Assessment of Biophysical Factors for Storm Surge Hazard and their Implications for Food Security

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It is hereby declared that this thesis or any part of it has not been submitted elsewhere for the award of any degree or Diploma.

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Abstract

Due to the physical factors associated with cyclonic storm surges, including area, depth and duration of inundation, some impacts are immediate in nature and some are prolonged. Impacts also very across different vulnerable livelihood groups. The study was conducted to assess the physical factors of cyclonic storm surge Aila, the immediate physical impacts, prolonged inundation impacts and the resulting implications for food security of different livelihood groups in polder 32 of Dacope upazila. The study demonstrates the efficient use of Participatory Geographic Information System (PGIS) method along with a range of PRA tools to collect and integrate the community knowledge and the capability to develop reliable and realistic storm surge inundation maps of different time periods since the occurrence of Aila. While the storm surge caused a number of immediate physical damages, which made thousands of people homeless, the prolonged impacts due to continued tidal inundation for several years meant that people could not recover quickly, mostly falling into food insecurity. While the polder was overtopped at many locations, it was the 5 major breaches that were the major contributors to surge inundation as well as repeated tidal inundation for several years. Repeated inundation was enhanced by slow and difficult infrastructure rehabilitation process, scouring of major breaching locations, widening of breaches, siltation of drainage channels, and man-made depressions. It took two years for Kamarkhola union and three years for Sutarkhali union to get fully free from inundation. Farmers, traditional fishermen, shrimp cultivators, wage laborers and Sundarban dependent people constitute the major livelihood groups who were affected by immediate storm surge inundation and prolonged tidal inundation. Consecutive loss of three to four cropping years happened due to water logging followed by adverse condition of land and soil quality (it took substantial time for the salts in soils to get flushed out), which were prominent as long term effects to farmers. Farmers in Kamarkhola union missed three complete cropping seasons (equivalent to 7,20,000 mounds of rice production), while the impact on farmers in Sutarkhali union was more severe as they lost four cropping seasons. While monsoon (Aman) cropping was possible after water receded, yield was reduced in the first year in Kamarkhola due to increased soil salinity from 20 to 22 mound/bigha before Aila to 15 to 16 mound/bigha after Aila. The loss of shrimp production in Sutarkhali union was 60,79,590 kg/year causing loss of income and livelihoods. Also, reduced production from 2,350 kg/ha to 470 kg/ha was a major source of income loss to shrimp cultivators. As Aila damaged all the belongings, the Sundarban dependent people suffered a significant loss of livelihood activities. About 30 to 60% reduction in income resulted for marginal to large farmers, while income reduced by 20% for small scale fishermen and 50% for the Sundarban dependent people. Large farmers were found to spend almost 70% of their income as food expenditure after Aila while it was 80 to 90% for medium and marginal farmers and small and medium farmers. Large, medium and small farmers were consuming almost 100%, 60% and 40% food (staple food rice) from own household production. But they were considered to be food insecure for spending more than 70% of their income as food expenditure after Aila.

Wage laborers and Sundarban dependent people, who were food insecure prior to Aila were the most vulnerable to food insecurity in terms of all four dimensions, viz. availability, access, stability and utilization.

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Abbreviations and Acronyms

AEZ	Agro Ecological Zone
BBS	Bangladesh Bureau of Statistics
BDT	Bangladeshi Taka
BUET	Bangladesh University of Engineering and Technology
BWDB	Bangladesh Water Development Board
CEGIS	Center for Environmental and Geographic Information Services
CZ	Coastal Zone
ESPA	Ecosystem Services for Poverty Alleviation
FAO	Food and agriculture Organization
FGD	Focus Group Discussion
GO	Government Organization
GoB	Government of Bangladesh
IPCC	Intergovernmental Panel on Climate Change
IWFM	Institute of water and flood management
KII	Key Informant Interview
NGO	Non Government Organization
NGO	Non-Governmental Organisation
PRA	Participatory Rural Appraisal
UN	United Nation
UNO	Upazila Nirbahi parishad
WARPO	Water Resources Planning Organization
WHO	World Health Organization

CHAPTER ONE
INTRODUCTION

1.1 Introduction

The coastal zone of Bangladesh constitutes 32 percent of the land area and hosts nearly 28 percent of the population. The coastal zone is rich in natural and socio-economic resources. Some of them are: agricultural land, livestock, fisheries, forestry, waterways and salt production etc. It is a treasure house of wetland resources and bio-diversity. There are a number of livelihood groups in the coastal community because of availability of the numerous coastal resources. However, the vulnerability of the coastal population is on the rise due to climate change and variability. Vulnerabilities in the coastal zone of Bangladesh are increasing with accentuations of natural hazards and sea level rise caused by various factors. The region, having vast low-lying areas enclosed by man-made polders, is considered to be highly vulnerable to climate change induced hazards. The economy of the coastal area is predominantly agriculture based, and the poverty level is the highest in the area compared with other areas of Bangladesh (PDO-ICZMP, 2004). The combination of natural and man-made hazards has adversely affected lives and livelihoods in the coastal zone and slowed down the pace of social and economic developments in this region (MoWR, 2005). Every year natural calamities puts millions of people‟s lives at risk and traps poor household in food insecurity and poverty.

In the backdrop of changing climate and the ever increasing anthropogenic pressure on water resources systems, the importance of deriving a better understanding of how current and future climate risks can undermine water and food security in coastal Bangladesh and how adaptation measures can be taken up in harmony with the bio-physical and socio-economic environments ensuring food security, is now widely recognized. Coastal zone of Bangladesh is the climate change hotspot and prone to different biophysical hazards, including cyclonic storm surges, coastal flooding, river bank erosion, and salinity intrusion (MoWR, 2005; MoEF, 2008; MoEF, 2009). Of all the natural hazards, cyclonic storm surge is the severest environmental shock, and arguably the biggest driver of poverty in the coastal

Bangladesh. In every three years on average, a severe tropical cyclone hits Bangladesh, resulting in extensive damage to houses and high loss of life to humans and livestock in coastal communities (MoEF, 2009).

Two recent tropical cyclones "Sidr" (in 2007) and "Aila" (in 2009) affected 2.3 and 5 million people, respectively and caused huge infrastructure damage (UN, 2010). The impact on food security has been severe resulting from structural damages to polders and consequently continuous inundation of agricultural fields and fish farms (e.g. shrimp ghers) for long periods with saline tidal water. The recovery of agricultural ecosystems from these shock events has been extremely difficult (UN, 2010). The future situation looks gloom given that IPCC 5th assessment report (CCES, 2014) predicts more frequent and intense storms with higher rainfall in tropical cyclones, exacerbated by sea level rise, and the fact that high-intensity cyclonic events will be far more damaging due to increasing density of both population and infrastructure in the coastal plains. Climate change will have increasing threats to sea-facing polders due to sea level rise induced increasing surge heights (CCC, 2009). UNDP has identified Bangladesh as the most vulnerable country in the world to tropical cyclones (UN, 2004). The largest adverse impacts of a cyclone occur from the inundation resulting from the storm surges that cyclones induce in coastal regions.

Cyclones hit the coastal regions of Bangladesh, in early summer (April-May) or late rainy season (October-November). The cyclones “Sidr” in 2007 and “Aila” in 2009 caused widespread damage to property and havoc to people‟s livelihood. Even though Aila was a weak category cyclone by the definition, its economic cost outweighs the impacts of Super cyclone „Sidr‟ and brought in long-term sufferings for the southwestern people of Bangladesh. About 2.3 million people were affected by Aila and many of them were stranded in flooded villages as they had no alternative to save themselves (UN, 2010).

Due to the physical factors associated with storm surges, including area, depth and duration of inundation, the physical damages incurred to the polders and typically slow recovery process, some impacts are immediate in nature and some are prolonged. During cyclonic storm surges, polders are typically overtopped at many places since they were originally designed to protect against tidal wave, without much consideration to storm surges. However, breaches occur in the embankments during cyclones with high velocity onrush of surge water, which have long standing effects. This was particularly evidenced in the recent cyclones Sidr and Aila (BWDB, 2013a). Usually rain cuts and public cuts are the major causes of embankment breaching of the polders. However, lack of regular maintenance creates weak point at sensitive locations of the embankment. The risk of embankment failure is thus accelerated by the intensity and magnitude of the cyclone and storm surge (simultaneously have accelerated the risk of embankment failure (BWDB, 2013a). Because of delay in repairing the breaches and rehabilitating polders, the usually protected lands continue to suffer severe tidal flooding because of existing breach points of the embankment and low height of the embankment. It is to be noted here that the polder heights are designed so as to protect the tidal floodplains from maximum spring tidal flooding. The government is currently implementing (through Bangladesh Water Development Board, with financial support from the World Bank) the Coastal Embankment Improvement (CEIP) projects in which polder heights are being redesigned and re-sectioned so as to protect the tidal floodplains from storm surge floods (BWDB, 2013b).

The immediate impacts of cyclonic storm surges refer to damage to standing crops, saline water inundation of sweet water ponds and shrimp ponds (gher) and damage to households and infrastructures. The prolonged impacts refer to persistent sufferings of people over several years because of continued effect of saline water inundation and water logging due to slow process of rehabilitation of important infrastructure such as polders, sluice gates, roads etc. This has been particularly true in the case of cyclone Aila.

The impacts also vary across different vulnerable groups (e.g. farmers, fishermen, Sundarban dependent livelihood groups and women) who experience different degrees of vulnerability to food insecurity (CCC, 2009; CEGIS, 2004). Socio-economic vulnerability domains for farmers, agricultural laborers, fishermen and others are different (CEGIS, 2004) and food insecurity risks to hazards, including cyclones, for these groups are different as shaped by different vulnerability dimensions. Food security as defined in FAO (2008) has four key components, viz. availability, access, utilization and stability of food, which are affected by different physical components of storm surge to different degrees to different vulnerable groups. Food access and utilization are frequently affected indirectly via collateral effects on household and individual incomes, such as loss of access to drinking water and damage to health (Wheeler et al., 2013).

The present study is an attempt to assess biophysical hazards and vulnerability of storm surge and the linkage between physical factors and impacts on food insecurity in a poldered area in southwest coastal Bangladesh. Polder 32 was chosen for the study. This area is situated at the Dacope Upazila of Khulna district. Polder 32 was the most affected area due to the storm surge Aila in 2009.

1.2 Objective of the Study

The goal of the study was to assess the biophysical factors for storm hazard and their implications for food security. The major focus was on short term and prolonged impacts of storm surge on different vulnerable livelihood groups. The specific objectives of the study were:

1. To identify and analyze the biophysical factors associated with storm surge hazard, including inundation area, depth and duration (both short term and long term).
2. To assess implications for food security to different vulnerable groups.

1.3 Organization of the Thesis

Chapter two contains the review of the literature on the vulnerabilities of the coastal area of Bangladesh. It includes review of the bio-physical hazards, historical cyclones and associated storm surges in the coastal areas, physical vulnerability factors of storm surge. The chapter also discusses the coastal resources and livelihoods including the damages and losses of cyclone Aila. In addition, major dimensions of food security, review of analysis of food security and relation of livelihood vulnerability to food insecurity are reviewed.

Chapter three includes a comprehensive description of the study area. Apart from delineation of climate, river system and hydrology of the study area, it also includes a brief description of natural hazards, cyclones and storm surges and prevailing food insecurity in the study area.

Chapter four describes the methodology for the present study in details. It elaborates different steps and processes of participatory Geographical Information System (PGIS) in hazard mapping. The chapter also includes the description of in-depth Focus Group Discussions (FGDs), interview and others methods employed in the study for assessing impacts of short term and prolonged inundation. In addition, selection of food security indicators, impacts on food security and the process of developing food security assessment framework are discussed in this chapter.

Chapter five delineates the important factors of storm surge, viz. depth and duration, their immediate physical impacts, and areas subjected to prolonged inundation with relevant causes. Also performance of drainage system within the polder with the prolonged inundation is linked in this chapter.

