spices	92	17.0	14	No
Potato	100	106	80	No
Vegetables	100	49.0	100	2.0

Note: Self-sufficiency ratio of spices was calculated taking onion and chili into account.
Source: Yusuf and Islam 2005, BBS 2007 and BBS 2009

at a balanced food basket in 2029-30. It is important to consider that per capita consumption of rice in Asia declined over time, would eventually lead to a declining production in many Asian countries (Ito, 2005). Under this continuous trend, Bangladesh would require to cope up with rice declining consumption and to reduce rice dependency that might lead to the production of more diversified crops.

Re-distribution of Crop Area to Cope up with Challenges

On-going trend of crop farming would remain it concentrated on water-intensive rice farming in 2029-30. An adjustment in distribution of projected crop areas could reach the country at a level of balanced food intake and would reduce water requirement. The proposed re-distribution of crop areas for the year 2029-30 is presented in Table 13. It is found that the country would have a surplus crop area of 1,490,000 ha in 2029-30 producing at a level of consumption and self-sufficiency in 2005-06. This surplus area could be distributed among other crops in order to attain a balance food basket. However, a shortage of 1,120,000 ha was found after adjustment as per the expansion requirement, which was reduced from pulses because of its higher water requirement. In this process of re-distribution of surplus area, an amount of 7,973 million m^3 water could be saved from crop farming in Bangladesh.

The surplus over required area was proposed to distribute among pulses, oilseeds, potato, vegetables and other cereals grown mostly in winter season.

Table 13 - Projected distribution and proposed re-distribution of crop area for the year 2029-30

FOOD CROPS	Projected area in 2029-30 (000' ha)	Required area at 2005-06 level of consumption and self-sufficiency (000' ha)	Area after preliminary adjustment (000' ha)	Re-distribution considering water requirement (000' ha)
Rice	9,690	8,095	8,095	8,095
Other cereals	826	447	894	894
Pulses	579	345	1,587	467
Oilseeds	429	299	718	718
Spices	189	601	601	601
Potato	242	461	461	461
Vegetables	216	502	1,004	1,004
Excess	0	1,490	(-) 1,120	0
Total	12,240	12,240	12,240	12,240

Source: Author's calculation

Assuming the existing distribution of crop areas among crop seasons remained unchanged in 2029-30; a seasonal distribution was made for re-distributed areas and presented in Table 14. A higher intensity of land use was estimated for all crop seasons, which would reach nearly to 80% in winter season. For intensification and diversification of non-cereal crops among crop seasons, it would require greater efforts along with disaster resilient varieties. As per proposed re-distribution, crop production would require about 38,481 million m^3 water in winter season. It was found necessary to care for the groundwater stock limited to 23,000 million m^3 from which 10,000 million m^3 was withdrawn in winter season in 2003 (Ahmed and Roy, 2007). Yet 44% of groundwater was reported economically non-viable for irrigation purposes (WARPO, 2001).

A total of 25,203 million m^3 water was used for crop farming during winter season in 2005-06, of which 46% came from soil moisture, 15% from surface and 39% from ground water source. The country would be required about 1.6 time water in winter season in 2029-30. However, water supply from soil moisture and surface water would be limited only to 29% and 9% of requirement, respectively. The required withdrawal of groundwater would even be higher than its stock, which would be difficult to minimize from scarce surface water in winter season. An action plan for re-distribution of areas for diversified crop among crop seasons was found necessary because of their existing concentration merely in winter season.

The scarcity of groundwater might be severe in Bangladesh even after huge discharge during monsoon season. Upcoming water crisis could be comparable to the situation of Indian state of Punjab, where the groundwater crisis became acute because of gradual low rainfall. Meanwhile, water crisis in Punjab led a change from a rice-intensive cropping pattern to a diversified pattern with soybean, vegetables and some other cash crops (CWC, 2009). Despite water problem, Bangladesh government provided a series of incentives on irrigation, research and floor price to encourage rice farming in winter season. With a vision to reduce water pressure, it was found necessary to reduce concentration on winter rice farming. Under this situation, some incentive measures for shifting of pulses and oilseeds to summer and monsoon seasons might promote crop diversification in Bangladesh.

