Impact of Sea Level Rise in Bangladesh: A Socio Engineering Overview

Sabrina Ali[1*] and Faruk Kader[2]

[1] School of Computing, Engineering and Mathematics, University of Western Sydney, New South Wales, Australia

[2] Private Consultant

Peer Review History[1]

Abstract: Sea Level Rise (SLR) is currently a burning issue for the coastal zone of Bangladesh. The main cause of the SLR is the changes in climate conditions. Approximately 28% of the total populations of this country are under threat of being 'climate refugee' due to SLR. The projection of SLR has raised the concern of permanent inundation, land erosion, salinity intrusion, fresh water and food security along with existence of ecosystems in the coastal zone. This study emphasizes the present and future scenario of the SLR projections rather identifying the root causes of SLR as well as global warming. As an integral part of SLR, the impacts of sea surface water temperature rise and the possible threat on the coastal ecology of the country have been pointed out using secondary data sources. Intensive information on salinity-intrusion and possible coastal storms are also studied. Furthermore, how the poverty and the dependency on the foreign aid are linked with the climate change and SLR are demonstrated in the study from the socio engineering aspect. The critical combinations of location, geography and climate of Bangladesh coupled with its high population density are not only influencing the country to be a disaster prone one, but also placing difficulty in adopting protection measures. The proposed study is expected to provide useful information regarding socio-economic impacts of SLR, so that sustainable adaptation measures can be identified to cope with SLR in the coastal region of Bangladesh as well as other parts of the world.

Keywords: *Coastal region, climate change, SLR, salinity intrusion, socio engineering, Bangladesh.*

1. Introduction

Sea Level Rise (SLR) is one of the climate change issues that first drew global attention of climate scientists. The greenhouse gas emissions are resulting global warming which in turn causing glacier melting and sea-level rise (SLR). According to the Intergovernmental Panel on Climate Change (IPCC, 2007a), Bangladesh has been described as one of the most vulnerable countries in the world facing SLR and storm surges from the Bay of Bengal (IPCC, 2007b). The geographical location, geomorphology and local factors like subsidence and sediments play a catalytic role for turning it to be a disaster prone country (Khan *et al.*, 2011; Bhuiyan and Dutta, 2012; Bose, 2013; Saroar and Routray, 2010). In recent time, the coastal zone of Bangladesh was hit by a series of tropical cyclone, SIDR, AILA and NARGIS, which have exposed the vulnerability of the people living in the zone (Khan *et al.*, 2011). About 28% of the population lives in the coastal zone (Karim and Mimura, 2008), so a minimum increase in SLR could spell disaster for the whole country (Nicholls, 2002). It is estimated that the projected rise in the sea level would inundate 16% of the populated land in the 21st century which would results a displacement of around 10-30 million people and may reduce the GDP of the country by 10% (Houghton *et al.*, 2009). However, the projected figures of the impacts on the land and GDP due to the SLR were termed not realistic enough in a recent study by Brammer (2014). Coastal zone does not only have an enormous conservation value but is also one of the most productive and diverse ecosystems in the world (Loucks *et al.*, 2009). Thus, the predicted sea surface temperature rise combined with the sea level rise in the coastal zone would be a potential threat to the overall socio-economic development of the country. This study revealed a pragmatic and comprehensive understanding about the socio-economic impacts of SLR and will add value to the existing body of knowledge related to flood plain management authorities and SLR refuges.

[1] *Paper JHER0306, submitted on 30/04/2015, accepted for publication after peer review and subsequent revisions on 25/06/2015*

[*] *Corresponding author may be contacted at sabrina.hoque@yahoo.com*

2. Overview of the coastal zone of Bangladesh

Bangladesh, stretching from the Himalayan at north to the Bay of Bengal at south, is one of the largest geosynclinals in the world. With an area of 147, 570 km^2, the country is bounded between 20°34′–26°38′N and 88°01′–92°41′E (Figure 1). Most of the land, except the north-eastern and south-eastern regions, lies in the flat and low- lying floodplains of three major rivers- the Ganges, the Brahmaputra and the Meghna (Brammer, 2014). This tropical country is mainly undergoing sea level rise along its 710 km long coastline as a result of the global warming and the subsidence of the Bengal Delta over the last 11,000 years (Alam, 1996; Haque, 1997). All these scenarios make the country susceptible to the natural catastrophic disasters (Ali and Chowdhury, 1997).