Chapter six analyzes the impacts of inundation caused by Aila. Percentage of areas under prolonged inundation and persistent sufferings of different vulnerable livelihood groups are presented in this chapter. The Chapter also includes assessment of associated impacts on the food security of different vulnerable livelihood groups.

Chapter seven includes the conclusions and recommendations of the study.

CHAPTER TWO
LITERATURE REVIEW

2.1 Introduction

In line with the stated objectives of the present research, a review of literature was done focusing on climate-related hazards and disasters in Bangladesh, with a major focus on cyclones and associated storm surges, which are thought to be the major poverty driver in the area. The review starts with a short description of the hazards and disasters typically experienced in the country. It is followed by a detailed review of cyclones and storm surges in terms of processes, historical incidences and the resulting impacts. Coastal livelihood groups who are vulnerable specifically to cyclonic storm surges are briefly reviewed. Since one important objective of the study was to analyze the impacts of storm surges on food security, the concept of food security together with its different dimensions is discussed from literature.

2.2 Biophysical Hazards in Coastal Bangladesh

Bangladesh is a least developed country, frequently wrecked by a multitude of natural hazards such as floods, droughts, cyclonic storm surges, salt water intrusion, and river erosion (Figure 2.1). South Asia is considered to be the most vulnerable region of the world to climate change impacts (McCarthy *et al.*, 2001), and Bangladesh ranks high in the list of vulnerable countries. Today‟s climatic hazards are already difficult for Bangladesh to cope up with considering its socio-economic conditions; they influence economic opportunities and development potentials, with a significant part of the development efforts being thwarted to meet the emergency demands imposed by climate related hazards. The climate change impacts would in fact reinforce many of the baseline stresses that already pose a serious impediment to the economic development of Bangladesh (Agrawala *et al.*, 2003).

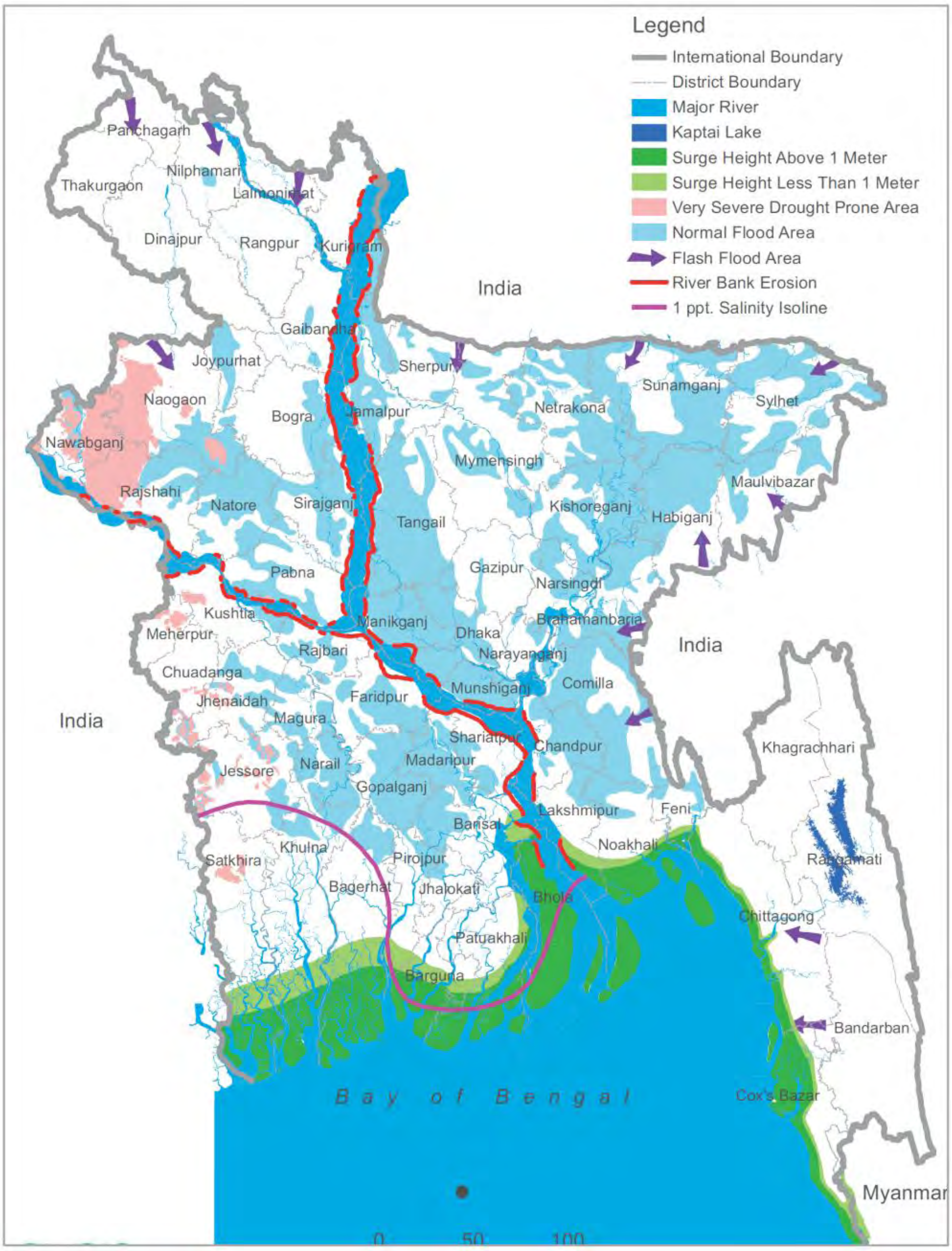


Figure 2.1: Different biophysical hazards in Bangladesh (Source: CEGIS)

The country‟s high vulnerability can be attributed to its geographical location, a setting in the tropics in the floodplain delta of the three major river basins – the Ganges, the Brahmaputra, and the Meghna), an extremely flat and low-lying floodplain topography, a low lying coastline, extreme climate variability reflected in wide temporal and spatial distribution of water, very high population and population density, poverty incidence, and climate-dependent crop agriculture (Rahman and

Salehin 2013; Chowdhury *et al.*, 1997). With a population of about 160 million, Bangladesh is one of the most densely populated countries of the world (BBS, 2016).

Flood is an annual phenomenon, which creates havoc in extreme events that happen roughly every 8-10 years, inundating more than 60% area. People suffer a lot both during and after a flood due to loss of agricultural production, shortage of safe drinking water, outbreak of water borne diseases, salinization of water sources, loss of income opportunities, etc. With the increase of population, more and more people are settling in the flood prone areas, making them more vulnerable to floods. Some 45.5 million people (with more than 50% of female) were exposed to severe and moderate floods in 2000s (CCC 2009). Studies have also shown that flood-prone zones are the worst off among different disaster prone areas in terms of food shortages, the incidence of extreme poor, insufficient income, illiteracy, and a high concentration of wage laborers (BIDS 2006).

Important secondary consequences of climatic hazards include riverbank (along 75 rivers), char (river and deltaic islands), and coastal erosion. Recurrent floods of high velocities and alluvial character of bank materials are among the major causes of river erosion. Erosion makes thousands of people homeless and landless every year. About 7 million people were displaced by riverbank erosion between 1970 and 1990 (Mott MacDonald *et al.*, 1993).

Tropical cyclones accompanied by storm surges are one of the major disasters in Bangladesh. About 5.5% of the world‟s tropical storms form in the Bay of Bengal (Ali, 1999). Apart from human casualties, the economic damages to properties, which include physical infrastructures, livelihood means and various direct/indirect, tangible/intangible items, are typically substantial (Mallick and Rahman, 2013).

Water and soil salinity are normal hazards in many parts of the coastal area. A total of 1.65 million ha of land (70%) out of 2.34 million ha is affected by soil salinity within the Khulna and Barisal divisions of coastal Bangladesh, with soil salinity varying across the cultivable areas (Rahman and Ahsan 2001). Livelihoods in Bangladesh are largely dependent on agricultural practices but agricultural productivity in this region is lower than the national average and this is one of the major reasons for high incidence of poverty (Alam, 2014; BWDB and WARPO, 2004). In the southwestern region, surface water salinity has been aggravated by the reduction in dry-season flows entering the Gorai distributaries, following the diversion of the Ganges flow upstream of the border. Salinity now reaches as far as Khulna, creating problems to normal agricultural practices and affecting the supply of clean water for industrial use (PDO-ICZMP, 2004a). River water salinity has also important implications for the natural environment, such as functioning of the Sundarban ecosystem, sedimentation rates in tidal rivers, and human health.

2.3 Cyclones and Storm Surges in Bangladesh

Tropical cyclones are among the most destructive natural disasters of the world. About 80 tropical cyclones (with wind speed greater than 17 m/s) form in the world‟s waters every year (McBride, 1995; cited in Ali, 1999), of which about 6.5% form in the North Indian Ocean (Bay of Bengal and Arabian Sea) (Neumann, 1993; cited in Ali, 1999). The share of the Bay of Bengal share is far greater (5.5%) because of much higher frequency of cyclones in the Bay of Bengal (about 5 to 6 times) than that in the Arabian Sea. Bangladesh is hit by about 1% of the world‟s total tropical storms, India by 3.34%, Myanmar by 0.51%, Sri Lanka by 0.22%, and 0.50% die in the Bay without hitting any country (Ali, 1996, 1999a, 1999b).

When minimum death tolls over 5000 are considered, it turns out that Bangladesh is the worst sufferer of all cyclonic casualties in the world, with a death toll of about 53% of the global total (Ali, 1999). Given that over two-thirds of the country are less than 5 m above mean sea-level and densely populated, storm surges contribute to flooding and loss of life and livelihoods far beyond the coast. The intense precipitation that usually accompanies the cyclone only adds to the damage through inland and riverine flooding (Agrawala *et al.* 2003). A cyclone in 1970 resulted in close to 300,000 deaths, and another in 1991 led to the loss of 138,000 lives, although greater success in disaster management in recent years (through growing successful institutional arrangement for disaster management and the fact that there are now over 2000 cyclone shelters spreading along the coast) has significantly reduced the lives lost (CCC, 2009c; WB, 2000). In the two recent cyclones, Sidr and Aila, the human casualties were 3347 and 190, respectively.

Major Cyclones crossing the Bangladesh coast

Storm surge amplifications on the Bangladesh coast are facilitated by a number of factors, including the shallow water in the north of Bay, the northward-converging or funneling coastal configuration, and high astronomical tides (Ali, 1999). Murty and El-Sabh (1992) while analyzing tropical cyclones and storm surges impacts reported that Bangladesh is on the receiving end of about 40% of the impact of total storm surges in the world. The reasons for this disproportional large impact of storm surges on the coast of Bangladesh were reported to be the recurvature phenomenon of tropical cyclones in the Bay of Bengal, shallow continental shelf (especially in the eastern part of Bangladesh), high tidal range, triangular shape at the head of the Bay of Bengal, almost sea-level orography of the Bangladesh coastal land, and high density of population and coastal defense system.

Figure 2.2 shows the path of 50 major cyclones along the Bay of Bengal coast crossing Bangladesh. The coast line of Bangladesh is characterized by a wide continental shelf, especially off the eastern part of Bangladesh. This wide shelf amplifies the storm surges as the tangential sea-level wind- stress field associated with the tropical cyclone pushes the sea water from the deep water side onto the shelf. Being pushed from the south by wind stress, the water has no place to go but upwards; which is the storm surge. The triangular shape at the head of the Bay of Bengal helps to funnel the sea water pushed by the wind towards the coast and causes further amplification of the surge. This is basically what contributes to the amplification of surges on the Bangladesh coast. The Meghna estuarine region is the area where most of the surge amplifications occur.

