ASSESSMENT OF STORM SURGE INDUCED VULNERABILITY AND CHANGING ADAPTATION STRATEGIES IN THE SOUTH-WEST COAST OF BANGLADESH

THESIS

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UNDER THE SUPERVISION OF

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CERTIFICATE OF APPROVAL

This is to certify that Ms Nazmun Nahar, Registration No. 160, Session 2014-15, Department of Geography and Environment, University of Dhaka has completed her doctoral research on the title '**Assessment of Storm Surge Induced Vulnerability and Changing Adaptation Strategies in the South-West Coast of Bangladesh**' under my supervision.

The present research work in my opinion is acceptable for evaluation.

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CANDIDATE'S DECLARATION

I, Nazmun Nahar, Department of Geography & Environment, certify that the work embodied in this PhD thesis is my own bonafide work carried out by me under the supervision of Prof. Naznin Afrose Huq (Ph.D.) at Dhaka University, Dhaka. The matter embodied in this PhD thesis has not been submitted of the award of any other degree.

I declare that I have faithfully acknowledged, given credit to and referred to the research works wherever there works have been cited in this thesis. I further certify that I have not wilfully lifted up some others' work, para, text, data, result, etc. reported in the journals, books, magazines, reports, dissertations, theses, etc. or available at websites and cited as my own work.

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This is to certify that Ms Nazmun Nahar, Department of Geography & Environment, University of Dhaka has satisfactorily completed two pre-submission seminars on '**Assessment of Storm Surge Induced Vulnerability and Changing Adaptation Strategies in the South-West Coast of Bangladesh**'.

These were required part of her PhD programme.

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ABSTRACT

Tropical cyclones, storm surges and floods are frequent and severe along the coastal region in the recent years due to the impact of global climate change. Inhabitants of the coastal area has adapted new, innovative and environmental friendly techniques for their survival. The study has assessed storm surge vulnerability in the south-west coast and the prevailing coping strategies. The study distinguished two distinct zones, namely, 'Low vulnerable area' and 'Highly vulnerable area' considering the vulnerability of risk factors using GIS spatial analysis. Highly vulnerable areas are mainly located in the southern part while a few areas are far inland along the estuarine rivers is low vulnerable area. Major physical and environment aspects of the study area have been severely impacted by cyclone, storm-surge, flood, waterlogging and salinity. Risks and vulnerability increased in the recent decade due to prolongation of hydro-meteorological events which affecting the life, livelihoods and adaptation practices and ecosystem of the coastal region. About 33% of the households were displaced due to extreme condition of the hazard events. Inhabitants of the low vulnerable area found to have higher percentage of dislocation in the present time than past which indicates the rate of increasing vulnerability in the area.

The hazard events had caused extensive damages of infrastructure, agriculture, homestead and service facilities while waterlogging coupled with salinity is the main cause for agriculture failure in the coastal region. The study revealed that level of salinity is higher in the highly vulnerable area while the rate of salinity intrusion is more in the low vulnerable area. Its proved with statistical significance that severity of salinity has increase slightly along the south-west cost while people's concern on impact of salinity has sharply increased in the low vulnerable area. The inhabitants have taken some indigenous, traditional and local strategies in individual and collective settings to cope with the impact of cyclone and waterlogging. The study observed that the people's tendency of building better house has increased all along whereas, practice of taking loan for repair works has decreased remarkably in the recent years; livelihood adaptation practices like new agricultural activities have increased in highly vulnerable area while non-agricultural activities have increased in the low vulnerable areas; rain water harvesting for drinking water has become popular in the recent years; and reconstruction of roads and embankments has increased about three times in highly vulnerable areas and two times in low vulnerable areas.

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ORGANIZATION OF THE DISSERTATION

This dissertation has been divided into eight chapters and these have been divided based upon different issues that needs to be addressed step by step including findings of the study. Chapter 1, which is the introductory chapter, describes the vulnerability of coastal Bangladesh due to cyclone and storm surge. The chapter tries to delineate and classify the coastal region of Bangladesh and also address the basic livelihood characteristics of the zone. Frequency of past cyclones and their implications has also been highlighted in the introductory chapter.

In Chapter 2 the overall conceptual framework and research design has been presented. Some operational definitions of key terms referred in the study has been presented. Relevant published literature has been reviewed and presented in order to establish a link between climate change and storm surge. Subsequent implications on the intensification of vulnerabilities and established adaptation measures has been highlighted. Based upon the major factors that needs to be addressed in the study, the objectives have been set. In order to achieve the set objectives, the methodology has been designed. The justifications for choosing the study area, sampling techniques and major data sources have been highlighted.

Chapter 3 presents the mapping of community vulnerability. The factors considered for zoning of the study area along with the tools and methods used have been presented. Validation of the samples and final vulnerability zoning map has been produced.

Chapter 4 presents the analysis of inundation intensity and relations with climate change. The chapter presents the major climate change indicators and their trends in the study area. The major impacts of climate change have been presented sector-wise.

Chapter 5 presents the changing perception of people regarding cyclonic hazards. Intensity of disaster along with the changing disaster response has been addressed. People's perception regarding the sector wise impact of climate change has been delineated.

Changing migration patterns due to the result of cyclonic impacts has also been a major topic of discussion in the chapter.

In chapter 6, the findings related to vulnerability of the study area according to people's perception has been presented. Physical vulnerability, Social Vulnerability and Environmental vulnerability has been discussed and the results presented based on a comparative analysis between high risk and low risk areas and also on a temporal basis.

In chapter 7, the major adaptation findings have been discussed. The study has highlighted traditional adaptation practices and their current state. Community adaptations related to agriculture and also water related factors have been highlighted.

In chapter 8, the major findings from the study has been summarized. Based upon the findings, some recommendations have been presented which shall facilitate efforts for effective disaster management in the future.

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Chapter – I:

INTRODUCTION

INTRODUCTION

Bangladesh ranks 9th with Climate Risk Index score of 16.00 in the 'Global Climate Risk Index 2019' which explains to what extent countries have been affected by the impacts of weather-related loss events (storms, floods, heat waves etc.) prepared on the basis of a time series data from 1997 to 2016 (Eckstein, 2019). The extent of vulnerabilities is not equal in all regions of Bangladesh, past studies show that the south-western part of the coast of Bangladesh is one of the most vulnerable regions. The south west coast of Bangladesh is extremely vulnerable to storm surge inundation and the scale of disaster is also very high as has been observed in the contemporary two major cyclones namely cyclone 'Sidr' and cyclone 'Aila'. Natural disasters such as cyclones, tidal surges, storms, saline water intrusion and waterlogging are very common in this area. The region is mainly flat and low-laying delta, extremely riverine and considerably populated along the river coasts. Settlement pattern in this area is quite unplanned which has spread without considering the natural threats due to the burden of over population.

According to the Assessment Report-4 of Intergovernmental Panel on Climate Change (IPCC), tropical cyclones, storm surges and severe flood are likely to become more frequent and severe in the future as a result of climate change, making Bangladesh even more vulnerable (IPCC, 2007). Further, the consequences of these disasters will have a great impact on the nine coastal districts having a land area of 25,504 km^2 with 541 people/km^2 and four interior districts having a land area of 6238 km^2 with 853 people/km^2 (Karim and Nabura, 2008). Hence, identifying and grading the vulnerable areas prone to tidal and storm surge inundation deemed essential to plan settlement in the coastal area and to make effective preparedness plan.

Tropical storms (Typhoon) forming over the Bay of Bengal generally tend to be funnelled towards Bangladesh. Situation becomes worse being the most densely populated country in the world except for the microstates. Coastal disasters like tropical cyclones (Typhoons), storm surges and coastal floods are very frequent in the country that ruin almost every year. Coastal flood generated from storm surge takes the major death toll along the coast of Bay of Bengal. R A Flather identified the following reasons (Flather,1994) that make the country particularly vulnerable to cyclone and thereby induced storm surge:

1) Bangladesh lies in the common path of tropical cyclones, which typically originate in the central and southern parts of the Bay of Bengal around the Andaman Sea;
2) It has a wide and shallow continental shelf; strong winds acting over shallow water are the primary generating mechanism for the storm surges which in conjunction with substantial astronomical tides can produce exceptionally high water levels;
3) The coastal areas of Bangladesh comprise low lying and poorly protected land much of it being delta of the Ganges and Brahmaputra rivers;
4) Coastal regions support a large population, mostly the poorest people forced to live in vulnerable areas in order to feed themselves by farming and fishing.

During the last half century there were eighteen (18) major cyclones that devastated the country cruelly. The most severe one was in 1970 that killed about 300,000 people. In the recent past, two major cyclones are 'Sidr' of November 2007 that caused 3,363 deaths affecting 8.9 million people and 'Aila' of May 2009, caused more than 200 deaths affecting 0.5 million people. Recently hit Cyclonic Storm 'Roanu' which was a relatively weak tropical cyclone that caused severe flooding in Bangladesh during 17 May 2016. Cyclonic activity in the Bay of Bengal has become more frequent, causing rougher and furious sea for fisherman and local people of coastal Bangladesh.

Disaster management in Bangladesh has evidently improved over the last decade. Government of Bangladesh in association with international donor agencies and NGOs has initiated a number of activities to minimize the human casualties and damage of properties due to cyclonic surges. The National Plan for Disaster Management 2010–2015 was prepared aiming at reducing vulnerability according to the Hyogo Framework for Action 2005–2015 and adopting the SAARC Frame-work. It emphasizes to work together with all stakeholders to build strategic, scientific and implementation partnerships with all relevant government departments and agencies, other key non-government players including NGOs, academic and technical institutions, the private sector and donors. According to the Disaster

Management Bureau (DMB) the role of Government is mainly to ensure that risk reduction and comprehensive disaster management is a focus of national policy and programmes. Improvement has done mainly through expansion of cyclone shelters, embankments and forestation program, increasing public awareness and formation of Cyclone Preparedness Program (CPP) volunteers. Despite considerable progress in cyclone preparedness, still there is room for further improvement that may significantly reduce vulnerability of storm surge along the coast and surrounding low lying areas. Knowing the coastal environment, characteristics of cyclone and storm surge and simulation of inundation likelihoods could aid in further improvement in coastal disaster preparedness.

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1.1 Coastal Environment of Bangladesh

The coast of Bangladesh covers about 710 km in length and extends along the Bay of Bengal from the mouth of the Naf River in the south east to the mouth of the Rymongol River in the south west and hosts a unique diversity of ecosystems. Flora and fauna of the region are more diverse and unique having the largest mangrove forest with the habitat of some rare animal species, wild migratory birds and with large breeding and nursing ground of fish and aquatic life (Sikder, 1999). There are about 36 million people live in the coastal area of Bangladesh and their livelihood primarily depend on agriculture, fishery, forestry, near shore transportation, salt farming, etc. (DOE, 2007).

Bangladesh is located in the Bengal Basin. Majority of the coastal area consists of Holocene alluvial and estuarine deposits in the valleys between the Pleistocene terraces and along the coast of Bay of Bengal. It is an active delta, development and morphological changes are in progress by the Ganges-Brahmaputra-Meghna (GBM) river system. All major rivers in Bangladesh bring billions of tons of sediments into the Bay of Bengal. Following are some basic characteristics of Bangladesh coastal hydrodynamic (Sikder, 1999):

1) Monsoon substantially raises water level in the estuary at the Bay of Bengal;
2) Discharged water of the river system amplifies tide and surge height;
3) Back-water effects of tides and surges make flood situation more disastrous;
4) Tidal range increases from west to east up-to Meghna estuary, then decrease south-eastward;

5) Storm surge is higher during high tide;
6) Severe cyclones occur during pre-monsoon and post-monsoon period.

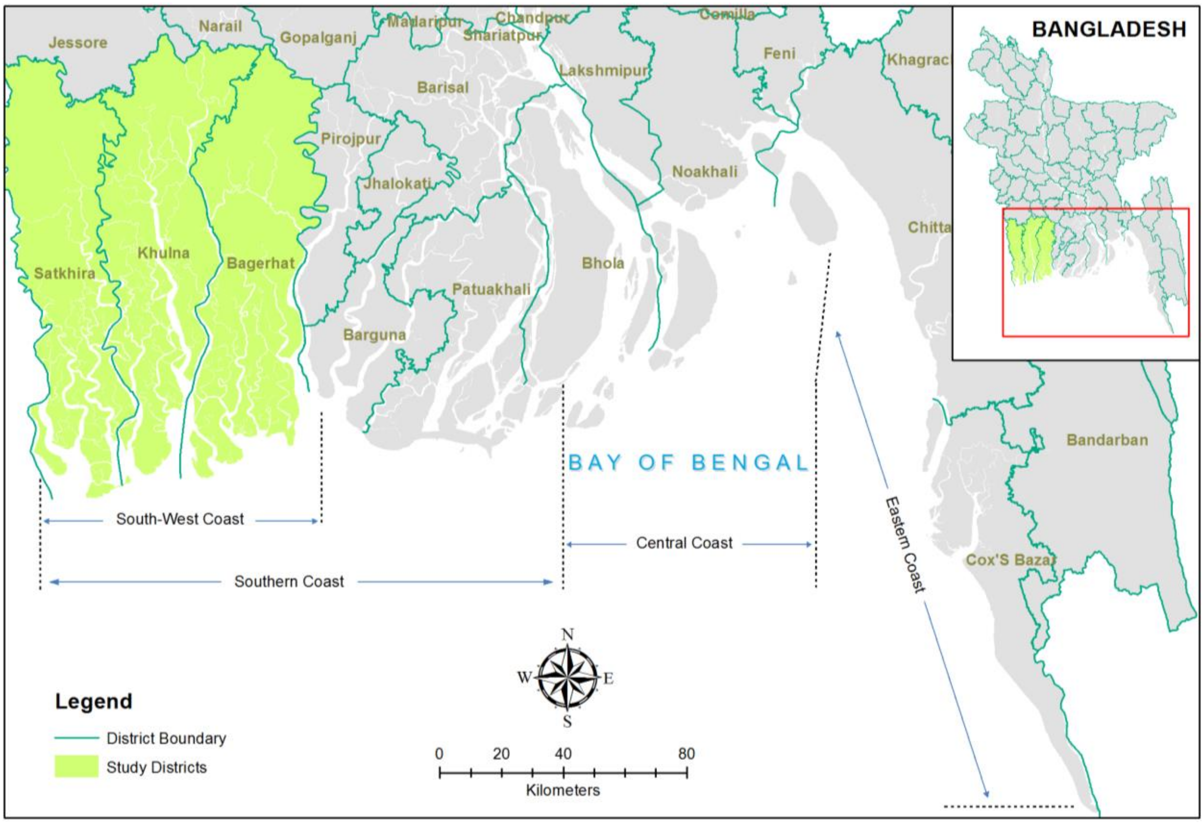
1.2 Coastal Zones of Bangladesh

The coastal zone of Bangladesh forms the lowest landmass and is part of the delta of the extended Himalayan drainage ecosystem. Sixty-two percent of the land of the coastal zone has an elevation of up to three meters and 86 percent up to five meters (MoWR, 2005). PDO-ICZMP (2003b) classified the coastal areas of Bangladesh under two broad zones, interior coast and exterior coast (Figure: 1) on the basis of threshold levels (tidal fluctuations 0.3m; soil salinity 4 dS/m; surface water salinity 5 dS/m; groundwater salinity 2 dS/m) and cyclone risk (wind risk). Out of 19 coastal districts (147 sub-districts), a total of 48 sub-districts in 12 districts that are exposed to the sea and or lower estuaries, are defined as the exposed coast and the remaining 99 sub-districts of the coastal districts are termed as interior coast.

The coastal area of Bangladesh is further broadly divided into three distinct regions depending on the geo-morphological features namely the eastern region, the central region and the western region. Major characteristics of these regions as noted in the government report 'Bangladesh: National Programme of Action for Protection of the Coastal and Marine Environment from Land-Based Activities (GOB 2007) are given below:

The Eastern Region: Morphologically the eastern coastline of Bangladesh is from the big Feni river to Badar Mokam (southern tip of the mainland) along Chittagong can be classified as a "Pacific Type" coast running parallel to the young (Tertiary) folded hill ranges. The East Coast is regular and unbroken and is protected along seacoast by mud flats and submerged sands. Smaller rivers and the Chakaria and Teknaf mangrove forests of the eastern region (Karnafuli, Sangu, Mathamuhuri and Naaf) play an important role in determining the coastal ecosystem.

The Central Region: This region begins from the Tetulia River to the big Feni River estuary including the mouth of the Meghna River up to the confluence of the rivers Padma (Ganges-Brahmaputra) and the Meghna near Chadpur. Heavy sediment load and one of the most complex tropical estuarine ecosystems of the world characterized this region. The coastline is very irregular, and consists of a series of islands, where the rivers are continuously changing their courses; the funnel shaped apex of the Bay of Bengal is relatively shallow, surrounded by numerous islands and estuarine channels. Since the last two hundred years the Meghna estuary went through intensive morphological changes with migration and the growth of islands in the southern direction. This region is also subject to the impact of cyclone and storm surges causing an innumerable loss of life and property.



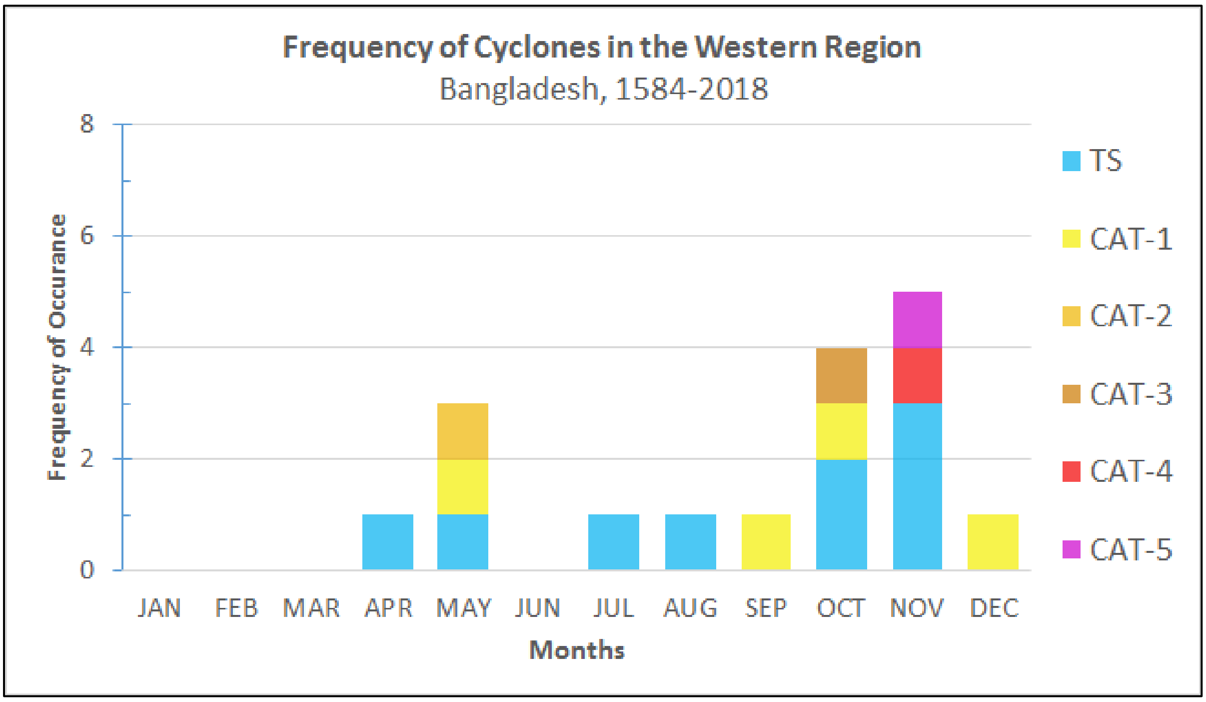
Source: Department of Environment, 2007

Figure 1: Coastal regions of Bangladesh along the Bay of Bengal

The Western Region: The western region covers the coastline westward from the Tetulia River to the international boundary (India) located at the Hariabangha River. The region is mostly covered with dense mangrove forests with deeply scoured tidal channels of the tidal plain overlapping abandoned Ganges delta. Western coastal zone is particularly vulnerable to storm surge floods as it is a low-lying deltaic plain, characterized by wide rivers and estuaries that allow sea surges to propagate faster and to intrude far inland. Low land elevation, large estuary opening and poor defence against floods are some of the major causes of disastrous surge flooding in this region.

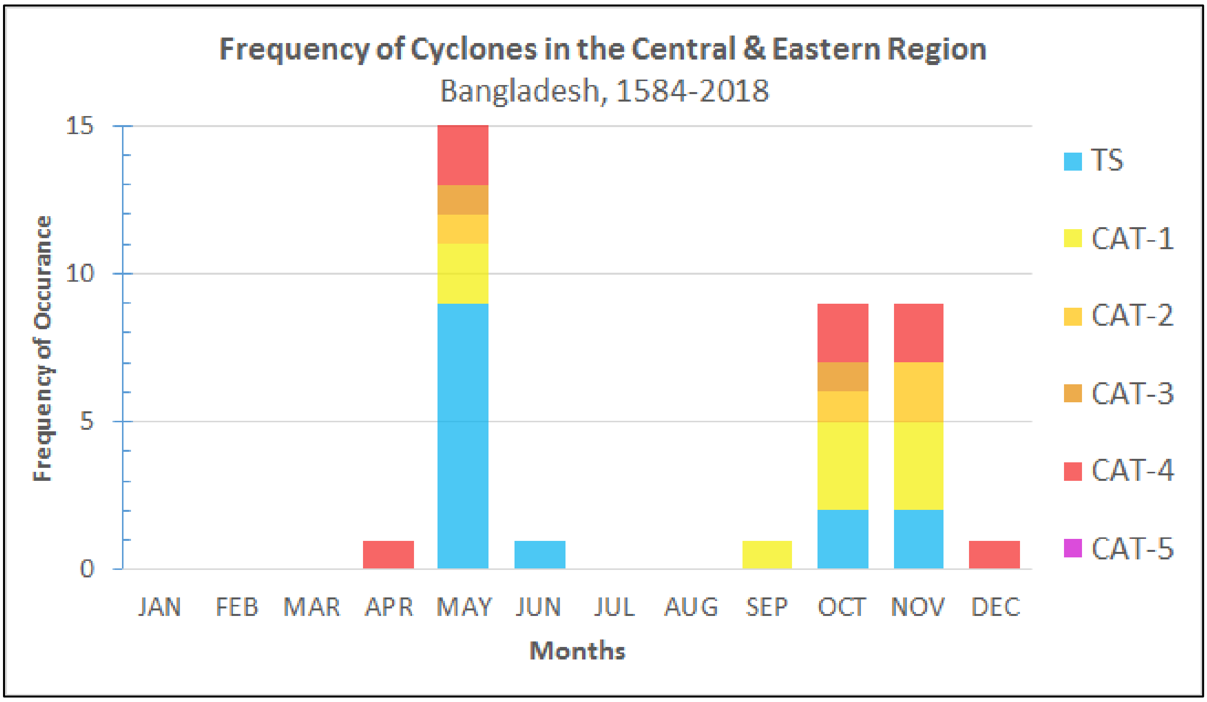
1.3 Coastal livelihood of Bangladesh

People in the low-yielding coastal area of Bangladesh are engaged with paddy (adapted varieties) cultivation, fishing, traditional shrimp culture, salt production, etc. Peak fishing time and harvesting season are during the months of April and May and October and November when considerable immigration to coastal regions take place, unfortunately it coincides with the cyclonic season (Islam, 1971). This makes a huge population vulnerable to the cyclone induced threats. The following figures (Figure: 2 and Figure: 3) shows frequency of cyclones in the west coast with the strength of cyclone.



** TS = Tropical Storm (wind speed 63 to 118 km/h), CAT-1 = Category 1 (wind speed 119 to 153 km/h), CAT-2 = Category 2 (wind speed 154 to 177 km/h), CAT-3 = Category 3 (wind speed 178 to 208 km/h), CAT-4 = Category 4 (wind speed 209 to 251 km/h), CAT-5 = Category 5 (wind speed over 251 km/h)*
Source: Produced from Banglapedia (http://en.banglapedia.org/index.php?title=Cyclone)

Figure 2: Frequency of cyclone the Western Region.



** TS = Tropical Storm (wind speed 63 to 118 km/h), CAT-1 = Category 1 (wind speed 119 to 153 km/h), CAT-2 = Category 2 (wind speed 154 to 177 km/h), CAT-3 = Category 3 (wind speed 178 to 208 km/h), CAT-4 = Category 4 (wind speed 209 to 251 km/h), CAT-5 = Category 5 (wind speed over 251 km/h)*
Source: Produced from Banglapedia (http://en.banglapedia.org/index.php?title=Cyclone)

Figure 3: Frequency of cyclone in the Central & Eastern Region.

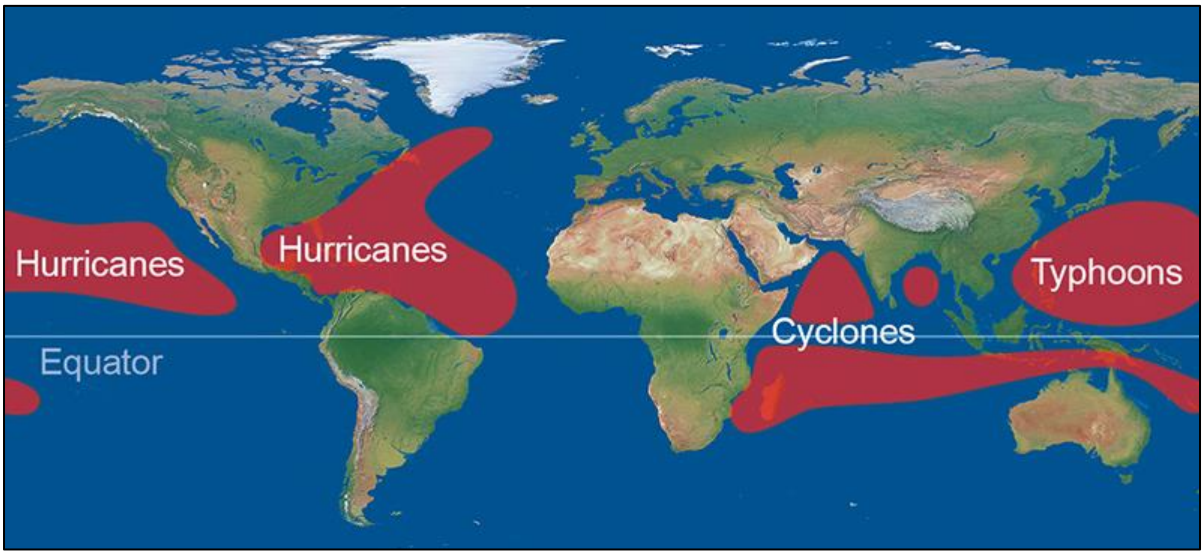
Population of the coastal area is increasing rapidly than the country average, it was36.8 million in 2001 whereas only 8.1 million just a century earlier (Ahmad, 2004). The coastal population is projected to grow to about 43.9 million in 2015 and 60.8 million by 2050 (Ahmad, 2005). Official poverty indicators show a slightly higher percentage of the population living below the absolute poverty line in the coastal zone compared to the country as a whole (52 percent and 49 percent respectively), while the Gross Domestic Product (GDP) per capita and the annual GDP growth rates in the coastal zone are more or less similar to the national averages.

1.4 Cyclone Hazard in Bangladesh

The coastline of Bangladesh is one of the world's most active areas for the development of tropical low-pressure systems. The average annual number of tropical depressions in the Bay of Bengal ranges between 12 and 13, out of which an average of five attain cyclonic strength, i.e., wind speed greater than 73.9 mph or 118.24 kmph (Paul, 2009).

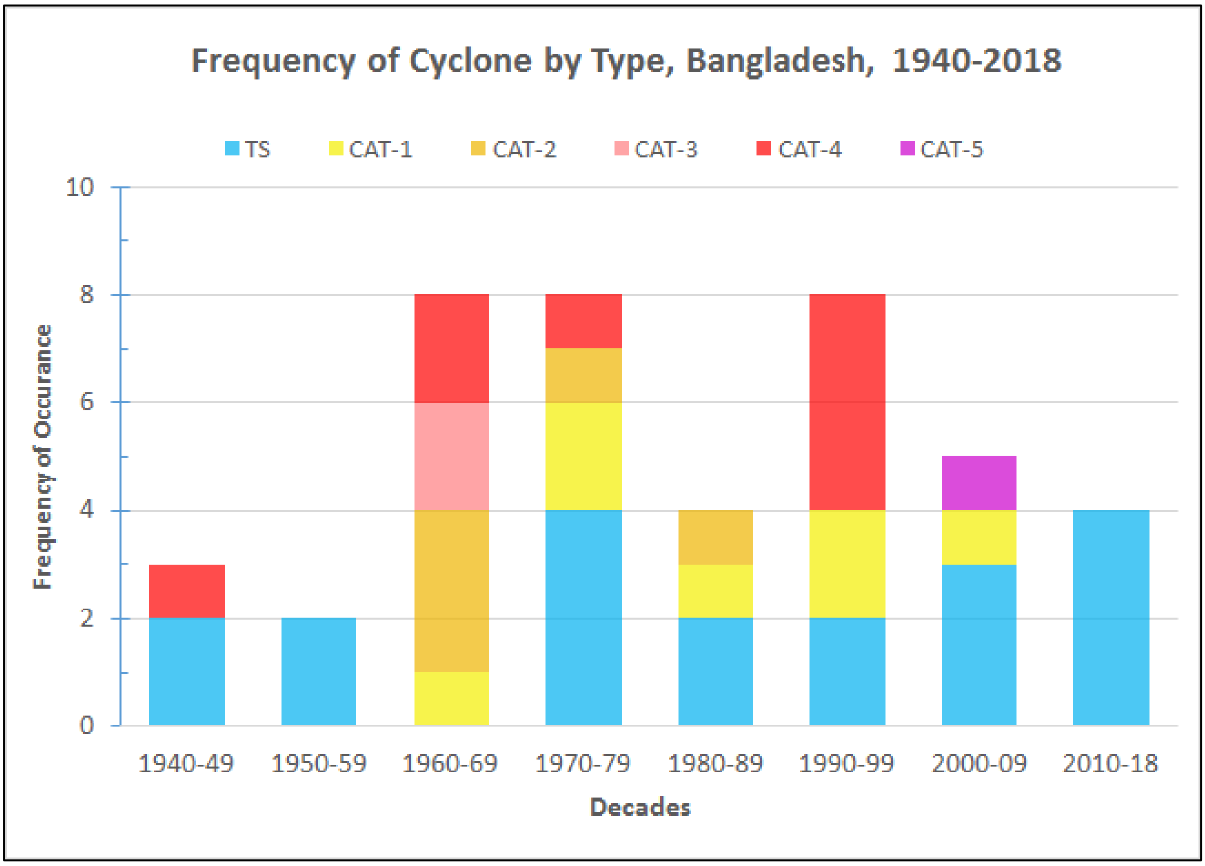
Cyclones forming in the Bay of Bengal constitute only 5–6% of the global total but they are the deadliest of all the cyclones, accounting for about 80–90% of global losses in terms of lives and property, caused by cyclones (Chowdhury, 2002). Fifty-three percent of all the cyclones that have claimed more than 5,000 lives took place in Bangladesh (GOB 2008). Nicholls et al. (1995) reported that during the past two centuries, 42% of tropical cyclone-associated deaths have occurred in Bangladesh. Following are some salient features as presented in a special lecture at Nagoya University (Rahman, 2010):

1) About 1/10th of the global total cyclones occur in the Bay of Bengal (Figure: 4);
2) About 1/6th of tropical storms generated in the Bay of Bengal hit the Bangladesh coast;
3) At least 70 major cyclones have hit the coastal belt in the last 200 years (Figure: 5);
4) 37% hit in May-June and 44% hit in October-November;
5) About 60% of all deaths world-wide associated with tropical cyclones occurred in Bangladesh between 1980 and 2000.