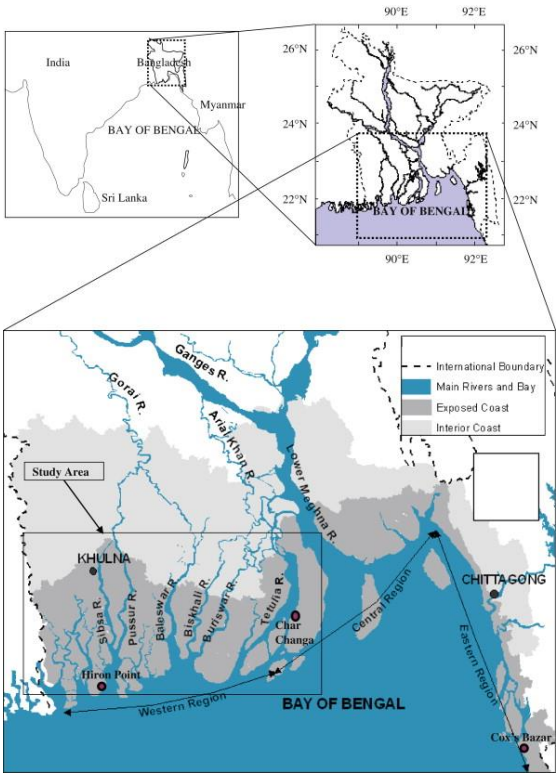

Figure 1 Coastal region of Bangladesh (Karim and Mimura, 2008)

About 28% of the country's population occupying with the 32% of the land area live in the coastal zone under tidal influence (Karim and Mimura 2008). Moreover, during the fishing season a significant number of migratory fishermen come to the coastal zone from all over the country. The south-western zone, which is the home to around 14 million people, is considered as the exposed coast for its extreme vulnerability from water logging, salinity intrusion and storm surges (BBS, 2005).

3. Future climate change scenarios and the SLR projections

The global temperature has increased by about 0.6 °C and global sea levels have risen by around 10–20 cm during the last 20th century (Houghton *et al.*, 2001). The apparent rise of the sea level of the twentieth century is predicted to continue or get worsen in the twenty first century (Nicholls *et al.*, 2011, Ahmed and Alam, 1999). Bangladesh has already become warmer by 0.5o C over the past 100 years (Karim and Mimura, 2008). The monsoon rainfall (long term mean 166 ± 12 % cm) has been observed to increase abruptly since 1950 in Bangladesh (Bhuiyan, 2005). The Organization of Economic Co-operation and Development (OECD) conducted a study which found a steady increase in temperature in future in comparison to the current climate pattern of Bangladesh (Agarwala *et al.*, 2003). The meteorological research council of the South Asian Association for Regional Cooperation in a research found relative sea level rise at three significant parts of coastal zone. They found that the SLR has risen by 4.0, 6.0 and 7.8 mm/ year based on the sea level data of 22 years during the period of 1980-2002 (SMRC, 2003). This rise in sea level in Bangladesh was found to be much higher than that of global average (1-2 mm/year in the last century) (Karim and Mimura, 2008).

According to the Fourth Assessment Report of the Intergovernmental Panel on Climate Change (IPCC), the global mean sea level is estimated to rise in the range of 18- 59 cm from 1990 to 2100 (IPCC, 2007a). The predictions were found to be higher in the Second and Third Assessment Report, which were in between 23 and 96 cm, and 9 and 88 cm, respectively (Church *et al.*, 2001; Warrick *et al.*, 1996). In 2005, the National Adaptation Program of Action (NAPA), based on the result of the available existing studies and reports, came up with the following result (Table 1) for future Bangladesh where it was projected that Bangladesh may experience an SLR of 14, 32 and 88 cm by the year 2030, 2050 and 2100, respectively.