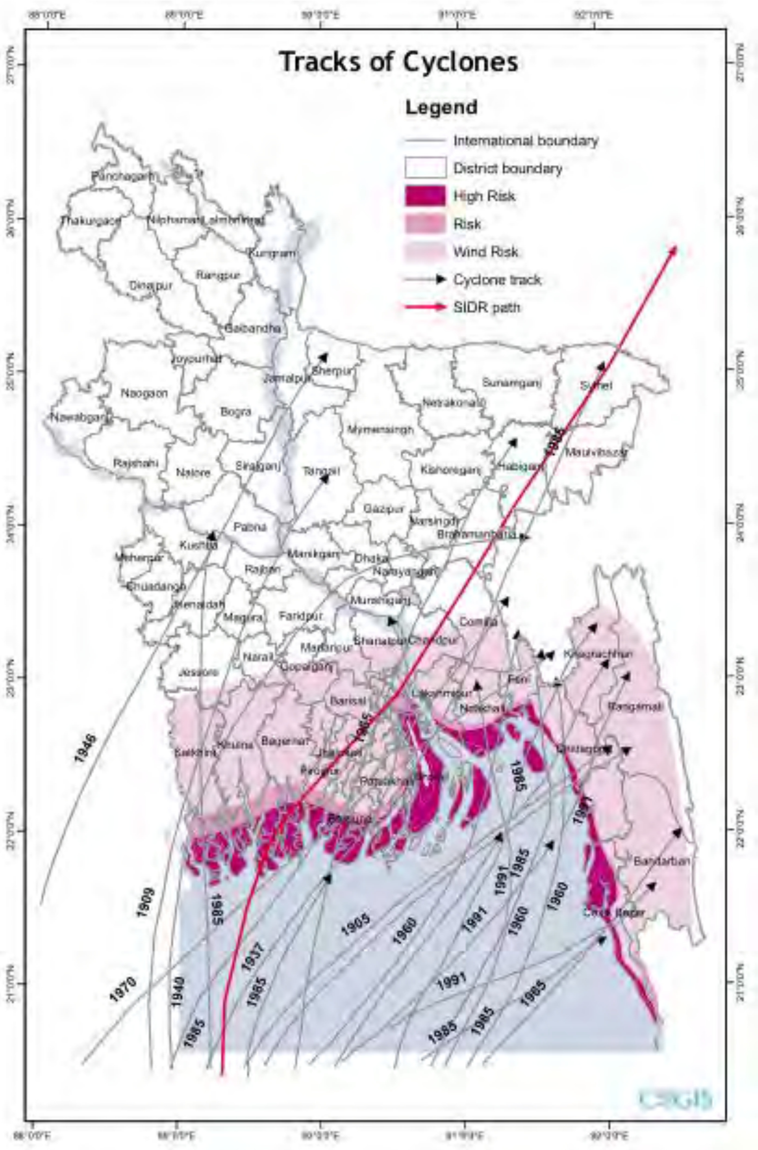


Figure 2.2: Travel Path of 50 major Cyclones (excluding Sidr and Aila) crossing Bangladesh Coast (Source: MoFDM, 2008)

Historical cyclones and associated storm surges

A cyclonic storm surge is the most extreme meteorological event faced by the coastal community. The occurrence of these events in close sequence is a reminder of the country's extreme vulnerability to frequent hydro-meteorological hazards, which stand to be further exacerbated because of climate change. Cyclones hit the coastal regions of Bangladesh almost every year, in early summer (April- May) or late rainy season (October-November). Between 1877 and 1995 Bangladesh was hit by 154 cyclones (including 43 severe cyclonic storms, 43 cyclonic storms, 68 tropical depressions), with storm surges of notable magnitudes occurring in the years of 1960, 1961, 1963, 1965, 1970, 1985, 1988 and 1991. Since 1995, five severe cyclones hit coast of Bangladesh coast in May 1997, September 1997, May 1998, November 2007 and May 2009. On average, a severe cyclone strikes Bangladesh every three years (GoB, 2009). The 1970 cyclone and associated storm surge alone caused deaths of 0.5 million people. Storm surges also cause colossal damage to crops, properties and economic assets. In addition, there is a risk of salinization of open drinking water pond, fresh groundwater sources and productive farm lands due to storm surge flooding.

The 1991 Bangladesh cyclone was among the deadliest tropical cyclones on record. The storm forced a 6 meter (20 ft.) storm surge inland over a wide area, killing at least 138,000 people and leaving as many as 10 million homeless. The storm caused an estimated $1.5 billion (1991 US dollars) in damage. The high velocity wind and the storm surge devastated the coastline. The storm surge subsequently caused the embankment, as well as whole villages, to be swept away. For an additional three to four weeks after the storm had dissipated, mass land erosion resulted in more and more farmers losing their land, and therefore, the number of unemployed rose. In several areas up to 90 percent of crops had been washed away. The shrimp farms and salt industry were left devastated.

On 15 November 2007, Cyclone “Sidr” struck the south-west coast of Bangladesh with winds up to 240 kilometers per hour. The category4 storm was accompanied by tidal waves up to five meters high and surges up to 6 meters in some areas, breaching coastal embankments, flooding low-lying areas and causing extensive physical destruction. High winds and floods also caused damage to housing, roads, bridges, and other infrastructure. Electricity and communication were knocked out, and roads and waterways became impassable. Drinking water was contaminated by debris and many sources were inundated with saline water from tidal surges, and sanitation infrastructure was destroyed. Damage and loss from Cyclone Sidr was concentrated on the southwest coast of Bangladesh. Four of Bangladesh's thirty districts were classified as "severely affected" and a further eight were classified as "moderately affected". Of the 2.3 million households affected to some degree by the effects of Cyclone Sidr, about one million were seriously affected.

Cyclone "Aila" was the second tropical cyclone to form within the Northern Indian Ocean during 2009. The disturbance that was to become Cyclone Aila formed on 21 May 2009. Cyclone Aila became a severe cyclonic storm on 25 May. The system maintained a cyclonic intensity for approximately 15 hours after making landfall. Hitting during high tide, the cyclone brought with it tidal surges of up to 6.5 meters, affecting 11 coastal districts. This surge of water damaged and washed away over 1,742 km of embankments, removing the only protection available to many people along the coast. The storm delayed over the coast of Bangladesh for a comparatively longer time than Cyclone Sidr (2007), which further increased its impact. In many areas the damage to the network of embankments has resulted in a prolonged continuation of what affected communities faced in the immediate aftermath of the cyclone and flooding. Breeches in the embankments, which became severe during daily high tides, and particularly during periods of full moon, have prevented the high levels of self-recovery normally seen in Bangladesh following disaster events. The impact of Cyclone Aila is being felt by the affected communities many months after the disastrous event of May 2009. In most of the communities, entire shrimp and agriculture productions have been lost as well as businesses and livestock. Income generating activities are almost non-existent and families are reducing (quantity and quality wise) their food intake, selling their possessions, migrating to other urban centers and increasing their exposure to human trafficking, primarily for adolescents.

Physical vulnerability factors of storm surge

Inundation due to storm surges generated by severe cyclones pose a threat to lives and properties in the coastal region of Bangladesh. Historical records of storm surge height are scarce in Bangladesh. A surge can be even more devastating if it makes a landfall during high tide. In general, it has been observed that the frequency of a wave (surge plus tide) along Bangladesh coast with a height of about 10 m is approximately once in 20 years, and the frequency of a wave with a height of about 7 m is approximately once in 5 years (MCSP, 1993). According to SMRC (2000), storm surge heights in excess of 10 m or even more are not uncommon. A partial listing of major cyclones and accompanying surge heights provided by Agrawala *et al.* (2003) (modified from Ali, 2003) is presented in Table 2.1.

Table 2.1: Partial listing of cyclones along coastal Bangladesh and respective surge heights

Cyclone event	Season	Storm surge height (in meter)
November 1876	Post-monsoon	3.0~10.0
May 1941	Pre-monsoon	4.0
May 1960	Pre-monsoon	3.2
October 1960 (first event)	Post-monsoon	5.1
October 1960 (second event)	Post-monsoon	6.6
May 1961 (first event)	Pre-monsoon	3.0
May 1961 (second event)	Pre-monsoon	6.0~8.0
May 1965	Pre-monsoon	7.6
December 1965	Post-monsoon/winter	8.8
October 1967	Post-monsoon	7.6
May 1970	Pre-monsoon	5.0
October 1970	Post-monsoon	4.7
November 1970	Post-monsoon	9.0
September 1971	Monsoon	5.0
December 1973	Post-monsoon	4.5
August 1974	Monsoon	6.7
November 1975	Post-monsoon	3.1
May 1985	Pre-monsoon	4.3
November 1988	Post-monsoon	4.4
April 1991	Pre-monsoon	4.0~8.0
November 2007	Post-monsoon	5.0
May 2009	Monsoon	6.5

Adapted from Agrawala (2003), GoB(2008) and UO (2010)

Predicted behaviour of cyclones and storm surges

The IPCC Third Assessment had observed that the available climate models could not adequately resolve the influence of climate change on cyclones (IPCC, 2001). However, based on emerging insights from a few climate model experiments as well as the empirical records, it had concluded that "there is some evidence that regional frequencies of tropical cyclones may change but none that their locations will change". There is also evidence that the peak intensity may increase by 5% and 10% and precipitation rates may increase by 20% to 30%" (IPCC, 2001). These estimates however were for tropical cyclones in general and not location specific. However, IPCC revised its stance on the frequency of cyclones in its 4th assessment report and predicted that while the frequency and location both might not change the intensity of cyclonic storms are most likely to increase due to increase in average temperature

(IPCC, 2007). The possibility of an increase in peak intensities by 5-10% has potentially serious implications for a country already very vulnerable to storm surges driven by strong winds (Agrawala *et al.*, 2003). According to the IPCC AR5 (the 5th assessment report), "changing climate leads to changes in the frequency, intensity, spatial extent, duration, and timing of extreme weather and climate events, and can result in unprecedented extreme weather and climate events". Increased sea surface temperature will intensify cyclone activity, and storm surges and related floods are likely to become more severe with increases in intense tropical cyclones in future (IPCC, 2014). These surges will, in turn, create more damaging flood conditions in coastal zones and adjoining low-lying areas. The destructive impact will generally be greater when storm surges are accompanied by strong winds and large onshore waves. Tropical cyclone "Sidr" in Bangladesh in November 2007, cyclone Nargis in the Irrawaddy delta of Myanmar in May 2008 and cyclone "Aila" in 2009 provide recent examples of devastating storm-surge impacts in developing countries. Not only in Bangladesh but also worldwide the damaging effect of storm surge has been increased. Some scientific studies do 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, 2005; Webster *et al.*, 2005; Bengtsson *et al.*

, 2006). During the past 200 years, 2.6 million people may have drowned during surge events (Nicholls 2003). Although the science is not yet conclusive, Pielke *et al.* (2005) has noted that, "If the projected rise in sea level due to global warming occurs, then the vulnerability to tropical cyclone storm surge flooding would increase" and "It is likely that some increase in tropical cyclone peak wind-speed and rainfall will occur if the climate continues to warm". Model studies and theory projected a 3-5% increase in wind-speed per degree Celsius increase of tropical sea surface temperatures. The 4th Assessment Report of the Intergovernmental Panel on Climate Change (IPCC AR4, 2007) using a range of model projections, also has asserted a probability of 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; Woodworth and Blackman, 2004; Woth *et al.*, 2006; and Emanuel *et al.*, 2008).

2.4 Physical Features of Polder 32

This polder was planned in the year 1960 under the Coastal Embankment Project. The construction of the polder started in 1966-67 and was completed in 1971-72. The original concept of construction of this polder was only to protect the agricultural lands from salinity intrusion caused due to tidal inundation from the river. The entire embankment of the polder is classified as Interior Dyke having side slopes C/S: 1:2 and R/S: 1:3. Total length of the embankment is 49.50 km with a design crest level is 4.27 m PWD (Paleo Water Depth) (BWDB, 2013a, 2013b and 2013c). The water control structures in the polder include 16 drainage sluices and 35 flushing inlets. Total length of drainage channel 45 km. Gross protected area by the polder is 8,097 ha and net benefited area is 6,500 ha (BWDB, 2013c). The polders were designed to keep the land safe from the daily tides and allow agriculture activities inside the polder. Without embankments the coastal communities would be exposed to diurnal tidal fluctuations.