Source: MetOffice (https://www.metoffice.gov.uk/)

Figure 4: Tropical Storm prone areas of the World.



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Source: Produced from Banglapedia (http://en.banglapedia.org/index.php?title=Cyclone)

Figure 5: Frequency of cyclone by type (1940-2018).

Chapter II:

CONCEPTUAL FRAMEWORK

CONCEPTUAL FRAMEWORK

2.1 Operational Definition

2.1.1 Vulnerability

According to UNISDR, the conditions determined by physical, social, economic and environmental factors or processes which increase the susceptibility of an individual, a community, assets or systems to the impacts of hazards. Vulnerability is one of the most complicated components of risk assessment due to its nature. Hazards, disasters and vulnerability is a concept that links the relationship between people and their physical, environmental, economic forces and institutions, it also includes the cultural values that sustain and contests them.

Bangladesh is known as a severe disaster prone country especially for coast related disaster. On the other hand, its tropical monsoon climate characterized by heavy seasonal rainfall, moderately warm temperatures and high humidity makes Bangladesh more vulnerable. Traditional farming system, inadequate supply of quality seeds, fertilizers, pesticides, as well as lack of proper irrigation facilities of the coastal area besides various natural calamities like flood, storm surge, salinity also substantially affect agricultural of this area.

In this research, vulnerability analysis has been done by using a set of indicators covering physical, social, economic and environmental vulnerability of different types of coastal hazard. Physical vulnerability refers to potential physical impacts on physical elements like settlement, infrastructure and transportation system due to hazard. Social vulnerability is the inherent condition of society which make them unable to cope with the hazard such as education, dependency, ownership etc. It also identifies the community group which needs high level of pre-disaster assistance and monitoring so that they become more capable to adapt to the situation. Economic vulnerability means the potential impacts on the economic wellbeing of the community. It refers to the inherent economic situation that causes a particular community to be vulnerable. It includes the impacts in agriculture, livelihood water resources etc. Environmental vulnerability means the degraded environmental condition of a community that makes it vulnerable to any hazard. People are made more vulnerable due to the environmental conditions in the surrounding area. The important indicators are vegetation, drinking water, sanitation etc.

2.1.2 Adaptation

The IPCC defines adaptation as the, "adjustment in natural or human systems to a new or changing environment. Various types of adaptation can be distinguished, including anticipatory and reactive adaptation, private and public adaptation, and autonomous and planned adaptation.

Adaptation to climate change is urgent. Adaptation is about more than infrastructure and ecosystems. It is about people-their characteristics and resources, and how they come together in communities and countries. We must understand how people, not just places, are vulnerable to climate change, and how they are and can become more resilient.

According to Rashid 2009, Adaptation has two-fold importance in the climate change issue, one relating to the assessment of impacts and vulnerabilities, the other to the development and evaluation of response options. The process of adaptation reduces the level of damages that might have otherwise occurred. Adaptation management process depend on many factors. Success of adaptation depends critically on the availability of necessary resources, not only financial and natural resources, but also knowledge, technical capability, and institutional response.

In 2005, National Adaptation Programme of Action (NAPA) was introduced by the Government, where following regional consultations, NAPA suggested range of adaptation strategies for Bangladesh.

It is important to note that the proposed adaptation measures are primarily based on existing coping mechanisms and practices, as well as 'needs based suggestions' forwarded by national experts in the relevant field/sector. The following are the adaptation measures which have received endorsement of the Government of Bangladesh through NAPA exercise, these are:

- Intervention type measures and
- Facilitating type measures.

Present study selects some important indicators related to their daily life to assess the adaptation situation for the south west coast of Bangladesh. In addition, the study identified the strategical gap between contemporary adaptation strategy with previous adaptation strategy (approximately 15 years back). Information has been collected to make a comparison with past and present adaptation measures.

2.1.3 Changing Adaptation Strategies

In Bangladesh, there has been recent changes in the adaptation strategies that are adopted by the people in response to changes in the climate. Some of the major types of adaptation measures are:

Changes in Adaptation in Agriculture

In recent years, Bangladesh had significant success in developing several climate-smart seeds which are resilient to stress- tolerant conditions of salinity, submergence and drought. Most of these species (Table: 1) have been developed by Bangladesh Rice Research Institute (BRRI) and Bangladesh Institute of Nuclear Agriculture (BINA).

Table 1: Climate Smart Rice varieties/species

Stress type	New Varieties Adaptation
Salt tolerant	BRRI Dhan 53*, 54*, 55*, 61, 65, 67 and BINA Dhan 8, 10
Submergence tolerant	BRRI Dhan 51,52 and BINA Dhan 11**, 12 **
Drought tolerant	BRRI Dhan 56,57, 66

* these new seeds have less shattering (fall of grains before ripening) compared to the earlier released BRRI Dhan 47

** these seeds have the potential to withstand submerged conditions for up to 20-25 days

Hydroponic technique for changing adaptation

Floating bed cultivation has proved to be a successful means of agricultural crop production in different wetland areas of the world. In fresh water lakes and wetlands, vegetables, flowers and seedlings are grown in Bangladesh using this floating cultivation technique, without any additional irrigation or chemical fertilizer. People with indigenous traditional knowledge have been raising plants and vegetables successfully for centuries in a remote marshy area in Bangladesh using technologies that have only recently caught the attention of western scientists.

A floating platform is made of decomposing heaps of water hyacinth, where the upper surface is stuffed with mud or soil. The size and shape of the floating beds vary from region to region. The platform is built to allow the easy penetration and spread of plant roots, facilitating uptake of water and nutrients. There are also several other changes that are being achieved mostly through the application of indigenous knowledge for adaptation.

2.2 Literature Review

Several studies were carried out during the last decade for identifying silent characteristics of storm surge but very few studies are available on inundation risk assessment and adaptation pattern. Review of literature has been categorized in to six important areas according to the research interest.

2.2.1 Coastal Bangladesh: Climate Change Present and future

Climate change is a dynamic phenomenon, the changes occur over time and the impacts are understood in the future. It is therefore, not possible 'to define a changing climate' that might occur 'within a defined period in future' (Ahmed, 2006). Thus, the predication of climate change depends on speculative scenario. However, some key assumptions must be made to formulate this scenario. Some of these assumptions include a plausible socio-economic trend predication which as a lot to do with CFC and Greenhouse gas emission, carbon accumulation etc. These key assumptions together form a bio-geo-physical equation (Ahmed, 2006) known as physical models. These models incorporate both empirical equations with narrative statement. However, since scenarios are based on assumptions, approximations, and considerations (social, political, economic, cultural etc.), a scenario 'cannot truly represent' a future climate. Rather it should represent a 'plausible future climate' in view of facilitating assessments of physical, environmental, social, economic and human aspects of the geographic region and/or country in question.

For Bangladesh, efforts have been made to develop climate change scenarios using various generic methods. In early stages of assessing climate change impacts, in absence of appropriate models and modelling facilities, researchers have used 'expert judgments' to come up with climate scenarios.

With the proliferation of computer assisted Atmosphere-Ocean Global Circulation Models (AOGCM), scientifically more rigorous and acceptable scenarios have been developed in the second stage. Only in recent times, with further development of regional models as well as strengthening of computational capabilities, scenarios have been developed by using Regional Climate Models (RCM).

The following sub-sections highlight the three different set of scenarios which have been developed in Bangladesh at different stages of their development process. Scenarios based on 'expert judgments' portrayed speculative future climate. Scientists have developed these speculative scenarios and posed some key questions: 'what would happen' to the bio-geo-physical system 'if' climate parameter(s) change by a given extent. Mahtab (1989) speculated that a general surface warming of 0.3 °C to 5 °C would occur by the year 2050. It is also thought that rainfall would increase by 5% to 20%. For sea level rise, a range of 30 to 150 cm was assumed by the year 2050. However, Mahtab (1989) considered a median value by taking the mean of the two limits and adding 10cm for local subsidence, which provided for 100 cm 'net sea level rise' by the year 2050.

Similarly, the effects of 2 and 4 °C change in average temperature were speculated for defining 'moderate' and 'severe' climate change scenarios, respectively (BCAS-RA-Approtech, 1994). The two scenarios also speculated a rise in peak monsoon rainfall by 18 and 33%, respectively. It was anticipated that the increase in monsoon rainfall would cause an increase in river discharge during peak flow periods by 8 and 15%, respectively, for the two scenarios. The corresponding sea level rise was speculated to be 30 and 100 cm, with a corresponding rise in cyclonic intensity by 10 and 25%, respectively. The same study also considered two other very important 'decision statements' to construct future scenarios: one dealing with water development in international rivers with sharing option (with the upstream neighbour), and the other having 'no sharing option' for the same. Based on these speculative considerations, a set of ten composite scenarios have been considered for the analysis (Huq *et al.*, 1996).

Ali (1999) considered 2 °C and 4 °C changes in average temperature as lower and upper bound thresholds for 2010, respectively, in order to analyse impacts of climate change on cyclonic storm surge along the Bay of Bengal. The same study speculated rise in sea level by 30 and 100cm, for the two scenarios, respectively. The base case however considered no change in sea level.

In the early 1990s, several attempts have been made to generate climate change scenarios by the use of available General Circulation Models (GCM). The BUP-CEARS-CRU (1994) study reported 0.5 to 2.0 °C rise in temperature by the year 2030 under 'business as usual' scenario of IPCC. The same modelling effort estimated 10% to 15% rise in average monsoon rainfall by the year 2030. The study could not draw an inference in relation to change in sea level; however, it commented that both sedimentation and subsidence were likely to complicate an expected net change in sea level along the Bangladesh coast.

ADB (1994) study also made use of four GCMs: CSIRO, CCC, GFDL, and UKMOH. A host of IPCC scenarios available at that point have been considered which provided a number of scenarios. In order to avoid complications, only the IPCC IS92a and its results (modelling outputs) are summarized here. It was reported that, for 2010 the temperature would rise by 0.3 °C and for 2070, the corresponding rise would be 1.5 °C. The four models used for developing scenarios all provided different results for monsoon rainfall. The high-estimating GFDL model (GFDL) projected 59% higher rainfall in South Asian monsoon with a corresponding withdrawal of dry season rainfall by 16%. CCC model, however, projected an increase of monsoon rainfall by 20% and withdrawal of dry season rainfall by 6%. Both considered a doubling of CO_2 concentration in the atmosphere (therefore, time independent).

It is important to note here that the two above modelling experiments haven't tried validation of the GCM outputs for Bangladesh. This is why the area-averaged results for the South Asian domain were used in a bid to develop climate change scenarios for Bangladesh. Recognizing the fact that, the extent of monsoon rainfall diminishes as the front advances towards north-western parts of the sub-continent, technically one may argue that South Asian domain might not have represented the country-specific rainfall conditions.

The other major attempt to generate a model-driven climate change scenario was made under the 'Climate Change Country Studies Programme' (Ahmed *et al*., 1996; Asaduzzaman *et al*., 1997 and Huq *et al*., 1998). A number of GCMs have been used including Canadian Climate Centre Model (CCCM), Geophysical Fluid Dynamics Laboratory equilibrium model (GFDL), and 1% transient model of GFDL (i.e., GF01). Observed climate data were supplied by the CLIM database, as provided by National Centre for Atmospheric Research (NCAR), USA. The outputs of the three GCMs for the 1990 base year were validated against long-term 'climate normal', as provided in the published report (FAO-UNDP, 1988).

The downscaling of climate data for Bangladesh down from GCM scale was possible by comparing different GCM outputs. The GFDL 1% transient model represented the long-term climate normal the best and was considered for the development of time-bound climate change scenarios (Ahmed *et al*., 1996). Applying the same methodology, Ahmed and Alam (1998) reproduced the climate change scenarios, which were largely used for a number of subsequent national assessments. It was reported that the average increase in temperature would be 1.3 °C and 2.6 °C for the two projection years, 2030 and 2075, respectively. It was found that there would be a seasonal variation in changed temperature: 1.4 °C change in the winter and 0.7 °C in the monsoon months in 2030. For 2070 the variation would be 2.1 °C and 1.7 °C for winter and monsoon, respectively. It was reported that the winter rainfall would decrease at a negligible rate in 2030, while in 2075 there would not be any appreciable rainfall in winter. On the other hand, monsoon precipitation would increase at a rate of 12 per cent and 27 per cent for the two projection years, respectively.

Mirza (1997) used a number of GCMs and developed climate change scenarios based on ensemble technique. The results have been used for the World Bank Study (WB, 2000). By the year 2030, the projected rise in monsoon temperature was 0.7 °C with a corresponding rise in winter temperature of 1.3 °C. WB (2000) results showed similarities with respect to result of Ahmed and Alam (1998). The corresponding rise in rainfall was projected at 11% for monsoon, while a decrease in rainfall by 3% was also projected for winter by the year 2030. For the year 2050, the study projected an increase in temperature by 1.1 °C and 1.8 °C for monsoon and winter, respectively. For the same year, the projected changes for rainfall were 28% in monsoon and -37% in winter. These results have been adopted for the First Initial National Communication for Bangladesh. Moreover, a linear rise in sea level by 1mm/year was considered, which resulted in 30 cm and 50 cm rise in sea level by the year 2030 and 2050, respectively.

Mirza (2002) considered an ensemble of GCMs, instead of validating outputs of any specific model for observed values of Bangladesh, and projected an ensemble scenario. In another modelling exercise, Mirza (2005) considered three 'temperature change scenarios' with 2 °C, 4 °C, and 6 °C changes in average temperature and then computed its response in relation to changes in rainfall over the South Asian subcontinent, particularly over Bangladesh. There have been huge variations in output results, varying from 0.8% to 13.5% increase in mean annual rainfall for the Ganges basin and -0.03% to 6.4% change for the same for the Brahmaputra basin for a 2 °C temperature change scenario. There would be increasing mean annual rainfall in both the basins with increasing global warming, as reported by Mirza (2005). The UKTR model suggested as high as 63.3% increase in mean annual rainfall over the Ganges basin associated with a change in surface average temperature of 6 °C. The corresponding change in Brahmaputra basin would be much less (Mirza, 2005).

Agrawala *et al*. (2003) have used another ensemble of a dozen GCMs, which were driven by MAGICC model using SCENGEN database. A total of 17 GCMs have been run initially for model validation for Bangladesh' observed data sets. An analysis of the results thus obtained revealed that only 11 of 17 models could best simulate current climate over Bangladesh. Consequently, the most suited ones have been selected for the study. It is important to note that the models have been run with the IPCC B2 SRES scenario (IPCC, 2001). Various predictions from different models have been compiled and presented in

Table: 2. Also, In the recent past, one attempt has been made under a South Asia regional modelling programme to develop climate change scenarios for the Brahmaputra basin of Bangladesh. A Regional Climate Model, HadCM2 was run. For the Brahmaputra basin, slightly increased rainfall was obtained for the monsoon and post-monsoon periods (Choudhury *et al*., 2005). The surprising results were obtained for winter rainfall: unlike other model results, an increase in winter and pre-monsoon rainfall was observed for 2020 and 2050. It was perhaps due to especial downscaling technique, which considered area-averaged values for each parameter for the entire domain. For temperature, warming appeared to be inevitable and increasing over time. The post-monsoon and winter seasons showed higher values compared to values for the pre-monsoon and monsoon seasons. Overall, the changes in rainfall and temperature for 2020 were 9.1% and 1.4 °C, with a corresponding increase by 22.7% and 2.8 °C, respectively, by the year 2050.

Table 2: Climate models: Predictions on the impact of climate change in Bangladesh

Climate Model (Publication)	**Study Year**	**Predictions**
General Circulation Model (CEARS-CRU Report)	1994	Temperature rise 0.5 °C to 2 °C rise (Business as Usual scenario) Monsoon Rainfall 10 to 15% rise by 2030
CSIR09, CCC, GFDL and UKMOH (ADB)	1994	Temperature rise- 1.5 °C (2070) Rainfall- GFDL- 59% higher rainfall CCC- 20% increase
Canadian Climate Centre Model (CCCM), Geophysical Fluid Dynamics Laboratory equilibrium model (GFDL) and GF01 (Climate Change Country Studies Program)	1996	Temperature rise- 1.3 °C and 2.6 °C in (2030 and 2075) Monsoon Rainfall- 12% and 27% (2030 and 2075)
General Circulation Models (Mirza, 1997)	1997	Temperature rise- 1.1 °C rise for monsoon and 1.8 °C for winter (2050) Rainfall- 11% monsoon (2050)
17 General Circulation Models (Agrawala et al. 2003)	2003	Temperature rise 1 °C (2030), 1.4 °C (2050) Rainfall- 3.8% annual rise (2030) 5.6% annual rise (2050)

Source: Compiled by Author

In Bangladesh the coastal zone has been delineated based on three criteria, namely the limits of tidal fluctuation, salinity intrusion and cyclone risk. The coastal zone comprises 19 administrative districts encompassing a land area of 47,201 km^2 (32% of the total area of the country). It has been broadly classified as an exposed zone that demonstrates the above three criteria, and as an interior coast that demonstrates one or two criteria (Islam, 2004). Based on geomorphologic characteristics, the coastal zone is divided into three distinct coastal regions, namely the western, central and eastern regions. Coastal zone among which is particularly vulnerable to storm surge floods. The western coastal zone (also known as Ganges Tidal Plain) consists of nine exposed districts having a land area of 25 504 km^2 (65% of total exposed zone) and 541 people per square kilometre, and four interior districts having a land area of 6238km^2(79% of total interior zone) and 853 people per square kilometre (BBS, 2005). About 4520km^2 of land (18% of the western coastal zone) is currently demarcated as High Risk Zone (HRZ) where surge flooding may exceed 1m flood (BUET and BIDS, 1993). The western coastal zone is a low-lying deltaic plain and is characterized by wide rivers and estuaries that allow sea surges to propagate faster and to intrude far inland (Barua, 1991). There are six major estuarine rivers having widths of several kilometres and depth in the range of 20–30 m. Low land elevation, large estuary opening and poor defences against floods are some of the major causes of disastrous surge flooding in this region (SMRC, 1998).

2.2.2 Climate change & Storm surge

South Asia is one of the most vulnerable regions of the World in terms of Climate Change (McCarthy, *et al.*, 2001). It is also assumed by the researcher that Bangladesh is highly susceptible to severe adverse impacts of climate change in the upcoming years. (Ahmed, 2006). A great number of Hydro-geological and socio-economic factor works together to increase the vulnerability of the country. These factors include: Geographical location of Bangladesh, flat, downstream deltaic catchment topography, extremely diverse climate and erratic monsoon, high density of population, unemployment and primitive agricultural practices, which is highly climate dependent. Thus the potentiality of development for Bangladesh is faced with significant challenges posed by Climate change. (Ahmed, 2006).

The coast of Bangladesh is a global Hotspot for tropical cyclone. (Dasgupta *et el.*, 2011). Almost every year the country is hit by cyclone. Since 1995, five severe cyclones have hit the country's coast, causing devastation to millions of lives and properties. On average, once in every three years a severe cyclone strikes (GOB 2009) Bangladesh coast.

As the global temperature rises, it is assumed by scientists that this will intensify cyclone activity as well as heighten the impacts of storm surge. (Dasgupta, 2010). The associated destruction will also likely be high causing devastation in the coastal region of Bangladesh. Tropical cyclone Sidr in Bangladesh (November 2007) and cyclone Nargis in the Irrawady delta of Myanmar (May 2008) provide recent examples of devastating storm-surge impacts in the Bay of Bengal.

Some scientific studies also suggest that increases in the frequency and intensity of Tropical cyclones in the last 35 years can be attributed in part to global climate change (Emanuel et al 2008). Although the science is not yet conclusive (IWTC 2006: Pielke et al. 2005), the International Workshop on Tropical Cyclones (IWTC) has recently noted that "The projected rise in sea level due to global warming occurs, then the vulnerability to tropical cyclone storm surge flooding would increase". Model studies and theory project a 3-5% increase in wind-speed per degree Celsius increase of tropical sea surface temperatures." The Intergovernmental Panel on Climate Change (IPCC AR4, 2007) using a range of model projections, also has asserted a probability greater than 66% that continued sea-surface warming will lead to tropical cyclones that are more intense, with higher peak wind speeds and heavier precipitation (IPCC 2007; Emanuel et al. 2008) hence, the effects of climate change, increase in sea surface temperature and sea-level rise, are likely to exacerbate Bangladesh's vulnerability to cyclones. Larger storm surges threaten greater future destruction, because they will increase the depth of inundation and will move further inland - threatening larger areas than in the past. The destructive impact of storm surges will generally be greater when the surges are accompanied by strong winds and large onshore waves. This scientific evidence points to the need for greater disaster preparedness in Bangladesh (Dasgupta, 2010).

2.2.3 Frequency & Intensity of Storm Surge in Bangladesh

Cyclone poses tremendous threat to property and lives, especially so in the low-lying coastal belt of Bangladesh. Has historical data demonstrates the greatest devastation is caused by storm surge induced by cyclone. Despite limited time series data on storm surge height and intensity, available data shows a height range between 1.5m to 9m. (Dasgupta et al., 2010).

However, height of 10m and more is also been observed. Such as the 1876 Cyclone (Bakerganj) that had a reported height of 13.6m (SMRC, 2000). An average of 1 to 3 cyclone of severe to moderate intensity hit the coast of Bangladesh each year.

Heavy rains accompanying cyclones and the tidal waves due to wind effects initiates storm surges. Storm surge heights are directly related to cyclone intensity. Besides that, coastal configurations and bathymetry are also related to surge heights at the time of cyclone landfall. Tides in combination with storm surges lead to further amplification of surge heights, causing severe flooding that can reach as far as 200 km inland (Milliman *et al.* 1989)

It has been estimated that Bangladesh receives about two-fifths of the world's total impact from storm surge (Dasgupta et al., 2011). The causes are many and can be attributed toward the coastal configuration of the Bay of Bengal, recurvature of tropical cyclone within the bay due to Monsoon. High tidal range, shallow continental shelf and triangular shape of the Bay of Bengal also further amplify the intensity. (Ali, 1999). Meghna estuarine region is the most susceptible area for storm surge as has been observed that once every 20 years a storm surge of 10m height occurs in the region. While a 7m high wave is very obvious once in every 5 years (MCSP 1993).

The IPCC AR4 indicates that future storm surges and related floods in Bangladesh will likely become more severe as future tropical cyclones increase in intensity (IPCC 2007). A study using dynamic, Regional Climate Model (RCM)-driven simulations of current and future climates indicates a significant increase in the frequency of highest storm surges for the Bay of Bengal, despite no substantial change in the frequency of cyclones (Unnikrishnan et al.

2006). Emanuel (2005) projects increased intensity of tropical storms by 2100 for the North Indian Ocean, as measured by the percent change in landfall power using the Model for Interdisciplinary Research on Climate (MIROC) General Circulation Model (World Bank and United Nations 2010). Hence, from a practical perspective vulnerability of Bangladesh to cyclones/ storm surges may increase even more as a result of climate change.

2.2.4 Community Vulnerability

Cyclones and floods have occupied the greatest risk to Bangladesh (ISDR, 2009a). Cyclone is one of the hazards that Bangladesh suffers most frequently and most of the people die due to cyclone hazard shows that the number of occurrences of cyclone hazard is 137 which is the highest in comparison with other hazards that occurred during 1907-2004 depicts that the maximum number of people died in Bangladesh due to cyclone hazard. So, it is clear that Bangladesh is exposed to cyclone hazard and Bangladesh remains one of the worst sufferers from cyclonic casualties in the world. Floods in Bangladesh affect a greater number of populations in comparison with any other natural hazards. Millions of acres crops and millions of houses and livestock were washed out and affected by cyclones and storm surges hazard during 1822-2017 (Table: 3). Institutions, bridges, culverts, roads and embankments were also directly affected by cyclones and coastal erosions.

Table 3: Chronology of major cyclonic storms in the Bay of Bengal during 1822-2017

Year	Month	Category	Impact Region	Death	Surge (m)
1822	MAY	CAT-1	Central	40,000	
1831	OCT	CAT-1	Central		
1872	OCT	Tropical Storm	Eastern		
1876	OCT	CAT-4	Central, Eastern	2,00,000	12.2
1897	OCT	CAT-1	Eastern	14,000	
1898	MAY	Tropical Storm			
1904	NOV	Tropical Storm	Eastern	143	
1909	OCT	Tropical Storm	Western	698	
1917	SEP	CAT-1	Western	432	
1941	MAY	Tropical Storm	Central		
1942	OCT	CAT-4	Western	40,000	
1948	MAY	Tropical Storm	Central, Eastern	1,200	
1958	MAY	Tropical Storm	Central	870	
1958	OCT	Tropical Storm	Eastern		
1960	OCT	CAT-3	Central	3,000	3.1

Year	Month	Category	Impact Region	Death	Surge (m)
1960	OCT	CAT-4	Central, Eastern	10,000	6.1
1961	MAY	CAT-2	Western	11,468	3.1
1962	OCT	CAT-2	Central	1,000	3.0
1963	MAY	CAT-3	Central, Eastern	11,520	5.2
1965	MAY	CAT-2	Central	19,279	3.7
1965	DEC	CAT-4	Central, Eastern	873	6.1
1966	OCT	CAT-1	Western, Central, Eastern	850	9.1
1970	NOV	CAT-4	Central, Eastern	5,00,000	10.6
1971	NOV	CAT-1	Eastern		
1971	NOV	Tropical Storm	Western		1.0
1973	DEC	CAT-1	Western		
1974	AUG	Tropical Storm	Western	600	
1974	NOV	CAT-2	Eastern	200	5.2
1975	MAY	Tropical Storm	Central, Eastern	5	
1977	MAY	Tropical Storm	Western, Central, Eastern		
1983	OCT	CAT-1	Central, Eastern	150	
1983	NOV	CAT-1	Central, Eastern	300	1.5
1985	MAY	Tropical Storm	Central, Eastern	11,069	4.6
1986	NOV	Tropical Storm	Central, Eastern		
1988	NOV	CAT-2	Central	5,708	4.5
1991	APR	CAT-4	Central, Eastern	1,50,000	8.0
1991	JUN	Tropical Storm	Central, Eastern		1.9
1994	MAY	CAT-4	Eastern	400	
1995	NOV	CAT-4	Eastern	650	
1997	MAY	CAT-4	Central, Eastern	126	3.1
1997	SEP	CAT-1	Central, Eastern		3.1
1998	MAY	CAT-1	Central, Eastern		2.4
1998	NOV	Tropical Storm	Western, Central		2.4
2002	NOV	Tropical Storm	Western	49	
2007	NOV	CAT-5	Western, Central	3,447	3.0
2008	OCT	Tropical Storm	Western, Central	28	
2009	APR	Tropical Storm	Western, Central, Eastern	7	3.0
2009	MAY	CAT-1	Western	190	3
2013	MAY	Tropical Storm	Central, Eastern	107	2.5
2015	JUL	Tropical Storm	Western, Central, Eastern	280	2.0
2016	MAY	Tropical Storm	Eastern	227	7.0
2017	MAY	Tropical Storm			1.5

Source: Compiled from Banglapedia (http://en.banglapedia.org/index.php?title=Cyclone)

Cyclone 1991 hit Bangladesh and caused about 150,000 people's death. Mohal et al. (2006) calculated that if the same cyclone occurs with sea level rise (32 cm), then the inundated delta area would increase from 42% to 51.2%. Again, due to the climate change, if SST increases 2 °C then the maximum wind speed will increase by 10% (Ali, 1996). Therefore, if cyclone 1991 hit Bangladesh with 10% increased wind speed along with 32 cm SLR, then it would increase the surge height by 1.2-1.7 m near Kutubdia-Cox's Bazar, eastern coast of Bangladesh (Mohal et al., 2006).

The people who live in the exposed coast are considered as vulnerable partly or fully to surge flooding. More than 8.5 million (BBS, 2011) people live in the coastal zone of Bangladesh who were exposed to cyclones, storm surges, rough seas, salinity intrusion and permanent inundation due to sea level rising. Over 3 million people who lived in an area of 4,200 km^2 in 72 offshore islands were extremely vulnerable. The main source of income of around 0.5 million households is fishing in the Bay of Bengal. Working days were lost due to rough weather in the Bay (DMB, 2010). Population density in coastal area is 816 population/ km^2 whereas the density for the whole Bangladesh is 976 population/km^2 which is higher compared to the coastal zone. One of the reasons for this density scenario is people's migration from the coastal area to inner parts. The number of female is higher than the number of male in the coastal area. This may be due to travelling of men for job around the country for life sustenance against the poverty in the coastal zone. But, a significant number of transitory people come to the coastal areas during the fishing period from the inner parts of the country. These fishermen are one of the most vulnerable groups in the coastal zone (Karim and Mimura, 2008).

