Climate scenarios in Bangladesh

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Climate Scenarios for Bangladesh

Introduction

Lying at the terminus of three major South Asian rivers and with two-thirds of its land area less than 5 m above the mean sea level, Bangladesh is often cited as one of the world's most exposed countries to the impacts of climate change. A high density of population, extensive poverty and a heavy dependency on natural resource based livelihoods make Bangladesh socially and economically vulnerable to climatic stresses and shocks (Agarwala et al 2003). Past climate shocks have exerted a heavy toll on lives and livelihoods in Bangladesh, particularly with regard to cyclones and flooding. Future climate shocks and stresses are predicted to result in increased flooding, drought, riverbank erosion, and salinisation of water resources. Eighty percent of the land area consists of floodplains of the major rivers including the Ganga, Brahmaputra and Meghna, which are highly prone to flooding. In catastrophic years such as 1988, 1998, and 2004 more than 60% of the country or an area of approximately 100,000 square km was inundated for the duration of nearly 3 months (CEGIS, 2010). In many parts of the country such events could mean multiple displacement of the people affected.

In the following paper we review the literature on future climate scenarios for Bangladesh by updating previous climate model estimates of the range of precipitation and temperature futures for the country and the catchment area of the rivers emptying into Bangladesh. These data are taken from the 5th Climate Modelling Intercomparison Project (CMIP5) and consists of outputs of a number of state-of-the-art climate models using various present-day and future emission scenarios of greenhouse gases. The CMIP-5 data form the basis of the climate scenarios used in the upcoming 5th Assessment report of the Intergovernmental Panel on Climate Change.

Climate scenario futures:

The most recent impact assessments for Bangladesh are based on the climate model results of CMIP3 used in the 4th assessment report of the IPCC. Summarised by Yu et al (2010) these scenarios document the changes in temperature and precipitation predicted by 16 global circulation models, for three emission scenarios for the latitude-longitude grid squares covering Bangladesh. In Figure 1 the projected monthly, annual, and seasonal temperature changes projected by these models in the 2050s are shown relative to the corresponding data for 1980–99. As with the rest of the globe the temperature over Bangladesh is projected to rise during all months and seasons by 2050, with a median projection of a 1.55°C rise. Figure 2 shows the projected monthly, annual, and seasonal precipitation changes for the 2050s relative to the corresponding data for 1980–99. Clearly it can be seen that there is a range of precipitation futures for Bangladesh projected by the models with some models depicting an increase in precipitation and others a decrease. Overall annual and wet season precipitation is projected to increase with only simulations for the post-monsoonal rabi dry season not suggesting a rise in precipitation. The median prediction for Bangladesh across the models is for precipitation increases of 4 percent by the 2050s (World Bank 2011).

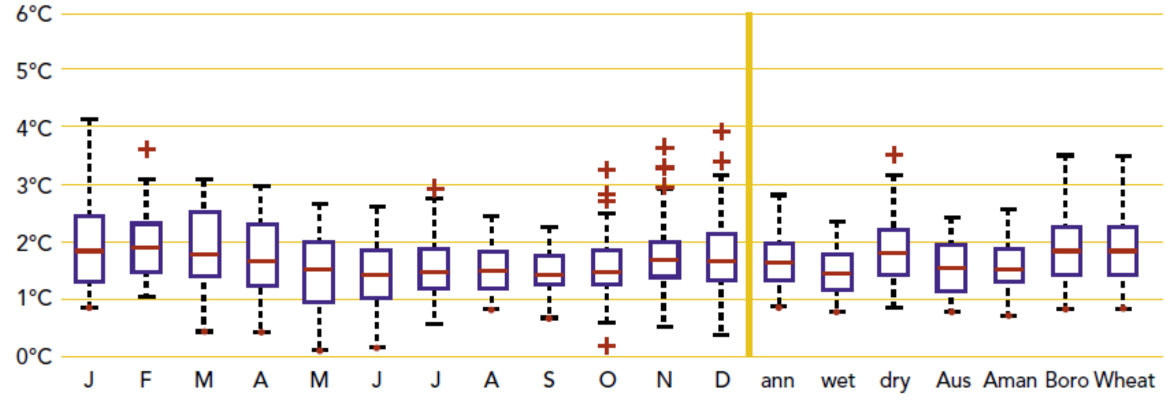


***Figure 1**. Monthly temperature changes for 2050s relative to the corresponding data for 1980–99. The red line representing the median value, a box enclosing the inter-quartile range, dashed whiskers extending the to the furthest model that lies within 1.5x the inter-quartile range from the edges of the box, and red plus symbols for additional models that are perceived as outliers. Source: Yu, W.H. et al. (2010)*