2.5 Coastal Resources and Livelihoods of Different Vulnerable Groups

2.5.1 Coastal resources

The coastal zone is a region of multiple vulnerabilities and opportunities (PDO-ICZMP, 2004). On the one hand, it is prone to severe natural hazards (e.g. cyclones, storm surges, floods, and salt water intrusion), which is compounded by high density population, with three-fourths of population representing poor livelihood groups. On the other hand, the coastal zone is the source of diversified biological (agriculture, fisheries, forestry, livestock), mineral (sand, metals, salt production) and energy (wave energy) resources, is endowed with Export Processing Zones, harbors, airports, land ports and tourism complexes, sea ports (Chittagong and Mongla) and other industrial units, and contains several ecosystems of conservation values, such as the Sundarban mangrove (a World Heritage Site) and coral ecosystem of St Martin"s Island. It is a treasure house of wetland resources and bio-diversity. The Sundarban, the world"s largest single tract of mangrove forest that has been declared a World Heritage Site is located in the Ganges tidal plain. The Sundarbans contain a considerably high floral (245 genera and 334 plant species) and faunal (453 species) diversity. The Sundarbans provides livelihood and employment to wood cutters, fishermen, honey and wax collectors, shell collectors, timber traders and workers, workers of fish drying industries, etc. The Sundarbans is the major producer of honey in the country and account for about 20 per cent of the total honey production of Bangladesh (CCC, 2009a).

2.5.2 Livelihoods

The livelihoods have been adversely affected by the combination of natural hazards, man-made hazards and socio-economic activities, such as tropical cyclones and associated storm surge floods, river erosion, drainage congestion and water logging, saline water intrusion, soil salinity.

Livelihoods in the coastal zone are quite varied and influenced by socio-economic and physical environment of the coastal area. A vulnerability analysis of livelihood groups in the coastal zone carried out by CEGIS (2004**)** revealed that small farmers, artisan fishers, rural wage laborers and urban wage laborers are the four major livelihood groups that together form about 73% of coastal population while small farmers alone form approximately 50%. Small farmers and artisan fishers together form approximately 69% of coastal population. A total of 156 vulnerability factors were identified, which were later clustered along four major thematic areas: environmental issues, economic issues, social issues and governance issues.

Environmental issues are more prominent for the small farmers and artisan fishers that are involved in primary production activities. Directly linked to the environmental issues are storm surge flood, water logging, salinity, crop damage, resource degradation, deterioration of soil fertility etc. Particularly for storm surge flood, water logging/drainage congestion, sand deposition and soil salinity were the major physical hindrance to small farmers‟ farming and production, and were also found as the major causes of sudden crop damage. These findings by CEGIS (2004) indicate the importance of water related issues in the livelihood activities of the coastal people.

Storm surge "Aila" proved to be an enormous potential threat to human lives, properties, resources and livelihoods. The damage to the coastal embankment network was severe and directly contributed to the continuation of the post-cyclone scenario (continued widespread flooding and tidal inundation) faced by the worst affected communities (UN, 2009). People"s livelihood largely depends on their vulnerabilities and resources that they depend on.

A huge area of agricultural land was inundated all of a sudden, and a number of shrimp ghers were damaged by the thrust of the Aila. The coastal embankments and the sluice gates all around the area got damaged extremely, which enhanced the flooding and water logging situation of the coastal areas. There are a number of livelihood groups directly or indirectly dependent on the coastal resources for their livelihood. Most of the livelihood is resource based. The two major livelihoods in the affected areas, farming and fishing, suffered significant damage and loss due to continuous inundation of paddy fields and shrimp *ghers*/ fish ponds by saline water (UN, 2009). Farmers" community faced a huge damage due to the inundation of their agricultural lands. Also longer time of inundation imposed an additional pressure on the resources like salinization of the agricultural lands. According to the Department of Agriculture Extension, only a minor portion of total cropland in the affected four upazilas was possible to bring under cultivation after Aila and approximately 70-80 percent crop production was lost. These communities were unable to commence the process of self-recovery as they remained on the embankments.

The main livelihood in the affected areas is fishing, with more than 60% people directly or indirectly involved in fishing sectors. About 52961 acres of shrimp ghers (fish pond) as well as 1074 acres of sweet fish ponds were damaged by Cyclone Aila. The estimated loss is approximately BDT 1.5 billion. Aila hit when gher people were preparing to harvest the season"s first output, meaning that all valuable ready to export (grade) shrimp was washed away.

Day laborers (mostly female) and small traders involved in collecting shrimp from farm and selling to mainland wholesalers were seriously affected. Many people lost their boats, many were damaged and needed to be repaired, and many people had to sell their boats to pay for day to day family expenses. In the fishing sector, many people especially women are engaged in catching shrimp fry and crab collecting in the forest, but prices decreased by 5 times as compared to before Aila situation (UN, 2009). Although there were other fishing opportunities available in open water bodies such as rivers, canals, and inside the forest, but people did not have the necessary capital or equipment such as boats, nets and tools.

2.5.3 Damage and losses due to Cyclone Aila

Despite being a Category-1 cyclone, Aila took a heavy toll on the coastal people‟s livelihoods. The main damage was done by the flooding of water breached through the damaged embankments all-round the coastal areas. Frequent breaching of the embankments to lift saline water in *ghers* made the half-century old embankments quite weak and led it to break down during the tidal surge inflicted by cyclone Aila. Negligence in properly repairing the embankments with a buffer zone in a place also contributed to the damage of the embankment. Moreover, silting up of the river beds in region also forced the tidal surge and usual river flow to put immense continuous pressure on the embankments to make them even weaker. It was not Aila that solely responsible for the havoc in the coast of Bangladesh, rather it was the failure of the embankments to protect the coastal belt from storm surge that was mostly responsible for the damages.

According to the official estimates of the Relief Control Cell of Ministry of Food and Disaster Management, 109,842 households were affected by Aila in Khulna District (58,499 Households fully damaged, 51,343 Households partially damaged (UN, 2009). Almost 99 percent of earth-made households turned into ruins in the flooded areas. As those flooded regions were slowly turning into waterlogged areas, the remaining partially affected earth-made households had no chance to stand tall.

Roads and embankments were one of the worst affected sectors in Aila. According to the local Roads and Highway authorities, Aila caused full damage of 367 km of road and partial damage of 1065 km of road only in Khulna District (UN, 2010). There were 35 breaches in the embankment system around the district as referred by local people, while the Disaster Management Information Centre estimated about 597 km of embankment to have been damaged. The government took initiatives to repair the embankments. However, most repairs were not successful due to high pressure of tidal prism and continuous water flow through the breaches.

Tidal surge induced by Aila breached the coastal embankments and washed away the earth-made houses of the poor communities. In the affected areas of Koyra, Dcaope and Paikgacha, at least 90 percent of the families lost their households. Along with those, they lost their everyday essentials like cooking equipments, earth-made burners (locally known as *Chula*), furniture and many others.

There are no official estimates of the damage of the Sundarbans during Aila. The mangrove forest is a remote place to enter and it is much harder in the rainy season when the height of tide water reaches the highest. The Sundarbans was inundated with 6 m of water as per the different reports. Considering the astronomical tidal wave at the time of landfall, which was about 4-5 meters, the maximum storm surge over Sundarbans area may be estimated to be about 2 m (UO, 2009). A large number of trees were uprooted; infrastructures damaged and seized logs of Sundari trees swept away by 10-12 feet high tidal surge whipped up by Aila. At least 35 percent of forest camps in the west part of the Sundarbans were totally damaged.

Cyclone Aila had the worst impact on the local food security situation in Khulna District. Damage of 7392 acres of standing crops was reported officially, of which 3412 acres (46%) are fully damaged. Dacope upazila tops the list of worst affected standing crop (3280 acres, 44% of total standing crop destroyed in Khulna District) (UN, 2010). The main crops damaged are dry season vegetables, sesame, pulses and *Boro* paddy. A total destruction of 260 ha of Jute, 32 ha of *Aus* paddy, 271 ha of dry season vegetables, 29.6 ha of *Aman* paddy, 49 ha of sesame has been reported at different literature.

The Fisheries department estimated a loss of total of 59,045 acres of land under shrimp ghers along with 1,074 acres land under ponds culturing white fish. The official estimates of the economic loss in southern most three union; Dacope, Paikgacha and Batighata is about BDT 900 million (UO, 2009).

Most of the affected areas were still under water for a long period after Aila had hit the coastal area. Long term waterlogging caused damage to the soil quality in the region which in consequence will affect the upcoming Aman season. As a result, the chain of economic loss in the agricultural sector might be continuing in future. Due to flooding and standing water of the areas by saline water, the soil fertility and moisture levels were decreasing. The immediate result was a decrease in food production leading to increased food insecurity for the whole community. Thus the food security is at stake even after a few years of Aila.

2.6 Four Major Dimensions of Food Security: Theoretical Underpinnings

Food security exists when all people, at all times, have physical and economic access to sufficient, safe, and nutritious food to meet their dietary needs and food preferences for an active and healthy life (WFS,1996). The food security status of any household or individual is typically determined by the interaction among a broad range of agro-environmental, socio-economic, and biological factors. There is no single, direct measure of food security. However, the complexity of the food security problem can be simplified by focusing on four distinct, but interrelated, dimensions: aggregate food availability, household food access, and individual food utilization and stability. Achieving food security requires addressing all four of these separate dimensions, ensuring that: the aggregate availability of physical supplies of food from domestic production, commercial imports, food aid, and national stocks is sufficient.

Availability: Food availability addresses the “supply side” of food security and is determined by the level of food production, stock levels and net trade. Food availability is the net amount remaining after production, stocks and imports have been summed and exports deducted for each item included in the food balance sheet (FAO, 2008). Adequacy is assessed through comparison of availability with the estimated consumption requirement for each food item. Food availability plays a prominent role in food security.

Access: Supplying enough food to a given population is a necessary, although not a sufficient; condition to ensure that people have adequate access to food. Major contributions to food availability come not only from agriculture, but also from fisheries, aquaculture and forest products. Forests provide a wide range of highly nutritious foods, in the form of leaves, seeds, nuts, honey, and fruits. An adequate supply of food at the national or international level does not in itself guarantee household level food security. Concerns about insufficient food access have resulted in a greater policy focus on incomes, expenditure, markets and prices in achieving food security objectives. Food accessibility is a measure of the ability to secure entitlements, which are defined as the set of resources (including legal, political, economic and social) that an individual requires obtaining access to food (A. Sen, 1989, cited in FAO, 2003a). The ability to access food rests on two pillars: economic and physical access. Economic access is determined by income, food prices and the provision of and access to social support. Physical access is determined by the availability and quality of infrastructure, including roads, railways, communication and food storage facilities and other installations that facilitate the functioning of markets. Incomes earned in agriculture, forests, fisheries and aquaculture play a primary role in determining food security outcomes. Economic access to food is also refers to people‟s purchasing power.

Utilization: Utilization is commonly understood as the way the body makes the most of various nutrients in the food. Sufficient energy and nutrient intake by individuals is the result of good care and feeding practices, food preparation, and diversity of the diet and intra-household distribution of food. Combined with good biological utilization of food consumed, this determines the nutritional status of individuals. The Outcome indicators of food utilization convey the impact of inadequate food intake and poor health. Effectively and hygienic food helps maintain a healthy body. Access to clean water is crucial to preparation of clean, healthy food and maintaining a healthy body.

Stability: Stability of the other three dimensions over time even if food intake is adequate today, implies that individuals will still be considered to be food insecure if they have inadequate access to food on a periodic basis, risking a deterioration of nutritional status. Adverse weather conditions, political instability, or economic factors (unemployment, rising food prices) may have an impact on food security status.

Chronic and transitory food insecurity

Food security analysis is primarily a static view of food access and household constraints to that access, from either a short- or long-term perspective. According to the duration there are two general types of food insecurity (FAO, 2008); chronic food insecurity and transitory food insecurity. Chronic food insecurity is long term or persistence. It occurs when people are unable to meet their minimum food requirements over a sustained period of time which may results from extended periods of poverty, lack of assets and inadequate access to productive or financial resources and can be overcome with typical long term development measures also used to address poverty, such as education or access to productive resources, such as credit. They may also need more direct access to food to enable them to raise their productive capacity.