Disasters adversely affect all aspects of children's daily life because children have the right to get clean water, sanitation, food, health and education which is seriously hampered due to disasters. Increase of disaster's frequency and intensity weakens people's resilience and increases poverty as a result it affects the children, other dependent and vulnerable groups. Under these circumstances, infants, young children, and pregnant and lactating women (PLW) are vulnerable to malnutrition and micronutrient deficiencies. For their dependent and risk prone positions, women and children are particularly prone to any form of vulnerability. From the analysis of the damage and loss assessment of different disasters, it is clear that children are more vulnerable to every disaster. Climate change or particularly SLR will intensify the problems or alter the problems to new social dimensions (MoWCA, 2010).

Women's responsibilities in the family make them more vulnerable to environmental changes such as increasing salinity or waterlogging. Women are primarily responsible for food processing and gathering water, fodder and fuel, and generally their workload increases with increasing environmental degradation. This has secondary impacts in that girl children are more often kept at home to help out with household duties, rather than going to school. Women are primarily responsible for homestead production, however men tend to be the dominant seller and in control of family finances, and so women's ability to enter into productive activities is often limited by a lack of capital. As a result of their close connections with their natural environment, women have a great deal of knowledge regarding environmental change and coping strategies that can inform adaptation initiatives. They are excellent environmental managers, and are often already employing effective coping strategies to deal with their current challenges. There is a need to capture these successful strategies and disseminate them in order to reduce vulnerability to longer-term climate change (CARE, 2006).

Typical coastal scenarios show that 35.6% of coastal populations are children and 5.1% is old. Thus, at least 40.7% people are vulnerable or dependent. 1.5% of coastal population is disabled which includes speech, vision, hearing, physical, mental, autism and disability. Scenarios also show that 72.6% houses are vulnerable to cyclone hazard due to unstable construction by earth or other unstable materials (*Hossain, 2012).*

Shameem et al (2014) explores the process by which major stresses and hazards shape the vulnerability of people's livelihoods in dynamic social-ecological environments in the southwest coastal region of Bangladesh. Drawing on qualitative and quantitative data from a case study, Shameem *et al.* (2014) identifies the key drivers of change in social-ecological systems and evaluate whether these drivers have affected livelihood outcomes and various components of human wellbeing. This analysis suggests that increasing salinity intrusion, tropical cyclone and land-use change (directly and through changes in ecosystem services) affect the access to livelihood assets at household scale.

Community vulnerability is also very apparent in the coastal regions of Bangladesh. Mallick et al (2011) concentrates on the affected peoples' reaction and perception patterns with regard to disaster prevention measures, striving to identify the problem areas with the help of survey findings collected in the small coastal city of Mongla, the second largest sea port of Bangladesh. Only 19% of the respondents had left their houses and taken shelter in safer places like cyclone centres.

According to Khan et al (2015), land use land cover changes are intensifying the vulnerabilities due to disaster in the coastal region. Land use in coastal Bangladesh has evolved through natural forces as well as through response to human needs. Cultivated land, forestland and homesteads are the major land-use types in coastal Bangladesh. Specifically, within the study area, the growing population and their increasing needs have resulted in changing land-use patterns in which the areas under cropped land and forest land is gradually shrinking. This implies that during the time of disaster, the exposure of the people to disaster has increased along with the scale of damage. Therefore, we can conclude that vulnerabilities due to disaster are affected by a various human and physical factors.

2.2.5 Adaptation Practice in the Community

After the devastating cyclone of 1970, GOB and other agencies undertook construction of multi-purpose cyclone shelters. Since then, the number of shelters have increased from 300 to 1275 through new constructions. Besides, with external assistance additional 2500 shelters have been constructed. For protection of the low lying agricultural land in the coastal belt from inundation and intrusion of saline water during high tide coastal, embankments of low height have been provided by the government in almost all the coast belt. These embankments have so far been protecting the agricultural land from high tide and also resisting the small surges. But during the 1991 cyclone these embankments could not resist the high and severe surge. Although it has been able to dissipate the impact of the forceful surge at the initial stage but as the tidal surge toppled the embankments, the embankment got damaged and washed away in many places. Further the water which entered the main land while receding damaged the embankment. The sluice gates were not sufficient to cope with the rush of receding water.

It has been observed that places where the embankments did not have sufficient forestation got easily damaged. As such adequate attentions are being paid by government to this aspect under the Integrated Coastal Zone Management Plan. As to coastal forestation at present in quite a significant areas forestation have been developed along the embankments for protection of the embankments against cyclonic surge and monsoon waves. This has worked very well. It not only saved the embankments but also reduced the impact of the surge to a great extent.

Following the devastating cyclone of 1991, disaster management activities have been upgraded through a 3 year UNDP technical assistance project of 5 million US dollars involving various programmatic steps. The result of which was observable in the public response to 1994 cyclone. Another comprehensive Disaster Management Programme with technical assistance of UNDP is presently in operation for integration of disaster and development concept as well as for improvement in coordination in response to disasters at all levels. The different components of the programme include logistics and operational support, community participation perspective, social and gender issues, public health, physical facilities and urban disaster with very limited emphasis on coastal forestation as a strategy towards mitigation of cyclone and related storm surge impacts. There are many other adaptation projects are ongoing in the coastal area of Bangladesh as mentioned in Table: 4.

Table 4: Other ongoing adaptation projects

Project	**Period**	**Funding Agency**	**Activities**
National Adaptation Programme of Action to Climate Change	2005	UNDP	The project was implemented by Ministry of Environment and Forests to cover the area of agriculture, water, forestry, fisheries, livestock, health, infrastructure, industry, communication and socio-economic aspects to identify the required action.
Climate Change and Disaster Risk	2006-2007	DFID	Screening of DFID –Bangladesh Portfolio.
Climate Change Cell	2004-2009	DFID	To support the Ministry of Environment and Forests to establish the Climate Change Cell (CCC). Current support focuses on adaptation that includes work on modelling, research, cross ministerial coordination and inputs to community risk assessment processes.
Chars Livelihoods Programme	2004-2010	DFID	A programme working in Jamuna chars on a range of livelihoods support activities.
Structured consultation on a Climate Change Strategy and	2007-2008	DFID	To develop a climate change strategy by the Department of Environment/CCC.

Project	Period	Funding Agency	Activities
Action Plan for Government of Bangladesh			
Economic Empowerment of the Poorest Challenge Fund	2008 - 2015	DFID	Challenge fund for NGOs targeting the extreme poor – to help them lift themselves out of Poverty.
Community based Adaptation to Climate Change through Coastal Forestation.	2007-2010	UNDP	To reduce vulnerability of coastal communities to impacts of climate change by increasing Resilience.
Community-Based Adaptation (CBA) Programme under CDMP (Comprehensive Disaster Management Programme).	2007-2009	UNDP	Interventions are in line with national priorities with respect to vulnerability and/or adaptive capacity development of local communities
Climate Management Plan for the Agricultural Sector	2008	DANIDA	Assist GoB partners to conduct a climate screening and develop a climate management Plan for the Agricultural Sector.
EC Support to NAPA Implementation	2008-2012	EC Banglad esh	To implement one or more of the priority projects identified under NAPA
Comprehensive Disaster Management (CDMP-II)	2009-2014	EC & DFID	To implement climate change related Components.

Source: Compiled by Author

Adaptive measures such as the construction of (multi-purpose) shelters and measures at a household scale, are important to save lives, property and livelihood. Community-based initiatives empower the communities to build on their existing local knowledge and provide confidence to the most vulnerable people to explore the long-term benefits of investing small amounts on flood-resistant construction towards making safer homes (IFRC, 2008).

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Cyclone warning system in Bangladesh started in 1966 by the Bangladesh Red Crescent Society (BDRCS). After a devastating cyclone in 1970, the BRCS started the cyclone preparedness program (CPP) in 1972 to minimize the loss of lives and property by strengthening the capacity of coastal people in disaster management. The field level work of the CPP is based on 'UNITS', which typically encompasses a village of 2000–3000 people having land area of roughly 2 km2. The CPP teams presently work in all the coastal districts, but not all the risk-prone areas.

The network of CPP is expanding with time, but there are still remote locations where CPP teams have yet to be formed (BDRCS, 2005). Dissemination of cyclone warning in appropriate ways is another important aspect of cyclone disaster management. It is therefore important to improve the existing cyclone warning and dissemination system in all parts of the country. Initiative should be taken to evaluate the existing warning signals and to develop simplified, easily understandable signals and messages that are scientific and realistic. Efforts should be made to ensure that the warnings reach the entire population in the affected area.

2.3 Objectives of the Study

Bangladesh is highly vulnerable to coastal inundation. Being in the low deltaic flat land, coastal areas of the country are flooded by tidal surge and storm surge. The present study focused on a particular area namely Western region (Fig. 1.1) of Bangladesh which is low elevated and flat delta, extremely riverine and considerably populated area. This area has been selected purposively due to the following reasons:

1) Western coastal zone is extremely vulnerable to inland inundation particularly for storm surge and global Sea Level Rise, SLR (Alam, 1996);
2) The impacts of SLR are profound throughout the western coastal zone as it is low lying and gradually subsiding (Mohal et al., 2007);
3) Being low-lying deltaic plain, characterized by wide rivers and estuaries, sea surges in the western region intrude far inland and propagate faster (Barua, 1991);
4) Despite of such severe vulnerability of the western zone, there is only little research about storm surge propagation at this zone and done by older data and low resolution maps. Moreover, risk assessment for surge inundation is simply unexplored in this zone.

The research attempts to design a model to identify and grade the vulnerable areas prone to tidal and storm surge inundation in the west coast region of Bangladesh considering the environmental, physiographic, demographic, social, economic and settlement characteristics influenced by impending climate change scenarios. The research will apply advanced Geographic Information System (GIS) techniques to model inundation pattern in different climate change scenarios and plot changing coping strategies in the vulnerable areas.

Major objectives of the study are as following:

1. Mapping community vulnerability of storm surge considering inundation intensity;
2. Assessing intensity of storm surge inundation in respect to Global Climate Change;
3. Analysing the changing coping strategy of the community people according to the vulnerability.

This research will be helpful particularly in the area of Disaster Risk Reduction (DRR). By knowing inundation risk in a particular area, disaster management authorities can achieve sustainable risk reduction interventions both in preparedness for response and reducing the vulnerability to hazards.

2.4 Methodology of the Study

The study area (South West coast of Bangladesh) is suitable for piloting the proposed methodology. This is because, the magnitude of coastal inundation and environment would have great variety. Population characteristics and natural habitat makes the study area more suitable for the analysis.

The methods of investigation of the present study involved a multistage analysis. Both primary and secondary data has been extensively used. To understand the past situation, trend analysis of historical data has been undertaken. Literature review, field survey, field observation and focus group discussion has also been conducted for collecting data and information.

While assessing the intensity of storm surge inundation a GIS model is developed using suitable DEM analysis. Here, the historical tidal data in the region has also been included in the model. The impact of the storm surge is then modelled using 3D GIS analysis Details of the DEM analysis have been elaborated in the following chapter.

Relevant demographic, socio-economic and behavioural characteristics of the inhabitants has been determined through questionnaire survey (Plate: 1) to establish vulnerable zones considering the intensity of inundation. While, few of the demographic and socio-economic information have been utilised with spatial importance using ArcGIS spatial analysis for the establishment of the vulnerable zones.

Finally, the prevailing changing coping strategies of the inhabitants at different vulnerable zones is assessed through focus group discussion with the community people.

To properly represent the people of the coastal areas who are affected by the storm surge, a multi-tiered approach was followed. Three upazillas were selected from the three coastal districts of Khulna, Satkhira and Bagerhat. From each of these Upazilla, two unions were picked, one from the highly vulnerable area and the other from the low vulnerable area. One village from each of these unions have been randomly selected for representing the study area.

Selection criteria was based on vulnerability of the areas in terms of storm surge and its associated calamities. Of the six villages that were chosen, three were from Highly vulnerable areas and three from Low vulnerable areas. Therefore, a comparative analysis was done between Highly vulnerable and Low vulnerable areas. Some case study for knowing the historical situations of the study area from the elder people (Plate: 2) have been incorporated in this research.

2.4.1 The Study Area

This Research focused on the western region of Bangladesh coast. Particularly, the study area is between 88º54′–89º47′E longitudes and 21º42′–22º55′N latitudes of the coastal region of Bangladesh (Figure: 6). This area was inundated by both the cyclone Sidr (2007) and cyclone Aila (2009). The area is also known as the Ganges tidal plain and consists of nine exposed districts having a land area of 25,504 km^2 and 541 people/km^2 and four interior districts having a land area of 6238 km^2 and 853 people/km^2 (Karim and Nabura, 2008).

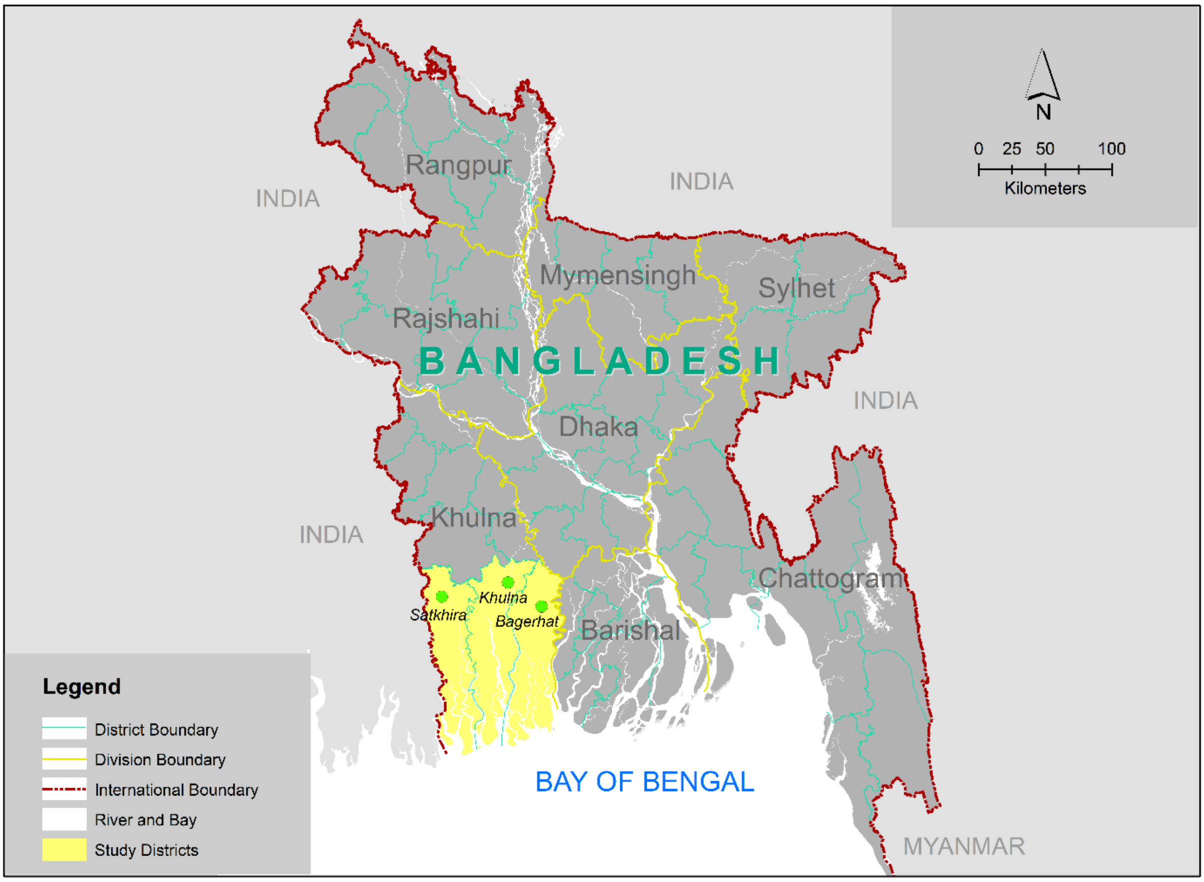


Figure 6: Location of the Study Area

2.4.2 Sampling

Goal of this research is to *determine* the extent of the impacts caused by cyclone associated storm surge in the coastal Bangladesh as well as *investigate* the adaptation strategies that are currently in practice in the study area.

The study considers Cochran's (Cochran, 1977) formula for calculating requires sample size, which is:

$$n_0 = \frac{z^2 pq}{e^2}$$

Where, n_0 is the sample size (infinite population), z is the selected critical value of desired confidence level, p is the estimated proportion of an attribute that is present in the population, q = 1− p and e is the desired level of precision.

Considering a low level of variability, which is equal to 5% (p =0.05) and taking 95% confidence level with ±5% precision, calculation for the required population size is:

(p = 0.05 and hence q=1-0.05 = 0.95;   e= 0.05;   z =1.96)

So,

$$n_0 = \frac{(1.96)^2(0.05)(0.95)}{(0.05)^2} = 73$$

For a finite population Cochran pointed out that the sample size can be reduced slightly. This is because of a very large population provides proportionally more information than that of a smaller population. He proposed a correction formula to calculate the final sample size in this case which is given below:

$$n_x = \frac{n_0}{1 + \frac{(n_0 - 1)}{\mathrm{N}}}$$

Where, n_1 is the calculated sample size for a finite population, n_0 is the sample size derived for the infinite population and N is the population size.

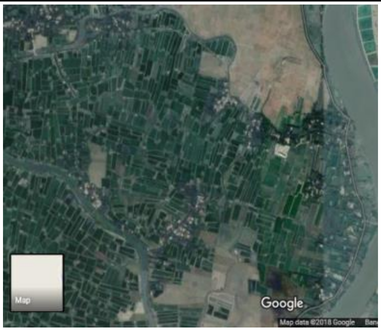
Considering the given formula, the study finds 371 sample households from all the six study locations (Figure: 7) as shown in the Table: 5 and Table: 6 below:

Table 5: Study Sample by location

District	**Zone**	**Upazila**	**Union**	**Village**	**HH**	**Sample (n_x)**
Satkhira	Low	Kaliganj	Nalta	Naua Para	315	57
	High	Shyamnagar	Gabura	Napitkhali	283	57
Khulna	Low	Batiaghata	Batiaghata	Kismat Phultala	326	60
	High	Dacope	Dacope	Dacope-2 & South Dacope	402	60
Bagerhat	Low	Rampal	Baintala	Barai Para	645	68
	High	Mongla	Chila	Chila West & South	775	69
					2,746	**371**

Low Vulnerable Area

Naua Para, Kaliganj, Satkhira

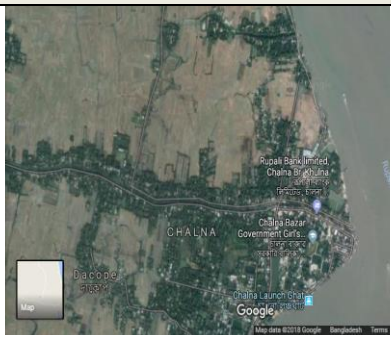


Kismat Phultala, Batiaghata, Khulna

Barai para, Rampal, Bagerhat

Highly Vulnerable Area

Napitkhali, Shyamnagar, Satkhira



Dacope-2, Dakope, Khulna

Poschim Chila, Mongla, Bagerhat

Source: www.maps.google.com

Figure 7: Satellite view of the study villages

Table 6: Sample interval for the study locations

Village	Household	Sample (n_x)	Sample interval
Naua Para	315	57	5
Napitkhali	283	57	5
Dacope-2 & South Dacope	402	60	6
Kismat Phultala	326	60	5
Chila West & South	775	69	12
Barai Para	645	68	10

Distribution of some of the important demographic characteristics like age (Figure: 8), sex, literacy, occupation depicts normal distribution prevailing among the sample size. All the responders are in the adult age group (18+ years) with an average of 40 years (SD: 13.6) with minimum 18 to maximum 81 years (Range: 63).

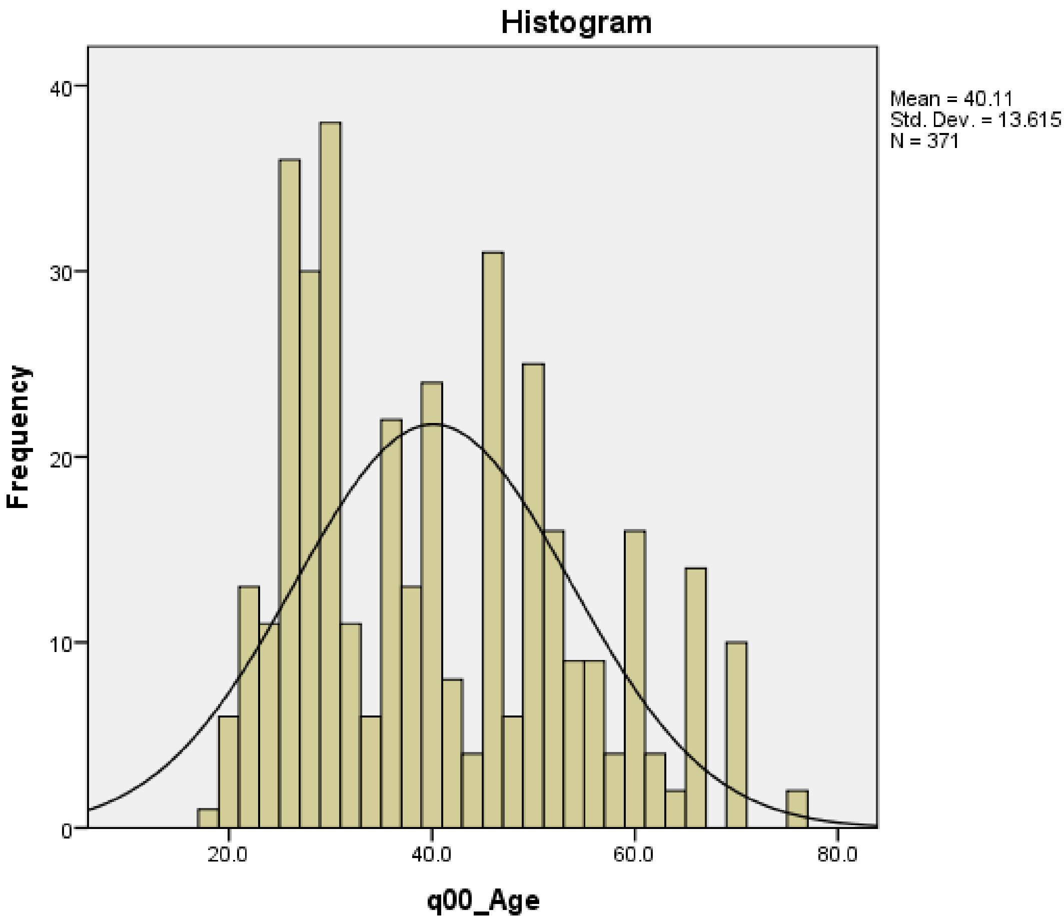


Figure 8: Distribution of Sample by Age

Age-Sex distribution along the region are representative both vertically and horizontally as such by district and by risk zone as shown in the following tables (Table: 7, Table: 8 and Table: 9):

Table 7: Distribution of Age by Gender

Mean Age by Gender	N	Minimum	Mean	Std. Dev.	Maximum	Skewness
Female	161	19	37.04	10.95	75	.61
Male	210	18	42.49	15.01	81	.29
Total	371	18	40.11	13.62	76	.52

Source: Field Survey, 2016-17

Table 8: Distribution of Age by Location

Age by Districts	N	Minimum	Mean	Std. Dev.	Maximum	Skewness
Bagerhat	137	18	38.64	13.64	70	.53
Khulna	120	20	39.10	12.10	75	.51
Satkhira	114	19	42.06	15.02	81	.46
Total	371	18	40.13	13.65	81	.52

Source: Field Survey, 2016-17

Table 9: Distribution of Age by Education level

Literacy by location	Satkhira		Khulna		Bagerhat	
	High	Low	High	Low	High	Low
Illiterate	45%	36%	65%	53%	57%	40%
Primary	22%	40%	23%	15%	16%	31%
Secondary	27%	24%	10%	33%	22%	22%

Literacy by location	Satkhira		Khulna		Bagerhat	
	High	Low	High	Low	High	Low
Higher Secondary	2%	0%	0%	0%	3%	3%
Graduate	4%	0%	2%	0%	3%	4%
Total	100%	100%	100%	100%	100%	100%

Source: Field Survey, 2016-17

From the statistical point of view, it seems clearly that the sample represents similar age group literacy pattern irrespective of spatial and demographic characteristics. This may ensure mature/sensible responses from the respondents while their response and preferences may vary in terms their characteristics.

2.4.3 Data Sources

Necessary data has been collected from relevant governmental sources of Bangladesh and some private organizations engaged in similar research work. Following are some of the major data sources for the study (Table: 10):

Table 10: Sources of data collection

Data	**Purpose**	**Source**
Digital Elevation Model	For GIS modelling	SRTM
Tidal data	For GIS modelling	BWDB
Observed inundation map	For inundation validation	IWM, SPARRSO
Community Perception	For assessing perception	Questionnaire Survey

2.4.4 Data Analysis Process

Data analysis process (Figure: 9) in the study has been divided into two major parts. i) GIS modelling for identifying vulnerable zones and ii) assessing community perception to compare between the vulnerable zones. GIS vulnerability analysis has been conducted utilizing DEM data, Stream network and Tidal data. Using GIS spatial analysis, a map was produced to demark the levels of vulnerability in the study area.

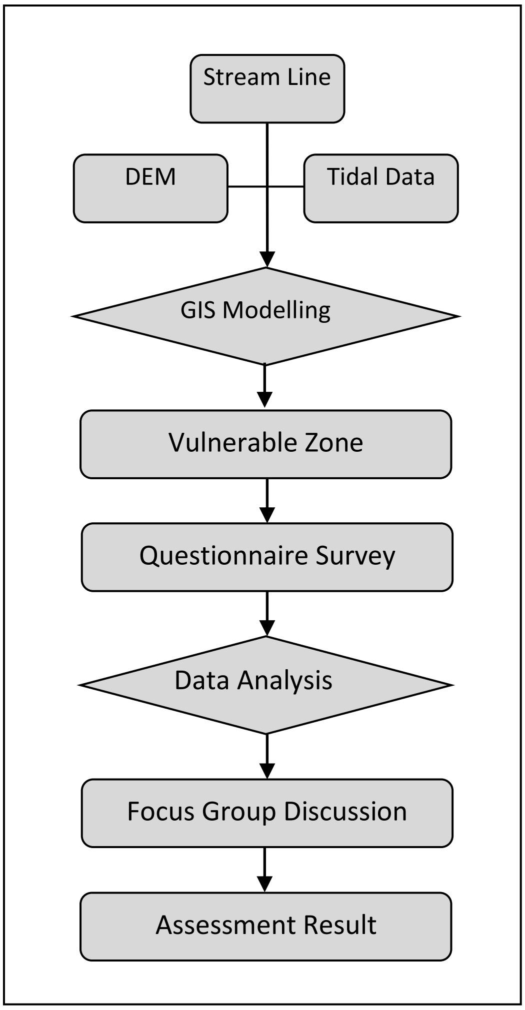


Figure 9: Data Analysis Process Flow Chart

A questionnaire survey (Annexure: iii) was conducted among the community people to learn about their perception on disaster vulnerability and changing adaptation strategies. The samples were taken through a systematic sampling process having equal samples from the vulnerable zones. The preliminary assessment was discussed with the community people through Focus Group Discussion (Plate: 3) to have insights of the issues before finalizing the report.

2.4.5 Analysis of Respondents' Perception

A psychometric scale has been applied for scaling responses of the respondent samples in terms of their perception on the vulnerability and impact of disaster and rating their preferences. Likert scale (named after their creator, American social scientist Rensis Likert) is one of the most reliable ways to measure opinions, perceptions, and behaviours. It includes a series of questions that is asked to answer, and ideally 3-7 balanced responses (Figure: 10). people can choose from. It often comes with a neutral midpoint.

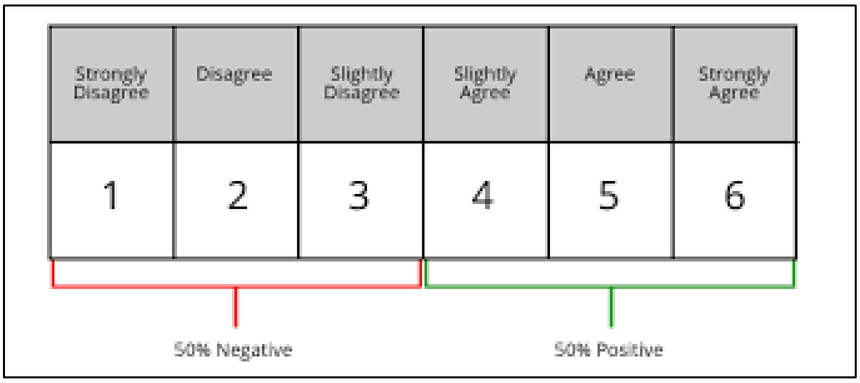


Figure 10: An example of 6-Point Likert Scale

It is always and debate on methodological discussion, whether to use a scale with a neutral middle category (e.g. 3, 5 or 7 categories) or to "force" the responded to give a certain tendency of in your example "agree/disagree" (e.g. 4 or 6 categories). Lozano et all (2008) showed "that the optimum number of alternatives is between four and seven. With fewer than four alternatives the reliability and validity decrease, and from seven alternatives onwards psychometric properties of the scale scarcely increase further."

Jamieson (2004) suggested to treat Likert scale as ordinal level scale & hence non-parametric statistics need to be used e.g. Reason being they claimed the interval from "1 – No effect" to "2 – Little effect" is not the same interval magnitude from "3- Considerable effect" to "4 – Severe effect". However, compared to binary questions, which gives only two answer options, Likert-type questions return more granular feedback. This method uncovers degrees of opinion that could make a real difference in understanding the feedback from the respondents. Therefore, the research utilized the Likert 4-type scale as the most suitable rating scale. The study considered these four scales for assessing and prioritizing respondents' perception on disaster impact and priority needs:

1) Not affected;

2) Minor affected;

3) Significantly affected; and

4) Severe affected.