Table 1 Future climate change scenarios for Bangladesh, revealed by NAPA, 2005 (IWM, 2005)

Year	Temperature change (C) mean		Precipitation change (%) mean		Sea level rise(cm)		
	Monsoon Season	Dry Season	Monsoon Season	Dry Season	3rd IPCC	SMRC	NAPA scenario
2030	0.8	1.1	+6.0	-2.0	14	18	14
2050	1.1	1.6	+8.0	-5.0	32	30	32
2100	1.9	2.7	+12.0	-10.0	88	60	88

4. Impacts of the SLR

Among the adverse impacts of climate change conditions, sea level rise is one of the major issues that first triggered the concern globally. Several assessment reports of the Intergovernmental Panel on Climate Change (IPCC) have revealed that the SLR may have unprecedented impacts on low-lying deltaic coasts, where one-fifth of the global population live (IPCC 1996, 2001, 2007). Hence, it is one of the major challenges for the coastal habitants as well as the whole nation of Bangladesh to reduce and manage the impact of SLR. Bangladesh is prone to various detrimental hydro-meteorological calamities, such as, flood, cyclone, tidal surge and river bank erosion; the estimated SLR may increase the intensity and magnitude of the disaster. The overview of the possible impacts of SLR of 0.10 m, 0.25 m and 1.00 m for Bangladesh had been assessed by the World Bank in its report, titled as "Bangladesh: Climate change and Sustainable Development report in 2000" (World Bank, 2000). The report unveils that a 1.0 m rise in sea level would affect 17.5% land area of Bangladesh. It would result in devastating storm surge along with significant inundation and salinity intrusion in surface and groundwater which would eventually affect the agriculture, livelihood and ecosystem of the country (Table 2). Based on the study of (Bijlsma, 1996; Singh *et al.*2001; Nicholls, 2002; Cannon 2002; Saroar and Routray, 2010) the four major impacts of SLR in the coastal zones can be identified as shown in Figure 2.

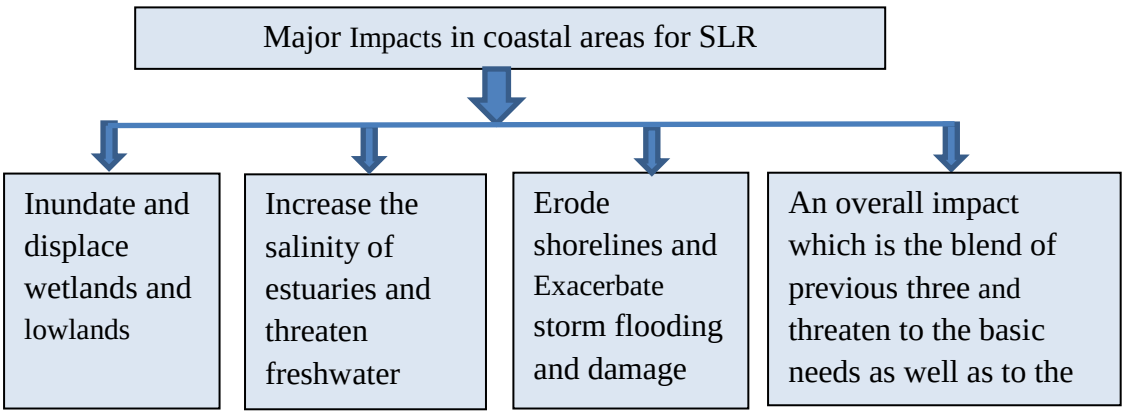

Figure 2 Major impacts of the Sea Level Rise in the coastal zone

Table 2 Possible impact of SLR in Bangladesh (World Bank, 2000; Sarwar and Khan, 2007)