On the other hand, transitory food insecurity is short-term and temporary. It occurs when there is a sudden drop in the ability to produce or access enough food to maintain a good nutritional status which may results from short-term shocks and fluctuations in food availability and food access, including year-to-year variations in domestic food production, food prices and household income (WB, 1986). Transitory food insecurity is relatively unpredictable and can emerge suddenly. This makes planning and programming more difficult and requires different capacities and types of intervention, including early warning capacity and safety net programmes (FAO, 2008: Published by the EC - FAO Food Security Programme.

2.6.1 Analyzing food security

A Comprehensive Food Security and Vulnerability Analysis (CFSVA) is a baseline survey that provides an in-depth picture of the food security situation and the vulnerability of households in a given country. It is conducted at normal times, and not during a crisis, in countries subject to vulnerabilities. A CFSVA provides a breadth of information on the political, socio-economic and agro-ecological context, food supplies, markets, livelihoods, coping strategies, nutrition, health, education, etc.(WPS, 2013). The analysis identifies the root causes of food insecurity and vulnerability; provides an in-depth profile of food-insecure and vulnerable people, and their livelihoods; provides an analysis of markets, their functioning and price trends in the country; includes an analysis of risk (hazards, natural disasters, economic shocks, etc.) and their potential impact on the most vulnerable. Knowing in advance where the most vulnerable people are located and what causes their vulnerability facilitates the drawing-up of the first emergency needs assessments after a crisis strikes.

Within the broadly accepted conceptual pillars of access, availability, utilization, and stability, the Food Security and Nutrition Analysis System of FAO operationally and conceptually draws together Core sectors for food security analysis including agriculture, climate, markets, nutrition and natural resources.

The analysis of food security also begins with an examination of livelihood assets; the agro ecological, political and institutional context of the area; and the resulting livelihood strategies adopted by the people that may lead to food security. Where, a livelihood comprises the capabilities, assets (stores, resources, claims, and access) and activities required for a means of living. A livelihood is sustainable which can cope with and recover from stress and shocks, maintain or enhance its capabilities and assets, and provide sustainable livelihood opportunities for the next generation and which contributes net benefits to other livelihoods at the local and global levels in the long and short term (Chambers and Conway, 1992).

Livelihood systems are made up of several components: The activities households engage in to earn income and make a living which includes a range of on-farm and off-farm activities that together provide a variety of procurement strategies for food and cash, The assets and other resources a household possesses, Social networks and safety nets, the human and social capital that a household possesses or can call on in times of need. Thus, livelihood systems are quite diverse. Each household can have many possible sources of entitlement (i.e. the rights, privileges, and assets a household has, and its position in the legal, political, and social fabric of society) (CARE, 2002). Livelihood also relates different types of capital requirements such as Human capital (skills, knowledge, ability to labor, nutritional status of adults and children); Financial capital (financial resources, savings, credit, liquid assets); Natural capital (types and quantities of crops grown and harvested); Physical capital (assets and land available to households); Social capital (informal community support networks, extended family structures, or community labor-sharing systems); and Political capital (participation in community decisions and power relations).

2.6.2 Agriculture, climate and food security

Agriculture is important for food security in two ways, it produces the food people eat and (perhaps even more important) it provides the primary source of livelihood for 36 percent of the world"s total workforce. In the heavily populated countries of Asia and the Pacific, this share ranges from 40 to 50 percent, and in sub-Saharan Africa, two-thirds of the working population still make their living from agriculture (ILO, 2007). If agricultural production in the low-income developing countries of Asia and Africa is adversely affected by climate change, the livelihoods of large numbers of the rural poor will be put at risk and their vulnerability to food insecurity will increase. Agriculture, forestry and fisheries are all sensitive to climate. Their production processes are therefore likely to be affected by climate change.

The food security implications of changes in agricultural production patterns and performance are of two kinds. Impacts on the production of food will affect food supply at the global and local levels. Impacts on all forms of agricultural production will affect livelihoods and access to food. Producer groups that are less able to deal with climate change, such as the rural poor in developing countries, risk having their safety and welfare compromised. Other food system processes, such as food processing, distribution, acquisition, preparation and consumption, are as important for food security as food and agricultural production are. Evidence indicates that more frequent and more intense extreme weather events (droughts, heat and cold waves, heavy storms, floods), rising sea levels and increasing irregularities in seasonal rainfall patterns (including flooding) are already having immediate impacts on not only food production, but also food distribution infrastructure, incidence of food emergencies, livelihood assets and human health in both rural and urban areas.

2.7 Stability: Affects the Long Term Food Insecurity

Food system stability is determined by the temporal availability of, and access to food. In Long distance food chains, storage, processing, distribution and marketing processes contain in-built mechanisms that have protected the global food system from instability in recent times. However, if projected increases in weather variability materialize, they are likely to lead to increases in the frequency and magnitude of food emergencies.

Various hazards and more gradual changes affect the macro context and household-level assets and strategies, and hence household food security. Two types of indicator have been identified by World Bank to measure the extent and exposure to risk and hazard. Key indicators for exposure to risk include the area unused for agriculture or non-availability of irrigation, which provides a measure of the extent of exposure to climatic shocks such as drought, cyclonic storm surge, water logging. A second group of indicators captures risks or shocks that directly affect food security, such as swings in food and input prices, production and supply. The suite of indicators covers a number of stability measures, including an indicator of political instability available from the World Bank.

The vulnerability dimension of food security is increasingly cast in the context of climate change. The number of extreme events such as droughts, floods and cyclones has increased in recent years, as has the unpredictability of weather patterns, leading to substantial losses in production and lower incomes in vulnerable areas. Changeable weather patterns have played a part in increasing food price levels and variability. Smallholder farmers and poor consumers have been particularly badly affected by these sudden changes. Also impact on natural resources impacted the depended group of people in attaining food security. Food security in Bangladesh is challenged by a host of factors ranging from the country"s ever-increasing population density, climate change, scarce natural resources (with nearly no agricultural land left untilled), vulnerability to price shocks and persistent poverty (WFS, 2013).

2.8 Livelihood Vulnerability and Food Insecurity

Household livelihoods provide adequate access for all members of the household to those food supplies through home production, market purchases, or transfers from other sources; and the utilization of those food supplies is appropriate to meet the specific dietary and health needs of all individuals within a household. Viewing food security from a livelihoods perspective makes it possible to assess the different components of food security holistically at the household level. Livelihoods can be defined as the bundle of different types of assets, abilities and activities that enable a person or household to survive (FAO, 2003a). These assets include physical assets such as infrastructure and household items; financial assets such as stocks of money, savings; natural assets such as natural resources; social assets, which are based on the cohesiveness of people and societies; and human assets, which depend on the status of individuals and can involve education and skill. These assets change over time and are different for different households and communities. The amounts of these assets that a household or community possesses or can easily gain access to are key determinants of sustainability and resilience. It is usually people‟s few productive assets that are at greatest risk from the impacts of climate change. Physical assets can be damaged or destroyed, financial losses can be incurred, natural assets can be degraded and social assets can be undermined.

Agriculture is often at the heart of the livelihood strategies of these marginal groups; agricultural employment, whether farming their own land or working on that of others, is key to their survival. In many areas, the challenges of rural livelihoods drive urban migration. As the number of poor and vulnerable people living in urban slums grows, the availability of non-farm employment opportunities and the access of urban dwellers to adequate food from the market will become increasingly important drivers of food security.

Agriculture-based livelihood systems that are already vulnerable to climate change face immediate risk of increased crop failure, loss of livestock and fish stocks, increasing water scarcities and destruction of productive assets. These systems include small-scale rainfed farming, inland and coastal fishing/aquaculture communities, and forest-based systems. Rural people inhabiting coasts, floodplains, mountains, dry lands are most at risk. The urban poor, particularly in coastal cities and floodplain settlements, also face increasing risks. Among those at risk, pre-existing socio-economic discriminations are likely to be aggravated, causing nutritional status to deteriorate among women, young children and elderly, ill and disabled people.

CHAPTER THREE
STUDY AREA

3.1 Introduction and Overview of the Study Area

Among three polders of Dacope Upazila of the Khulna district, *viz*. Polder 31, 32 and 33, polder 32 was the most severely affected polder during Aila in 2009 and hence was selected as the study area. The Polder covers two union parishads namely Sutarkhali and Kamarkhola of Dacope upazila. In 1960, polder 32 was constructed under the Coastal Embankment Project (CEP). The main objective of construction of this polder was only to protect the agricultural lands from salinity intrusion caused due to tidal inundation from the sea through rivers. Protection against storm surges was not considered at that time. At present, the embankment of the polder is under tremendous threat of cyclone surge, wave attack, river erosion and increasing risks brought about by climate change. Polder 32 is surrounded by embankment including various water controlling structures for draining and flushing the poldered area.

3.2 Area and Geographical Location

Polder 32 is located in between 89°27′37″E longitude and 22°24′22″N latitude to 89°27′40″E longitude and 22°34′1″N latitude, consisting of two unions, namely Kamarkhola and Sutarkhali as shown Figure 3.1. The southern part of the area is surrounded by the Sundarbans. Kamarkhola union has two mouzas and fourteen villages having a total area of 2921 ha (BBS 2001). Sutarkhali union has four mouzas and nine wards having a total area of 4896 ha. Total area of the polder 32 is 7800 ha. The percentage areas of the two unions are shown in Table 3.1.

Table 3.1: Percentage of area within the unions of polder 32

Name of the District	Name of Upazla	Name of the unions	Percentage of union within polder
Khulna	Dacope	Kamarkhola	85
		Sutarkhali	72

Source: (BWDB, 2013a)

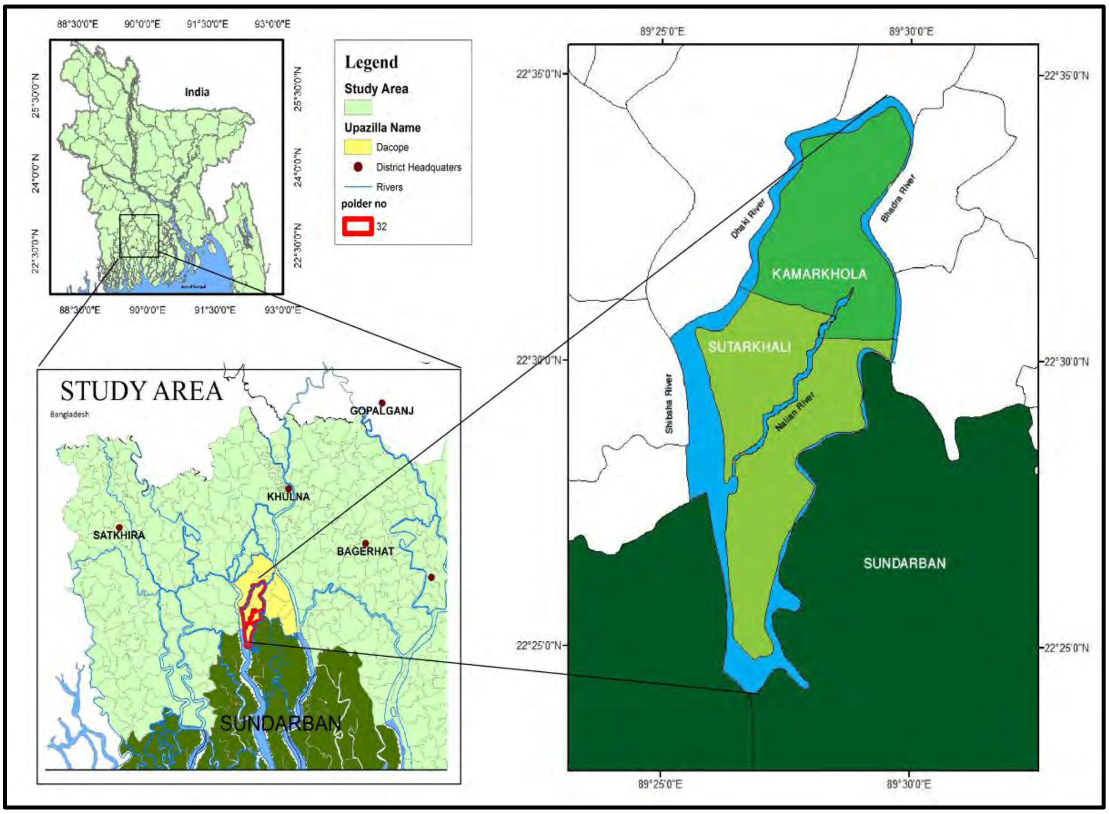


Figure 3.1: Map of the study area

3.3 Demographic Features

Population density in polder 32 is low compared to other parts of the country, with the density being 456 and 622 per sq. km for Kamarkhola and Sutarkhali unions, respectively. Based on the Census Report of Bangladesh Bureau of Statistics (BBS, 2011), the population in Polder 32 is 33,456. This includes 16, 985 males and 16,471 females. A total of 8,399 households exist in the polder with average size of 3.98 persons per household. The key demographic data of the Polder is presented in Table 3.2.