2.4.6 Study Hypothesis

In order to understand spatial and temporal variation of the perception of local community on disaster impact following two research hypotheses have been formulated:

1. There is difference in peoples' perception on salinity impact between the highly vulnerable and low vulnerable areas; and
2. There is difference in peoples' perception on salinity between past and present impact in the low vulnerable area.

ASSESSMENT OF STORM SURGE INDUCED VULNERABILITY AND CHANGING ADAPTATION STRATEGIES IN THE SOUTH-WEST COAST OF BANGLADESH

Chapter III:

MAPPING COMMUNITY VULNERABILITY

MAPPING COMMUNITY VULNERABILITY

3.1 Vulnerability Zoning

A risk-based zoning map is an essential part of comprehensive flood-loss prevention and management programmes, and has been widely used by global communities in recent years (ISDR, 2004). It identifies priority areas in the risk zone, which is particularly useful when there is a budget constraint. Ground elevations modelled by DEMs are important for a number of natural hazard risk management applications including flood inundation modelling (storm tide and riverine).

Risk zoning using DEM and tidal data is a very widely accepted methodology that has been adopted by researchers. If we can identify the zones that are more vulnerable in terms of flooding during storm surge, we can take the socio-demographic and safety measures accordingly. Also this zoning might be helpful in terms of making plans and policies for the regions that are vulnerable.

3.2 Tools and Methods:

The study area is comprised of three administrative districts named Satkhira, Khulna, and Bagerhat. DEM data has been downloaded through Ortho-rectification and subset using ArcGIS Application according to the study area boundary. The vulnerability area of the coastal vulnerability map is drawn by using the tidal surge height data and DEM analysis data (Figure: 11). DEM data is classified into 5m interval and tidal surge data superimposed on this classification. Considering the river width and distance from the sea the vulnerable zone is marked.

Shuttle Radar Topography Mission (SRTM) data has been used to assess low-lying areas in this delta (Syvitski et al. 2009). The vertical precision of SRTM data depends considerably on location, terrain characteristics, and surface feature properties. SRTM C-band data with a 5.6 cm wavelength, with its near-global relative vertical accuracy of &3.7 m (Berry et al. 2007) has been used, and for many of the world's flat-lying (deltaic) areas error between 1.1 and 1.6 m (Schumann et al. 2008).

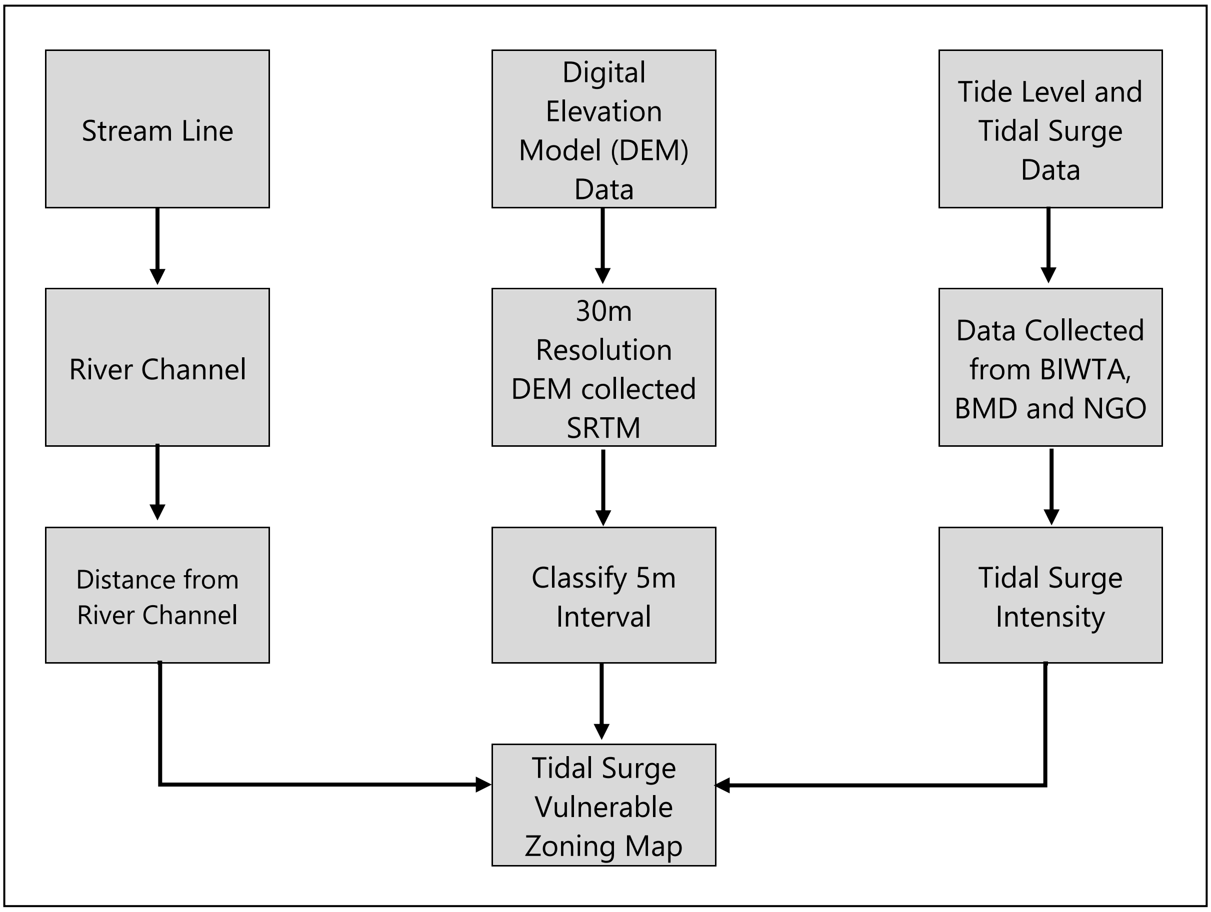


Figure 11: Flow Diagram of the Vulnerability Zoning Process

Digital Elevation Model (DEM) data is collected from Shuttle Radar Topographic Mission (SRTM) source using USGS (United State Geological Survey) earth explorer website. This data is 30m resolution and DEM acquisition time is 2006. The administrative data is collected from Bangladesh Bureau of Statistics (BBS) and tidal data is collected from Bangladesh Inland Water Transport Authority (BIWTA). The tidal surge data is collected from Bangladesh Meteorological Department (BMD) and other early warning reports of relevant Non-Government Organization (NGO)s.

3.3 Zoning of the Study Area

The study revealed two distinct zones, '**Low vulnerable area**' and '**Highly vulnerable area**', considering the vulnerability risk factors using GIS application. Classified zones and location of the sample sites are shown in Figure: 12.

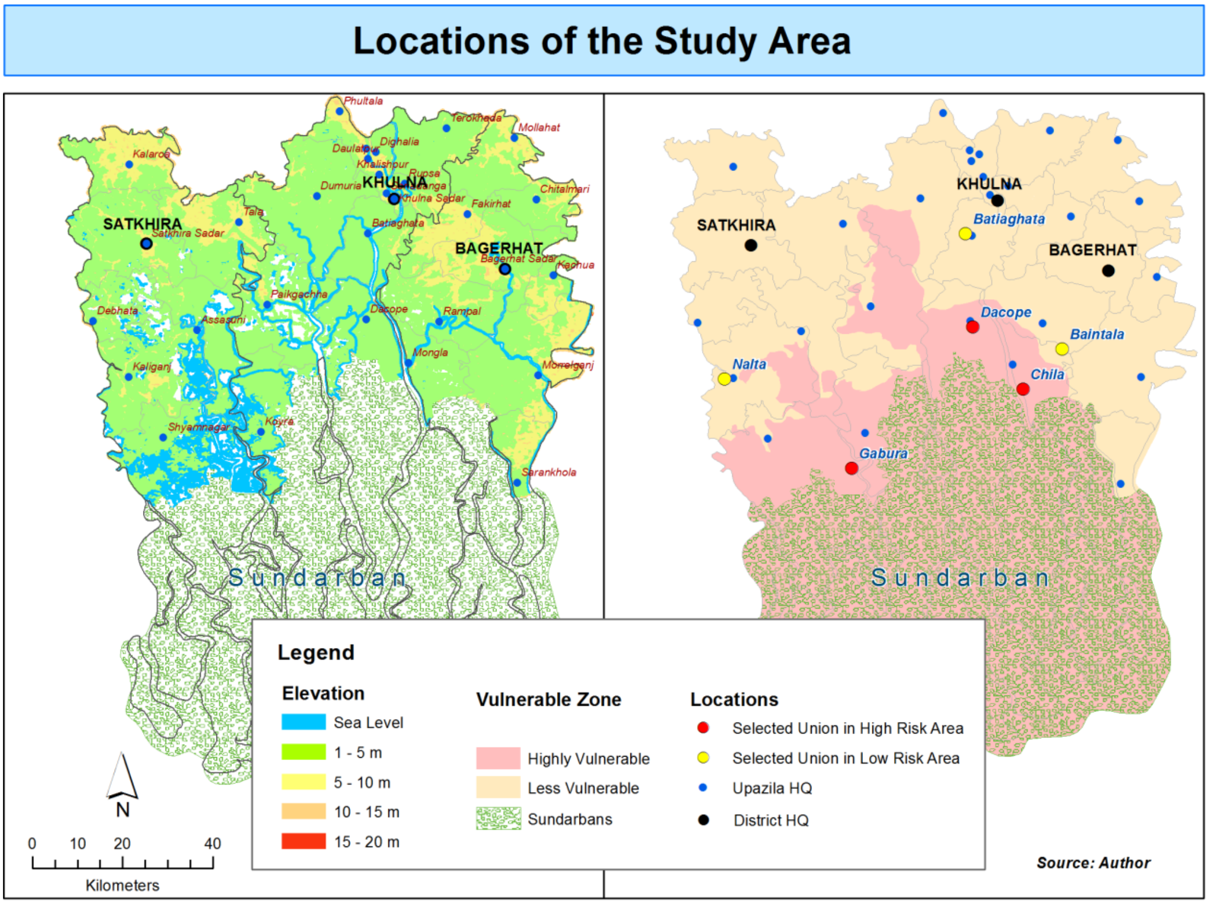


Figure 12: Location of the Sample sites

Most of the south-western part of Bangladesh is vulnerable in tidal surge. The highly vulnerable areas are mainly located in the southern part while there are few highly vulnerable areas seen far inland along the estuarine rivers. A major part of the highly vulnerable area is covered by the 'Sundarbans' (mangrove forest).

3.4 Validation of Sampling

Distribution of samples have to be homogeneous and representative along both the vulnerable zones. An assessment of the samples in terms of dispersion of respondent's Age is given below (Table: 11) to compare among the zones.

Table 11: Central tendency of the Age variable

Age by Risk Level	N	Minimum	Mean	Std. Dev.	Maximum
High Vulnerable Area	186	18	38.98	13.63	76
Low Vulnerable Area	185	19	41.25	13.54	70
Total	**371**	**18**	**40.11**	**13.62**	**76**

Source: Field Survey, 2016-17

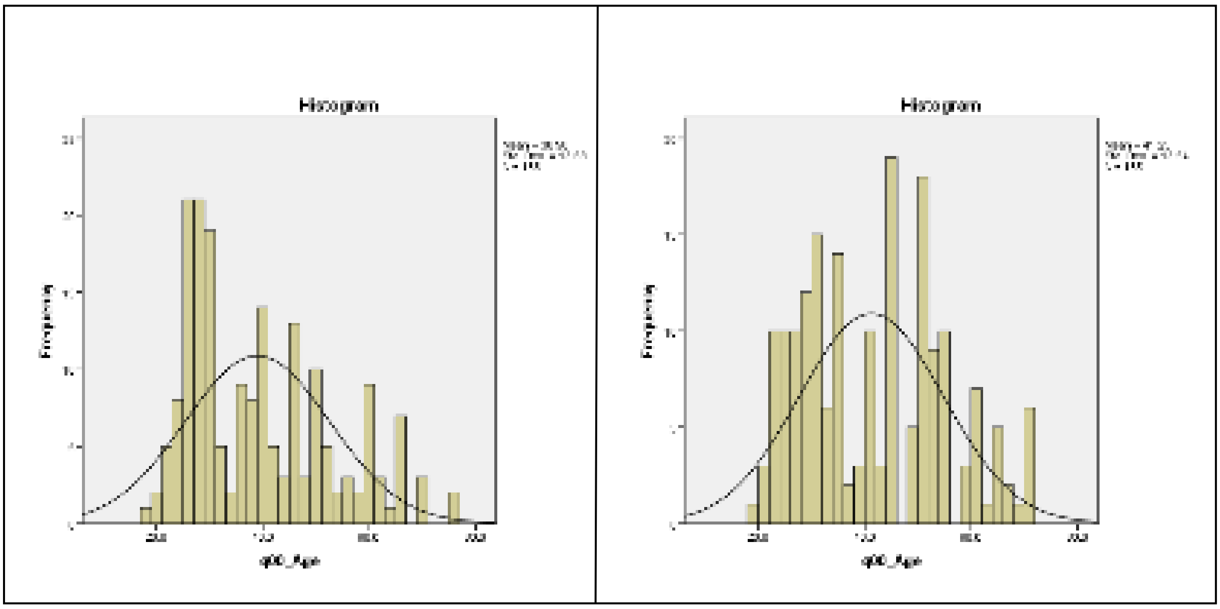


Figure 13: Distribution of Age among the vulnerable zones

Highly Vulnerable Area   Low Vulnerable Area

Respondents' Age distribution in both the zones are bell shaped within the range of 18 and 76 years and with mean age of 38.98 (±13.63) and 41.25 (±13.54) for High Vulnerable Area and Low Vulnerable Area respectively (Figure: 13). We find similar balanced age distribution in terms of gender and administrative unit as shown below (Table: 12):

Table 12: Age distribution by Administrative unit (District) of Samples

Age Distribution	Satkhira		Khulna		Bagerhat	
	High	Low	High	Low	High	Low
Sample	57	57	60	60	69	68
Male Avg. Age	49.7	38.1	35.8	47.5	35.6	45.3
Female Avg. Age	41.3	35.6	37.4	39.0	32.0	38.4
Min Age	22	19	20	20	18	20
Mean Age	47.2	36.9	36.8	43.1	34.1	43.2
SD	14.7	13.4	11.5	11.8	11.3	14.2
Max Age	81	70	75	70	65	70

Source: Field Survey, 2016-17

Distribution of samples by occupation among the vulnerable zone are also distinct. In all three districts it is clear that household affaires, farming and business are the main occupation of the respondents and the occupation rate is slightly higher than low vulnerable area (Table: 13 and Table: 14).

Table 13: Distribution of Samples by Literacy level by Vulnerable Zone

Education	Satkhira		Khulna		Bagerhat	
	High%	Low%	High%	Low%	High%	Low%
Illiterate	45	35	65	53	57	42
Primary	21	39	23	15	16	32
Junior	20	19	10	25	7	11
Secondary	7	4	0	7	14	12
Higher Secondary	2	0	0	0	3	3
Graduate	4	0	2	0	3	0
Others	2	4	0	0	0	0
Total	100	100	100	100	100	100

Source: Field Survey, 2016-17

Table 14: Distribution of Samples by Occupation by Vulnerable Zone

Occupation	Satkhira		Khulna		Bagerhat	
	High%	Low%	High%	Low%	High%	Low%
Retired	9	5	12	2	0	3
Household affaires	23	38	40	46	15	13
Jobless	0	2	2	2	2	5
Farming	25	11	13	9	14	3
Business	13	16	13	15	26	34
Service	0	0	0	7	8	2
Others	30	29	20	19	35	41

Occupation	Satkhira		Khulna		Bagerhat	
	High%	Low%	High%	Low%	High%	Low%
Total	100	100	100	100	100	100

Source: Field Survey, 2016-17

It indicates that age distribution of the respondents in both the zones are very similar which will ensure sensible response from both sides.

Chapter IV:

INUNDATION INTENSITY AND GLOBAL CLIMATE CHANGE

INUNDATION INTENSITY AND GLOBAL CLIMATE CHANGE

Recent events of the cyclones in Bangladesh, in terms of intensity, speed and direction, it is clearly evident that the south-west coast is more vulnerable than the central and eastern coasts. Severity and consequence of the recent cyclones put emphasis on this area and seeks in-depth investigation of livelihood of the inhabitants of south-west coastal region. In order to distinguish unique and common livelihood characteristic and preferences of the inhabitants, the region has been classified in to two major vulnerable zones considering the level of inundation during cyclone, tidal data, elevation of the surface.

On average, a severe cyclone strikes the country every three years. The country's topography is extremely low and flat with two thirds of its land area less than 5 m above sea-level. As a result, lives and property in low-lying coastal districts along the Bay of Bengal are highly vulnerable to inundation from cyclone-induced storm surges. Cyclone Sidr (NOV 2007) and Cyclone Aila (May 2009) provide recent example with high impact.

4.1 Impact of Climate Change

The geographical locations of Bangladesh and impacts of climate change makes the country more vulnerable. In its fourth assessment report, the IPCC concluded that the warming of the climate system was unequivocal, as it was evident from observations of increase in global average air and ocean temperatures, widespread melting of snow and ice and rising global average sea level (IPCC, 2007). The impact of accumulation of greenhouse gases for more than two centuries has been a significant factor in the increase of global average temperature i.e. about ±0.9 °F (±0.5 °C) (Seinfield, 2011). Temperature, Rainfall and Sea Level rise are considered to be the three most important factors that have been going through various changes and therefore are very important to understand the impact of climate change in Bangladesh.

4.2 Climate Change Indicators

Temperature

The average surface temperature has already increased by 0.3 ºF to 1.8 ºF between 1974 and 2004 (IPCC, 2007). Recent researches showing that the components of weather phenomenon are changing in Bangladesh rapidly. Further details of this change has been upheld in the study of Islam and Neelim (2010) as shown below (Table: 15).

Table 15: Changes in Annual Mean Temperature in Bangladesh, 1950-2008

Period	Annual mean temperature (°C)	
	1950	2000
Annual (January-December)	25.1	26.4
Pre-monsoon (March-May)	27.5	28.5
Monsoon (June-October)	28.1	28.4
Winter (November- February)	20.0	22.6

(Source: Modified from Rashid and Paul, 2014)

Rashid and Paul (2014) showed that greater insights can be gained by using data on average summer maximum and minimum and winter minimum temperatures for a sample of coastal stations. Spatial variations in these changes among the four stations in the coastal districts are not entirely consistent, but the eastern stations (Hatiya and Cox's Bazaar) have registered greater increase in temperature (Table: 16).

Table 16: Changes in Average minimum and maximum temperatures

(a) Average summer maximum temperatures

Coastal Stations (coastal zone)	Average maximum temperature in °C (30-60 years average)	Increase in percentages (from the lowest base temperature)
Khepupara (West central)	33.3	6.93%
Bhola (East Central)	34.3	1.7%
Hatiya (East)	33.4	18.6%
Cox's Bazaar (East)	34.5	10.75%

Source: Rashid and Paul, 2014

(b) Average winter minimum temperatures

Coastal Stations (coastal zone)	Average maximum temperature in °C (30-60 year average)	Increase in percentages (from the lowest base temperature)
Khepupara (West central)	14.5	11.5%
Bhola (East Central)	16	20.3%
Hatiya (East)	13.9	12.09%
Cox's Bazaar (East)	17.9	33.4%

Source: Rashid and Paul, 2014

Rainfall

Most of the preceding analyses of changes in rainfall regimes throughout Bangladesh indicates that compared to more consistent increases in air temperature, changes in rainfall have been less consistent. Compared to annual rainfall, it is seen that summer rainfall has shown more consistent increase. The details of annual temperatures have been presented below (Table: 17).

Table 17: Annual Rainfall in the coastal region

Coastal Stations	Annual Rainfall in Inches		
(Coastal zone)	2003	2006	2008
Khepupara (West central)	70.32	136	120.4
Bhola (East Central)	72.76	85.68	79.72
Hatiya (East)	146.56	100.76	141.84
Cox's bazaar	164.52	137.2	141.7

Source: Modified from Rashid and Paul, 2014

Sea level

Net sea level changes along the coast of Bangladesh involve several competing terrestrial variables. Therefore, the sea level rise in coastal Bangladesh is subject to great uncertainties. Based on limited tide gauge data from three stations for the period of 1977-1998 (Table: 18), the mean tidal levels along the southern and south-eastern coasts of Bangladesh had been increasing at rates of 0.16 inches/year to 0.32 inches/year (Rashid and Paul, 2014). This rate of increase is much higher than the longer term (1900-2010) global record of increases in sea levels, which ranges between 0.072 inches and 0.088 inches/year. (Shum and Kuo, 2011)

Table 18: Trend in Storm surge increases in Three Tide gauge stations: 1977-1998

Station (Coastal zone)	Rate of increase (mm/year)
Hiron Point (West)	4.0
Char Changa (Central)	6
Cox's Bazar (East)	7.8

(Source: Rashid and Paul, 2014)

4.3 Sector-wise Climate Change Impacts in Bangladesh

The major sectors of climate change impacts are grouped into two categories, biophysical and socio-economic or human. According to IPCC Assessment report, the main sectors where climate change has most impacts in coastal zone are: hydrology and water resources, agriculture, forestry, extreme weather events and health.

Coastal Zone

The most alarming aspect of climate change in Bangladesh is the sea level rise in the Bay of Bengal that could potentially submerge a major portion of the coastal zone. The low lying coastal physiography further intensifies the risk from sea level rise. Sea level rise in the Bay of Bengal is expected to produce changes in three areas of environment (WB 2001). They are:

(a) Water level, submergence and water-logging

(b) Soil, ground and surface water salinity

(c) Coastal morphology

The ultimate consequences could be increased coastal flooding along with salinity intrusion. Salinity intrusion reaches its peak in the winter months. The Sundarbans could be severely impacted due to sea level rise. According to CEGIS (2005), the richest biodiversity areas in Sundarbans might reduce from 60% to 30% by 2100 with a sea level rise of 88 cm.

Hydrology and Water Resources

Hydrology and Water resources is another sector that would be severely impacted by Climate Change. Variations in the spatial-temporal aspects of precipitation is the main driver of the impacts in the hydrology. The projected increase in precipitation in the Ganges-Brahmaputra-Meghna (GBM) could increase the frequency, duration and depth of floods in Bangladesh. The riverine and coastal morphological processes are extremely dynamic and climate change induced impacts could disturb the balance between the river sediment transport and deposition in rivers.

Agriculture

Food security threat is the main concern resulting from the impact of climate change on agriculture. Both land use pattern and the productivity of crops is likely to change under global warming. Agricultural activities in Bangladesh are subject to various aspects of the bio-physical environment like early rains, excessive inundation or prolonged flooding, soil salinity, moisture insufficiency, storms etc. Three types of stress situations are particularly worrying for the agricultural sector in Bangladesh they are: submergence from flooding, drought and salinity. It is very likely that all of the stresses would become more severe with global warming.

Forestry

About 17.5% of the total area of Bangladesh is covered by forest according to official statistics (Forest Department of Bangladesh) but the actual tree cover is less than 7% (Rasheed 2016). All forest ecosystems in Bangladesh are under tremendous threat, due to various human interventions including illegal logging, the annual rate of deforestation being between 3-4% of the forest area. Among the forests in Bangladesh, Sundarban forests are the most vulnerable to the impact of climate change and the associated sea level rise. A rise of 40 cm by the middle of this century could submerge nearly two-thirds of the Sundarban forests (Rasheed 2016).

Extreme Weather Events

The frequency and magnitude of many weather events might be enhanced with global warming. Conditions of heat stress leading to higher number of heat strokes could be resulted from higher summer temperatures. It is estimated that as a result of climate change, the drought prone areas of Bangladesh could experience increased moisture stress leading to parching of vegetation, lowering of water table and decline of crop yields (WB, 2001).

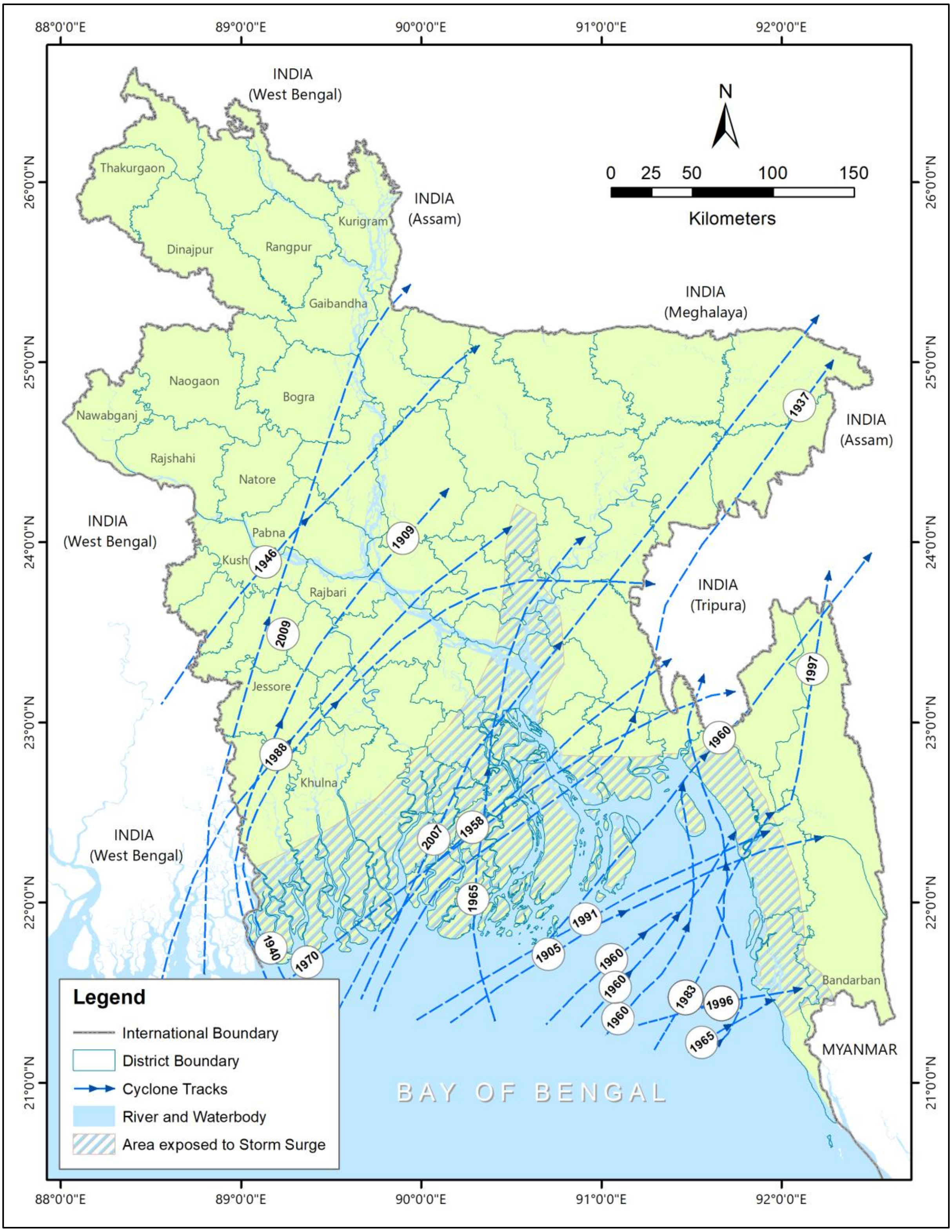
Due to increased precipitation in Bangladesh as well as the upstream catchment areas the monsoon flows in the rivers would be substantially increased and this would lead to increase in the frequency, extent, depth and duration of floods in Bangladesh. There is also a possibility of increase in high intensity rainfall or heavy rains of short duration. Tropical cyclones in Bangladesh originating in the Bay of Bengal is the extreme event that is of main concern. These cyclones cause massive damages in the coastal zone in the pre-monsoon and post monsoon seasons.

Human Health

Adverse effects of human health could be resulted from a rise in atmospheric temperature and changes in precipitation. Heat stress from more intense and frequent heat waves will severely affect the vulnerable population like the elderly, children and the poor. Poor nutrition and poor sanitation are responsible for the prevalence of several water borne and vector borne diseases like diarrhoea, dysentery, typhoid, cholera, etc. The incidence of mosquito borne diseases would increase due to changing climate change scenario model studies. Warmer temperatures and more humid climate would be favourable for malaria in Bangladesh.

4.4 Historical Cyclone Tracks

Cyclones that affect Bangladesh normally originates between 5° and 15° N latitudes in the southern Bay of Bengal, and often proceed in a northerly and north-westerly direction in the beginning, and then recurve north-eastwards following the Coriolis effect and hit Bangladesh coast (Rasheed, 2016). Cyclones in their initial stages move at a rate of 5 to 10 km/hr. In their final stage they may move at a rate of 20 to 30 km/hr or even up to 40 km/hr. Cyclones in the Bay of Bengal usually move northwest in the beginning and then curve eastwards. But this pattern is not uniform as seen from the tracks of various cyclones (Figure: 14). Cyclones accompanied by heavy rains and sea swells are called storm surges. In cyclone forecasting, it is often assumed that a cyclone follows the direction of the upper atmospheric current.