SLR (m)	0.1	0.25	1.0(high end estimate)
Affected Land Area (m2)	2,500 (2 %)	6,300 (4 %)	25,000 (17.5%)
Storm surge	-	Storm surges with a 10% increase in intensity from the cyclone of 1991, wind speed increases from 225 to 248 km/h; Storm surges goes from 7.1 to 8.6 m with 0.3 m SLR.	Storm surge goes from 7.4 to 9.1m with1 m SLR.
Flooding	20%increase in inundation	Increased flooding in Meghna and Ganges floodplain. Monsoon floods increase yield loss.	Both inundation area and flood intensity will increase significantly.
Agriculture	Inundate 0.2 Mmt.of production <1%of current total.	0.3m SLR inundate 0.5 Mmt.of production;2% Of current total.	Devastating flood may cause crop failure for a year.
Ecosystem	Inundates15% area of the Sundarbans	Inundates 40% area of the Sundarbans.	The Sundarbans would be lost. Loss of the Sundarbans and other coastal wetlands would destroy the ecosystems.
Salinity	Increase	Increase	Increase

4.1 Coastal Inundation

Permanent inundation is the most apparent consequence of the SLR in certain parts of the coastal region of Bangladesh. The country is situated at the lowest riparian area of the world's second largest catchment Ganges-Brahmaputra-Meghna (GBM). The combined flow and the sediment yield of the total catchment from the melting of Himalayan glaciers and ice sheets with an annual runoff of 1200 km3 will raise the sea level; inundate deltas, coastal lowlands and coral islands; erode lands and worsen coastal flooding (Mirza, 2002). The monsoon rainfall along with air temperature and extreme climatic events are expected to increase more in these geographical regions in future.

A mathematical model was developed by the Institute of Water Modelling (IWM), Bangladesh in 2005 to estimate the impacts of SLR. Through analysing the existing and estimated SLR scenarios, the model predicted that 11% of the total land area would be permanently inundated within the century. The Sundarbans, the world's largest mangrove ecosystem, declared as the Ramsar Heritage Site in 1997, will be destroyed by the year 2100 as a result of the projected SLR by IWM (2005). As in other Asian countries, the numbers of coastal flooding events in Bangladesh have tripled with financial losses and human casualties rising by more than five folds in the last 30 years (Bhuiyan, 2005).

4.2 Salinity Intrusion

The effect of salinization and its consequences to the surface water and ground water resource is one of the pressing issues of SLR. The salinity intrusion will ultimately affect the fresh water quality (Bashar and Hossain, 2006) and in turn will affect the coastal habitats, agricultures, fisheries, industries, aquatic plants and animals and the ecosystems adversely (Zhang *et al.*, 2011). A recent study showed that the amount of salinity and the extent of salinity intrusion will increase due to sea level rise in Bangladesh (Bhuiyan and Dutta, 2012). The study developed an

integrated model to simulate salinity intrusion in the exposed coast (south- western part shown in Fig-1) of Bangladesh. The upper range of the SLR value (59cm), predicted by the fourth assessment report of IPCC, was applied in the model for simulating the worst possible impact (Bhuiyan and Dutta, 2012).

Table 3 Results of increase in salinity showed by the model from the two different stations in the coastal zone of Bangladesh (Bhuiyan and Dutta, 2012)

Station	Without SLR(ppt)	With 59 cm SLR(ppt)	Increase of Salinity(ppt)
1st station	14.8	15.7	0.9
2nd station	17.3	18.0	0.7

The results from the two different stations demonstrate the increase in salinity due to SLR at the range of 0.7-0.9 ppt. Furthermore, National Adaptation Programme of Action (NAPA), in 2005, represented an indication of increase of salt water intrusion through an example of a power station situated in the coastal zone of Bangladesh. The study found that, the fresh water (free from salt impurities) that the power station needs has been collected from noticeably further upstream since the last decade (NAPA, 2005). The largest continuous mangrove ecosystem, Sundarban, has been affected already by the salt water intrusion and as an impact, its historical natural heritage, Sundari Tree is ceasing to exist (Rahman *et al*., 2011).