Table 3.2: Demographic data

Households	Population			Size of the household
	Total	Male	Female	
	33456	16985	16471	3.93
8399		50.8%	49.2%	

Source: (BBS, 2011)

3.4 Socio-Economy

3.4.2 Education

In terms of national average literacy rate is not satisfactory in the study area. It comprises 58 percent in Kamarkhola union and 50 percent in Sutarkhali union (Table 3.3).

Table 3.3: Literacy rate of the study area

Union	Literacy Rate (%)		
	Total/Both	Male	Female
Kamarkhola	58.1	65.9	50.1
Sutarkhali	49.5	56.3	42.6

Source: (BBS, 2011)

3.4.2 Livelihood groups

Agriculture dominates the livelihood of people in both Kamarkhola and Sutarkhali unions, with the distribution of different categories as: landless farmer- 30%, marginal farmer- 26%, small farmer - 21%, medium farmer - 19% and large farmer- 4% for Kamarkhola union; and landless farmer- 25%, marginal farmer- 35%, small farmer- 17%, medium farmer- 13% and large farmer- 10% for Sutarkhali union (MoL, 2011). Livelihoods of the people are largely dependent on the resources available at the household level in terms of ownership and access to land. Land is considered as the major determining factor of socio-economy in the area. About 67.1% of the dwelling households depend on agriculture as a main source of household income with 45.0% on cropping, livestock, forestry and fisheries, 21.1% on selling agricultural labor, 12.9% on business, 4.9% on non- agricultural labor, 4.1% on employment and 18.1% on others.

3.4.4 Income and expenditure

The income and expenditure at the household level in the polder area is shown in Table 3.4. Annual income varies from BDT 12000 to BDT 240000.

Table 3.4: Income and Expenditure data

Range in BDT	Percentage (%) of households	
Upto 12000	8	5
12000 to 24000	25	20
24000to 60000	30	52
60000 to 10800	28	20
10800 to 240000	9	3
More than 240000	-	-

Source: (BWDB, 2013a)

3.5 Topography

Polder 32 is located in the coastal area which consists of extremely low and flat land (Figure 3.2). It is also located near the Sundarbans. The whole polder is surrounded by rivers. The elevation of the land varies within the range from 0.4 m to 4.34 m. Average land level is 2.12 meters above the mean sea level (MSL). The land of the middle part of this polder is comparatively low and gently slopes down towards Nalian and Sibsa rivers. The north-eastern and south-western sides of the polder have high elevation.

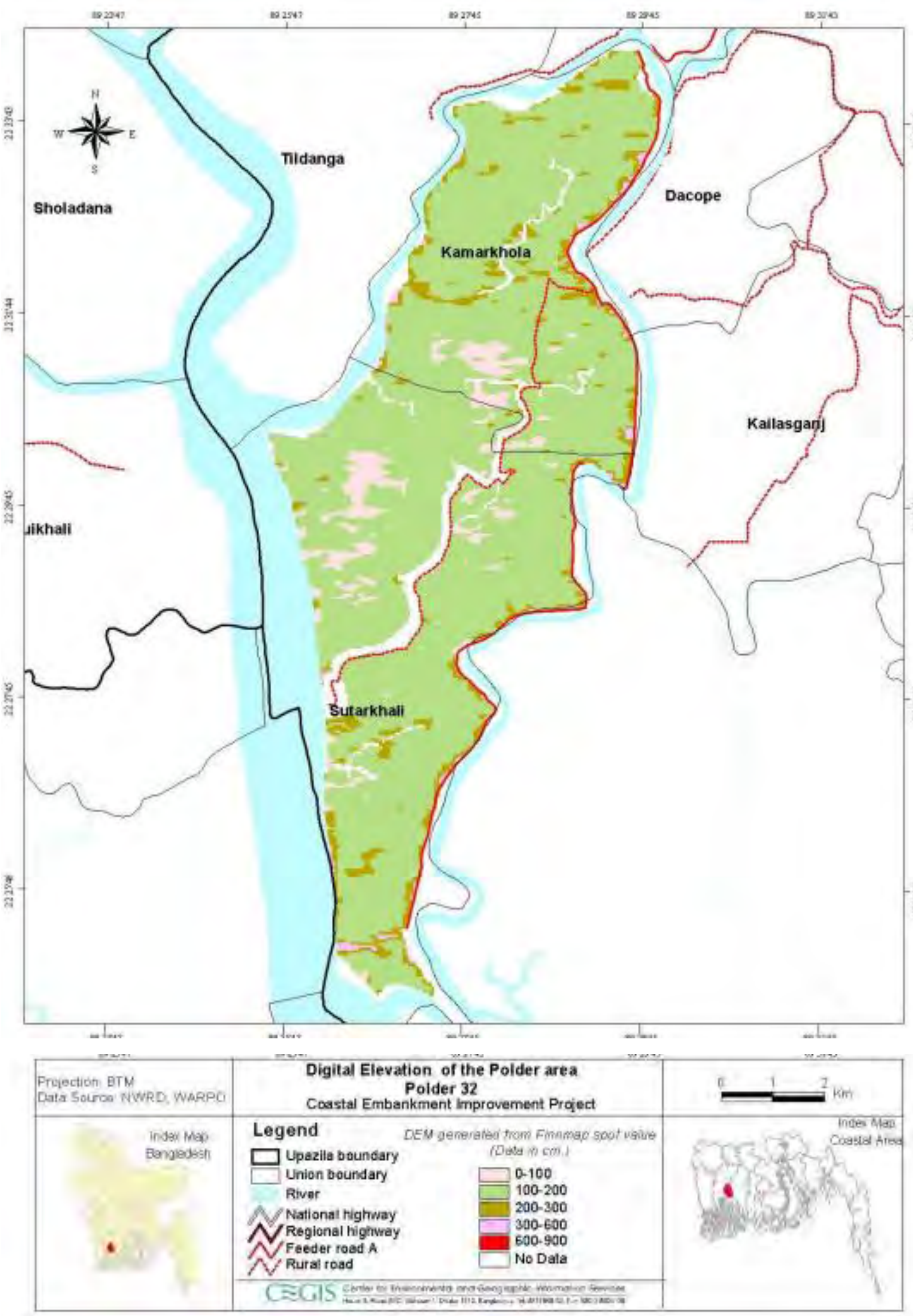


Figure 3.2: Land elevation of Polder 32 (BWDB, 2013a)

3.5.1 Land type

Land type classifications presented in Table 4.5 are based on depth of inundation during monsoon season due to normal flooding on agriculture land. There are five land type classes: F0- High land (Above flood level), F1-Medium highland (Flooding depth 0-90 cm), F2- Medium lowland (Flooding depth 90-180 cm), F3-Low land (Flooding depth 90-270 cm) and F4- Very lowland (Flooding depth >270 cm). The percentages of highland and medium highland are 44% and 56% respectively. Detailed land type is presented in table 3.5 below.

Table 3.5: Land type of polder 32

Land type	Area (ha)	% of NCA
High land (F_0)	2847	44
Medium high land(F_1)	3650	56
Medium Low Land(F_2)	0	0
Low land(F_3)	0	0
Very low land(F_4)	0	0
Total	6497	100

Source: (BWDB, 2013a)

3.6 Land Use

Kamarkhola union constitutes about one-third of the area (2921 ha) within polder-32, with a net cultivable area of 1900 ha (65% of the total area of the union), while Sutarkhali union constitutes about two-thirds of the area (4896 ha), with a net cultivable area of 2546 ha (52% of the total area of the union) (BBS, 2001). However, cropping patterns are dominated by *Aman* (monsoon) cropping and fisheries aquaculture in both unions, with a cropping intensity of about 104%, since dry season cropping is severely constrained because of high soil salinity during the dry season. Soil salinity ranges from high to very high (13-30 ds/m) in the dry season. In Kamarkhola the soil possess high to very high (13-30 dS/m) saline condition in the dry season and soil pH level ranges from 5.5 to 7.5. The area is dominated by agricultural crops such as *Aman*, *Boro* and some vegetables followed by fisheries and other activities. Present cropping pattern is shrimp bagda and white fish-*Boro*- *Aman*. In Sutarkhlai, the major land type of this union is medium high land. The soil possess high to very high (13-30 ds/m) saline condition in the dry season and soil pH level ranges from 6.5 to 8.5.

3.7 Farming Practices

The farming practices in polder 32 are complicated due to physical, biological, climatological and socioeconomic factors. The siltation of rivers and channels cause drainage congestion/water logging during monsoon. Natural calamities like cyclone and surge cause devastating crop damage within the study area. Scarcity of sweet water for irrigation during dry season is also responsible for the non-expansion of the agriculture farming practices. A limited variety of crops are grown due to unfavorable situation prevailing in the area. Rice is the main crop grown because of its adaptability in diversified ecological conditions.

3.8 River, Canal and Drainage System

The landscape of polder-32 has a combination of plain land, canals and beels. The polder is surrounded by Sibsa and Dhaki River to the west and North, Chunkuri, Bhadra and Sutarkhali River to the East and South. The surrounding rivers with tidal influence control the flood and drainage dynamics of the polder. These rivers act as both feeding channels and drainage canals for the small river Nalian that passes through the polder as well as a number of canals (Gulbonia, Oramukhi, Mistripara, Jaliakhali) within the polder. There are several small khals inside the polder namely Joynagar khal, Charar khal, para khal, Sahar khal, Kaynatoli khal, Samsur moktar khal, Clozarer khal and other khals linked with Nalian river, having tidal effects which flow from north to south and control the main drainage system and supplementary irrigation during monsoon. Kamarkhola khal works as major drainage channel for Kamarkhola union. The drainage network is shown in the figure 3.3 below.