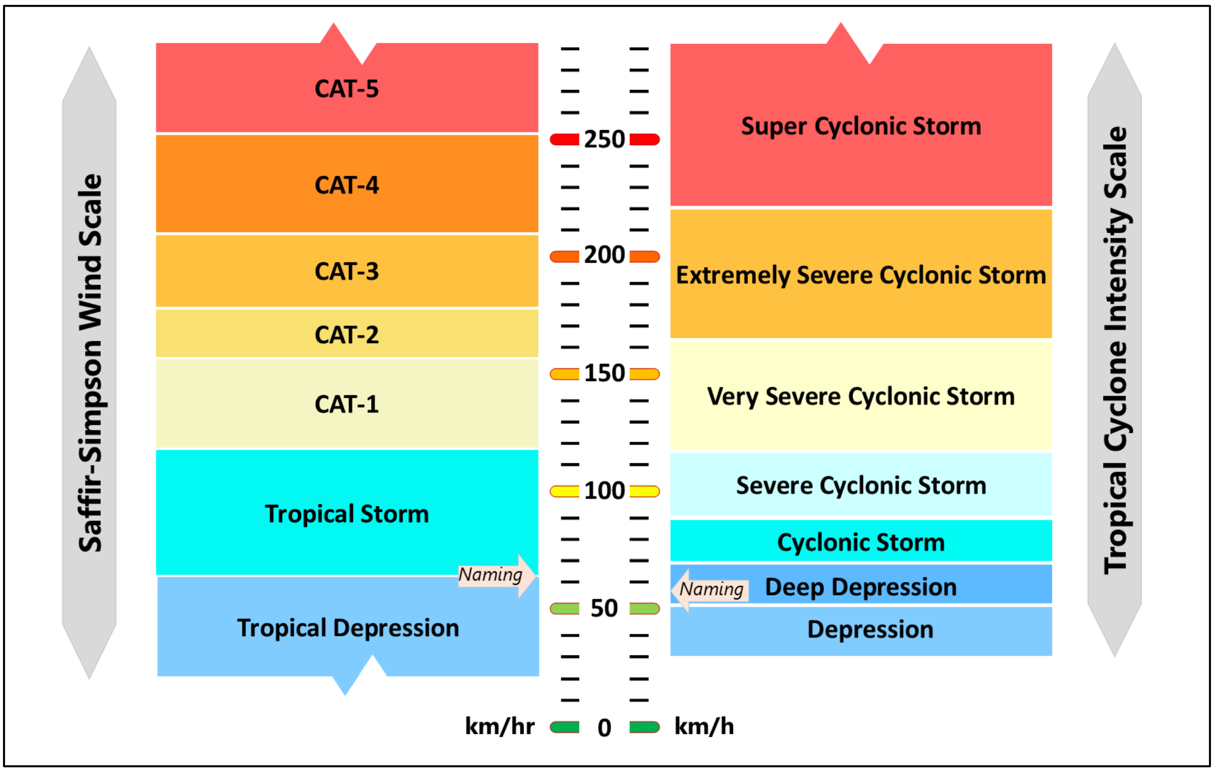


Source: Reproduced from Rasheed, 2016

Figure 14: Historical Cyclone Tracts in the Bay of Bengal

4.5 Intensity of cyclones in Bangladesh

According to National Oceanic and Atmospheric Administration (NOAA), Cyclone intensity is defined as the maximum wind speed in the storm. This speed is taken as either a 1-minute sustained or 3-min average or 10-minute average at the standard reference height of 10 meters. There are different scales for measuring the intensity of cyclone (Figure: 15). Saffir–Simpson wind scale considers one-minute sustained wind speed to measure cyclone's intensity. The India Meteorological Department's scale uses 7 different classifications for systems within the North Indian Ocean, and are based on the systems estimated 3-minute maximum sustained winds.



Source: National Hurricane Centre, National Oceanic and Atmospheric Administration, USA; and https://en.wikipedia.org/wiki/Tropical_cyclone_scales

Figure 15: Saffir-Simpson wind scale and Tropical Cyclone Intensity Scale

It is clear that the intensity of cyclone is increasing and climate change is contributing to the fact by accelerating Sea Surface Temperature (SST). Apart from empirical data the relationship between cyclone intensity and SST is well discussed in the literature. For example, compare to the threshold sea surface temperature of 27 °C, if we assume the International Panel for Climate Change (IPCC) lower bound and upper bound temperature to increase 2 °C and 4 °C, the likelihood of increasing the maximum wind speed of future cyclone is 10% and 22% higher respectively (Ali, 1999).

4.6 Cyclone Induced Storm Surges

An unusual, often destructive rise in sea level above normal high-tide level in a coastal area, caused by a combination of low atmospheric pressure and strong onshore winds during a storm. They strike the coast nearly at the same time that the centre of the storm crosses the coast. In Bangladesh maximum value of this storm surge has been reported to be as high as 13m. Most of the damage during a cyclone is done by the storm surges, which sometimes wash over entire offshore islands and large areas on the coast.

The most destructive element of a cyclone is its accompanying surge. There is little that can withstand a great mass of onrushing water often as high as 6m. In Bangladesh, cyclones occur in April-May and also in September-December. Surge-heights increase with the increase of wind speed. Astronomical tides in combination with cyclonic surges lead to higher water levels and hence severe flooding.

4.7 Assessment of inundation intensity of South-west coast

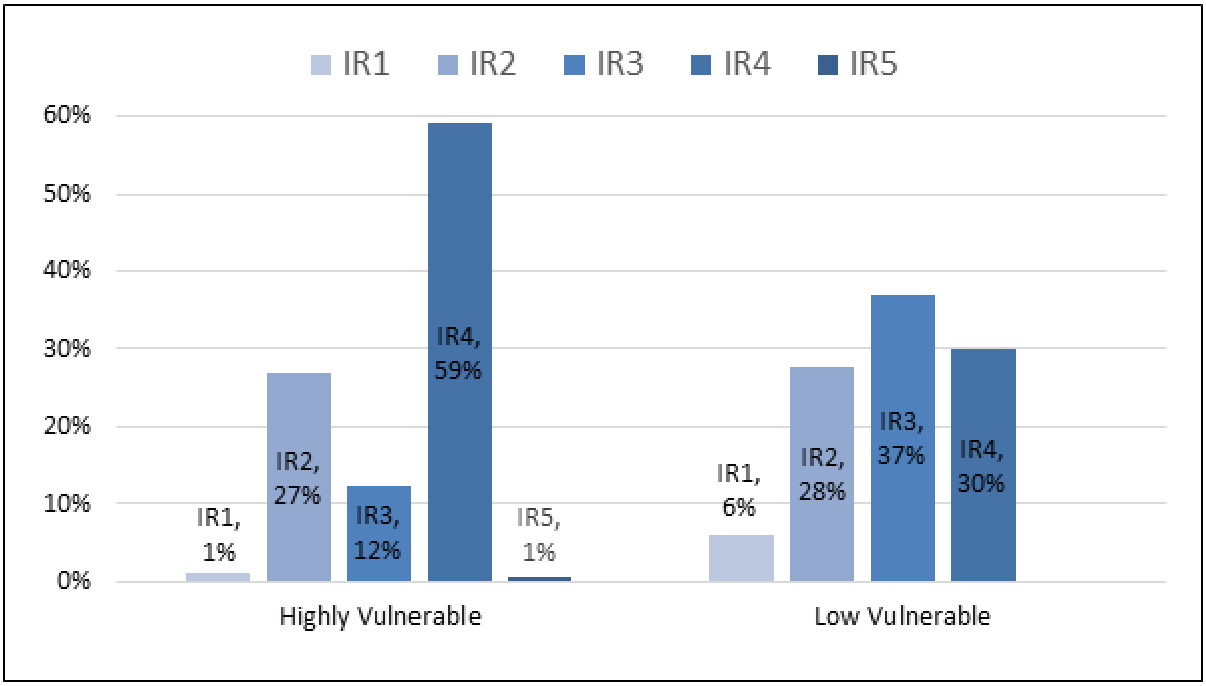
Assessment of inundation intensity is a process to identify hazards due to inundation, evaluate the risk associated with this hazard. Intensity assessment helps to determine appropriate ways to reduce the hazard. In practical terms, an assessment is a thorough look at the vulnerable areas that may cause harm, particularly to people. Inundation intensity assessment is an essential tool for creating awareness of hazards and risks, identifying the population at risk, determining existing hazard control measures, preventing casualties and for prioritizing hazards and control measures.

The study aimed to understand the behaviour of inundation depth and assess the inundation risk of the study area according to respondents' perception, in this study few factors are considered for understanding the inundation intensity assessment; i.e. inundation depth and inundation velocity and inundation frequency. Further to process risk level, these two factors have been converted into some common indices considering possibility of evacuation by walk. There are 5 indices for inundation depth (Table 19) and 3 indices for inundation velocity which have been determined considering the physical characteristics of female inhabitants (mean height 147.9 cm, weight 40.5 kg, and BMI 18.5 according to Hosegood and Campbell, 2003) and types of structural establishments in the western coastal region of Bangladesh.

Table 19: Risk by inundation depth

Risk Level	Inundation depth (m)	Indices	Evacuation possibility
Inundation Risk 1	< 0.4	Below knee	Possible
Inundation Risk 2	0.4 – 0.9	Below waist	Difficult
Inundation Risk 3	0.9 – 1.2	Up to chest	Not possible
Inundation Risk 4	1.2 – 3.0	Above chest	Not possible
Inundation Risk 5	> 3.0	Above roof (1st floor)	Not possible

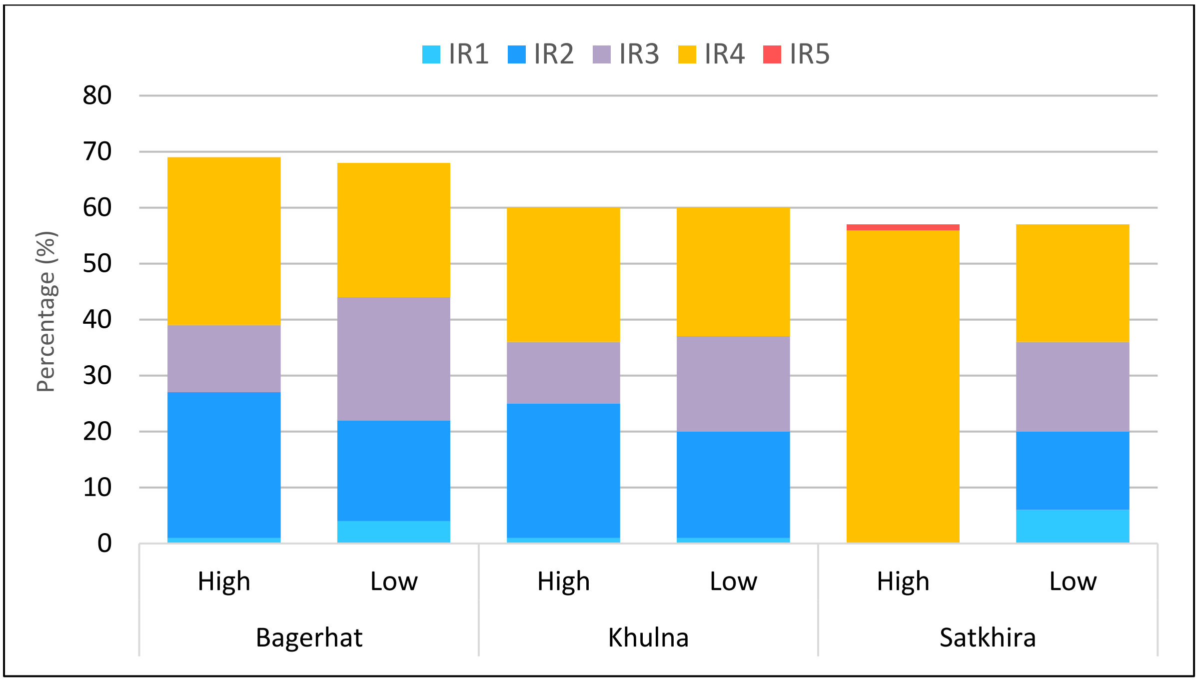
Source: Nahar & Kawashaki (2014)



** IR-1: Inundation Risk 1, IR-2: Inundation Risk 2, IR-3: Inundation Risk 3, IR-4: Inundation Risk 4, IR-5: Inundation Risk 5*

Figure 16: Inundation Intensity by Vulnerable zone

Figure: 16 depicts risks from inundation depths as observed in the study area. Only 6% respondents of the low vulnerable area mentioned that evacuation is possible during storm surge as the surge water remains below knee while this figure is 1% in the highly vulnerable area. About one-fourth of the respondents from both of the vulnerable zones mentioned surge level below waist. Majority of the respondent experience surge height above the waist, when evacuation is not possible, particularly this is 67% in the low vulnerable area and 72% in the Highly vulnerable area.



** IR-1: Inundation Risk 1, IR-2: Inundation Risk 2, IR-3: Inundation Risk 3, IR-4: Inundation Risk 4, IR-5: Inundation Risk 5*

Figure 17: Inundation Intensity by Location

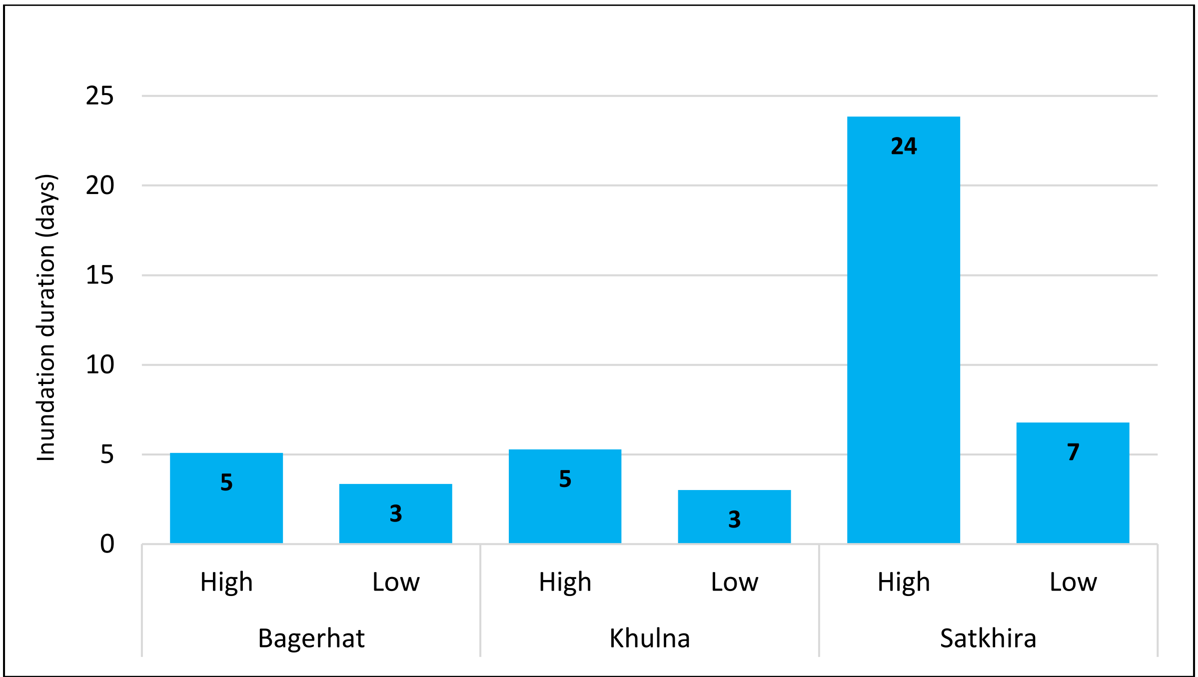
The above graph (Figure: 17) Inundation risk level by district shows that risk level 4 is prevailing along all three districts irrespective of their vulnerability zone. Highly vulnerable area in Satkhira district has its uniqueness where the risk levels are at the higher end with only level 4 and level 5 (Table: 20).

Table 20: Average Inundation duration (days) in the study area

Risk Level	Bagerhat		Khulna		Satkhira	
	High	Low	High	Low	High	Low
IR 1		1.0	8.0	5.0		
IR 2	6.0	3.3	4.8	3.0		9.8
IR 3	3.9	3.5	3.9	3.2		6.3
IR 4	4.7	3.5	6.3	2.8	23.6	5.3
IR 5					36.0	

Source: Field Survey, 2016-17

The following graph (Figure: 18) is showing the average inundation duration in days. In Bagerhat and Khulna district inundation duration is longer in Highly vulnerable area than the low vulnerable area. In Satkhira, inundation duration is remarkably longer in the highly vulnerable with an average value of approximately 24 days.



Source: Field Survey, 2016-17

Figure 18: Inundation duration by Location

The chapter tries to delineate the impacts of climate change in the context of Bangladesh. It has been observed that almost all major physical and environment aspects of the country. Among the impacts, of the most worrying impacts would be that of increased storm surges in the context of global climate change.

Analysing the trends of recent cyclones, i.e. Sidr and Aila, we see that the south west coast is most vulnerable. The intensity of cyclone according to the Saffir-Simpson scale has been analysed for the coastal region of Bangladesh. Assessment of inundation intensity of the study area shows that inundation intensity is a major factor of vulnerability as seen in highly vulnerable areas.

Chapter V:

CHANGING PERCEPTION ABOUT CYCLONIC HAZARD

CHANGING PERCEPTION ABOUT CYCLONIC HAZARD

Introduction

Impacts of cyclonic hazards in coastal Bangladesh is becoming more visible day by day that needs to be analysed and documented. The challenges facing communities living with cyclonic hazards within Bangladesh's coastal areas are complex. This study also characterizes four hydrological indicators (risks of cyclone and storm-surge, coastal flood and tidal fluctuation, river erosion and salinity) for critical understanding and analysing the impacts of the coastal hazards. The Communities share a collective desire to face the challenges during hydrological natural hazards, but often their common interests end there. Moreover, in the coastal Bangladesh, scientists have noticed an increased frequency and intensity of cyclones and associated disasters. It is now often noticed that sings and distinctiveness of the country's 'six seasons' are getting increasingly blurred.

5.1 Intensity of Disaster impacts

This chapter has analysed community's perception and experiences by focusing past and present disaster impacts, level of community's vulnerability and scale of effects. In the study area, the respondents have identified five types of major hazards such as cyclone, flood, river/soil erosion, salinity and waterlogging that adversely affected various sectors of life, livelihood, agriculture, fishery, infrastructure, health, forest, livestock and business. Like the sectors, the concerned sub-sectors and social elements have also been affected by the hazards. They have also been exposed by increased intensity and frequency of these hazards that have proliferated their severity and vulnerability. Recently the community has been affected by number of mega cyclones (Cyclone Sidr in 2007 and storm-surge Aila in 2009), flood in 2000 and prolonged waterlogging in 2017.

The respondents also said that in last 15 years, they were affected by several major hazards including cyclones, storm-surge, flood, waterlogging and salinity due to location in extreme south, distance from Bay of Bengal, low land area, deforestation, lack of operation and management of embankment and behaviour changes of the community. Many households have migrated due to loss of family and property to survive. They also assumed that the possibility of adverse effects may amplify in the future due to intensity of natural hazards, lack of copping capacity and increased vulnerabilities.

5.2 Scale of Hazard Impact

IUCN Bangladesh (2011), Hydro-meteorological impacts may be categorized by hazards or disasters for understanding frequency, intensity and severity of the disasters. Hereby, climate extreme events such as increasing frequency and magnitude of floods, cyclones, droughts, salinity and storm-surge etc. demand short-term trend analysis. This entails simulating changes for short-term weather pattern of seasonal cyclones and observing trends of annual extremes. On the other hand, relevant short records may not reveal the full extent of natural variability and long term reconstruction can place recent trends and extremes in a broader context.

The scale of effects has been analysed between past and present severity considering into four categories of response, for instance (1) not affected, (2) minor affected, (3) major affected and (4) severely affected. The present vulnerability/the present severity to cyclone, flood, salinity and waterlogging has relatively been increased in all study sites out of 4 scale parameters of effects than past situation.

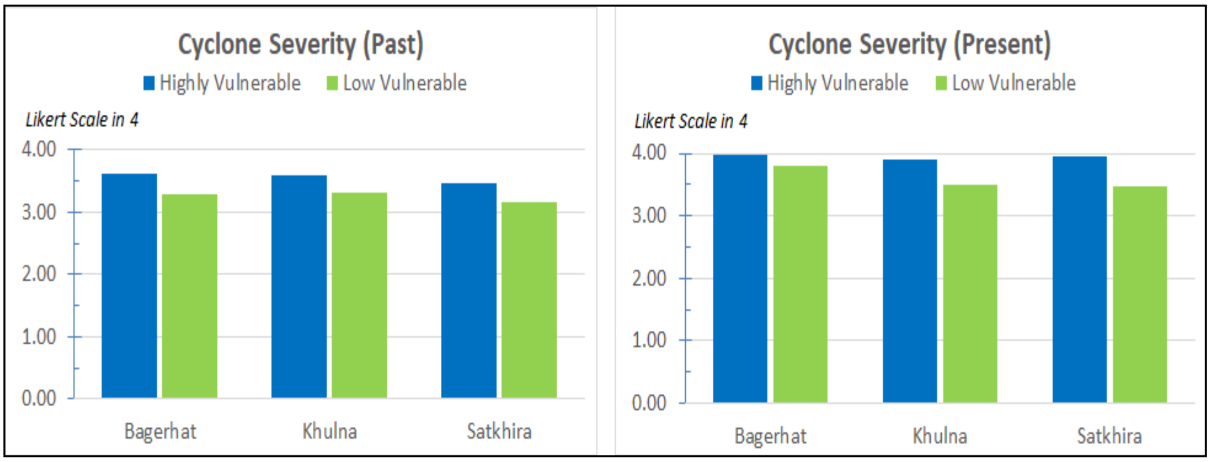
All the respondents were somehow affected by natural disaster like Cyclone, Flood, Erosion or Salinity. Of them 91% are severely exposed to disaster. The respondents in the study area have perceived that present situation of cyclone, flood and salinity are different from the past. Intensity and frequency of the cyclones and floods, duration of waterlogging and level of salinity have increased.

Quadir and Iqbal (2008) in their assessment of the tropical cyclones of the Bay of Bengal for the period of 131 years (1877-2007), found that while the frequency of Depression (D: wind speed 40-50 km/hr), Cyclonic Storm (CS: wind speed 62-88 117 km/hr) and Severe Cyclonic Storm (SCS: wind speed 89-117 km/hr) is decreasing, the very intensive tropical cyclones (SCS-H: wind speed > 117 km/hr) are increasing. Like that of Sidr with a 100-milelong front covering the breadth of the country and with winds up to 240 km per hour, hit Bangladesh in November 2007. Salinity intrusion will result from less availability of freshwater and sea level rise. The coastal zones are the most vulnerable areas to salinity intrusion. Soil Resources Development institute (SRDI, 1998) compared salinity map for the period of 1967 and 1997 and found evidence of intrusions in the soil of the coastal area in two decades.

Coastal polders built by Bangladesh Water Development Board (BWDB) enabled bringing 1.2 million hectares of land under agriculture or aquaculture and provided protection of lives and properties of coastal communities against flood, storm surge and salinity intrusion. However, there have been unintended consequences such as river sedimentation and waterlogging that has become increasingly problematic in the last three decades in certain parts of the coastal zone.

Sea level rise is likely to cause significant changes in river salinity in the southwest coastal zone of Bangladesh during the dry season (October to May) by 2050, which will likely to lead in significant shortages of drinking water in the coastal areas, scarcity of water for irrigation for dry season agriculture and significant changes in the coastal aquatic ecosystems. Changes in river salinity and the availability of freshwater severely affected the fish habitat and productive freshwater fisheries.

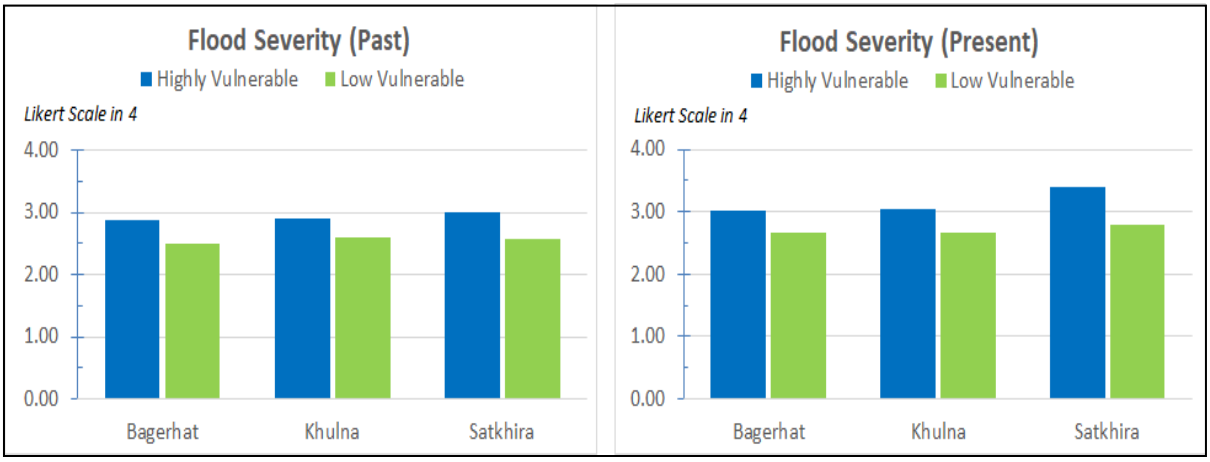
Data shows severity of cyclone is higher in the highly vulnerable areas as obvious but it is observed that cyclone severity has increased in the recent years (from 3.4 to 3.8 on average) both in the highly vulnerable (from 3.5 to 3.9 on average) and low vulnerable areas (from 3.3 to 3.6 on average). Satkhira and Bagerhat seems to have more severe effect than Khulna (Figure: 19) according to the perception of the local people.



Source: Field Survey, 2016-17

Figure 19: Comparison of hazard impact - Cyclone severity

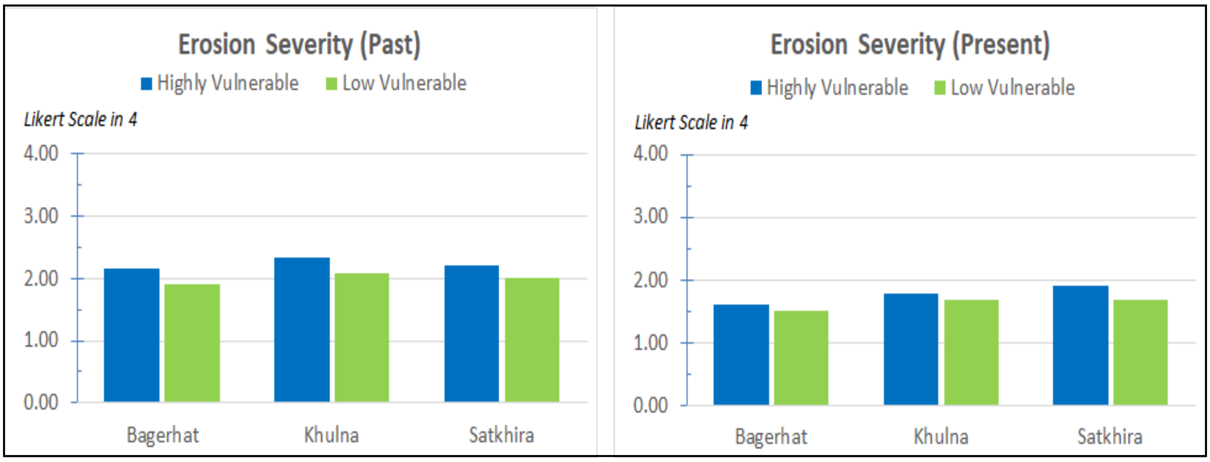
Flood hazard prevails in Satkhira and the hazard scale is higher in the recent days (Figure: 20) for all Satkhira, Khulna and Bagerhat (average 3.2, 2.8 and 2.9 respectively). General Economic Division (GED) of Bangladesh (2009) calculated a cyclone of 10 years inundating 37% of the area, however, in last 15 years such types of flood occurred 5 times and in last 10 years event of such flood occurred 3 times. Similarly, it can be said for a flood return period of 20, 25 and 50 years. GED (2009), based on the analysis concluded that the frequency and intensity of flood has increased significantly in last 15 years.



Source: Field Survey, 2016-17

Figure 20: Comparison of hazard impact - Flood

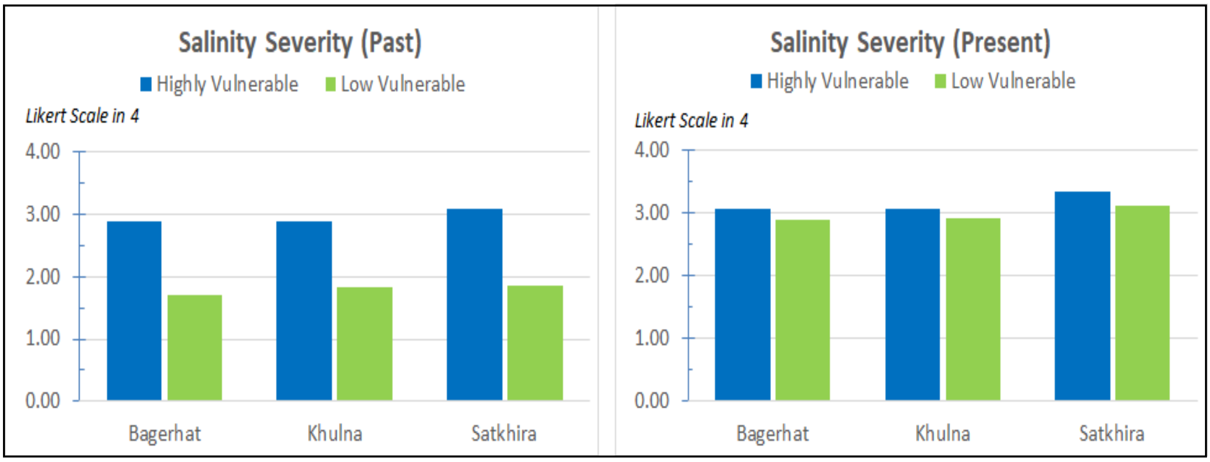
However, the inhabitants perceive that present severity to erosion (river bank/land erosion) has notably been decreased in all study sites particularly to Bagerhat and Khulna district compare to past as illustrated in Figure: 21. Respondents also said that construction of embankment, forestation and siltation of rivers might have advantages to reduce the present vulnerability.



Source: Field Survey, 2016-17

Figure 21: Comparison of hazard impact - Erosion

The study revealed severity of salinity in the south-west cost has increase slightly in the recent years but we find a sharp increase of people concern on severity of salinity in the low vulnerable area (Figure: 22).



Source: Field Survey, 2016-17

Figure 22: Comparison of hazard impact - Salinity

5.2.1 Hypothesis 1

H0: There is no difference in peoples' perception on salinity impact at present between the highly vulnerable and low vulnerable areas.