In the process of changing food habit, an introduction of sauces could play an important role to reduce demand for rice-based dishes and to stimulate consumption of other foods. Production of soybean could not only reduce dependency on imported oil but also promote balanced food intake in Bangladesh. It is noted that the country's total demand for edible oil was around 1.3 million

Table 14 - Seasonal distribution of area under food crops and their water requirement in 2029-30

Food crops	Year 2005-06 (area in '000 ha in different seasons)			Year 2029-30 (area in '000 ha in different seasons)		
	Summer	Monsoon	Winter	Summer	Monsoon	Winter
Rice	1,034 (9.8)	5,429 (51.6)	4,066 (38.6)	795	4,174	3,126
Other cereals	0 (0.0)	0 (0.0)	605 (100.0)	0	0	894
Pulses	35 (10.4)	135 (39.9)	168 (49.7)	49	186	232
Oilseeds	0 (0.0)	45 (15.0)	256 (85.0)	0	107	611
Spices	48 (14.8)	63 (19.5)	211 (65.7)	89	117	395
Potato	0 (0.0)	0 (0.0)	335 (100.0)	0	0	461
Vegetables	60 (31.1)	20 (10.1)	113 (58.8)	312	102	590
Total	(9.3)	(45.1)	(45.6)	1,141	5,519	5,580
% of area in use	14.84	71.76	72.56	16.22	78.45	79.32
Water requirement (million m^3)	5,387	26,692	25,203	8,033	37,025	38,481

Note: Figures in the parenthesis indicated percentages of crop area distributed among crop seasons
Source: MOA 2007 and author's calculation

MT against which about 0.2 million MT came from mustard oil in 2008. The demand for soybean oil used to meet mostly from import even with a bright prospect for soybean production of the country to produce nearly 40% of its demand (Daily Star, 2009). Moreover, production of soybean in other than winter season would reduce water pressure because it could even be grown in monsoon season (Chowdhury and Zulfikar, 2001). The crop area allocated for rice maintaining present level of consumption and self-sufficiency, which could even be reduced subject to a decrease in consumption. An endeavor of crop diversification on probable areas released from winter rice could also reduce pressure on groundwater.

Conclusions

Natural dependent crop farming of Bangladesh already experienced negatively influence of climate change and water crisis. Frequency and intensity of floods, cyclones and other natural disasters already increased due to climate change and would maintain a higher tendency in future. Inundation of coastal area due to sea level rise caused saline water intrusion leading to a maximum coastal erosion of 11% total landmass of the country by the year 2030. In addition, a decrease of river flow along with too little rainfall in dry season created unavailability of surface water that induced crop farming dependent on groundwater. The crop farming expanded with higher dominancy of winter rice, for which, area under other crops grown in winter decreased. Under this on-going water-intensive production practices and crop damages from natural disasters, the food security would be hard to achieve in future.

Structural changes in crop farming ensured higher level of availability of cereals, potato and vegetables in Bangladesh. The projected yield and crop area would make the country enable to produce food even with smaller amount of crop area in 2029-30 maintaining the 2005-06 level of self-sufficiency. Adoption of HYV winter rice influenced for declining farming of summer rice and many winter crops. Moreover, vegetables grown earlier in winter shifted over all crop seasons that increased its production. However, the efforts for crop diversification were not successful because of continuous government incentive policy to ensure self-sufficiency in food grain production. Gradual irrigation-led development of rice farming created huge pressure on groundwater. On-going trend of crop farming would produce a surplus amount of rice, wheat, pulses and oilseeds in 2029-30 maintaining present level of domestic availability.

This study focused on the challenges coming from climate change, water crisis and food habit. Food production would be hampered in future from crop damage due to frequent and intensive disasters and from yield-loss due to temperature extreme coming from climate change. The loss was found non-increasing might be from disaster resilient rice varieties and farmers' adaptive measures. Higher concentration on rice farming would be unable to meet the increasing demand for non-rice crops coming from food habit change. Moreover, a higher concentration on water-intensive winter rice farming would create shortage of groundwater for irrigation. This research recommended for concentrating towards diversified farming with oilseed, spices, potato and vegetables that would require lower water. To enable diversification, greater involvement in development of climate resilient varieties of wheat, pulses and oilseeds was identified necessary, which was negligible in the past. Beside production, adequate demand should be created through change in dishes to dispose additional production of diversified crops.

Government policy like incentives on irrigation, floor price, research, etc. encouraged production of winter rice, was found adverse to manage upcoming water crisis. A re-distribution of crop area towards non-rice crops could reduce water pressure in winter season. Moreover, a shifting of non-rice crops from winter to summer and monsoon seasons would intensify utilization of surface water. Soybean farming was identified as a new dimension of potential farming to contribute not only to produce edible oil but also to produce sauces. The sauces could preferably help the country to come out from curry-based and rice-dominated dishes and to reach at a balanced food basket. In this process of transformation, gradual incentive policy for expansion of diversified crop could contribute for encouraging farmers to concentrate on diversified crop farming.

Bibliography

Ahmed A. M. M. M. and K. Roy, 2007. *Utilization and Conservation of Water Resources in Bangladesh*. University of Tsukuba, Journal of Development in Sustainable Agriculture, Vol. 2: 35-44.

Akanda A.I., 2008. *Process of Agricultural Development in Bangladesh*. Academic Press and Publishers Library, Dhaka, 144 p.

Ateng B., 1998. *Comparative Advantage and Crop Diversification*. in Faruqee R. edited Bangladesh Agriculture in the 21st Century, University Press Limited, Dhaka, Chapter 8: 143-174.