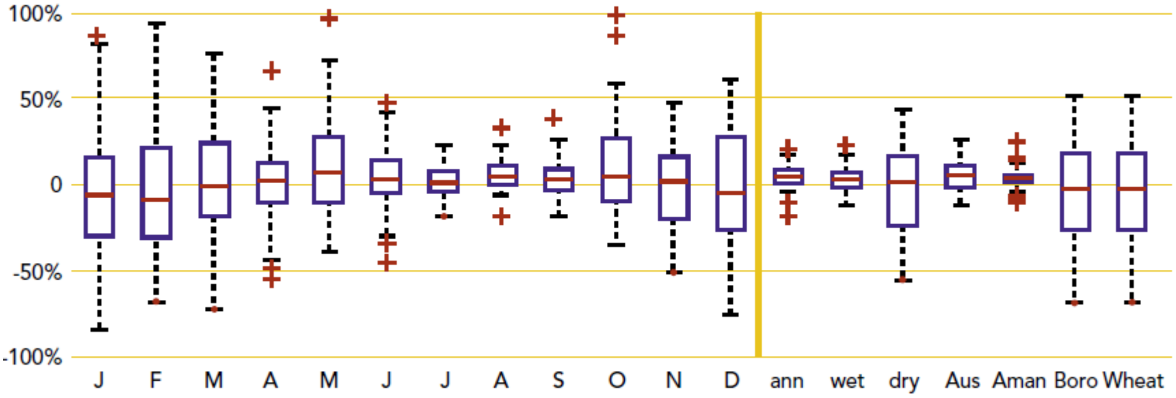


***Figure 2**. Monthly precipitation changes for 2050s relative to the corresponding data for 1980–99. The red line representing the median value, a box enclosing the inter-quartile range, dashed whiskers extending the to the furthest model that lies within 1.5x the inter-quartile range from the edges of the box, and red plus symbols for additional models that are perceived as outliers. Source: Yu, W.H., et al. (2010)*

In Figure 3 the changes in the mean and 90 percentile of annual precipitation are shown for the CMIP-5 results over Bangladesh.

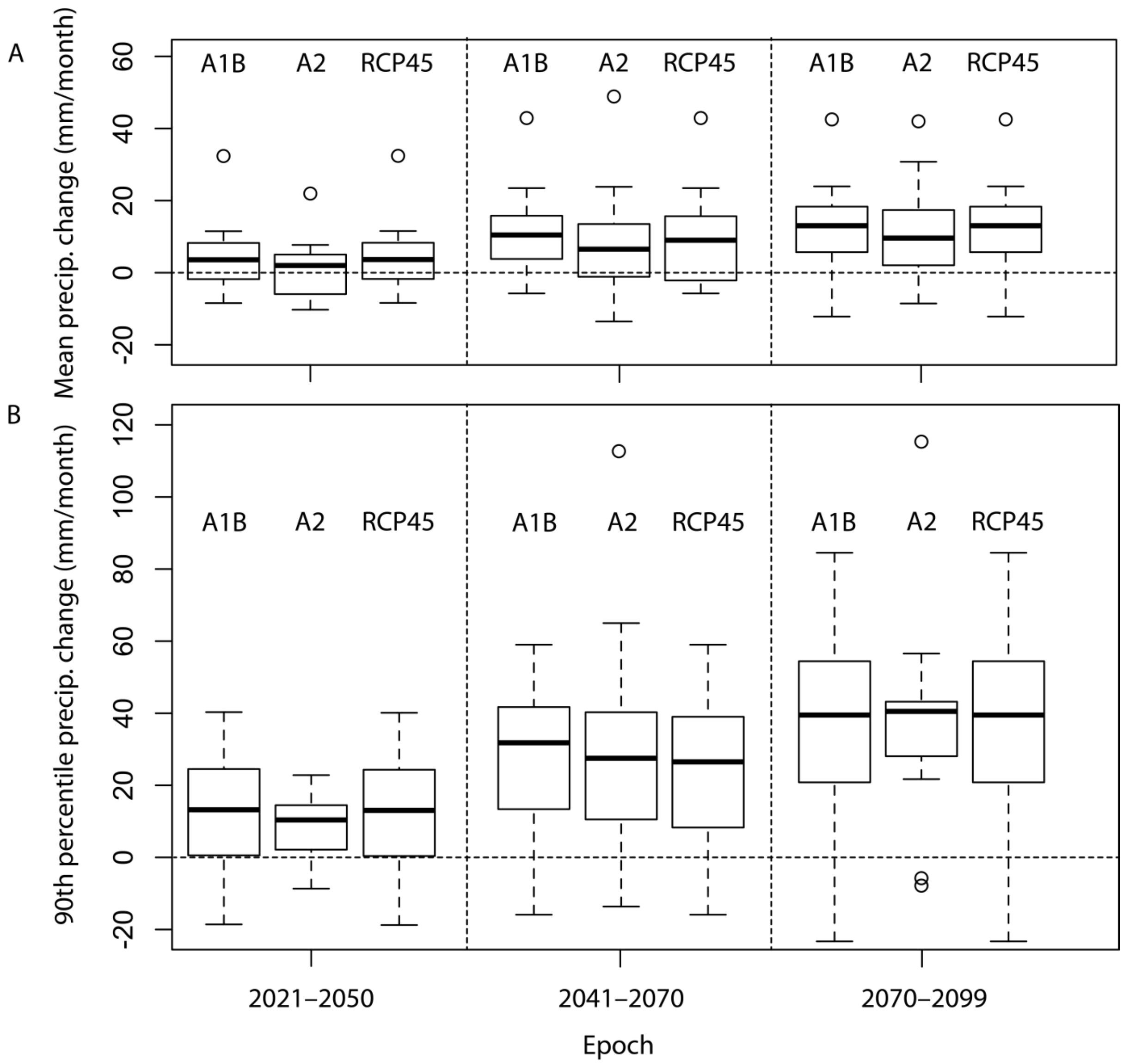


Figure 3. *a) Annual and b) 90th percentile precipitation changes for 2021-2050, 2041-2070 and 2070-2099 relative to the corresponding data for 1980–99 for three different emission scenarios (see Taylor et al 2009) . The lines represent the median value, a box enclosing the inter-quartile range, dashed whiskers extending the to the furthest model that lies within 1.5x the inter-quartile range from the edges of the box, and circle symbols for additional models that are perceived as outliers. (Source: this report)*

Clearly as time progresses it can be seen that the climate change signal points more to an increase in rainfall over Bangladesh with the largest increases in the 90th percentile rainfall. However some models still show a decrease in rainfall in the future. While the above results are applicable for the climate over Bangladesh only 7% of the GBM catchment of the rivers that drain into Bangladesh is situated in the country.