H1: There is difference in peoples' perception on salinity impact at present between the highly vulnerable and low vulnerable areas.

Frequency of Respondents' Perception Score		**q00_RiskLevel**		**Total**
		High	**Low**	
q06_PresentSalanity	2.0	83	59	142
	3.0	69	108	177
	4.0	34	18	52
Total		**186**	**185**	**371**

Chi-Square Tests

	Value	**df**	**Asymp. Sig. (2-sided)**
Pearson Chi-Square	17.570[c]	2	.000
Likelihood Ratio	17.741	2	.000
N of Valid Cases	371		

Since observed p-value is 0.000, which is less than level of significance (.05), we may reject the null hypothesis at 5% level of significance.

Therefore, we may conclude that we have enough evidence to say that there is a difference in peoples' perception on salinity impact at present (since last 15 years) between the highly vulnerable and low vulnerable areas.

5.2.2 Hypothesis 2

H_0: There is no difference in peoples' perception on salinity between past and present impact in the low vulnerable area.

H_1: There is difference in peoples' perception on salinity between past and present impact in the low vulnerable area.

Frequency of Respondents' Perception Score		q00_RiskLevel		Total
		High	Low	
q06_PastSalanity	1.0	67	72	139
	2.0	30	42	72
	3.0	30	11	41
	4.0	59	60	119
Total		**186**	**185**	**371**

Chi-Square Tests

	Value	df	Asymp. Sig. (2-sided)
Pearson Chi-Square	10.991[c]	3	.012
Likelihood Ratio	11.346	3	.010
N of Valid Cases	371		

Since observed p-value is 0.012, which is less than level of significance (.05), we may reject the null hypothesis at 5% level of significance.

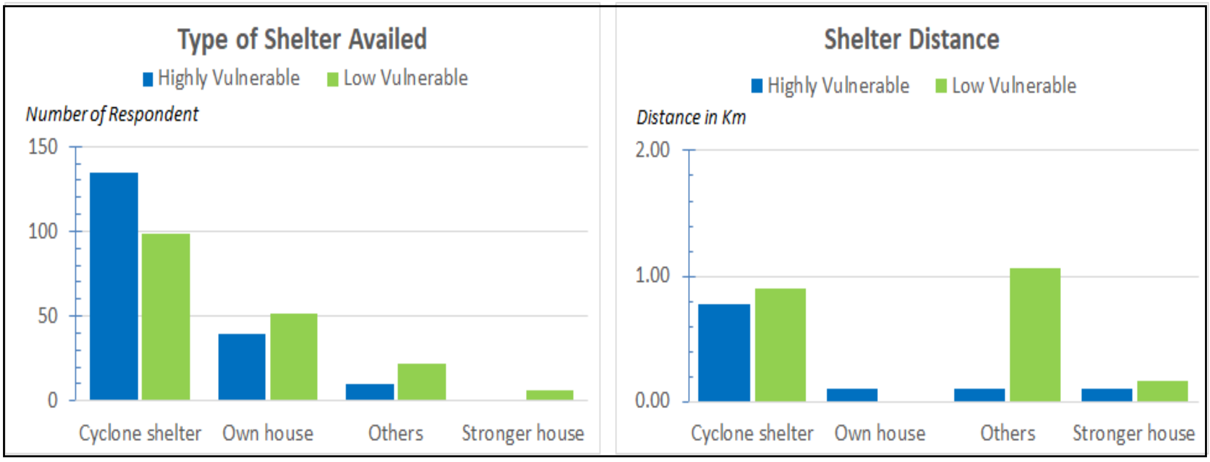
Therefore, we may conclude that we have enough evidence to say that there is a difference in peoples' perception on salinity impact in the past (before 15 years) between the highly vulnerable and low vulnerable areas.

5.3 Disaster Response of the Community

The community responded against disaster for saving life, livestock, important utensils, emergency food, family members and household assets by moving to the cyclone shelter, own house, neighbours' house and others e.g. embankment or a raised platform inside the house. Moreover, they remain engaged for shifting household chores, utensils, furniture, dry foods and fuel towards higher land or comparatively safer places. Although, agriculture and crop farming (Plate: 4) are the main economic activities of the study area, surprisingly the study has found limited response to save agriculture crops. On an average 63% of the respondents moved to cyclone shelters during cyclone while the figure is 73% and 54% for the highly vulnerable and low vulnerable areas respectively. Distance of cyclone shelter (about 0.78 km) was comparatively far away than other structures as presented in the

Figure: 23. They preferred the cyclone shelter and neighbour houses due to strong infrastructure and trust of safety.

Despite the disaster response by the respondents were aimed to save life and livelihood, some of them in the study area were reluctant to respond adequately during cyclone Sidr in 2007 and storm-surge Aila in 2009. The factors of the response were mainly influenced (1) awareness level (2) visibility of the hazard (3) sources of warning (4) the quality of information and (5) coping capacity of the recipient. It is observed that disaster responses were moderately varied between high and low vulnerable areas. They said that there are still some gaps in present early warning systems weather forecasting for access to vulnerable people in remote area although they have observed significant improvement of digital infrastructure and communication system. Early warning systems on cyclone in the study area were comparatively better than flood.



Source: Field Survey, 2016-17

Figure 23: Community response to Cyclone shelters

5.4 Disaster Impacts

As impacts of climate change or natural disasters, by the 2050s, freshwater availability in South Asia (of which Bangladesh is a part) is projected to decrease, coastal areas in this region will be at greatest risk due to increased flooding from the sea, endemic morbidity and mortality due to diarrhoeal disease primarily associated with floods and droughts are expected to rise due to projected changes in the hydrological cycle (IPCC, 2007). The major impacted areas are human health, agriculture, livestock, fisheries and forest, water resources, and coastal areas. Similar impacts can be expected at country level like coastal Bangladesh. According to the Bangladesh Climate Change Strategy and Action Plan 2009 (MoEF, 2009), the possible impacts of natural disasters are:

(a) increasingly frequent and severe tropical cyclones, with higher wind speeds and storm surges leading to more damage in the coastal region;
(b) higher river flows, causing over-topping and breaching of embankments and widespread flooding in rural areas;
(c) river bank erosion resulting in loss of homes and agricultural land to the rivers;
(d) increased sedimentation in riverbeds leading to drainage congestion and water-logging;
(e) increased riverbank erosion and saline water intrusion in coastal areas are likely to displace hundreds of thousands of people who will be forced to migrate, often to slums in Dhaka and other big cities; and
(f) shortage of drinking water is likely to become more pronounced specially in the coastal belt areas.

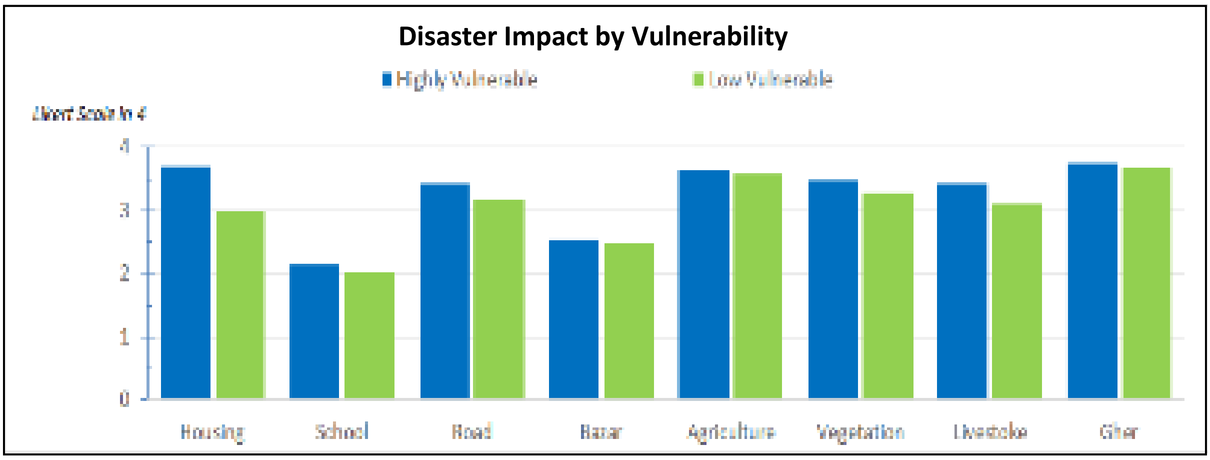
IUCN Bangladesh (2011) stated that the 12 bio-eco zone of Bangladesh and considering the severity of impact of climate change, monitoring protocols have been identified for eight thematic sectors:

(1) hydro-meteorology
(2) crop
(3) livestock
(4) forest flora and fauna
(5) fresh water fisheries
(6) marine water fisheries
(7) health and
(8) livelihoods; etc.

These eight sectors can be broadly classified to (a) hydro-meteorology/climate parameters as it is necessary to know changes and variations in climate parameters (b) the primary sectors of the economy (e.g., crop, forest, fisheries) as these directly relate to the climatic variables and (c) human dimensions (health and livelihood). The possible impacts referred by the national documents (e.g., MoEF 2009, MoEF 2005, MoEF 2002) as well as other studies stated that these are the impacts resulted due to climate change/natural hazards. Incidence of natural disasters may increase exponentially with the changing of climate and impact of higher temperature and other extreme events may have serious implications on crop production as well as other sectors. These changes will threaten the significant achievements Bangladesh has made over the last 20 years in increasing incomes and reducing poverty, will make it more difficult to achieve the SDGs. In view of these expected changes, a systematic monitoring mechanism should be put in place to assess the impact of climate change.

Salinity being getting severe in the south west belt of Bangladesh; climate change induced disaster is considered as one of the driving factors for the increase of salinity intrusion. It is reported that salinity affected areas in the coastal Bangladesh have increased from 0.83 million hectares in 2001 (Karim and Iqbal, 2001). CEGIS (2006) reported that the 5 ppt isohaline line would show a northward shift by about 90km inland due to sea level rise by 2070s. Salinity ingress directly affects the yield of the most preferred crops generally observed in the coastal zone (Karim, et al, 1990). Since the recession of saline water from a coastal embankment takes a few days, the crop lands become salty that destroys standing crops and triggers loss of livelihoods of farming communities.

As per collected data and respondents' perception in the study area using different methods (face to face interviews and Focus Group Discussions), the hazard events (such as cyclone, flood, salinity, erosion and waterlogging) in different years had caused extensive damages in the sectors of infrastructure (houses, roads, markets, bridges, and embankments), agriculture (crops, fishery and forestry), livelihoods (income and employment), Health (water & sanitation, drinking water, irrigation), environment (pollution), social (crime, demoralization of values, dependency syndrome) and service facilities.



Source: Field Survey, 2016-17

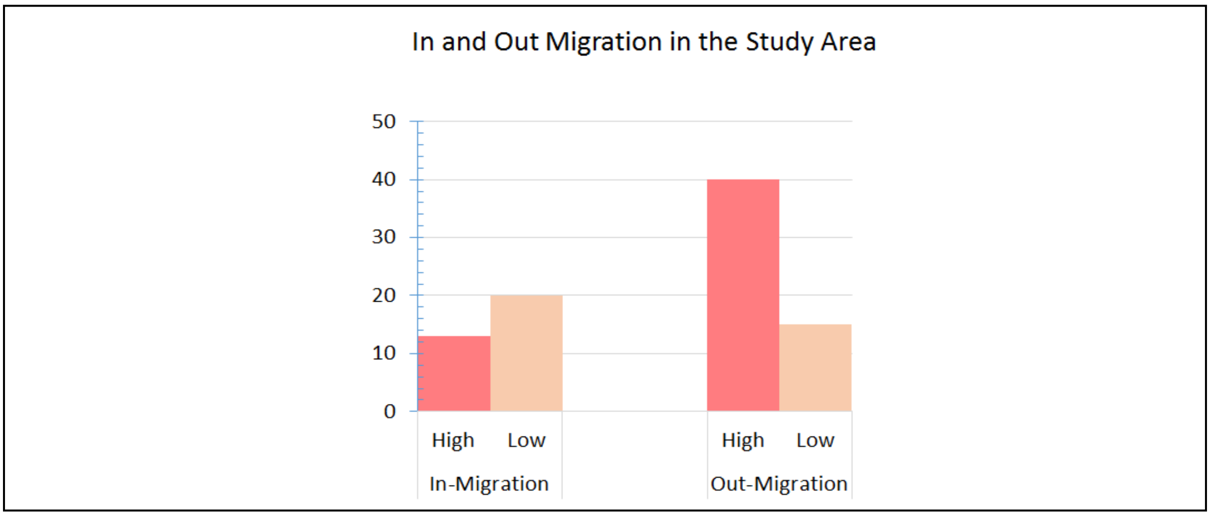
Figure 24: Community response to Cyclone shelters

The above graph (Figure: 24) presents the probable impacts of disasters on various sectors considering high and low vulnerability of the study sites. However, the sectoral impacts and the ratio of changes vary negligibly between high and low vulnerability study sites. The most affected sectors are fishery, housing and agriculture where moderately affected sectors are included infrastructure (road, market and school building), vegetation and livestock. Employment losses in different economic or livelihood pattern have the highest effects both in highly vulnerable (about 37%) and low vulnerable (30%) which pushed the affected households to internal migration. 20% of the respondents faced financial crises due to cyclone, storm-surge, flood and salinity. Every year the respondents face the losses in agriculture, livestock and livelihood due to waterlogging, flood and salinity. Sixty-five percent (65%) of respondents from Khulna and Bagerhat district said that they have been affected by the disaster impact while the ratio is 98% in Satkhira district. They claimed to have suffered from lack of work, financial crisis, impede household activities, hinder agriculture, restricts mobility due to waterlogging, change in economic activities and water crisis. Failure of agriculture highly affected the respondents of all study sites due to salinity and waterlogging. Long-term waterlogging in Satkhira study sites particularly in 2000, 2004, 2007 and 2017 extremely affected the people's mobility.

5.5 Migration Pattern

This chapter explores the hazards-induced migration pattern and migration causes of the study sites. The study has found four types of migration pattern such as (i) In / Internal migration (ii) Out / External Migration (iii) Seasonal Migration and (iv) Permanent Migration in both high and low vulnerable study zones.

According to the study findings, about one fifth of the households (20%) of the low vulnerable area were internally migrated to the study area from different neighbouring unions, sub-district and districts in the last 15 years (Figure: 25). Internal migration is much fewer (13%) in the highly vulnerable coastal area. Satkhira district found to be comparatively popular for internal migrants (about 30%), because social safety net programmes and livelihood supports were increased by the donors, Bangladesh Government and NGOs initiatives for the disaster affected people after cyclone *Sidr* in 2007, flood in 2007 and *storm-surge Aila* in 2009. Revealed from the study that about 40% of the households did out-migration in the highly vulnerable area and only 15% in the low vulnerable costal area out-migrated due to fear of recurrent disaster, unemployment and food insecurity.



Source: Field Survey, 2016-17

Figure 25: Migration Pattern in the study area

Main cause of migration from both high and low vulnerable zones of the study area was unemployment which is identified by 35% of the respondents from both high and low vulnerable coastal area. They also said that coastal flooding, prolonged waterlogging, cyclone, storm-surge and soil salinity intrusion in Satkhira, Khulna and Bagerhat district were the major cause of crop failure and loss of crop production. Cyclone Sidr in 2007, and storm-surge Aila in 2009 caused huge loss of life, livelihood, property, agriculture and infrastructure (house, sanitation facilities, drinking water sources). Increased intensity and frequency of regular coastal flooding and prolonged waterlogging and soil salinity are gradually affecting the people's life and livelihood. Likewise, repeated exposure to such disasters steadily declines the households capital based livelihood capacity which pushed the people to migrate from their places of origin.

Literature suggests that the adverse effect of sea level rise would further aggravate salinity ingress along the coastal rivers proportion of these farmers are found in their locality while a large majority have migrated out from their villages (Mirza, 2002). Due to increased salinity, a vast tract along the coastal zone is left fallow during the dry season in apprehension of severe crop loss. The most adverse effect of salinity ingress is observed in Satkhira district. While the wealthy investors have thronged and forced a rapid transformation of crop lands in to saline shrimp enclosures, the poor farmers have lost their agriculture-based livelihoods, forced to transfer their crop lands to the new gher owners and eventually become destitute. Only a small proportion of these farmers are found in their locality while a large majority have migrated out from their villages (Ahmed and Neelormi, 2007). Cyclone storm surges are also quite common that destroy weak dwelling structure of the poor households, drown people and livestock alike and inflict misery to the cyclone battered people. In the latter cases, reconstruction of livelihood activities takes long time while people try to collect food from whatever sources. Under such frustrating living conditions, people generally decide to move out from their ancestral homesteads.

Like salinity, waterlogging not only enhances forced out migration/displacement, it aggravated extreme economic hardship, it inflicts upon health care debacles and other social problems (Ahmed, 2008). Moreover, riverbank erosion has been regarded as the most common cause of failed livelihoods in Bangladesh, which triggers forced displacement. Migration is also becoming inevitable where there are repeated embankment failures. Again, one may tend to associate this rather new problem with increased wave actions coupled with poor maintenance of existing embankment system. In 2007, there had been 16 instances of embankment failures, where the same event took place thrice in (Gabura Union of) Shaymnagar sub-district of Satkhira district in the south-western coastal region despite repeated attempts to mend the breached embankment. Again in 2008, 12 embankments have reportedly been breached, leaving many poor families homeless. In Satkhira district alone, over 42,000 people had to seek alternative shelters for months due to sudden onrush of saline waters into their homesteads.

ASSESSMENT OF STORM SURGE INDUCED VULNERABILITY AND
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Chapter VI:

COPING WITH VULNERABILITY

COPING WITH VULNERABILITY

One of the most devastating climatic hazard 'cyclone' hit coastal zone of Bangladesh more or less every two to three years; damaging physical infrastructure, loss of life and livelihood, property damage, disruption of social system, economic loss. Factors that increase the vulnerability of local community includes location, economic condition, house pattern, lack of road connectivity, insufficient cyclone shelter, dependency ratio, lack of awareness etc. The coping strategies includes taking shelter in safe place, livelihood diversification, using indigenous knowledge in cyclone warning, getting relief from local GOs and NGOs etc.

Risks and vulnerability increased due to prolongation of hydro-meteorological events which affecting the life, livelihoods and adaptation practices and ecosystem of the coastal region. Major seven cyclones and storm-surges occurred in coastal area within last 50 years due to geographical location and weather condition. In view of such hazards, many people seem to have become destitute at the cost of their lives and properties. Both soft and hardware related activities such as awareness raising, capacity building on disaster preparedness and disaster management, early warning, developing information dissemination system, construction of community based shelter home, plinth level raising, ensuring food security, livelihood development, coastal forestation, technically sound infrastructure and water management with community ownership are playing important roles to improve community's resilience, ecosystem and adaptation practices.

The vulnerable sectors of the study area are agriculture, fisheries, infrastructure, health, forest, livestock, business etc. And with these, the concerned sub-sectors/social elements are also affected by different hazards. For instance, infrastructure is a sector and its components are said to be embankment, houses, educational institutions, hat-bazars, office buildings, bridge/culverts, roads, etc. However, the community risks are considered as a combination of an event, the likelihood that it will happen again and its consequences. Within vulnerable communities, women and children tend to be more vulnerable to environmental degradation and natural disasters (CARE, 2006). This is a result of poor socio economic and health status, roles and responsibilities within the household, a lack of mobility, and a lack of access to information.

Hazards are also identified by community as event or physical condition that has the potential to cause fatalities, injuries, property damage, infrastructure damage, agricultural loss, damage to the environment, interruption of business or other types of harm or loss. Community risks and vulnerability of the study area has been identified based on three elements: probability, exposure and consequences. Moreover, natural characteristics including geographical area, severity and time also have been considered for each risk. In most cases, an extreme event may create multiple hazards. Sometimes, the hazard is triggered to a large scale of effects. Damages, loss of assets, life and livelihoods depend on the nature of hazards, geographical coverage and their behaviour. The sectors such as agriculture, infrastructure, fisheries, health and forest were affected by hazards in different period of time and have probability to be affected again in the study area.

Despite the success of the economic growth, the country is on track to become a middle-income country by 2021, more than 50 million of the people still live in poverty (Fifth five-year plan, GOB 2007). Many of these people live in remote or ecologically fragile parts of the country, such as river islands (chars) and cyclone-prone coastal belts, which are especially vulnerable to natural disasters (MoEF, 2009). Climate change will severely challenge the country’s ability to change the high rates of the economic growth needed to sustain these reductions in poverty. In coming years, it is predicted that there will be increasingly frequent and severe flood, tropical cyclones, storm surges, and droughts, which will disrupt the economy of the nation. In the worst case scenario, unless existing coastal polders are strengthened and new ones built, sea level rise could result in the displacement of millions of people-‘environmental refugees’- from coastal regions, and have huge adverse impacts on the livelihoods and long term health of a large proportion of the population. It is essential that Bangladesh prepares now to face the challenge ahead and safeguard the future economic wellbeing and the livelihoods of her people (MoEF, 2009). Over the last three decades, the Government invested billions of dollars to make the country more climate resilient and less vulnerable to natural disasters. The Government has implemented important projects including construction of coastal embankment and cyclone shelters with the active participation of communities. The Government demonstrated its readiness in dealing with disasters in 2007 when the country suffered two serious floods and a severe tropical cyclone (Cyclone Sidr) in the same year (MoEF, 2009).

Disaster risk signifies the possibility of adverse effects in the future. It derives from the interaction of social and environmental processes, from the combination of physical hazards and the vulnerabilities of exposed elements. The hazard event is not the sole driver of risk, and there is high confidence that the levels of adverse effects are in good part determined by the vulnerability and exposure of societies and social-ecological systems.

6.1 Physical vulnerability

RVCC Project (CARE, 2006) identified during their Vulnerability Assessment, salinity was the major vulnerability context in Khulna, Satkhira and Bagerhat Districts, with severe impacts on access to potable water.

The experience with hazard events has influenced in both high and low risk level communities. People living in these areas have suffered adverse impacts of hazard events mostly stated about higher level of concern for those events. This chapter stands the mode of impacts and the intensity of impacts on physical environment including physical livelihood assets of the community people/the respondents. The three indicators of the physical vulnerability factors namely family, household structure and road reflect the hazard effects in all high and low risks areas.

As per Table: 21, in high risk area, the impacts, considering the relevant risks and the threat factors were reportedly higher in household destroyed (about 82.8%), road destroyed (about 62.4%) and family displacement with financial crisis (about 59%) respectively. Similarly, in low risks area, the percentage of the factors (household, road and family) was somewhat lower than high risk area. More than half of the respondents, in high risks area, suffered from financial crisis and about one fourth of them lost their family members. It is mentionable that financial crisis in the highly vulnerable areas dramatically reduced in the recent years because of increased NGO activities following cyclone Sidr and Aila in the study area.

Table 21: Status of Physical Vulnerability in the study area

Physical vulnerability	Highly Vulnerable		Low Vulnerable	
	Past Severity	Present Severity	Past Severity	Present Severity
Dislocation	25.7	30.8	7.7	39.4
Financial crisis	59.0	5.8	23.1	19.7
Lost family member	25.6	7.7	23.1	1.5
Household destroyed	60.0%	82.4%	32.6%	79.9%
Road destroyed	25.5%	62.4%	42.5%	64.4%
Waterlogging	26.7%	15.9%	37.2%	12.6%

Source: Field Survey, 2016-17

About one third of the households of both high and low risk areas were displaced at least for some days due to extreme condition of the hazard events of storm surge and waterlogging in last 15 years. Inhabitants of the low vulnerable area found to have higher percentage of dislocation in the present time than past which indicates the rate of increasing vulnerability in the area. Similarly, household structures destroyed about 80% of the households due to surge water and salinity in both high and low risks areas (Table: 22). Households affected for waterlogging were 15.9% in high risk area and 12.6% in low risk area. The negligible percentage of households was found no impacts to household structures. On the other hand, Impact of road damage was 62% in high risk area. This percentage, indeed, was reportedly the highest than the corresponding percentages of 28.8 in high impact, 6.4 in waterlogging, and 8 in movement problem.

Table 22: Impact of Salinity in the study area

Districts	Highly Vulnerable		Low Vulnerable	
	Past Severity	Present Severity	Past Severity	Present Severity
Bagerhat	2.88	3.06	1.69	2.88
Khulna	2.89	3.07	1.83	2.92
Satkhira	3.08	3.33	1.86	3.13
Grand Total	2.97	3.15	1.79	2.98

Source: Field Survey, 2016-17

Both high and low risks level areas indicated the highest concern for salinity and waterlogging respectively. As a whole, they indicated relatively low levels of concern about cyclone and floods. The FGDs revealed that the high risks and adverse impacts in the vulnerable areas increased over time, because of increasing population density, location of the settlement, increasing of salinity far in land.

6.2 Social vulnerability:

The negative impacts to hazard events were severely felt to the people in both high and low risk areas due to limited coping capacity and high dependence on natural resources such as agriculture, water and Sundarban forest. In the study area, poor people including old age, women and children were the most vulnerable to withstand adverse impacts to hazards particularly during cyclone Sidr in 2007, cyclone/storm-surge Aila in 2009, flooding in 2004 and 2007, waterlogging in 2009.

Vulnerability in education sectors increased relatively in both high and low risk study sites due to present hazard events than past as illustrated in Table: 23. The most adversely affected situation was inability to move to school for students and teachers due to prolonged waterlogging, damaged roads and school structures in Khulna, Satkhira and Bagerhat region during cyclone Sidr in 2007, cyclone Aila in 2009. Health problems and increased dependency on relief and social safety net programmes of the Government and NGOs remains static in both study areas and in both time periods. However, adverse impact on health or health problem increased negligibly in high risk area compared to past hazard events, where ratio of dependent household members and community people (child, women, physically challenged, sick and aged people) decreased slightly. Similarly, ownership of land and housing structures was relatively higher in high risk area than past. The respondents of FGD and survey also mentioned about psychosocial impacts for cyclone Sidr (2007), Cyclone Aila (2009) and Cyclone Roanu (2016). Women, children, senior citizens and sick people experienced fear of death, injury and damage. Women respondents also have mentioned about fear of hazard attack and gender disparity considering culture, religion, social attitudes and norms.

Table 23: Perception on Social vulnerability in the study area

Social vulnerability	Highly Vulnerable		Low Vulnerable	
	Past Severity	Present Severity	Past Severity	Present Severity
Could not attend school	47.1%	57.7%	31.7%	57.5%
Dependency	41.4%	35.4%	50.0%	31.3%
Health Problems	58.6%	60.4%	50.0%	50.0%

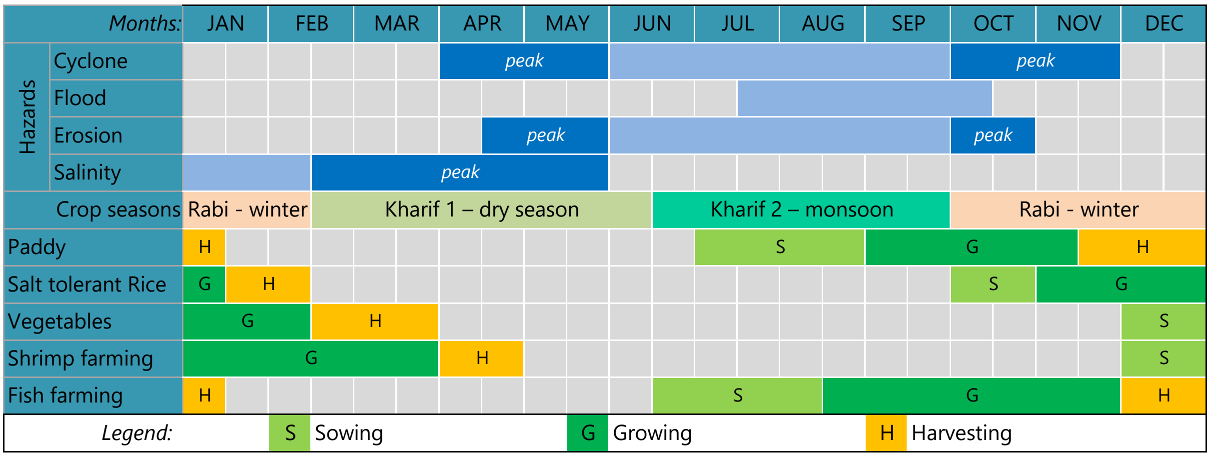
Source: Field Survey, 2016-17

6.3 Economic vulnerability

This study considers cyclone, flood, salinity and waterlogging together and compares economic impacts and vulnerability on the community in the study area. Economic vulnerability includes indicators of natural resources (agriculture land, water bodies such as pond, fish pond/gher) and livelihood to understand the effects and risks level between present and past disaster events. The findings show that families depend profoundly on natural resources, farming and unrecognized non-farming sectors for their livelihood, and that those low income people suffer greater losses than families with high income. The poor households/families were affected most from cyclone and salinity with the economic effect of these disaster events roughly.

A policy study report conducted by GED and UNDP in 2009, the country may lose about 20-30% of crop/yield reduction due to major changes and impacts of climate change (such as salinity intrusion, degradation of soil and soil related constraints, erratic rainfall, temperature and moisture related stress). Although over 60% of the people depend on agriculture directly or indirectly for their livelihoods, the higher temperature and changing rainfall patterns are likely to reduce crop production in the coastal belt (BCCSAP-2009). IPCC fifth assessment report estimates that by 2050, rice production in Bangladesh could decline by 8% and wheat by 32 percent (base year 1990).

Average cropping intensity in the coastal area has not been increased compared to flood plain agriculture during 1975-2006. About 30%-50% of net cropped areas remain fallow in the coastal area in Robi and Kharif-1 seasons, due to climate change impacts particularly for salinity (KGF 2011). Thus, south-west coastal region is therefore on the front line of climate change for farmers, it is not a future possibility, it is a current reality that is damaging the agriculture production, crops' yield and people's livelihoods (IOM 2010). A crop calendar of the study area given in the Figure 26.