BBS, 2009. *Statistical Yearbook of Bangladesh 2008*. Bangladesh Bureau of Statistics, Dhaka.

BBS, 2007. *Household Income and Expenditure Survey 2005*. Bangladesh Bureau of Statistics, Dhaka

BBS, 2005. *Compendium of Environmental Statistics of Bangladesh 2005*. Bangladesh Bureau of Statistics, Dhaka.

BBS (Agricultural statistics), *1993 - 2008. Yearbook of Agricultural Statistics of Bangladesh for the year 1992, 1995, 2000, 2004 and 2006*. Bangladesh Bureau of Statistics, Dhaka.

BWDB, 2008. *Annual Flood Report 2008*. Flood Forecasting and Warning Centre, Bangladesh Water Development Board, Dhaka, p 89.

CEDR, 2009. *EM-DAT International Disaster Database*. Visited on 11 January 2010, Centre for Research on the Epidemiology of Disasters, Brussels, Belgium, website: http://www.emdat.be/database

Chowdhury M.A.T. and Zulfikar H., 2001. *An Agricultural Statistical Profile of Bangladesh 1947-1999*. Working paper 54, CGPRT Centre, Bogor, Indonesia, 412 p.

CWC, 2009. *Concept Note on Water Security in Punjab*. Article discussed on the Water Security in India Conference, April 15-18, 2009, Columbia Water Center, Columbia University, New York.

Daily Star, 2009. *Bright Prospect for Soybean Farming in Bangladesh*. Metropolitan page of the Daily Star, November 21, 2009, Dhaka.

Dutta S.C., 1993. *On-farm Irrigation Management for Diversified Crops*. In Biswas, M. R. and M. A. S. Mandal, (ed.) Irrigation Management for Crop

Diversification in Bangladesh, University Press Limited, Dhaka, Chapter 8: 116-129.

FPCO, 1993. *Flood Action Plan 1993*. Flood Plan Coordination Organization, Former Ministry of Irrigation of Bangladesh, Dhaka, 25 p.

Ito S. and Kako T., 2005, *Rice in the World Verging on a Grave Crisis*. CMC Co., Ltd. Japan, Farming Japan, Vol. 39 (5): 10-33.

Mahtab F.U. and Karim Z., 1992. *Population and Agricultural Land Use: Towards sustainable food production system in Bangladesh*. Royal Swedish Academy of Sciences, Ambio, Vol. 21 (1): 50 -55.

Mirza M.M.Q., 1997. *Hydrological Changes in the Ganges System in Bangladesh in the Post Farakka Period*. Taylor and Francis, Hydrological Sciences Journal, Vol. 42 (5): 613-631.

MOA, 2007. *Handbook of Agricultural Statistics*. Ministry of Agriculture, Dhaka.

MOEF, 2008. *Bangladesh Climate Change Strategy and Action Plan 2008*. Ministry of Environment and Forests of Bangladesh, Dhaka, 68 p.

Ogura T., 2007. *Implication of Japan's declining Food Self-sufficiency*. Institute and Developing Economies, The Developing Economies, Vol. 14 (4): 419-448.

Pimentel D., *et al*., 1997. *Water Resources: Agriculture, the Environment, and Society*. American Institute of Biological Sciences, BioScience, Vol. 47 (2): 97-106.

Rahman, A. and M. Alam, 2003. *Mainstreaming Adaptation to Climate Change in Least Developed Countries: Bangladesh country case study*. International Institute for Environment and Development, IIED Working Paper 2, 37 p.

Rashid M.H. and Islam M.S., 2007. *Adoption to Climate Change for Sustainable Development of Bangladesh Agriculture*. Bangladesh country paper for the 3rd session of Technical Committee of Asian and Pacific Center for Agricultural Engineering and Machinery (APCAEM), November 20-21, 2007, Beijing.

Sattar M.A. and Moiruzzaman M., 2008. *Innovative Rice-based Farming Practices for Increasing Food Security in the Changing Coastal Environment in Bangladesh*. An article from the Souvenir of the 29th National Conference, Bangladesh Society of Agricultural Economics, Dhaka,

WARPO, 2001. *National Water Management Plan*. Water Resources Planning Organization, Ministry of Water Resources of Bangladesh, Dhaka, Volume 2, 212 p.

World Vision, 2008. *Disaster Monitor – Bangladesh fact sheet*. Asia Pacific Fact Sheet Series, Humanitarian and Emergency Affairs of World Vision, Singapore, 8 p.

Yusuf, H.K.M. and Islam A., 2005. *Setting a Standard Cereal Intake for Balanced*

Nutrition in Bangladesh. Proceedings of the National Workshop on Food Security in Bangladesh, World Food Program-Bangladesh, Dhaka, Chapter 5: 51-60.