Inland flooding

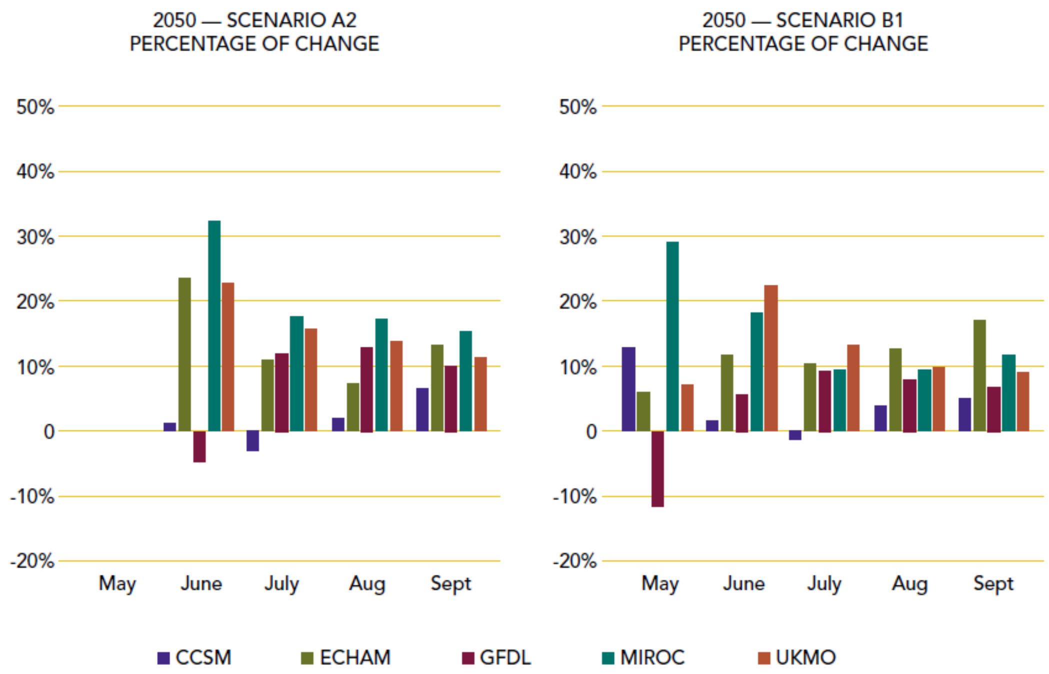
Changes in water flow into Bangladesh are related to rainfall and temperature over the whole of the catchment. A hydrological model is required to translate changes in these variables to water flows and flood patterns. Unfortunately such a process is beyond the current remit of the project. However previous future flood estimates have been modelled using 5 GCM outputs and 2 emission scenarios (A2 and B1) from CMIP3 (World Bank 2010a). The choice of models in the exercise were selected on their ability to skilfully replicate the dynamics of the monsoon in the GBM basin, provide sufficient spatial resolution for hydrologic modelling, and to capture the range of changes and climate sensitivity across GCMs (World Bank 2010a). The estimated changes in discharge from this modelling are shown in Table 1. They are based around multi-model increases in temperature ranging from 1° to 3° C by 2050 within the whole basin, with greater warming during the dry winter months; and an increase in rainfall of upto 20% during the monsoon season. According to World Bank (2010) the large changes at the onset of the monsoon (during May and June months), particularly in the Ganges, may reflect an earlier arrival of the monsoon season. The rainfall signal for the dry season is more mixed however between models with some showing increased, while others show decreased precipitation.

	2030s			*2050s*		
	Brahmaputra	*Ganges*	*Meghna*	*Brahmaputra*	*Ganges*	*Meghna*
May	7.5	9.3	0.0	17.4	11.8	12.3
June	5.4	11.9	3.1	10.9	16.7	7.7
July	3.4	13.5	0.0	6.9	15.0	3.6
August	5.5	8.8	3.7	9.5	12.0	7.8
September	3.7	7.3	-2.0	9.7	12.5	5.9
* 5 GCM x 2 SRES = 10 model experiments Source: Yu, W.H., et al. (2010)						

Table 1. *Estimate average change (in %) of discharge. Source: World Bank (2010a)*

From Table 1 it can be seen that on an average all three major rivers show an increase in discharge by 2050 by up to 12.5%. However it should be noted that not all models predict increases in discharge; with the largest model range for the Meghna (55 percent increase to 32 percent decrease in the GFDL scenario) (World Bank 2010a). The impact of these changes in hydrology on the extent of flooding over Bangladesh for the two emission scenarios of A2 and B1 shows that the flooded area is estimated to increase for most of the flood season for most (but not all) models. However, it should be noted that the changes in flood areas in many sub-regions fall within one standard deviation of the historical variability for these areas (World Bank 2010a). Spatially there are differences in the impact of the water flow on flooding throughout Bangladesh with many of the northern sub-regions showing statistically significant increases in the annual peak, while many in the southwest showing decreases.

The changes in timing of the flood extent (towards an earlier and a delay in the recession of flood waters) cannot be separated from the historical variability. In Figure 4 the spatial change in flood depths are shown for the increased river flow projected by the Model for Interdisciplinary Research on Climate (MIROC) 3.2 GCM, under the A2 emissions scenario of the IPCC compared to the flooding that occurred in 1998. The 1998 flood had a 90-year return period whereas the MIROC flooding extent was calculated from the highest flood depth for each grid point during the monsoon period for flooding of a minimum, 24-hour duration, during a 10 year period to 2050. The MIROC model shows the largest change in flood extent of the GCMs tested. Analysis of these changes reveals that under the baseline scenario, 45 per cent of land would be under at least 0.3 m of water and that under the climate-change scenario, the total flooded area would increase by 4% with the inundation depth in most flooded areas rising (see Table 2.)