Source: Field Survey, 2016-17

Figure 26: Crop Calendar of Gabura union located in the highly vulnerable area

The coastal region has faced devastating cyclone Sidr in November 2007, Aila in April 2009, series of flood in 2004, 2007 and 2009, Nargis in 2010 and Mahasen in 2013 (Ahmed, 2010; MoEF, 2009). It is predicted that food security and freshwater availability will be reduced by the impacts of less predictable weather, higher temperatures and salt water intrusion in agricultural land and storm surge (GED, 2009).

As per Table: 24, vulnerability to agriculture particularly harvest loss, land loss, decreased arable land increased mildly in both study areas due to intensity and frequency of the present hazard events than past, interestingly level of salinity intrusion in soil and water decreased sharply. While, fish loss substantial increased due to flooding in both high and low vulnerable areas than the past. Adverse impacts of livelihood vulnerability due to loss of employment or job scarcity increased about eight folds (increased from 5.1% to 38.2%) in the high risk area in the recent years than what happened during the past hazard events.

Impacts on financial crisis did not vary much over time in both the vulnerable areas (increased from 20.5% to 23.6% in highly vulnerable area and decreased from 30.0% to 28.4% over time) but in general low vulnerable area faces more financial difficulties than the highly vulnerable area (Table: 24). Changed livelihood to fishing decreased significantly in high risk area (from 28.2% to 8.2%) due to extreme hazard events of the recent past, but increased about three folds (from 5.0% to 14.7%) in low risk area because of increased number of 'gher's in the area.

Table 24: Perception on Economic Vulnerability in the study area

Economic vulnerability	Highly Vulnerable		Low Vulnerable	
	Past Severity	Present Severity	Past Severity	Present Severity
Arable land decreased	4.0%	12.0%	10.0%	5.2%
Harvest Lost	44.0%	49.6%	53.3%	45.4%
Land Lost	6.0%	6.8%	6.7%	2.1%
Gher Damaged	36.6%	29.6%	33.3%	57.1%
Financial difficulties	20.5%	23.6%	30.0%	28.4%
Job scarcity	5.1%	38.2%	20.0%	20.6%
Salinity Increased	24.0%	13.7%	10.0%	15.%
Livelihood changed to fishing	28.2%	8.2%	5.0%	14.7%

Source: Field Survey, 2016-17

6.4 Environmental vulnerability

The communities of the study area are highly exposed to environmental vulnerability including environmental characteristics of natural resource depletion, resource degradation such as damages of drinking water, sanitation and vegetation due to adverse impacts of hazardous events. Both high and low risk level study areas of this research are vulnerable to hazardous events/disasters of cyclone, storm-surge, flood, waterlogging and salinity due to location of the study area being near the Bay of Bengal. The study revealed majority of the inhabitants from both the vulnerable areas face water scarcity following cyclone and storm surge (Table: 25). Water scarcity in the area has increased about 10% in the recent years during cyclone Sidr in 2007, Aila in 2009 and Roanu in 2016.

Table 25: Perception on Water & Sanitation status of the study area

Environmental vulnerability	Highly Vulnerable		Low Vulnerable	
	Past Severity	Present Severity	Past Severity	Present Severity
Drinking water Scarcity	51.9%	69.3%	47.5%	58.8%
Water Salinity	19.9%	48.1%	16.3%	27.5%
Use unsafe toilet	28.6%	53.8%	75.0%	55.8%
Vegetation destroyed	91.2%	98.3%	60.9%	89.6%

Source: Field Survey, 2016-17

The respondents perceive severity of salinity is increasing in the study area (increased from 19.9% to 48.1% in the highly vulnerable area and increased from 16.3% to 27.52% in the low vulnerable area). As a result, drinking water scarcity is common in both the vulnerable areas. The respondents mentioned that they had to go far away for fetching water, sometimes they had to purchase the drinking water as well. The respondents also said that they suffered due to damage of sanitation facilities in both high and low risk areas. Destruction of dwellings are much higher in the highly vulnerable area which lead the inhabitants to use unsafe toilet following recent cyclone and storm surge. In particular, unsafe toilet uses increased from 28.6% to 53.8% in the highly vulnerable area while decreased from 75.0% to 55.8% in the low vulnerable area. Similarly, vegetation also suffered larger damage toll in the recent years by increasing from 91.2% to 98.3% in highly vulnerable area and from 60.9% to 89.6% in the low vulnerable area. Opinions from the FGDs mentioned that majority of the trees were broken and some of them were uprooted during cyclone Sidr in 2007 and cyclone Aila in 2009 in the study areas.

ASSESSMENT OF STORM SURGE INDUCED VULNERABILITY AND CHANGING ADAPTATION STRATEGIES IN THE SOUTH-WEST COAST OF BANGLADESH

Chapter VII:

CHANGING ADAPTATION

CHANGING ADAPTATION

Agriculture and water are the most climate vulnerable and adversely impacted sectors in coastal Bangladesh due to extreme risks from climate change. Over the last decade several studies have been assessed various adaptation practices of Bangladesh using different climate change scenarios. Most of the adaptation practices are found in the exterior coastal districts and are taken in response to chronic stresses such as salinity and regular flood and sudden shocks like cyclone and storm surge. The Reducing Vulnerability to Climate Change (RVCC) Project (CARE, 2006) identified two major community-level adaptation strategies that complemented the work at the household level are (i) reducing disaster threats and (ii) increasing income through access to common property. The good agriculture and water based solutions towards climate induced disaster impacts for resilience building of the coastal farming communities in Bangladesh are equally important for the study area. Some adaptation practices for resilience building of the farming communities adopted by local, national and international NGOs in the coastal area are found quite appropriate and beneficial to our ecosystem. Although majority of the adaptation practices are contemplated improved crop varieties, innovative cropping techniques and infrastructural development, some of them are considered suitable for climate affected coastal area.

Community based adaptation, farming ecosystem based adaptation, community based mangrove afforestation, hydroponics, homestead gardening, various salt and flood tolerable crop varieties, crab fattening, vertical agriculture, integrated farming, mangrove-shrimp farming, etc. are some examples of good adaptation practices in the study area. Public awareness regarding climate change and necessary adaptation measures have immensely increased in recent times and the community understand respond to such activities. Some studies were conducted for understanding adaptation practices and potential adaptation options which can be suitable for agriculture sector of Bangladesh. Nevertheless, none of study has focused on the documentation of climate adaptive agriculture and water management practices in the south-west coastal areas of Bangladesh (Saha et. al., 2016). This study has been performed to identify the adaptation measures taken by the coastal people to evaluate the present status and good practices of the coastal agriculture and water sectors to cope with potential climate change.

Bangladesh was amongst the first LDCs to produce National Adaptation Programme for Action (NAPA) in 2005 under United Nations Framework Convention on Climate Change (UNFCCC) (MoEF, 2005). NAPA suggested a range of adaptation practices for Bangladesh which was subsequently revised in 2009 (MoEF-UNDP, 2005). Technology Needs Assessment Report and National Capacity Self– Assessment (NCSA) was planned in 2009 (IUCN, 2009). In 2008-2009, the country has formulated the Bangladesh Climate Change Strategy and Action Plan (BCCSAP) as a foundation of all activities regarding climate change including Climate Change Adaptation (CCA) (MOEF, 2009).

There were several agricultures, water and community based adaptation projects undertaken in Bangladesh by Practical Action Aid, Bangladesh Centre for Advance Studies (BCAS), Comprehensive Disaster Management Programme (CDMP), Food and Agriculture Organization (FAO) of the United Nations in Bangladesh, International Union for Conservation of Nature (IUCN), Caritas-Bangladesh, Shushilan, Ahasania Mission, CODEC, Uttaron, Prodipan, Nabolok, and some other local NGOs. Besides, NGOs also demonstrated and piloted various crops and horticulture varieties to cope with climate change impacts in South-west coastal region by the assistance of agriculture research Institutions (such as IFPRI, IRRI, BRRI, BARI, BINA, SRDI) and Bangladesh Agriculture University.

The respondents of survey and FGD sessions commented that cyclone is one of the major hazardous events in both risk zones of the study sites. Considering the present situation, cyclones occur mainly in the months of April to May and mid-July to November. They also reported that cyclone Sidr attacked in both area in 15th November 2007 and cyclone Aila in 23rd May 2009. Floods are caused by storm surges in the months of July to October, whereas in the months of late December to April there is high salinity levels in this area due to tidal fluctuation and water scarcity of the river. After cyclone Aila, the salinity concentration increased. River erosion is one of the main hazards in this area. Extreme rainfall is seen in the months of mid-June to September and after heavy rainfalls waterlogging problem arises due to lack of drainage system.

Respondents said that they were affected for major infrastructure damages including the loss of many homes, roads and embankments. They had to accommodate on the raised land, embankment or roads after immediate waterlogging of cyclone Aila in 2009 and cyclone Sidr 2007. Since cyclones and waterlogging completely damaged their households and infrastructures, they built temporary houses, shelter and hut on raised road and embankment. Even many of them could not re-settle or rebuild their house. Many of them out migrated seasonally and permanently. Once the roads and embankments were repaired by the NGOs and Government initiatives after a few months, they returned home. During construction or renovation of houses, some families took opportunities to shift their homes comparatively to safer places such as raised plinths, position changed and materials changed so that they can cope with future disaster events. They also said that they participated in the social safety net programmes (such as relief work, road and embankment repairing, alternative livelihood support) as a day labour by NGOs initiatives to survive their livelihood after few days of cyclone attack.

They also received water and sanitation supports such as rainwater harvesting (Plate: 5), installation of tube-wells, repairing of tube-wells, repairing/installation of toilets, drinking water and sanitation kits as an emergency and post-disaster response of NGOs and Government. The respondents also said that the agriculture sectors particularly crop farming and shrimp gher/fish pond was acutely affected. All crops and fishes were destroyed and washed out during waterlogging of cyclone Sidr 2007 and cyclone Aila 2009. Moreover, the condition was extremely bad due to increased salinity and saline water.

Thus, they had to know about newly adaptive agricultures such as crops and vegetable cultivations including horizontal agriculture, dyke cropping, vertical agriculture and homestead vegetable gardening. They had to introduce new varieties of crops/rice and vegetables and their cultivation techniques. More importantly, the respondents or households were also taken some indigenous/traditional/local strategies to overcome the bad situation after cyclone and waterlogging. Sometimes, they took individual and sometimes collective initiatives for agriculture and fish farming.

RVCC Project (CARE, 2006) found approximately 40% of the household were implementing agricultural activities such as floating gardens and homestead gardening, approximately 40% were raising different types of livestock, approximately 60% were undertaking new income generating options such as crab fattening, cottage industries and cage aquaculture, and approximately 64% had identified new income sources as a result of project activities.

7.1 Analysis of agriculture and water adaptation practices

The study team observed different climate adaptive agriculture and water-based adaptation solutions in the South-west coastal Bangladesh. Most of the climate adaptive agriculture practices are found about crop technologies such as stress tolerant and short duration crop varieties, integrated farming practices and changing the cropping pattern. The study also found some innovative techniques such as floating vegetable gardening (Plate: 6), cage culture, raised bed culture, hydroponics, dyke cropping, vertical horticulture farming, mangrove shrimp farming, crab culture etc. The study also observed some direct engagement drivers for climate adaptive agricultures such as people's institution, farmers' school, agriculture extension agent, plant doctor, and water management groups. Agriculture cropping system productivity can be more than doubled in the south-west coastal region of Bangladesh by using improved varieties and management practices, cropping system intensification and diversification, available water resources and good water management (especially drainage) practices (Mondal et.al 2015). Besides, different non crop adaptation measures have been undertaken in the south-west coastal areas of Bangladesh in response to the impacts of climate change e.g. participatory water management and siphon for irrigation, rainwater harvesting and reverse osmosis for drinking water.

7.1.1 Climate adaptive crops, vegetables and pulses

Some good adaptation practices are identified in rice farming sectors against flood, drought and salinity. Saline tolerate rice varieties like Binadhan - 8, Binadhan - 10, BRRIdhan - 47, BRRI dhan-55 are cultivated by more than one million farmers in Bangladesh. Bina dhan - 8 and Bina dhan-10 have been cultivated by farmers in Satkhira, Khulna and Bagerhat districts of south-west coastal region in Boro season. These varieties have the salt tolerance capacity (Plate: 7) to survive up to 10-12ds/m. Farmers cultivate BRRI dhan - 47 variety that requires less water and tolerance capacity to dry soil is quite high (Alam et al., 2013). BINA dhan - 8 varieties has salt tolerance capacity of EC8-10ds/m at mature stage and also are cultivated by farmers in those regions (DCRMA, 2011). Saline tolerant sugarcane variety ISWARDI-40, BINA sarisa-5 and BINA sarisa-6, sweet potato varieties like BARI SP-6 and BARI SP-7, BARI Mung-5 and 6, BARI Sweet Gourd-1 and 2, spinach, BARI Tomato-1, Knolkhol and beet are being cultivated as adaptive options in the coastal areas. Jute kenaf varieties HC-2, HC-95, CVL-1 are identified as potential adaptive practices in Satkhira and Patuakhali stations (BARC, 2012, Sutradhar. et. al 2015). Two crop production cycles are also popular as nutrition requirement of crops is supplemented by each other cultivation like sunflower, chickpea and Khesari after the cultivation of T. Aman in coastal regions (Rashid et al., 2014). It is also accepted by coastal farmers to reduce food crisis.

7.1.2 Floating garden/Hydroponics

Vegetables in floating bed have huge potentials to mitigate coping problems against flood in south-western parts of Bangladesh (Oxfam, 2009). Farmers are raising seedlings and producing vegetables, spices and more than thirty crops (AAS, 2012) using floating gardens. Cultivated vegetables in floating bed include okra (lady's finger), cucumber, bitter-guard, khol rabi, pumpkin, water gourd, turmeric, ginger, karalla, arum, tomato, turturi and potato (Alauddin & Rhaman, 2013; UNFCCC, 2006). Flood affected coastal districts including Satkhira, Khulna, and Bagerhat farmers (including women farmers) are using their submerged lands for crop production by adopting scientific methods which were similar to hydroponic agriculture practices, i.e. floating agriculture, whereby plants were grown on the water in a bio-land or floating bed of water hyacinth, algae or other plant residue (Plate: 8). According to their needs, people in different parts of Bangladesh had adopted, modified and named this practice differently (baira, boor, dhap, gathua, gatoni, geto, kandi and vasoman chash and floating agriculture) (Islam & Atkins, 2007).

7.1.3 Homestead gardening:

Homestead gardening is a widely accepted practice in Bangladesh and mainly managed by women (Plate: 9). It ensures food security and additional income by enhancing livelihoods of poor people. Home stead production system (fruits, vegetables) in the saline coastal area made substantial contribution towards meeting daily food and nutrition needs, income, employment for the poor community (J.K. Sundary, 2015, Kabir 2015). Homestead based vegetable and fruits gardening also were popular to the coastal community in all Satkhira, Khulna, and Bagerhat districts.

7.1.4 White fish culture:

Fish farmers of south-west coastal area cultivate sweet water shrimp and saline tolerant fish (e.g. Tilapia and Pangus) as adaptive livelihoods options. The Department of Fisheries (DoF) has established a saline water tolerant fish breeding centre in Paikgachha Upazila in the western Khulna District to serve the poor fish farmers. After cyclone Sidr in 2007 and storm-surge Aila in 2009, white fish culture along with rice field were increased as an adaptive livelihood of the fish farmers in Satkhira, Khulna, Bagerhat, Patuakhali and Barguna district (Shushilan, 2011).

7.1.5 Crab fattening:

In South-west coastal region, shrimp cultivation started in the mid-eighties and is still popular, although production has fallen tremendously due to cultivation year after year on the same land, where paddy cultivation was not possible due to severe salinity. But, poor farmers were excluded from the benefits of shrimp farming. They prepare small pond/gher (Plate: 10), often adjacent to their homestead, put pata (made of bamboo) to protect the crabs. Rotten fishes are the main food for the crabs in the pond (locally called gher). Process of crab fattening takes a cycle of two weeks only. Thousands of poor crab fatteners are enjoying a significant financial return from crab fattening in a sustainable manner for bringing them out from extreme poverty (evaluation report and case study of Shushilan, 2015).

7.1.6 Vertical Agriculture:

Vertical agriculture addressed the loss of cultivable land by maximizing the space around households by suspending horticulture production in sacks along trees, houses and bamboo structures in Satkhira, Khulna, Bagerhat and Jashore districts. Vertical agriculture resulted in higher production rates and the use of less land and water. It also allowed women to better manage their own food security, nutrition and consumption of fresh vegetables. This types of agriculture was also replicated by other villages and local NGOs in south-west coastal areas of Bangladesh.

7.1.7 Integrated farming:

Integrated farming system is one of the good innovation of Paribartan project that was implemented by NGO-Shushilan in Satkhira, Khulna, Barguna and Jashore districts of south-west coastal Bangladesh where land-use is limited due to climate change impacts such as frequent tidal inundation, water stagnation and salinity intrusion. Considering this situation, NGO-Shushilan introduced integrated farming system for maximizing the land utilization through diversification of crop cultivation in same piece of land. Inclusion of vegetables in the rice-fish system have maximized the use of space and resources which increased the yield of rice, fish and vegetables (Plate: 11). In South-west coastal region, hundreds of farmers shaped their lands to raise the dyke of fish field/pond edge to make them disaster resilient where they cultivated fish and rice in pond and vegetables in dyke. They also innovatively fenced the pond so that rice and fish production were not affected. Thus, hundreds of farmers increased their food production and earning in same piece of land. This model is widely accepted by the coastal farmers to cope with climate change and increasing income three to four times (Shushilan, 2015).

7.1.8 Paradigm Shift of Shrimp Farming:

In Shyamnagar Upazila of Satkhira district, about hundred shrimp farmers are practicing environment friendly integrated mangrove shrimp farming method under ‘Road to resilience of Shyamnagar’ project implemented by NGO - Shushilan and Mostafa Organic Shrimp Products Ltd. (MOSPL), a local business, partnered with Mangrove for Future (MFF) of

IUCN-Bangladesh for building resilience to climate change and higher market return. This process was certified by the Naturland Association for Organic Agriculture (Naturland) to reverse the environmentally harmful trends and, contribute to building the resilience of coastal communities (Shushilan and IUCN, 2017).

7.1.9 Community based mangrove afforestation:

The village based mangrove forest preservation committee functionally worked through adoption of social forestry approach to plant and conserve the mangroves settlements and embankments from tidal surges and consequent erosion under the project "Community based small-scale mangrove restoration" (Plate: 12) through motivation and collaboration of the communities, Forest Department (FD), Union Parishad (UP) and local government in Shamnagor Upazila of Satkhira district (Shushilan 2012 and Rahman, 2014).

7.1.10 Canal re-excavation and management

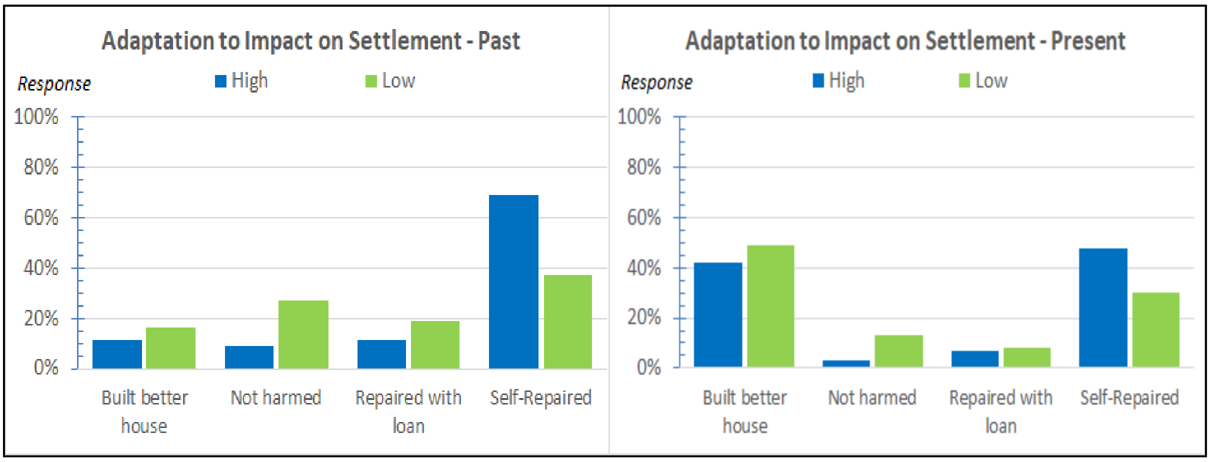
Canal re-excavation and its management is one of the good initiatives for the farmers for coping with climate change impacts. The community collectively take initiative to re-excavate and manage the canals for storage of fresh water to increase crop production in Boro season (Plate: 13). This process has effectively assisted to utilize the natural resources such as canals to turn the fallow land into agriculture productive landscape through irrigation practice (Shushilan, 2014). Re-excavation of canals not only ensured the required supply of freshwater, it also enhanced the ability of local communities to manage it for irrigation, fish culture and capture fisheries. These demonstrate that ecosystem (canal) restoration contributed to building community resilience in the face of climate change (IUCN, 2014).

7.1.11 Community Networking:

There are different activities ongoing in the coastal area for adopting with the climate change happening in the south-west cost of Bangladesh. BARCIK, an NGO working in the high risk area of the coastal belt is conducting change monitoring of livelihood adaptation to strengthen social and economic condition of the population living in that area. This initiative includes internal (within own village) and external (neighbour villages) communication, exchange of commodity and resources, learning types and number of activities related to exchange (Plate: 14). The villagers sit together every month spontaneously and update community map to identify available resources and locate local demands to fulfil their needs.

7.2 Settlement

As per FGD notes, respondents reported that they moved to relative's homes and many other took shelter on the roads, highways, embankments etc. during peak waterlogging period in cyclone Sidr in 2007, cyclone Aila in 2009, flood in 2005 and 2007. They also said they took initiatives to repair houses and raised plinth of homestead. Adaptation to dwellings through built better house has increased in both high and low risk areas. Construction of better houses after recent devastating hazardous event were increased about four times and three times in high and low risk areas respectively. However, community's tendency to repair houses with loan has decreased remarkably in recent years.



Source: Field Survey, 2016-17

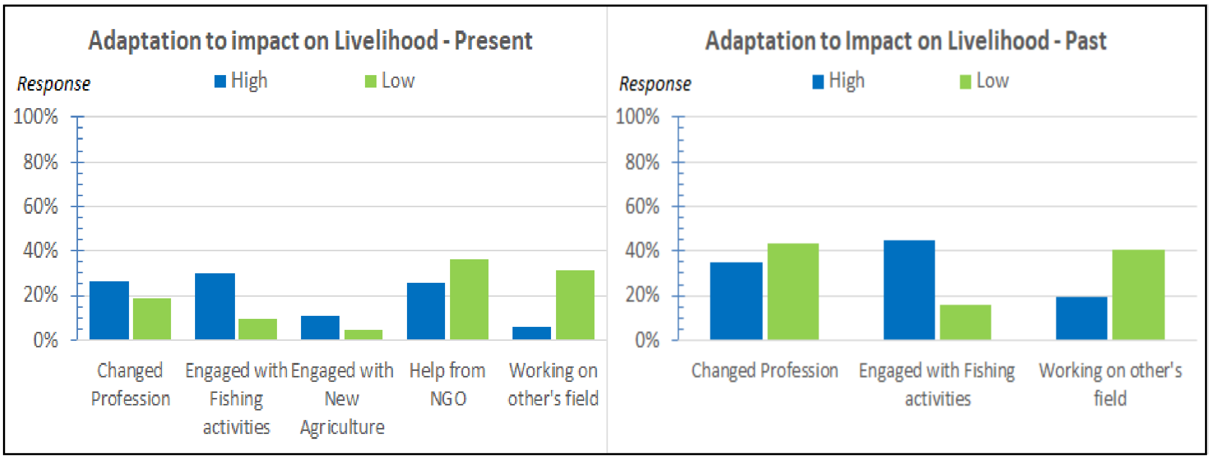
Figure 27: Adaptation to Impact on Settlement

7.3 Livelihood

The prospects of climate change impacts further exacerbated these problems adversely affecting habitation, economic activity and livelihoods of the poor and vulnerable. The impacts have already affected the well-being of the most vulnerable coastal farming households due to loss of agriculture production, seasonal migration and want of employment. Under these circumstances, adaptation is the only feasible choice to manage the climate change impacts for a country like Bangladesh having high population density and limited resources (IPCC, 2014). Coastal agriculture sector has been experiencing various adaptations for quite a long time considering climate change issues of this country. The coastal people have been spontaneously taking step to protect the agricultural activities from any natural or anthropogenic difficulties (Saha et.al, 2016).

Over the last decade some studies have been conducted on climate change impacts, vulnerability and adaptation assessments for Bangladesh using different climate change scenarios. Most of the studies focus on water, agriculture, biodiversity, human health, and infrastructure (BCAS et al., 1994; Huq et al., 1999; World Bank, 2000; ADB, 1994; MOEF, 2000). Recently several studies have been conducted at sub-national/geographical sub-region scale as well as on different sectors with special focus on coastal zone and agriculture sector (IWM and CEGIS, 2007; BCAS, 2007; CEGIS, 2006; CNRS, 2007).

While adaptation to livelihood such as changed profession, engaged with fishing activities and engaged with new adaptive agriculture increased extensively in the high-risk area than low risk area, interestingly help from NGOs and working on other's field were higher in low risk area (Figure: 28).

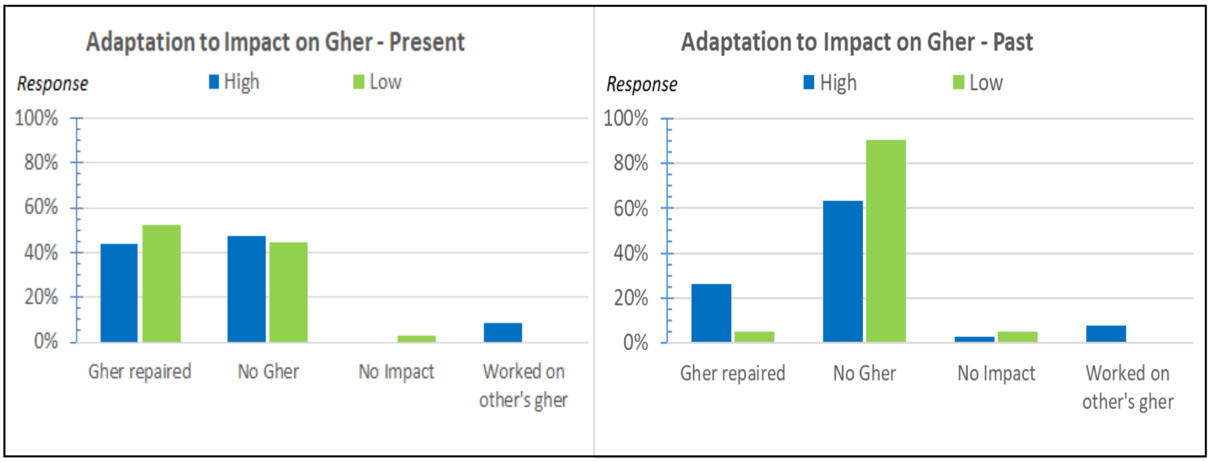


Source: Field Survey, 2016-17

Figure 28: Adaptation to Impact on Settlement

However, livelihood adaptation practices compare to present and past hazardous event particularly for changed profession, engaged with fishing activities and working on other's field were decreased drastically. Adaptation to adaptive agriculture for coping with present hazard situation, cultivation, fish pond/gher for shrimp farming and white fishes and new agricultural activities was increased comprehensively in the high risk areas than low risk area, but non-agriculture activity and poultry activity was increased notably in low risk areas (Figure: 29). Nevertheless, the respondents mentioned that cultivation and no agriculture activity were decreased exceptionally than past adaptation practices in both high and low risk areas.

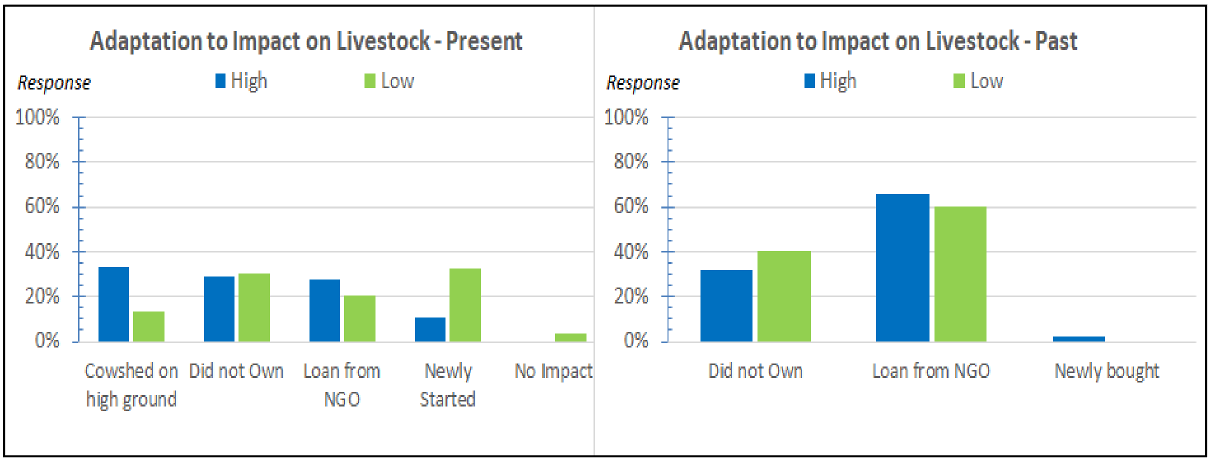
Gher/shrimp farming culture and poultry farming were increased substantially in both high and low risk area in the recent years. Interestingly gher/shrimp culture practices were newly introduced in low risk area as a livelihood adaptation to the community (Figure: 29).



Source: Field Survey, 2016-17

Figure 29: Adaptation to Economic Impact of Gher

As per adaptation mechanism for livestock, the respondents in both study areas said that loan from NGOs was decreased remarkably in recent times due to increased death ratio of livestock for salinity intrusion into water and lack of fodders (Figure: 30).