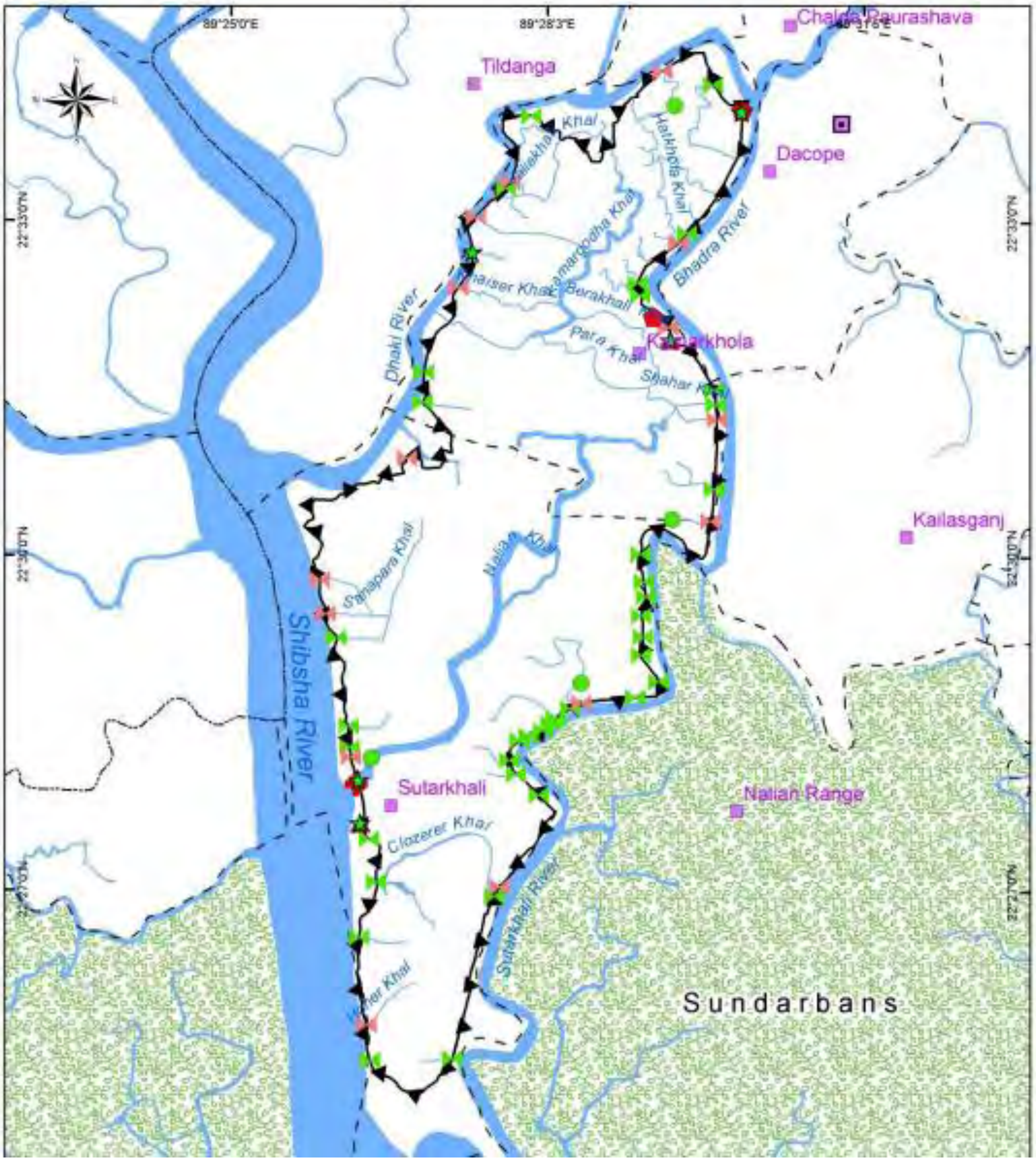


Figure 3.3**:** Canal network of polder 32

3.9 Natural Disasters

Tidal flooding, salinity intrusion and cyclonic storm surge are the major hazards in the area. The area was frequently affected by the cyclonic Storm Surges in the recent years. Details about the disasters and their affects in the area are presented in Table 3.6 below.

Table 3.6: Natural disasters in polder 32

Disaster	Year	Affected area (%)	Affected households (%)	Crop damaged (%)	Major damaged Crop
Tidal Flood	2007	80	50	90	Rice
Salinity	2007, 2009, 2011	90	90	98	Rice
Cyclone	2007(Sidr), 2009(Aila)	100	100	98	Rice

Source: (BWDB, 2013a)

Tropical cyclones and tidal flooding

Tropical cyclones are major threat to the coastal areas, causing loss of human lives and livestock and severe damage to crops, fisheries and properties. The recent most devastating cyclones hitting the south west coast under Khulna district were in 2007 (Sidr) and 2009 (Aila). These cyclones directly affected 70% people of the study area. Aila, the latest devastating cyclone hit the study area on 25th May 2009. At that time the water level on the study area from the ground was 3-5 feet. People reported that 15-20% of left bank of Sibsa River was inundated during this cyclone (BWDB, 2013a). During storms and cyclones, the short waves and storm surges are important morphologic factors. From 1901-1957 only 11 cyclones had hit the coastal areas of Bangladesh, while from 1957 to 2009 a total number of 55 cyclones have hit the area. So, in the last 52 years, the number of cyclones hitting coastal areas of Bangladesh has increased 5 times compared to the previous 57 years.

3.10 Water Management Problems and Issues in Polder 32

In the polder area, many segments of the embankment system are damaged mainly by overtopping due to cyclone and storm surges induced Sidr (2007) and Aila (2009). The river side slope in many places is subject to river erosion and damaged by wave action. There are 16 drainage sluices, 32 flushing inlet structures in Polder 32 (BWDB, 2013a). Many of the hydraulic structures are fully or partially damaged and are non-functioning. The gates are corroded by saline water and concrete surfaces of the structures are very much in deplorable condition. As a result internal drainage congestion was prevalent for long and also saline water enters into the Polder area. Moreover, construction of temporary embankment without regulators after Aila, poor maintenance of existing structures, the drainage canals cannot safely drain out the design discharges which ultimately cause drainage congestion inside the polder area.

3.11 Food Security

Poverty and food insecurity is widespread in polder 32 after Aila in 2009. More than two thirds of population are originally poor, and consuming 2122 Kcal/person/day or less (UN, 2009). More than half (55%) population are extremely poor and food insecure, consuming 1805Kcal/person/day or less. The impact of Aila on household food security is particularly severe as a major percentage of household in those cyclone affected areas were already suffering from high poverty and food insecurity as indicated above. Moreover, these households had experienced the impact of cyclone Sidr and high food price shock in 2007 from where they had yet to recover fully. The household level food insecurity was chronic as they were having less number of meals in a day after Aila. Beside this Aila induced inundation and poor soil quality affected the crop production and food availability at household level. Long term inundation and sufferings of people in terms of reduced livelihood and income affected the economic access to food for different vulnerable livelihood groups. A number of households found to be starving immediately after Aila until they got relief from different government and non-government agencies.

CHAPTER FOUR

METHODOLOGY

4.1 Introduction

The study followed an interdisciplinary approach, looking at and integrating the technical dimensions associated with storm surge hazard, such as area, depth and duration, and the socio-economic dimensions of different livelihood communities of the study area. Cyclone "Aila" of 2009 was considered as the base event. The methodology consisted of two parts: delineation of the storm surge inundation depth and duration; and assessment of impacts of both short-term and prolonged inundation upon different vulnerable groups and thereby impacts on food security. Four field visits from 2014 to 2015 (each of four to five days" duration) were conducted to gather relevant data and information to complete the study. The conceptual framework of the study is shown in Figure 4.1 below.

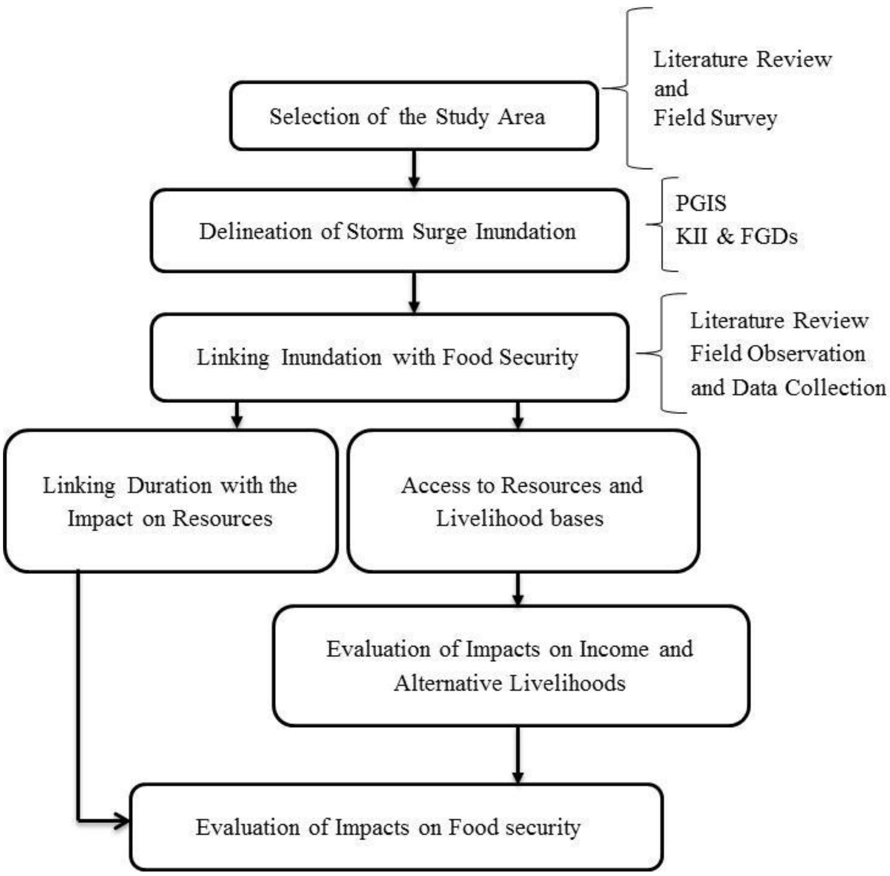


Figure 4.1: Framework of the study

4.2 Selection of the Study Area

There were some considerations in the study area selection process. The south-western part of the coastal region of Bangladesh was selected as a study area primarily because of the vulnerability of this area due to the frequent cyclonic storm surge. During previous devastating cyclones a number of coastal districts were inundated and caused serious damages. Cyclone "Sidr" in 2007 and "Aila" in 2009 are the most recent devastating cyclones that destroyed the lives and livelihood of the coastal community. Among this Cyclone Aila in 2009 was most devastating for which people suffered from substantial prolonged impact in addition to immediate impact. Dacope upazila of the Khulna district was the worst victim of Aila and among the three polders in Dacope polder 31, 32 and 33, polder 32 faced massive destruction and people were impacted more. In view of the above consideration, polder 32 of the Dacope upazila was selected as the final study area.

4.3 Methodology of Inundation Mapping by PGIS

Flood hazard maps are important tools for understanding the hazard situation in an area. The production of flood hazard map for any area using conventional methods and approaches (engineering and surveying) is an expensive and time consuming task and sometimes not viable in some places. In this context, this research was carried out to take advantage of Participatory GIS (PGIS) to produce acceptable and realistic storm surge hazard maps, that delineate the depth, duration of inundation and the areas subjected to prolonged inundation.

Participatory GIS (PGIS) is widely used in flood mapping (Jayasinghe *et al.,* 2013). It is an emergent practice in its own right, developing out of participatory approaches to planning and spatial information and communication management. The practice is the result of a spontaneous merger of Participatory Learning and Action (PLA) methods with Geographic Information Technologies (GIT). PGIS combines a range of geo-spatial information management tools and methods such as sketch maps, Participatory 3D Models (P3DM), aerial photographs, satellite imagery, Global Positioning Systems (GPS) and Geographic Information Systems (GIS) to represent people‟s spatial knowledge in the forms of virtual or physical, two- or three-dimensional maps used as interactive vehicles for spatial learning, discussion, information exchange, analysis, decision making and advocacy. Participatory GIS implies making Geographic Information Technology (GIT) available to disadvantaged groups in society in order to enhance their capacity in generating, managing, analysing and communicating spatial information.

This study demonstrates the use of PGIS methodology adopted to collect and integrate the community knowledge and the capability to develop reliable and realistic storm surge inundation maps of different time period from 2009 to 2011. Some PRA tools like focus group discussion; Key informant interview etc. have been used to facilitate the PGIS process in gathering information regarding the depth and duration of storm surge inundation for mapping. In this regard open source GIS technology was used for the digitization of the spatial data and preparation of the maps.

4.3.1 Preliminary field observation in the affected area

At the first stage of the study a reconnaissance survey was conducted in the study area to know the location, its geographic features and most importantly its suitability as study area for this specific study. Also it was done to get the initial impression of the study area in order to facilitate the research techniques. In this study the exiting footprint of Aila, its impact that people still facing, the lives, different livelihood groups, livelihood pattern and the adopted process regarding securing food for all were considered specifically.