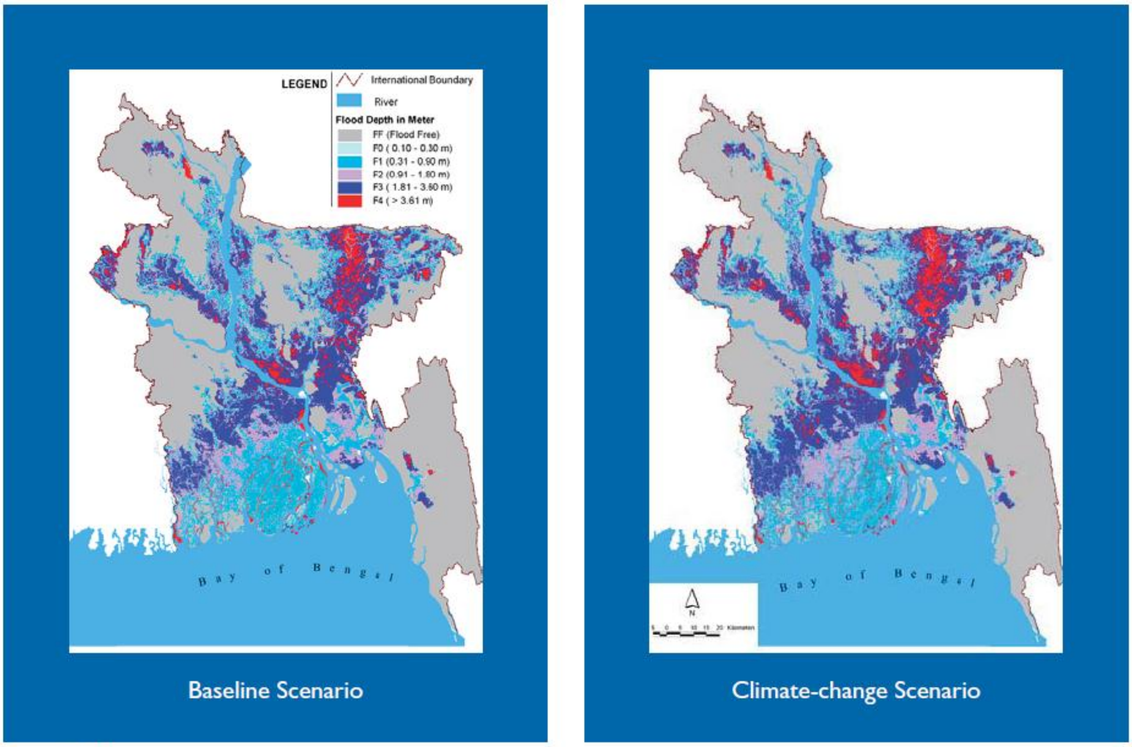


Source: Yu, W.H., et al. (2010)

Figure 4. *Total area flooded in Bangladesh for emission scenarios A2 and B1 in 2050. Source: World Bank (2011)*

	Baseline scenario		Climate-change scenario		Change due to climate	
Inundation	Km2	% total area	Km2	% total area	Km2	% total area
Flood free	69,439	52	64550	49	(4,889)	(3)
F0 (0.1-0.3)	2,950	2	2,251	2	(699)	
F1 (0.3-0.9)	14,123	11	11,975	9	2,148	(2)
F2 (0.9-1.8)	19,118	14	20,723	15	1,605	1
F3 (1.8-3.6)	22,115	16	26,153	19	4,038	3
F4 (>3.6)	5,777	4	7,870	6	2,093	2
Total flooded area	60,750	45	66,362	50	5,588	5

Table 2. *Inundation-area estimates out to 2050 (World Bank 2011)*



Source: IWM

Figure 5. *Comparison of risk-exposure zones for 24-hour duration floods (World Bank 2011)*

Interestingly despite this increase in area exposed to flooding the number of people at risk of increased inundation of greater than 0.3m was estimated by the World Bank (2011) to decrease by 9% compared to the baseline of 1998, due to ongoing urban migration (see Table 4). While not attributing the causes of this urban migration, this is presumed to be calculated by current urbanisation rates (and although not stated as such, seen as a process relatively independent of migration as a response to flooding). However it should be noted that this estimate does not appear to account for the increased flooding risk of those migrants who in search for work will be driven to those areas and forced to settle in newly evolving, informal, marginal settlements (termed ‘‘slums’’ in South Asia) of big cities such as Dhaka.

Currently more than 4.5 million of Greater Dhaka’s population live in these marginal settlements (Centre for Urban Studies 2006), of which it has been estimated that 2 million have experienced at least one major flood in and around their dwelling (Braun and Aßheuer 2011). Future climate change-induced inland flooding is likely to increase this number. There are multiple impacts of this flooding including diarrhoea, fever and/or skin diseases, levels of which in one study were reported to be 57% of the people living in hazardous zones (Braun and Aßheuer 2011). Table 3 shows the various impacts of these floods on a sample of 625 households affected by flooding in Dhaka from this study

Characteristics during or immediately after the flood	Results of the survey
House/dwelling has been damaged	70% of the households
People had to leave the house	51% of the households
Cutback in nutrition	90% of the households were forced to eat less or far less than during normal times
Preparation of food	85% had difficulties to prepare food
Diseases	At least one family member got severely ill in 57% of the households
Ability to continue work	75% of the households were not able to continue work (out of theses 70% did not work for 14 days or longer)
Reasons for not being able to work	Not able to reach the workplace: 48%
	Working area flooded: 35%
	Severe diseases: 11%
	Necessity to take care of household/children: 5%
Family income	70% of the households faced a significant decrease of the family income
Loss of savings	74% lost all their savings
Loss of valuables	70% of the households lost valuable assets