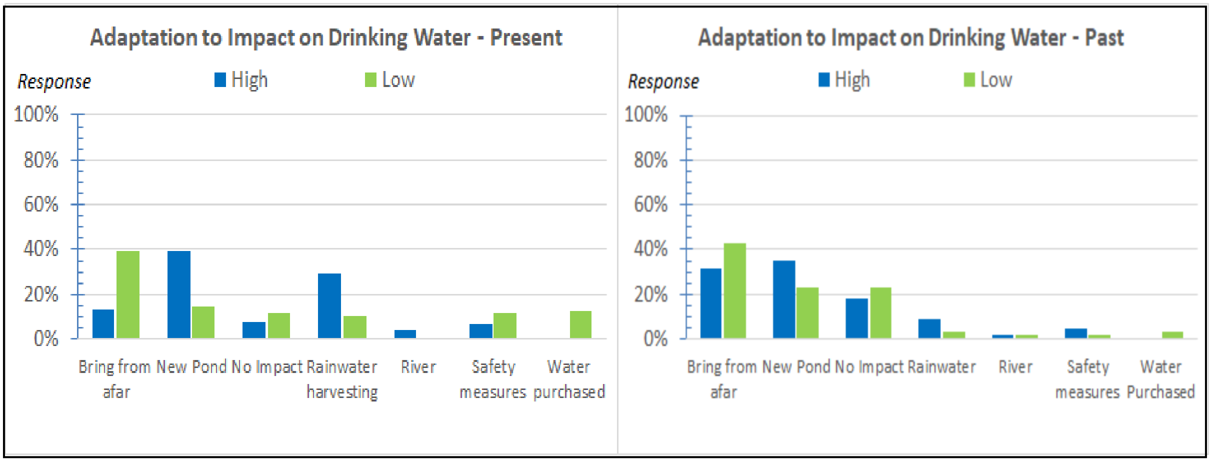


Source: Field Survey, 2016-17

Figure 30: Adaptation to Economic Impact of Livestock

7.4 Health & Sanitation

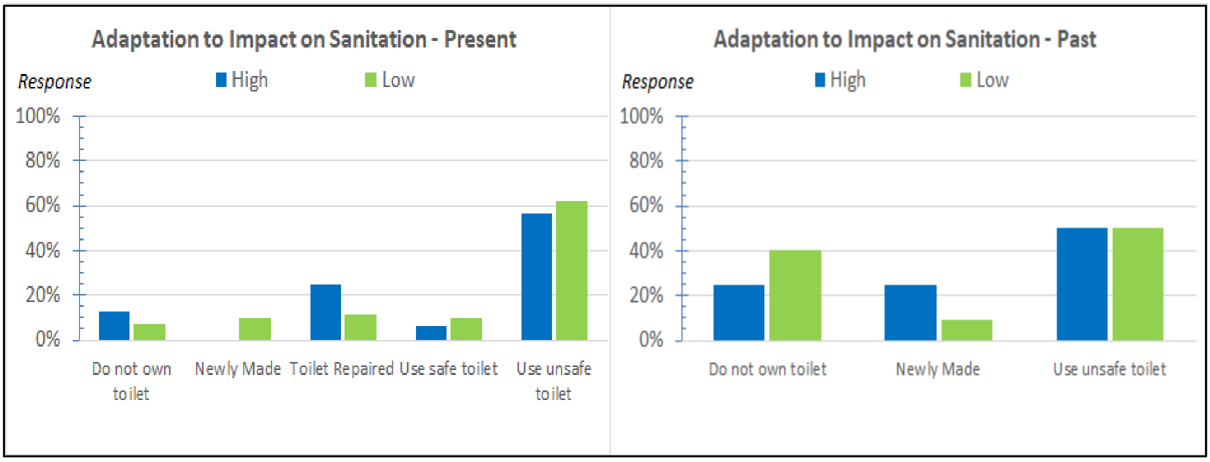
It was observed that the local inhabitants have already started to elevate their homestead especially house bed (i.e. plinth rising), latrines, tube-well, roads etc. As in Figure: 32, adaptation to drinking water particularly for new pond, rainwater harvesting was increased almost triple times in high risk areas than low risk areas, where purchased water was nil in high risk areas and about thirteen percent was in low risk areas. However, percentage of water purchased was increased about triple time in low risk areas in the recent times. Respondents commented that they comparatively moved less distance to fetch drinking water in high risk areas than low risks area in both present and past hazardous situation. Moreover, safety measures for drinking water, rain water harvesting system were increased in both high and low areas than past (Figure: 31).



Source: Field Survey, 2016-17

Figure 31: Adaptation to Environmental Impact of Drinking water

The respondents said that owning toilet has increased, but use of unsafe toilet was increased in both high and low risk areas at present. Percentage of toilet repaired was almost same compared to past situation. On the other hand, in high risk area as a post disaster adaptation in the past, about one fourth of the respondents made new toilet, whereas toilet repaired was nil at present (Figure: 32).

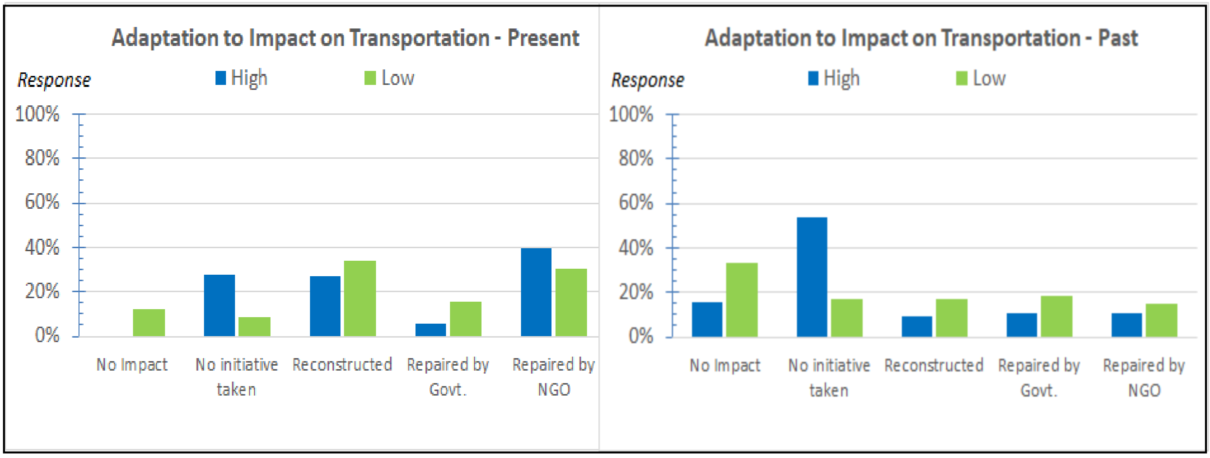


Source: Field Survey, 2016-17

Figure 32: Adaptation to Environmental Impact of Sanitation

7.5 Transport/Communication

The respondents commented that transport/communication sectors were affected severely in both present and past hazardous events. Reconstruction of rural roads, embankments, connecting roads to cyclone shelter has increased about three times in highly vulnerable areas and two times in low vulnerable areas than the past while involvement of Government for the repair works has decreased in the highly vulnerable areas. However, NGOs initiatives for repairing transports such as roads and embankments were increased extensively in both risk areas in recent times as illustrated in Figure: 33.

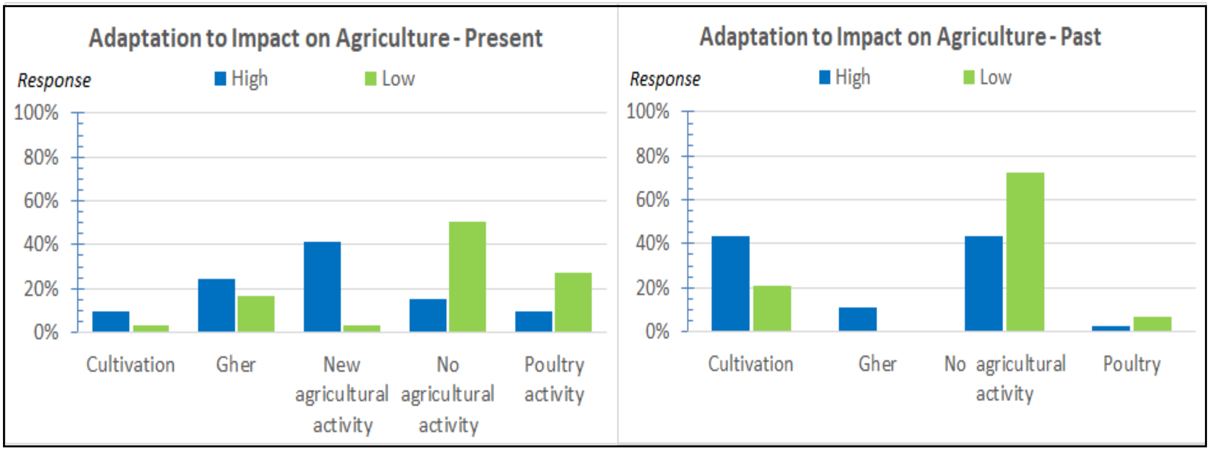


Source: Field Survey, 2016-17

Figure 33: Adaptation to Impact on Transportation

7.6 Agriculture adaptation practices response to stresses

The agriculture adaptation practices in south-west region were evolved in response to immediate and long term climate change impacts and stresses, which had affected the country's agriculture production and food security. The study had found that about 61% of the agriculture adaptations were responded to acute stresses. These include saline and submergence tolerant crop varieties. On the other hand, only 39% of the agricultural adaptations have practiced in response to unexpected shocks such as cyclones, storm-surge and major floods, which shows that, further importance needs to be given on building the vulnerable community more resilient to the present and future climatic events. Figure: 34 shows the agriculture adaptation practices in response to stresses and shocks of climate change.



Source: Field Survey, 2016-17

Figure 34: Adaptation to Economic Impact of Agriculture

Chapter VIII: CONCLUSION AND RECOMMENDATIONS

CONCLUSION AND RECOMMENDATIONS

Bangladesh is particularly vulnerable to storm surge due to its location and geographical characteristics. Tropical cyclones, storm surges and floods are likely to become more frequent and severe in the near future as the impact of global climate change. Inhabitants of the coastal area are naturally being habituated with the changing environment over decades while, there are new innovative and environmental friendly initiatives are being observed in the recent days that helps this vulnerable community to cope with the circumstances. This study is an initiative to assess the storm surge vulnerability in the south-west coast and impending vulnerability and changing coping strategies due to global climate change.

On average, a severe cyclone strikes the country every three years. The country's topography is extremely low and flat with two thirds of its land area less than 5 m above sea-level. As a result, lives and property in low-lying coastal districts along the Bay of Bengal are highly vulnerable to inundation from cyclone-induced storm surges.

8.1 Mapping Community Vulnerability:

The study revealed two distinct zones, 'Low vulnerable area' and 'High vulnerable area', considering the vulnerability of risk factors using GIS application. Most of the south-western part of Bangladesh is vulnerable in tidal surge. By nature, the highly vulnerable areas are mainly located in the southern part while there are few highly vulnerable areas seen far inland along the estuarine rivers. A major part of the highly vulnerable area is covered by the 'Sundarbans' (mangrove forest).

8.2 Storm Surge Inundation in respect to Climate Change:

The most alarming aspect of climate change in Bangladesh is the sea level rise in the Bay of Bengal that could potentially submerge a major portion of the coastal zone. The low lying coastal physiography further intensifies the risk from sea level rise. It is clear that the cyclones intensity is increasing and climate change is contributing to the fact by accelerating Sea Surface Temperature (SST).

The intensity of cyclone according to the Saffir-Simpson scale has been analysed for the coastal region of Bangladesh. Assessment of inundation intensity of the study area shows that inundation intensity is a major factor of vulnerability as seen in highly vulnerable areas. It has been observed that almost all major physical and environment aspects of the study area have been severely impacted by coastal disasters. The most worrying impact of these is from storm surges which has increased in the context of global climate change. While, analysing the recent major cyclones (i.e. Sidr and Aila) it is revealed that the south-west coast is becoming more vulnerable in the recent time.

8.3 Vulnerabilities and changing Coping Capacity:

The challenges that the communities are facing living in the south-west coast are very complex in nature. This study characterizes four hydrological indicators (risks of cyclone and storm-surge, coastal flood and tidal fluctuation, river erosion and salinity) for critical understanding and analysing the impacts of the coastal hazards. The Communities share a collective desire to face the challenges during hydrological natural hazards, but often their common interests end there.

The coastal population experienced several major hazards including cyclones, storm-surge, flood, waterlogging and salinity due to location in extreme south, distance from Bay of Bengal, low land area, deforestation, lack of operation & management of embankment and behaviour changes of the community. Many households have migrated due to loss of family and land property. They predict that the possibility of adverse effects may signify in the future considering increased intensity of natural hazards, lack of copping capacity and vulnerabilities.

During disaster the coastal inhabitants remain engaged for saving life, livestock, important utensils, emergency food, family members and household assets by moving to the cyclone shelter, own house, neighbours' house and others e.g. embankment or a raised platform inside the house. Moreover, they remain engaged for shifting household chores, utensils, furniture, dry foods and fuel towards higher land or comparatively safer places. On an average 63% of the respondents moved to cyclone shelters during cyclone while the figure is 73% and 54% for the highly vulnerable and low vulnerable areas respectively. Distance of cyclone shelter was comparatively far away which lead them to take shelter in strong neighbour houses for trust and safety.

Risks and vulnerability increased due to prolongation of hydro-meteorological events which affecting the life, livelihoods and adaptation practices and ecosystem of the coastal region. About one third of the households of both high and low risk areas were displaced at least for some days due to extreme condition of the hazard events of storm surge and waterlogging in last 15 years. Inhabitants of the low vulnerable area found to have higher percentage of dislocation in the present time than past which indicates the rate of increasing vulnerability in the area. Vulnerability to education sectors increased relatively in both high and low risk study sites due to present hazard events than past. The most adversely affected situation was inability to move to school for students and teachers due to prolonged waterlogging, damaged roads and school structures in Khulna, Satkhira and Bagerhat region.

8.4 Disaster Severity:

The hazard events had caused extensive damages in terms of infrastructure, agriculture, livelihoods, Health, environment, social and service facilities. The most affected sectors are fishery, housing and agriculture where moderately affected sectors are infrastructure, vegetation and livestock. Employment losses is common in both highly vulnerable and low vulnerable area following the disaster event. Lack of work leads to financial crisis which hampers household and agriculture activities. Waterlogging restricts mobility and influence change in economic activities. Waterlogging coupled with salinity is the main cause for agriculture failure in the coastal region.

Severity of cyclone is higher in the highly venerable areas but it is observed that cyclone severity has increased in the recent years both in the highly and low vulnerable areas. Satkhira and Bagerhat seems to have more severe effect than Khulna according to the perception of the local people. While, flood hazard prevails in Satkhira and the hazard scale is higher in the recent days for all Satkhira, Khulna and Bagerhat.

Level of salinity is higher in the highly vulnerable area but the rate of salinity intrusion is more in the low vulnerable area. The study revealed severity of salinity in the south-west coast has increased slightly in the recent years but we find a sharp increase of people concern on severity of salinity in the low vulnerable area.

The inhabitants perceive that present severity of erosion (river bank/land erosion) has notably been decreased in all study sites particularly to Bagerhat and Khulna districts compared to past. Respondents also said that construction of embankment, forestation and siltation of rivers might have advantages to reduce the present vulnerability.

8.5 Adaptation Practice

Agriculture and crop farming are the main economic activities of the study area, surprisingly the study has found limited response to save agriculture crops. Thus, they had to know how about newly adaptive agricultures such as crops and vegetable cultivations including horizontal agriculture, dyke cropping, vertical agriculture and homestead vegetable gardening. New varieties of crops/rice and vegetables and their cultivation techniques were introduced. More importantly, the respondents or households also taken some indigenous, traditional and local strategies to overcome the bad situation after cyclone and waterlogging. Sometimes, they took individual and sometimes collective initiatives for agriculture and fish farming.

The study found some innovative techniques such as floating vegetable gardening, cage culture, raised bed culture, hydroponics, dyke cropping, vertical horticulture farming, mangrove shrimp farming, crab culture etc. The study also observed some direct engagement drivers for climate adaptive agricultures such as people’s institutions, farmers’ school, agriculture extension agent, and water management groups.

Climate adaptive crops, vegetables and pulses, Floating garden, Homestead gardening, Crab fattening, Vertical agriculture, Integrated farming, Community based mangrove afforestation, Canal re-excavation and management and Community networking are the major initiatives for adopting with the climate change. All these initiatives have contributed to establish food security, while, community networking for risk mapping and resource management has reduced social vulnerability of the coastal livelihood to a great extent. Some of the remarkable adaptation findings of the study are:

- People's tendency of build better house has increased in both the high and low vulnerable area, whereas, practice of taking loan for house repair has decreased remarkably;
- Livelihood adaptation practices for coping with hazard such as new agricultural activities have increased extensively in highly vulnerable area but non-agricultural activities have increased more in the low vulnerable areas;
- Shrimp cultivation has newly introduced as livelihood adaption practice in the low vulnerable areas;
- Rain water harvesting for drinking water has become popular in both the vulnerable areas;
- In the recent years, reconstruction of rural roads, embankments, connecting roads to cyclone shelter has increased about three times in highly vulnerable areas and two times in low vulnerable areas.

8.6 Recommendations:

Despite of introducing many innovative adaptation activities, there are still room for improving the structural, social and economic condition of the south-west coastal area. Some of the major recommendations to aid coping with vulnerability are mentioned below:

- Settlements adjacent to the low-lying riverbanks should be relocated to further upland areas with government and NGO initiatives;
- Planned and systematic canal re-excavation and management is required to drain out prolonged rain water to the main river channels;
- Enhance saline tolerance agricultural activities to reduce unemployment by engaging more people with these activities;
- communities must be empowered in order to engage them in governance processes and facilitate them to make the best use of the policy environment;

- Strong structural embankment needs to be built around the coasts to protect from storm-surge;
- Increase coastal forestation in a planned manner;
- Increase number of cyclone centres nearer to settlements and improve facilities to ensure privacy, accommodation and utilities in the shelters;
- Increase number of drinking water sources by introducing reserved ponds;
- Popularise crab farming which has high potential of earning foreign currency;
- Enhance community networking activities to aid social and economic cooperation within and among the neighbouring communities;
- Enhance empowerment of communities to engage them in governance processes and facilitate them to make the best use of their potentials.

The research provided an excellent foundation for the design of future community-level adaptation and livelihood activities built upon the assessment of disaster vulnerability of the south-west coastal region of Bangladesh.

ASSESSMENT OF STORM SURGE INDUCED VULNERABILITY AND CHANGING ADAPTATION STRATEGIES IN THE SOUTH-WEST COAST OF BANGLADESH

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ASSESSMENT OF STORM SURGE INDUCED VULNERABILITY AND CHANGING ADAPTATION STRATEGIES IN THE SOUTH-WEST COAST OF BANGLADESH

Annexure: I

PALETS

Annexure I: **PLATES**

Plate 1: Questionnaire Survey Dacope union, Dacope, Khulna.

Plate 2: Interviewing an elderly woman at Gabura union, Shyamnagar, Satkhira.

Plate 3: Focus Group Discussion at Chila union, Mongla, Bagerhat.

Plate 4: Agricultural Activities at Gabura union, Shyamnagar, Satkhira.

Plate 5: Rain water harvesting at Gabura union, Shyamnagar, Satkhira.

Plate 6: Floating Vegetable Garden at Baintala union, Rampal, Bagerhat.

Plate 7: Salt Tolerant Rice at Gabura union, Shyamnagar, Satkhira.

Plate 8: Hydrophonic Grass produced for fodder.

Plate 9: Homestead Gardening at Dacope union, Dacope, Khulna.

Plate 10: Crab Farming at Shyamnagar, Satkhira.

Plate 11: Integrated Farming at Gabura union, Shyamnagar, Satkhira.

Plate 12: Mangrove afforestation, Shyamnagar, Satkhira.

Plate 13: Canal Re-excavation and Managment, Shyamnagar, Satkhira.

Plate 14: Community Networking for Resource Management

ASSESSMENT OF STORM SURGE INDUCED VULNERABILITY AND CHANGING ADAPTATION STRATEGIES IN THE SOUTH-WEST COAST OF BANGLADESH

Annexure: II

ABBREVIATIONS AND ACRONYMS

Annexure II:

ABBREVIATIONS AND ACRONYMS

ADB	Asian Development Bank
AOGCM	Atmosphere-Ocean Global Circulation Models
BBS	Bangladesh Bureau of Statistics
BCAS	Bangladesh Centre for Advance Studies
BCAS, RA	Bangladesh Centre for Advanced Studies, Resource Analysis
BCCSAP	Bangladesh Climate Change Strategy and Action Plan
BDRCS	Bangladesh Red Crescent Society
BIDS	Bangladesh Institute of Development Studies
BINA	Bangladesh Institute of Nuclear Agriculture
BIWTA	Bangladesh Inland Water Transport Authority
BMI	Body Mass Index
BRRI	Bangladesh Rice Research Institute
BUET	Bangladesh University of Engineering and Technology
BUP	Bangladesh Unnayan Parishad
BWDB	Bangladesh Water Development Board
CBA	Community-Based Adaptation
CCA	Climate Change Adaptation
CCC	Committee on Climate Change
CDMP	Comprehensive Disaster Management Programme
CEGIS	Centre for Environment and Geographic Information Services
CFC	Chlorofluorocarbon
CODEC	Community Development Centre
CPP	Cyclone Preparedness Program
CSIRO	Commonwealth Scientific and Industrial Research Organisation
DANIDA	Danish International Development Agency
DEM	Digital Elevation Model
DFID	Department for International Development

DMB	Disaster Management Bureau
DRR	Disaster Risk Reduction
FAO	Food and Agriculture Organization
FGD	Focus Group Discussion
GBM	Ganges-Brahmaputra-Meghna
GCM	General Circulation Models
GDP	Gross Domestic Product
GED	General Economic Division
GFDL	Geophysical Fluid Dynamics Laboratory
GIS	Geographic Information System
GOB	Government of Bangladesh
HadCM	Hadley Centre Coupled Model
HRZ	High Risk Zone
IFPRI	International Food Policy Research Institute
IRRI	International Rice Research Institute
BRRI	Bangladesh Rice Research Institute
BARI	Bangladesh Agricultural Research Institute
BINA	Bangladesh Institute of Nuclear Agriculture
SRDI	Soil Resources Development Institute
IFRC	International Federation of Red Cross and Red Crescent Societies
IPCC	Intergovernmental Panel on Climate Change
ISDR	International Society for Research and Development
IUCN	International Union for Conservation of Nature
IWM	Institute of Water Modelling
IWTC	International Workshop on Tropical Cyclones
LDC	Least Developed Countries
MAGICC	Model for the Assessment of Greenhouse Gas Induced Climate Change
MCSP	Multipurpose. Cyclone Shelter Programme
MIROC	Model for Interdisciplinary Research on Climate
MoEF	Ministry of Environment and Forest

MoWCA	Ministry of Women and Children Affairs
NAPA	National Adaptation Programme of Action
NCAR	National Centre for Atmospheric Research
NGO	Non-Governmental Organization
NOAA	National Oceanic and Atmospheric Administration
PDO-ICZMP	Program Development Office for Integrated Coastal Zone Management Plant
PLW	Pregnant and Lactating Women
RCM	Regional Climate Models
RVCC	Reducing Vulnerability to Climate Change
SAARC	South Asian Association for Regional Cooperation
SCENGEN	Scenario Generator
SD	Standard Deviation
SDG	Sustainable Development Goal
SLR	Sea Level Rise
SMRC	SAARC Meteorological Research Centre
SPARRSO	Space Research and Remote Sensing Organization
SRDI	Soil Resources Development institute
SRTM	Shuttle Radar Topography Mission
SST	Sea Surface Temperature
UNDP	United Nations Development Programme
UNFCCC	United Nations Framework Convention on Climate Change
UNISDR	United Nations International Strategy for Disaster Reduction
USGS	United State Geological Survey
WB	World Bank

ASSESSMENT OF STORM SURGE INDUCED VULNERABILITY AND CHANGING ADAPTATION STRATEGIES IN THE SOUTH-WEST COAST OF BANGLADESH

Annexure: III

STUDY QUESTIONNAIRE

Annexure III:

STUDY QUESTIONNAIRE

Group	Sample No.

Department of Geography and Environment,
University of Dhaka

Assessment of Storm Surge Induced Vulnerability and Changing Adaptation Strategies in the South-West Coast of Bangladesh

This question is being conducted for research purpose only under the Department of Geography and Environment, University of Dhaka. This questionnaire shall only be used for research purpose. The Department of Geography and Environment is sincerely thankful to the respondents for giving their information and time.

Study Area:

Village ______ Mauza No. ______ Ward No ______

Union ______ Upazilla ______ District ______

Name of Surveyor ______ Survey Date: ______

Respondent:

Name ______ Age (years) ______ Sex: M/F ______

---

1. Type of Family:
   A) Nuclear B) Joint Family C) Extended Family D) Others ______

2. How many members are there in the family? ______

Relation with the Family head	Level of education	Occupation
______	a) Illiterate b) Primary education c) Passed class 8 d) SSC e) HSC f) Honours/Graduate h) Masters i) Others ______	a) Reteired b) Household works c) Student d) Unemployed e) Agriculture f) Small business g) Service h) Others ______

DISASTER RELATED

3. How long do you live in this area? [ ] (years)

4. Have you migrated here from other areas in the last 10 years? Yes/No [ ]
If Yes,
District [ ] Upazilla [ ] Union [ ]

5. Causes of Migration (by priority)
   a) .. ..
   b) .. ..
   c) .. ..

6. What types of disasters have you faced in this area in the past 15 years?

Types of disaster	Degree of damage			
	1	2	3	4
a.				
b.				
c.				
d.				

* 1) Not affected 2) Minor effected 3) Significantly effected 4) Severe effected

What were the severity of these disasters in the past 15 years?

Types of disaster	Degree of damage			
	1	2	3	4
a.				
b.				
c.				
d.				

* 1) Not affected 2) Minor effected 3) Significantly effected 4) Severe effected

7. In spite of the disasters occur in this area, why you are staying in this area?
   a) ……………………………………………………………………
   b) ……………………………………………………………………
   c) ……………………………………………………………………

8. When you get early warnings of disasters where do you take shelter? [ ]
   a) In your own house
   b) Cyclone Shelter
   c) Relatives/ Neighbours House. How far?
   d) Others [ ] How Far? [ ] (km)

9. What types of damages are caused due to disaster?

Sector	Degree of damage			
	1	2	3	4
Residential Households				
Educational institutes				
Roads				
Haat/Bazaar				
Agricultural Land				
Trees/ vegetation				
Domestic animals				
Gher/ ponds				

* 1) Not affected 2) Minor effected 3) Significantly effected 4) Severe effected

10. In the last disaster, what was the depth of inundation here? (Feet) [ ]

    For how many days waterlogging stayed? (days) [ ]

11. What livelyhood impacts the local people face during disaster?
   a) ………………………………………………………………
   b) ………………………………………………………………
   c) ………………………………………………………………

VULNERABILITY RELATED

12. Vulnerability related Information:

Sl.	Type of Vulnerability	Damage in recent time (in last 15 years)
Physical Vulnerability		
01.	Family	
02.	Households	
03.	Roads	

Sl.	Type of Vulnerability	Damage in recent time (in last 15 years)
Social Vulnerability		
04.	Child Education	
05.	Child and elderly dependency	
06.	Household Ownership	
Economic Vulnerability		
07.	Agricultura Land	
08.	Pond/Gher	
09.	Livelihood	
Environmental Vulnerability		
10.	Drinking Water	
11.	Snitation	
12.	Vegetation	

Sl.	Type of Vulnerability	Damage in the past (before 15 years)
Physical Vulnerability		
01.	Family	
02.	Households	
03.	Roads	
Social Vulnerability		
04.	Child Education	
05.	Child and elderly dependency	
06.	Household Ownership	
Economic Vulnerability		
07.	Agricultura Land	
08.	Pond/Gher	
09.	Livelihood	
Environmental Vulnerability		
10.	Drinking Water	
11.	Snitation	
12.	Vegetation	

ADAPTATION RELATED

13. What steps have you taken to tackle disasters damages?

Sl.	Types of Adaptation	Steps in recent time (in last 15 years)
01.	House & homestead	
02.	Livelihood	
03.	Agriculture	
04.	Fish farming/Gher	
05.	Poultry/Livestock	
06.	Garden/Vegetation	
07.	Drinking Water	
08.	Snitation	
09.	Transport	
Sl.	**Types of Adaptation**	**Steps in recent time (before 15 years)**
01.	House & homestead	
02.	Livelihood	
03.	Agriculture	
04.	Fish farming/Gher	
05.	Poultry/Livestock	
06.	Garden/Vegetation	
07.	Drinking Water	
08.	Snitation	
09.	Transport	

14. How did you respond to the recent past disasters?

Year	Inundation	Duration	Shelter
2009 (cycline Aila)			
2007 (cyclone Sidr)			
1997			
Before 15 years (2000)			

15. How much land you own? (Decimal)

Present land [ ]

Owned in the past [ ]

16. Did you lose any land due to disaster? (Yes/No)
If Yes,
Amount of land lost (Decimal)

17. Howmuch you had to spend for repair/rebuilding after disaster?

Year	Inundation	Duration	Shelter
2009 (cycline Aila)			
2007 (cyclone Sidr)			
Before 15 years (2000)			

18. What are the disaster preparedness measures you have taken sofar?

Timeline	Type of preparedness
In last 1 year	
In last 15 years	
Before 15 years	

19. Please mention the following practice:

a. Source of drinking water

1) Tubewell 2) Pond 3) Others…………………

b. How do you purify drinking water?

1) Boiling 2) Filtering 3) None 4) Others

c. Sanitation measures:

1) Safe 2) Unsafe 3) No Toilet

e. Do you use Mobile Phones? (Yes/No)

f. Does the head of family have a National ID Card? (Yes/No)

g. Do you have any family member with disabilities? (Yes/No)

h. Does the children in your house regularly grow to school? (Yes/No)

THANK YOU VERY MUCH FOR GIVING YOUR VALUABLE TIME