4.3 Cyclone Storm Surge

IPCC (2007) has predicted that Bangladesh is likely to be affected by more extreme catastrophic weather events like cyclone and storms in the upcoming days due to climate change and SLR (IPCC, 2007a). However, the country's overall capacity to face the natural disasters has improved over the last decade as a result of better flood forecasting, warning and evacuation systems. For example, the cyclones of 1970 and 1991 washed away around 500 000 and 138 000 lives respectively in Bangladesh, whereas Sidr a cyclone of similar destructive magnitude caused 500 people in 2007 (Karim and Mimura, 2008).

An analysis was conducted in 2008 using a model calibrated with present climate condition to assess the impact of SLR due to cyclonic storm surge floods in Bangladesh by Karim and Mimura (2008). It was observed that the 2º C rise of sea surface temperature and 0.3m rise of sea level could lead to increase in flood risk area by 15.3% from the present conditions. This will worsen the depth of flooding by 22.7%, up to 20km from the borderline of the coastal zone. Consequently, the high risk zone areas are predicted to be 1.26 times larger than the existing one.

5. Socio- engineering aspects of SLR

The impacts of SLR (inundation, salinity intrusion and cyclone or storm) will ultimately affect the basic needs of the millions of people and will raise the issue of country's water and food security problem. Particularly the agricultural production like rice production, and fisheries sector like shrimp farming in the coastal zone will be impacted by SLR in Bangladesh. For example, a flood in the south-western part of Bangladesh caused damages to crops, fish farms (especially shrimp farms), property and infrastructures worth about at least $500 million in the year of 2000 (Basher, 2000). The physical geography of the Bangladesh's coastal area was stated as neither uniform nor static; it was rather identified as diverse and dynamic (Brammer, 2010), so are the people of Bangladesh. The casual loop diagram in Figure 4 (Haraldson, 2004) was developed to show the impact of SLR on the agriculture and fisheries sector of the coastal zone of Bangladesh.

From the above loop diagram, how the poverty and the dependency on the foreign aid are boosting up from the climate change and sea level rise are depicted. Here, the diagram is centralized with respect to the agricultural and fisheries sector, as because these two are the main driving factors of the coastal economy as well as national economy. Coastal inundation or flood, salinity intrusion, cyclone frequency, and damage and cyclone storm surge increases are shown in the figure as the three major impacts of SLR. All these three factors affect the coastal agriculture and fisheries adversely, so represented as inversely proportional. However, about 60-80% of animal protein intake by the people of Bangladesh comes from fish consumption (Alam and Thomson, 2001). So, diminishing coastal fisheries would cause protein deficiency and eventually cause

health hazards. Moreover, agricultural and fisheries industries (both frozen and fresh) are one of the largest foreign exchange earning sectors of Bangladesh. Hence, reduction of foreign exchange earnings would raise the poverty as well as dependency on foreign aid due to climate change conditions and SLR.