Table 3. *Range of impacts of flooding in slum areas of Dhaka. Source: Braun and Aßheuer (2011)*

Increased flooding in Bangladesh is likely to not just occur due to enhanced river flow but also due to sea level rise and storm surges due to changes in cyclone activity in the future. Potential global sea level rise is currently projected to be ranging from 18-59 cm by the end of the century (IPCC 2007). Locally within Bangladesh a combination of global sea level rise, accretion and erosion processes will work to both increase and decrease the land area available in the coastal areas. However currently there is a significant knowledge gap regarding the result of these different processes over time. Table 5 shows modelled changes in the total flood land type area based on a coastal zone modeling effort for a 15, 27 and 62 cm sea level rise (World Bank 2011). Clearly it can be seen that the total flooded area increases by 6, 10, and 20 per cent for the three sea level rise scenarios respectively.

Inundation level (m)	Population exposed under baseline scenario	Population exposed in 2050 under baseline scenario	Projected population exposed in 2050 under climate change scenario	Change (%) between baseline and climate change scenarios in 2050
F0 (0.1-0.3)	1,009,898	843,729	681,031	-19
F1 (0.3-0.9)	6,721,555	5,615,588	4,566,517	-19
F2 (0.9-1.8)	8,490,523	7,093,488	8,108,952	14
F3 (1.8-3.6)	7,105,158	5,936,072	7,543,397	27
F4 (>3.6)	699,027	558,945	899,066	61
Total exposed population	22,986,263	19,204,093	21,117,932	9

Table 4. *Vulnerable population estimates for inland monsoon floods Source: World Bank (2010a)*

	F0 (0-0.3m)	F1 (0.3-0.6)	F2 (0.6-0.9)	F3 (0.9-1.8)	F4 (>1.8)	Total Flooded Area	% of total area
Base	15,920	4,753	4,517	5,899	1,759	16,928	52
15cm	14,841	4,522	4,705	6,765	2,015	18,007	55
27cm	14,189	4,345	4,488	7,456	2,370	18,659	57
62cm	12,492	3,967	3,818	8,977	3,594	20,356	62

Table 5. Sea level rise impacts on flood land types

Storm surges

Bangladesh is affected by cyclones nearly every year, with severe cyclones striking on average every 3 years. Inundation is the largest adverse impact resulting from the storm surges associated with these cyclones. In Table 6 the inundation characteristics for cyclones of different strengths are shown for Bangladesh (MCSP 1993). Historically typical storm surge height during severe cyclones is between 1.5 and 9.0m.

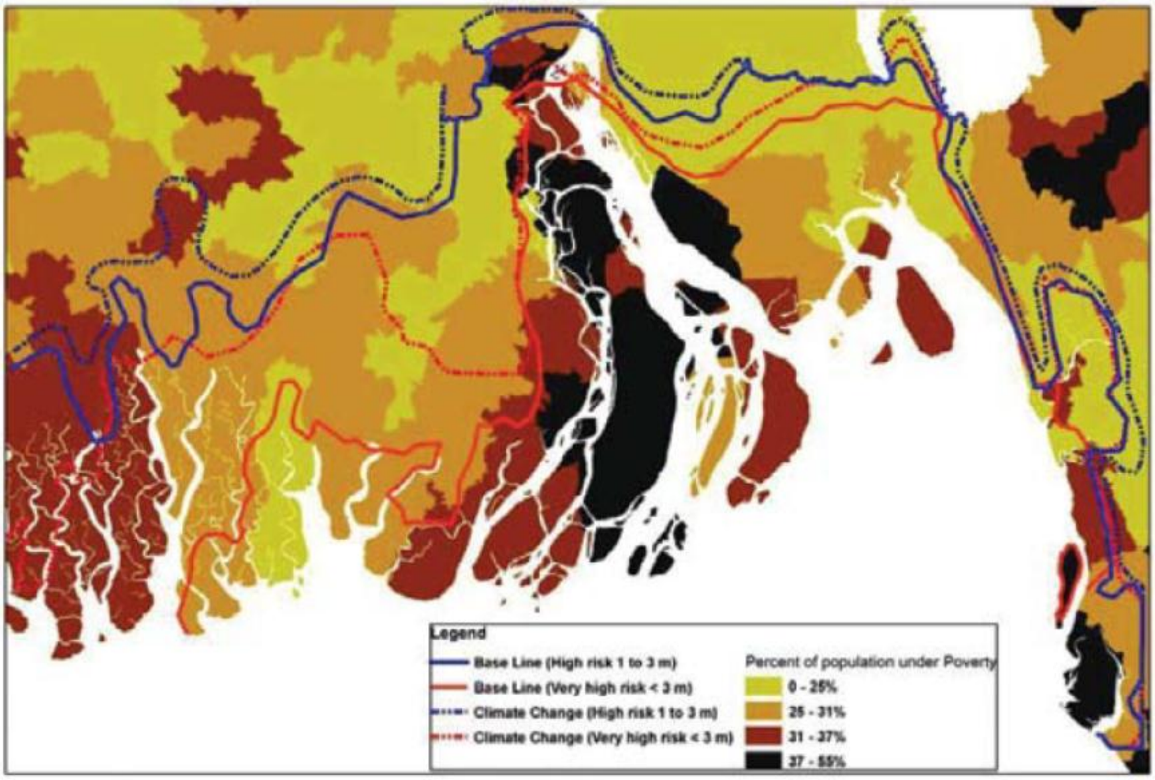
Wind Velocity (km/hr)	Storm Surge Height (m)	Limit to inundation from the Coast (km)
85	1.5	1
115	2.5	1
135	3.0	1.5
165	3.5	2
195	4.8	4
225	6.0	4.5
235	6.5	5
260	7.8	5.5

Table 6. *Typical storm surge characteristics for cyclones in Bangladesh. Source: MCSP (1993)*

Climate change is likely to increase the extent of storm surge induced inundation in Bangladesh due to the increase in ocean surface temperature resulting in more intense cyclones and rising sea levels resulting into large surge waves relative to the land. Estimates by the World Bank (2011) of the addition areas vulnerable to inundation depths of more than 1m and 3m, in a changed climate change are 14 and 69% respectively, compared to a baseline scenario taken from the tracks of the 19 major cyclones that made landfall from 1960 to 2009. The climate change scenario chosen in this study assumes a sea-level rise of 27 cm (UK DEFRA 2007), increased wind speed of 10 per cent (World Bank 2010a), and landfall during high tide (World Bank 2011). The number of people vulnerable to this increased inundation is shown in Table 7. From this table it can be seen that the combination of population growth and climate change is estimated to lead to a doubling of the number of people vulnerable to 1m of flooding from storm surges and near trebling of the number of people vulnerable to an inundation depth of 3m and above representing an added risk from climate change to just over 7 and 9 million people respectively.

Inundation depth (m)	**Current**	**2050 under baseline scenario**	**Change (%) between current and baseline scenario**	**2050 under climate change scenario**	**Change (%) between baseline and climate-change scenarios in 2050**
>1	16.83	28.27	+68	35.33	+25
>3	8.06	13.54	+68	22.64	+67

Table 7. *Vulnerable population estimates for cyclonic storm surges (World Bank 2010a)*



Source: CEGIS

Figure 6. *Population under poverty in relation to inundation risk (World Bank 2010a)*

The change in the spatial extent of inundation from storm surges with climate change is shown in Figure 6. alongside the distribution of poverty amongst the population. Clearly the highest inundation risks under both the baseline and climate change scenarios coincides with areas with the highest share of people living under conditions of poverty.

Estimates of the potential impact of the inundation from storm surges for the baseline and climate change scenario in terms of potential damages and losses for each of the major economic sectors is shown in Tables 8 & 9. These costs compare with the cost of Cyclone Sidr in 2007 of 2.6% of GDP.

Economic Sector	Average Severe Cyclone 2009	Baseline Scenario (a)	Climate Change scenario (b)	Additional due to climate change (b)-(a)
housing	900	1,825	3,772	1,947
Non-agriculture productive sector	56	1,333	2,505	1,172
Agriculture/Fisheries/Livestock	469	906	1,816	910
Transport	151	212	504	293
Power	15	239	449	210
Water Resource Control	83	83	100	17
Education Infrastructure	73	9	19	10
Other	55	n/a	n/a	n/a
Total Damages and Losses	1,802	4,607	9,166	4,560
Share of GDP	2.4%	0.3%	0.6%	0.3%

Table 8. *Damages and Losses from Cyclone Sidr (2007) by Economic Sector (World Bank 2010a)*

Economic Sector	Damages (Million USD)	Losses (million USD)	Damages and losses (million USD)	Share of Damage & losses (%)
Housing	1,947	-	1,947	43
Industry/commerce/tourism	88	1,084	1,172	26
Agriculture	75	835	910	20
Transport	240	53	293	6
Power	60	150	210	5
Coastal Protection	17	0	17	0
Education Infrastructure	9	1	10	0
Others	n/a	n/a	n/a	n/a
Total	2,437	2,123	4,560	100

Table 9*. Additional Damages and Loses Due to Climate Change in 2050 (World Bank 2010a).*

Clearly the extent of losses in agriculture is dependent on the time of the year when the cyclone hits. In Table 10 the expected crop damage estimates from storm surges by 2050 are shown for the three major rice crops *aman, as*, and *boro*. Despite an expected growth in yields by 2050 the estimated additional crop loss in 2050 due to climate change is $789 million. While agriculture represents a major livelihood option for the majority of the population of rural Bangladesh, industry, commerce, and

Crop	Baseline Scenario 2050	Climate Change Scenario 2050	Percent change
Aman	1,092,645	1,305,028	19
Aus	526,040	618,897	18
Boro	272,768	388,828	43

Table 10*. Cropped area exposed to Inundation risk in the baseline and climate change scenarios (Ha) (World Bank 2010a)*

tourism account for over 80 percent of GDP (World Bank 2010a). By 2050 this share is expected to increase to over 90%. Estimates of the additional damages and losses to these non-agricultural sectors due to the increased risk due to climate change and the larger areal extent of a storm under the climate change scenario are $88 million and $1,084 million respectively (World Bank 2010a).

Salinisation

One of the additional impacts of both storm surge and sea level rise based inundation apart from the direct effect of flooding is the salinisation of soil and water resources in the coastal region. Other causes of increased salinisation have been cited as a decrease of upstream flow due to Farrakka Barrage in the upstream of the Ganges River, the horizontal Expansion of shrimp farms and the Coastal Embankment Project (CEP) implemented during the 1960s (PRDI 2012). Another study by the World Bank (2010b) concluded that any future sea-level rise will increase the adverse impact of the already-occurring salinisation processes on groundwater. In particular within the current coastal zone, the primary impact of the sea level rise induced sea transgression on coastal groundwater resources will be the direct loss of land area and loss of the possibility to easily pump any fresh groundwater that remains below the areas covered by the sea. Additionally, an increase of the frequency of storm surges, or storm surges that cover a greater area of the land surface due to the higher sea stand, was suggested to increase the likelihood of vertical downward intrusion of saltwater to wells that currently produce fresh groundwater, wherever the saline floodwater is able to infiltrate. It was also noted that groundwater extraction in the coastal zone, even without climate change, will exacerbate salinisation rates. Despite this the study notes “careful management may enable use of the current coastal zone freshwater resource for a very long period of time, should sea level not rise appreciably” (World Bank 2010b).