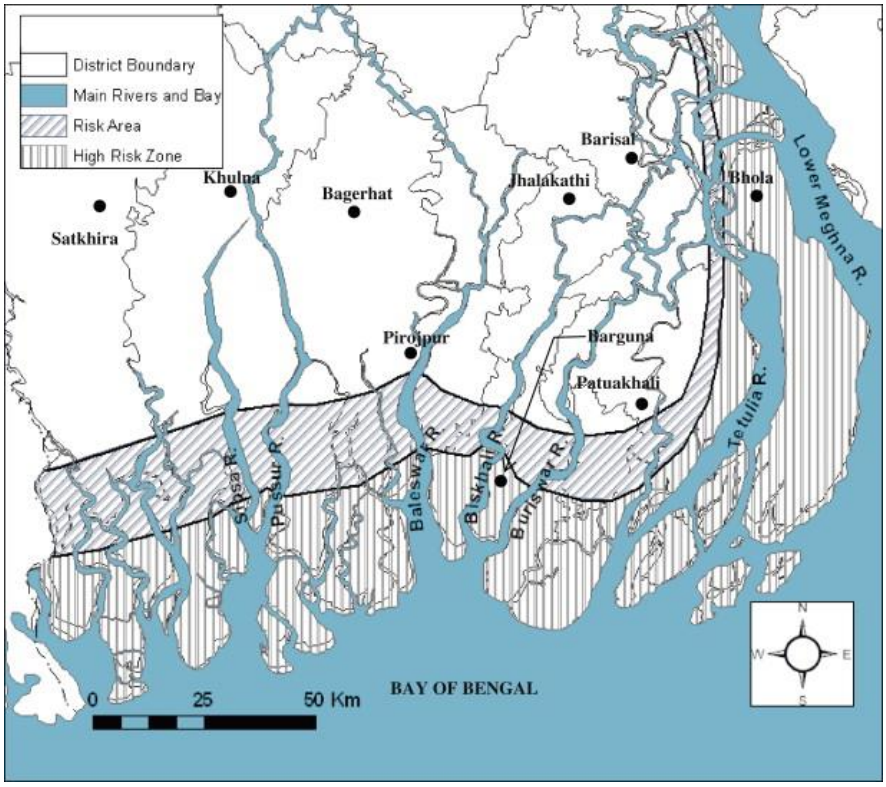

Figure 3 Map representing risk prone areas in the coastal zone of Bangladesh resulting from 2° C temperature rise and 0.3m sea level rise (Karim and Mimura, 2008)

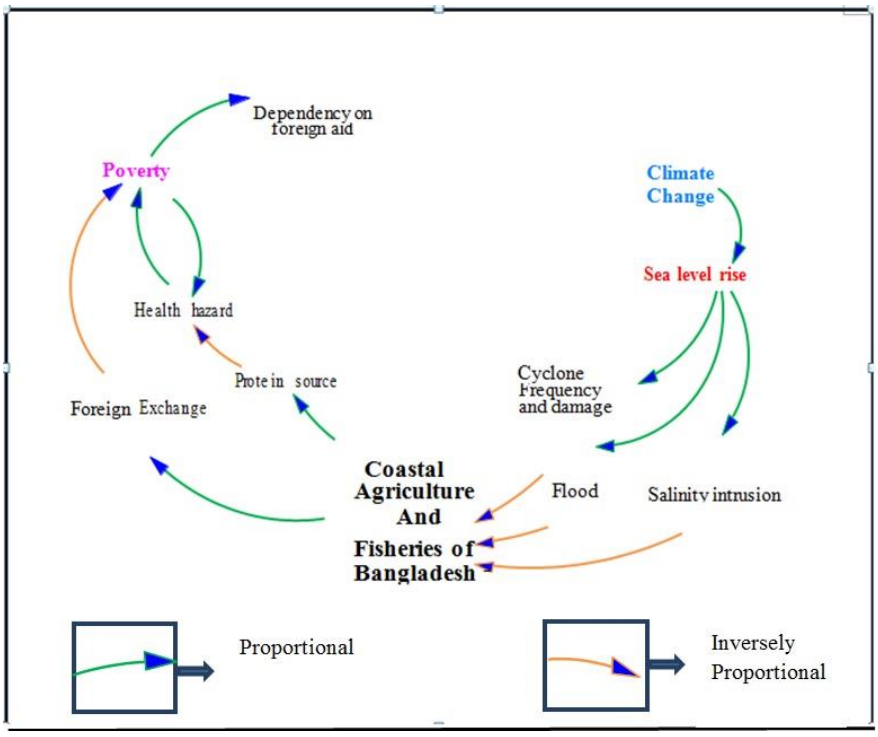

Figure 4 Casual Loop Diagram of Sea Level Rise Impacts on Coastal Agriculture and Fisheries Sector of Bangladesh (Sarwar and Khan, 2007)