However more recent research by Bhuiyan et al (2012) points to a larger impact of sea level rise on the salinisation of fresh water resources in Bangladesh. Accordingly they calculated for the Gorai river network for a sea level rise of 59 cm there was an increase of 0.9 ppt in salinity at a distance of 80 km upstream of river mouth, corresponding to a climatic effect of 1.5 ppt per meter sea level rise. Currently the estimated salt intake from drinking water in Bangladesh exceeds recommended limits with rises in salinity of water resources linked to declines in maternal health in coastal areas through increased hypertension (Khan et al 2011).

Agriculture

Sixty five per cent of Bangladesh’s workforce is currently engaged in agriculture. Despite increased climate threats agricultural production since the 1970s has nearly trebled due to the rapid expansion of surface and groundwater irrigation and the introduction of new high-yielding crop varieties (World Bank 2010a). Using the 16 GCM outputs described above and dynamic biophysical crop models the World Bank (2010a) estimates natural production for various crops, to decline by 2050 with *boro*[1] showing the largest median losses. The climate impacts include CO_2 fertilisation, temperature and precipitation changes, flood changes and sea level rise. Looking at the results of these simulations (Figure 7.) it can be seen that both for *aus* (-1.5 per cent) and *aman* (-0.6 per cent), the range of model experiments based yield changes covers both potential positive gains and losses. By contrast most GCM projections estimate a potential decline in *boro* production with a median loss of 3 percent by the 2030s and 5 percent by the 2050s. Importantly it should be noted that in line with all current crop models the gap between actual yields and modelled potential yields is large and that estimated *boro*

[1] *Aman* grows in the monsoon season, *aus* grows in pre-monsoon, and *boro* grows in the post-monsoon season

and wheat changes are likely to be larger, as it is assumed that farmers have limitless access to irrigation (World Bank 2010a). Spatially the agricultural production in the southern sub-regions of Bangladesh is most vulnerable to climate change. For example, average losses in the Khulna region are estimated at -10 per cent for *aus, aman*, and wheat and -18 percent for *boro* by the 2050s due in large part to rising sea levels (World Bank 2010a).

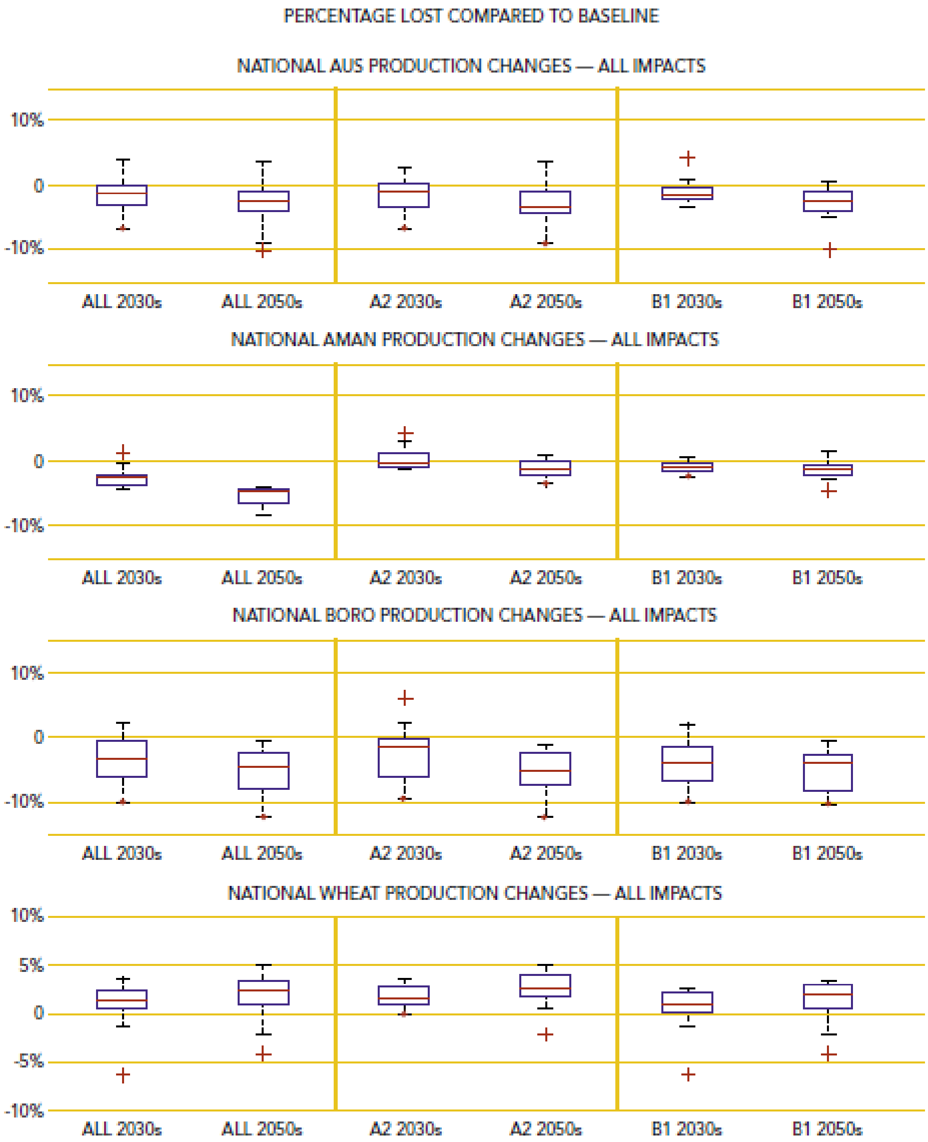


Figure 7. *Percentage change in national potential production for each crop (aus, aman, boro, and wheat) with the combined effects of CO2, temperature, precipitation, and basin flooding. Each panel has three sections, each containing two future time periods and presenting (from left to right) the combination of all emissions scenarios, the A2, and the B1 scenario. The distribution of potential yields projected by GCMs are presented as a box and whiskers diagram, consisting of a red line representing the median value, a box enclosing the inter-quartile range (the middle 50 percent of models), dashed whiskers extending to the furthest model that lies within 1.5x the inter-quartile range from the edges of the box, and red plus symbols for additional models that are perceived as outliers. Source: Yu, W.H., et al. (2010)*