6. Conclusion

The detrimental impacts of SLR are emerging even more pronouncedly in the future and this issue alone can let down the Millennium Developments Goal and can cause significant amount of ecological refugees. This paper identifies the key impacts of SLR in coastal Bangladesh that fall under the socio engineering overview. Using secondary data sources, intensive information on coastal inundation, salinity intrusion and possible cyclone storm surges are studied and showed how the poverty and the dependency on the foreign aid are boosting up with SLR. The investigation will provide opportunities to the responsible authorities and policy makers to better comprehend the coastal and flood management plan. The Government of People's Republic of Bangladesh has already taken some steps and articulated Coastal Zone Policy in 2005 (CZPo, 2005), still there are additional opportunities emphasising holistic, integrated and sustainable measures to combat SLR impacts. In addition, the study will facilitate the environmental inventors and researchers to develop methodologies for assessing the impacts of climate changes, so that they can establish and identify pragmatic, site specific mitigation measures based on the socio economic conditions. Nevertheless, the ability to develop, adopt and cope with climate change impact is a function of capital, scientific and technical understanding, skills, information, strategy and managing bodies and equity. This type of study is essential for the global communities as well as it is a global issue and their collective efforts are indispensable to apprehend the extent at which these climate elements will change and to realize the consequent impacts at the coast.

References

Agrawala S, Ota T, Ahmed AU, Smoth J, Aalst MV (2003). Development and climate change Bangladesh: Focus on coastal flooding and the Sundarbans, Organisation for Economic Co-operation and Development (OECD), Paris, 2003.

Ahmed AU, Alam M (1999). Development of climate change scenarios with general circulation models, Vulnerability and Adaptation to Climate Change for Bangladesh, Kluwer Academic Publishers, Dordrecht, 1999.

Alam M (1996) Subsidence of the Ganges–Brahmaputra delta of Bangladesh and associated drainage, sedimentation, and salinity problems and Coastal Subsidence: Causes, Consequences, and Strategies, Kluwer Academic Publishers, 169-192, 1996.

Alam M (2003). Bangladesh country case study, National Adaptation Programme of Action (NAPA) Workshop, 9–11 September 2003, Bhutan, 2003.

Alam MF, Thomson KJ (2001). Current constraints and future possibilities for Bangladesh fisheries, *Food Policy,* 26, 297-313.

Ali, A. & Chowdhury, J.U., Tropical cyclone risk assessment with special reference to Bangladesh, *MAUSAM* (formerly Indian Journal of Meteorology Hydrology and Geophysics), 48, 305–322, 1997.

BBS (Bangladesh Bureau of Statistics) (2005). Statistical Yearbook of Bangladesh, BBS, Dhaka, Bangladesh, 2005.

Bhuiyan MJAN (2005). Assessment of the economic impacts of floods under climatechange conditions in a coastal city in Bangladesh. Master Thesis, School of Civil Engineering, Asian Institute of Technology, Thailand, 2005.

Bhuiyan NM, Dutta D (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.

Bhuiyan NM, Dutta D (2012). Assessing impacts of sea level rise on river salinity in the Gorai River network, Bangladesh. Estuarine, Coastal and Shelf Science, 96, 219 – 227.

Bose S (2013). Sea-level Rise and Population Displacement in Bangladesh: Impact on India, *Maritime Affairs: Journal of the National Maritime Foundation of India*, 9:2, 62-81.

Brammer H (2014). Bangladesh's dynamic coastal regions and sea-level rise. *Climate Risk Management,* 1, 51-62.

Brammer H (2010). After the Bangladesh Flood Action Plan: looking to the future. *Environmental Hazards*, 9 (1), 118–130.

Chatterjee R, Huq S (2002). A Report on the Inter-regional Conference on Adaptation to Climate Change, *Mitigation and Adaptation Strategies for Global Change*, 7, 403-406.

CZPo (Coastal Zone Policy, Ministry of Water Resources) (2005). Government of the People's Republic of Bangladesh, Dhaka, 2005.

Haque CE (1997). Atmospheric hazards preparedness in Bangladesh: A study of warning, adjustments and recovery from the April 1991 cyclone, *Natural Hazards*, 16(2-3), 181–202, 1997.

Haraldsson HV (2004). Introduction to System Thinking and Causal Loop Diagrams, Department of Chemical Engineering, Lund University, Lund, 2004.

Houghton JT, Ding Y, Griggs DJ, Nouger PJ, Johnson CA (2009). IPCC, 2001; Climate change 2001: The scientific basis. Contribution of working group I to the Third assessment Reportof the IPCC, Cambridge University Press, 881, 2009.

IPCC (2007a). Climate Change 2007: The physical science basis, Summary for policymakers, 10th Session of Working Group I of the IPCC, Paris.

IPCC (2007b). Impact, Adaptation and Vulnerability. Contribution of Working Group II to the Fourth Assessment Report of the IPCC, Cambridge University Press, UK, 976.

IWM (2005). Impact assessment of climate change on the coastal zone of Bangladesh. Final Report, Institute of Water Modelling, Dhaka, Bangladesh, 37, 2005.

Karim FM, Mimura N (2008). Impacts of climate change and sea level rise on cyclonic storm surge floods in Bangladesh. *Global Environmental Change*, 18(3), 490-500.

Khan AE, Xun WW, Ahsan H, Vineis P (2011). Climate Change, Sea-Level Rise, & Health Impacts in Bangladesh, *Environment: Science and Policy for Sustainable Development*, 53:5, 18-33.

Mirza QM (2010). Global warming and changes in the probability of occurrence of floods in Bangladesh and implications, 12(3), 127-138, 2002.

Loucks C, Barber-Meyer S, Hossain MAA, Barlow A, Chowdhury RM (2010). Sea level rise and tigers: predicted impacts to Bangladesh's Sundarbans mangroves, *Climatic Change* , 98, 291–298.

NAPA (2005). Formulation of Bangladesh program of action for adaptation to climate change project. Bangladesh Centre for Advance Studies (BCAS), Bangladesh, 2005.

Nicholls JR (2002). Analysis of global impacts of sea level rise: A case study of flooding. Flood Hazard Research Cantre, Middlesex University, London, UK, 27(32-34), 1455-1466, 2002.

Nicholls RJ, Hoozemans FMJ, Marchand M (1999). Increasing flood risk and wetland losses due to global sea-level rise: regional and global analyses, *Global Environmental Change,* 9, S69-S87.

Nishat B, Rahman MMS (2009). Water resources modeling of the Ganges-Brahmaputra-Meghna river basins using satellite remote sensing data. *Journal of the American water resources association*, 45 (6), 1313-1327.

Rahman FA, Dragon D, Masri EB (2011). Response of the Sundarbans coastline to sea level rise and decreased sediment flow: A remote sensing assessment. *Remote Sensing of Environment*, 115(12) , 3121-3128.

Sarwar GM, Routray JK (2010). Adaptation in situ or retreat? A multivariate approach to explore factors that guide the peoples' preference against the impacts of sea level rise in coastal Bangladesh, Local Environment. *The international Journal of justice and sustainability*, 15:7, 663-686.

Sarwar GM, Khan HM (2007). Sea level rise; A threat to the coast of Bangladesh. *International Environmental Reporter*, 38(3-4), 375-397.

SMRC (2003). The vulnerability assessment of the SAARC coastal region due to sea level rise: Bangladesh Case, SMRC-No. 3, SMRC Publication, Dhaka, Bangladesh, 2003.

Shukla J, Paolino AD (1983). The Southern Oscillation and long range forecasting of the summer rainfall over India. Mon, Weather Re,111, 517–528.

Singh OP, Khan TM, Murty TS, Rahman MS (2001). Sea level changes along Bangladesh coast in relation to the Southern Oscillation phenomenon, Mar, Geod., 24 , 65–72.

Thapliyal V (1990). Long range prediction of summer monsoon rainfall over India: Evolution and development of new models, *Mausam*, 41, 339–346.

Warrick RA, Bhuiya AH, Mitchell WM, Murty TS, Rasheed KBS (1996). Sea level changes in the Bay of Bengal, The Implications of Climate and Sea level Change for Bangladesh, Kluwer Academic Publishers, Dordrecht, 432,1996.

World Bank (2000). Bangladesh: Climate change & sustainable development, Report No. 21104 BD, Dhaka, Bangladesh, 2000.

Zhang E, Savenije HHG, Wu H, Kong Y, Zhu J (2011). Analytical solution for salt intrusion in the Yangtze Estuary, China, *Estuarine,* 91, 492–501.