These estimated production impacts ignore economic responses to these shocks (e.g. land and labor reallocation, price effects). Taking these into account the World Bank (2010) estimates overall, agricultural GDP to be 3.1 percent lower each year as a result of climate change ($36 billion in lost value-added). The southern coastal region and the northwest are predicted to bear the largest losses, with the poor and the most vulnerable within these communities bearing the greatest burden (World Bank 2010a). A more recent paper on winter rice production over the country show decreases upto 33 % for 2046-2065 and 2081-2100 (Karim et al. 2012).

It should be noted that none of the above estimates of impacts of climate change account for adaptation efforts in Bangladesh including, diversifying household income sources; improving crop productivity; supporting greater agricultural research and development; promoting education and skills development; increasing access to financial services; enhancing irrigation efficiency and overall water and land productivity; strengthening climate risk management; and developing protective infrastructure. Shorter term and more locally livelihood based adaptation strategies include zero or minimum tillage to cultivate potato, aroid and ground nut with water hyacinth and straw mulch; (2) zero tillage cultivation of *mashkalai, khesari*, lentil,and mustard; (3) modified *sorjan* system (*zuzubi* garden) with vegetable cultivation; (4) floating bed vegetable cultivation; (5) cultivating foxtail millet (*kaon*); (6) parenga practice of *aman* cultivation system; (7) relay cropping of sprouted seeds of *aman* rice in jute fields; (8) raising vegetable seedlings in poly bags homestead trellises; (9) zero tillage maize cultivation; (10) zero or minimum tillage to cultivate potato with water hyacinth and straw mulch; (11) chickpea cultivation using a priming technique; (12) supplementary irrigation for *aman*; (13) year-round homestead vegetable cultivation; (14) pond water irrigation for vegetable cultivation; (15) sorjan system of cropping of vegetables and fisheries; and (16) raising vegetable seedlings in poly bags homestead trellises (World Bank 2010a).

References

Agarwala, S., T. Ota, A., Uddin Ahmed, J. Smith and M. van Aalst (2003) Development and climate change in Bangladesh: Focus on coastal flooding and the Sundarbans. Environment Directorate , Development Co-operation Directorate, Working Party on Global and Structural Policies Working Party on Development Co-operation and Environment, Paris: OECD, available at http//: www.oced.org/env/climatechange/21055658.pdf

Braun, B., and T. Aßheuer (2011) Floods in megacity environments: vulnerability and coping strategies of slum dwellers in Dhaka/Bangladesh. *Natural Hazards* 58:771–787.

Bhuiyan Md. Jabed Abdul Naser Bhuiyan and Dushmanta Dutta (2012) Analysis of flood vulnerability and assessment of the impacts in coastal zones of Bangladesh due to potential sea-level rise, *Natural Hazards* 61:729–743.

Centre for Environmental and Geographic Information Services (2010) Mid-Term report on Field-Based Research on the Impacts of Climate Change on Bangladesh Rivers. Dhaka: ADB, Bangladesh.

Centre for Urban Studies (CUS), National Institute of Population and Training (2006) Measure Evaluation, Slums of urban Bangladesh: mapping and census, 2005. Dhaka and Chapel Hill.

Intergovernmental Panel on Climate Change (2007) Climate Change 2007: The Physical Science Basis, Fourth Assessment Report of the IPCC, Working Group I. Geneva: IPCC.

Khan, Aneire Ehmar, Andrew Ireson, Sari Kovats, Sontosh Kumar Mojumder, Amirul Khusru, Atiq Rahman, and Paolo Vine (2011) Drinking Water Salinity and Maternal Health in Coastal Bangladesh: Implications of Climate Change. Environmental Health Perspective 119: 1328–1332.

Karim, Mohammed R., Mamoru Ishikawa, Motoyoshi Ikeda and Md. Tariqul Islam Karim (2012) Climate change model predicts 33 % rice yield decrease in 2100 in Bangladesh. Agronomy for Sustainable Development 32: 821–830.

Multi-purpose Cyclone Shelter Project (1993) Summary Report, Dhaka: Bangladesh University of Engineering and Technology and Bangladesh Institute of Development Studies.

UK Department for Environment, Food and Rural Affairs (2007) Investigating the Impact of Relative Sea-level Rise on Coastal Communities and Their Livelihoods in Bangladesh, London: UK DEFRA

World Bank (2010a) The Economics of Adaptation to Climate Change. Environment Department. Washington DC: World Bank.

World Bank (2010b) Implications of Climate Change for Fresh Groundwater Resources in Coastal Aquifers in Bangladesh, Dhaka: World Bank Office.

World Bank (2011) The Cost of Adapting to Extreme Weather Events in a Changing Climate BANGLADESH Development Series Paper No. 28. Washington, DC: World Bank.

Yu, Winston, Mozaharul Alam, Ahmadul Hassan, Abu Saleh Khan, Alex Ruane, Cynthia Rosenzweig, David Major, and James Thurlow (2010) Climate Change Risks and Food Security in Bangladesh. London: Earthscan.