4.3.2 Preparation of the base map

In PGIS mapping process there is a need for some forms of base maps that help to provide background details necessary to facilitate the data collection process from the local community using those maps. The Google earth image of the study area, the land use map collected from ESPA Deltas project of IWFM, BUET, the LGED Upazila map showing the word/units of the study area have been used as base maps which participants used as a reference to derive information about the depth and duration of storm surge. Also participants were allowed to draw on the maps to describe about the storm surge scenario in the study area, to locate the breaching locations together along embankment with the areas subjected to prolonged inundation. Photo 4.1 shows the PGIS exercise carried out in the field.

Photo 4.1: PGIS exercise carried out in polder 32 to map inundation depths and durations

Process of data collection for inundation mapping

To cover the whole area during the data collection process and for the ease of data and information collection on different places of polder 32, the whole needed to be divided into small parts. The base map was divided into a number of grids and the latitude and longitude of the grids were noted to reach that point and for collection of information of the inundation depth and duration at those specific locations. A combination of methods and processes were used for primary data and information collection. The principal methods used were semi-structured interviews (Photo 4.2), KII (Photo 4.3), and FGDs (Photo 4.4). The base maps were used in the data collection process. A set of checklist was prepared considering the research objectives and main research questions. Areas of concern for checklist preparations were:

- Inundation process during storm surge
- Spatial and temporal variations of the inundation depth
- Major damaged and breached location of the polder
- Polder rehabilitation process

Photo 4.2: Individual (semi-structured) interviews conducted at different locations of polder-32 with different groups of local people

Photo 4.3: Key informant interview conducted with local BWDB Engineer

Photo 4.4: Focus group discussions (FGDs) conducted at different locations of polder-32 with different groups of local people, including women

Data base preparation

Database including all information was required for map preparation. The collected information corresponding to the latitude and longitude of the grid point was arranged and a tabular database was prepared using MS Excel 2013.

Digitizing of data and map preparation

In the next step, the information was digitized and hazard maps have been prepared for different time periods from 2009 (the year when cyclone Aila hit the southwest coastal zone) to 2011using Geographic Information System. In this digitization process the prepared database in Ms Excel format was used as input data, which were converted to shape file in GIS environment. The shape file of polder 32 with proper geographic coordinates and references was added as another layer as the boundary of the study area. To convert the inundation values in a more comprehensive visualizing surface the inundation data was interpolated within the boundary of polder 32. The Kriging interpolation process was followed for the interpolation. Following the same procedure color ramp inundation maps were prepared for the year 2009, 2010 and 2011 which significantly describe the depth and duration of inundation at different years. The use of PGIS helped in establishing the links between inundation (both short-term and long-term) within the polder with different factors, including polder overtopping and breaching, siltation in drainage channels, rehabilitation process of water control structures and polders. Maps were then used to link the biophysical factors with the losses over different sectors such as agriculture and fishing, shrimp cultivation etc.

4.4 Validation of the Prepared Maps and Databases

Verification by local people

The prepared maps were further verified by the local people and required corrections were made accordingly. Then the database was changed accordingly and maps were updated using the changed data.

Verification with DEM

Inundation maps were verified using 30 m DEM to compare the inundation scenarios with the elevation profile of the location.

Verification with breaching location

Locations of the embankment breaches were identified during PGIS mapping followed by visit to the breach locations. Also Landsat images were used to verify the locations of the breaches. The areas subjected to higher degree of inundation were identified by PGIS mapping and were compared with the breaching locations.

4.5 Linking Inundation with Food Security for Different Vulnerable Groups

4.5.1 Identification of vulnerable groups

Livelihood groups presented in the study area were identified by reviewing some key literature regarding livelihood activities. Beside this, dominating livelihood groups and their income generating activities were identified from direct field investigation. From the collected information dependency of different livelihood groups on different activities were analysed to investigate the impacts of inundation to the livelihood system of different vulnerable groups.

4.5.2 Linking inundation with impacts on different vulnerable groups

To identify the impact of inundation over different vulnerable groups, duration of inundation had to be linked with the impact. The long term losses of inundation on different sectors was calculated using the inundation maps and the land use maps of the study area specially for the agriculture and fishing sectors. Along with this, a relationship was developed which show the long term impact of inundation on different vulnerable groups. For this duration of inundation was linked up with the access to resources and its consequence towards the livelihood activities of different vulnerable groups. Many primary data about the impact of prolonged inundation was collected through conducting group discussions and FGDs with different groups during field visits. Twenty FGDs with farmers, fisherman, wage labourer and Sundarban dependent people were conducted in this regard. Preparation of checklist involved the impact on resource bases like agriculture and fishing activities and the impact on the livelihood of those people who are directly dependent on the Sundarban for their income.

4.5.3 Selection of food security indicators

Based on the understanding of the field information regarding the prolonged impact of inundation on the resources, access to resources and livelihood activities which were derived from the FGDs, some food security indicators were selected that are directly linked with the duration of inundation. For the indicator selection process, FAO food security dimensions i.e., availability, access, utilization and stability were followed. Income, Percentage of household income to food was considered under the food access, household food production, dietary diversity and unit was considered under food availability. Also the loss of cropping seasons and the loss of livelihoods were considered under the stability of the food production and purchase system was considered for food security assessment. Information regarding the changes over these indicators was collected from the field linked with the duration maps of inundation.

Impact identification

Before developing food security assessment framework, the first step is subsequently link duration of inundation with impacts with a number of physical and socioeconomic resources. Resources of inundation on different livelihood groups were required. Some core sectors were selected, which were considered important for food security. These are:

- Physical or natural resources
- Social resources and
- Household resources

Impacts of inundation on the access to the above mentioned sectors were analysed. Field information was collected by FGDs and KII to assess the impacts on different resources. Six key informant interviews were conducted in this regard. Subsequently impacts were linked with the duration. Another step of analysis was the evaluation of livelihood and alternatives after the prolonged duration of inundation. Also impacts on the livelihood was identified from FGDs and unstructured interviews. A set of checklists were prepared focusing the impacts on livelihood bases, livelihood alternatives, income etc. Main indicators or dimensions of food security were identified based on field information that has link with the above mentioned resources. The changes of the food security indicators like household production, economic access to food etc. with the reduced access to different resources were calculated for the analysis of the impacts of inundation to the food security. Field information was collected using PRA tools and a set of checklist was prepared focusing the changes of the food security indicators like, change in household food production, availability, income from alternative livelihoods activities, economic access to food etc.

CHAPTER FIVE
BIOPHYSICAL FACTORS OF STORM SURGE AND ASSOCIATED IMPACTS

5.1 Introduction

As stated in chapter one, the objective of the study was to delineate the storm surge inundation for “Aila” at different years and its impact on the food security of different vulnerable groups. This chapter represents the inundation scenarios in different years after Aila by Participatory GIS (PGIS) mapping together with applying some PRA tools.

5.2 Storm Surge Inundation Due to Cyclone Aila

Cyclone Aila struck the West Bengal, India and south west Bangladesh on 25 May 2009. The storm was classified as Category 1 (wind speed of 75 to 120 Km per hour), yet the devastation in the south west coastal area within the polders was substantial. The principle reason was embankment failure in the form of breaches, which led to repeated tidal flooding. The fact that embankment breached at storm surge height just 0.5m above the spring tide level (Auerbach et al., 2015), points to the very weak pre-existing embankment conditions, for which embankment could not give protection. Auerbach et al. (2015) theorizes river bank erosion in the previous decade and scouring of breached tidal channels into fine sands as possible causes for breaching.

5.2.1 PGIS mapping of depth and duration of inundation

Participatory GIS (PGIS) mapping of inundation in polder 32 subsequent to the Aila event and a few years since the cyclone is shown in Figure 5.1. The figure shows the submergences of the areas at different time periods of year 2009, 2010 and 2011. Even though Storm surge Aila occurred in May 2009, it was evident that the inundation was prolonged for more than two years in some parts of the study area, as the areas were exposed to regular tidal inundation through the embankment breaches up to August 2011 until rehabilitation of the polder took place. Different areas of the study area were inundated at different depths and durations.

After a year of Aila in 2010, water receded from many parts of Kamarkhola union by natural drainage after construction of the closure (reconstruction of the damaged part of polder) in March 2010. But some areas of Kamarkhola and most parts of Sutarkhali were still inundated up to August 2010 (Figure 5.1). PGIS map suggested that some of these higher elevated areas (e.g. Jaliakhali and Gulbonia wards) were inundated and were waterlogged till 2010 (Jaliakhali) and 2011 (Gulbonia). As there were a number of natural and man-made depressions in Sutarkhali union, some of the depressed areas were in waterlogged condition up to year 2011, and it was only possible to get Sutarkhali union water free after more than 2 years of Aila when the local communities constructed small drainage channels.

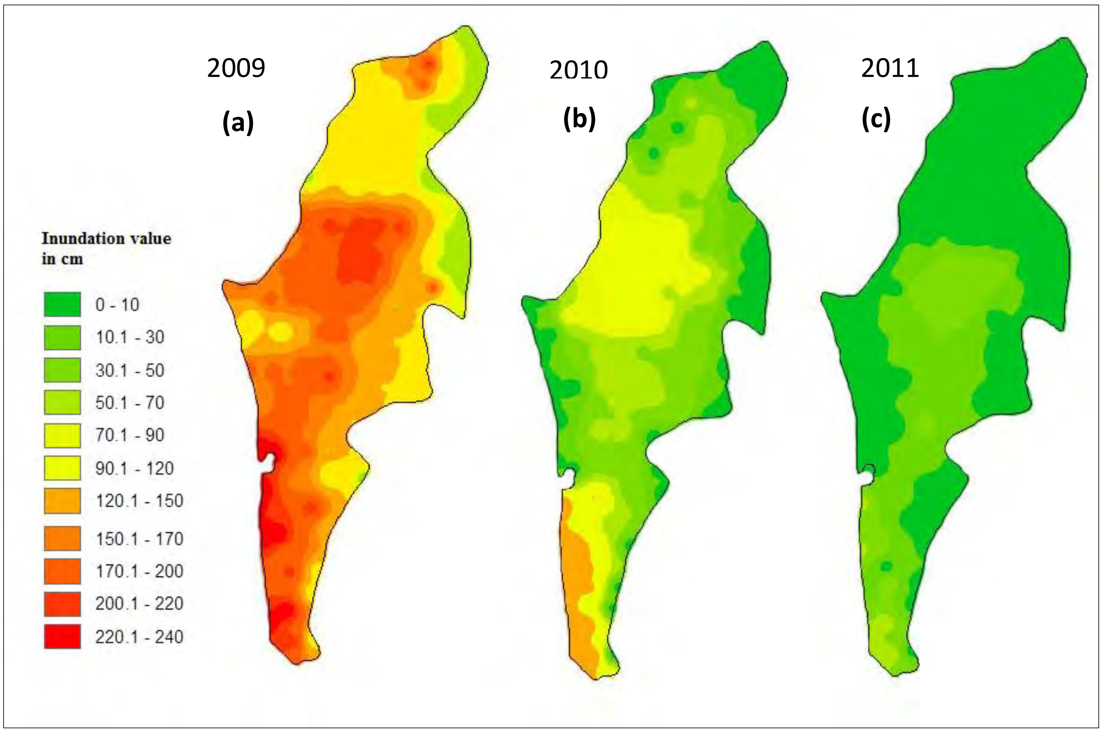


Figure 5.1: Area inundated due to cyclone Aila from 2009 to 2011

5.2.2 Overtopping and breaches in the embankments

From the field information it was found that more than 80% of polder 32 was inundated during Aila, and the areas were completely submerged under salt water for more than six months. It was found that the area of the polder 32 was inundated immediately by the overtopping of the polder at few locations. However, the failure of the embankment in forms of embankment breaches was a major contributor of immediate inundation impact as well as repeated tidal flooding over long periods.

Five breach locations including three major and two minor (shown in Figure 5.2) were identified during field visits. Major breach locations were found near Jaliakhali, Gulbonia, Vitevanga, Nalian and near Kalabogi. Photo 5.1 shows four such locations at Kamarkhola and Sutarkhali. The locations more or less matched with the locations identified in the study carried out by Auerbach et al. (2015). Identification of breach locations allowed relating the prolonged inundation shown in Figure 5.1 with the breaching of the polder.

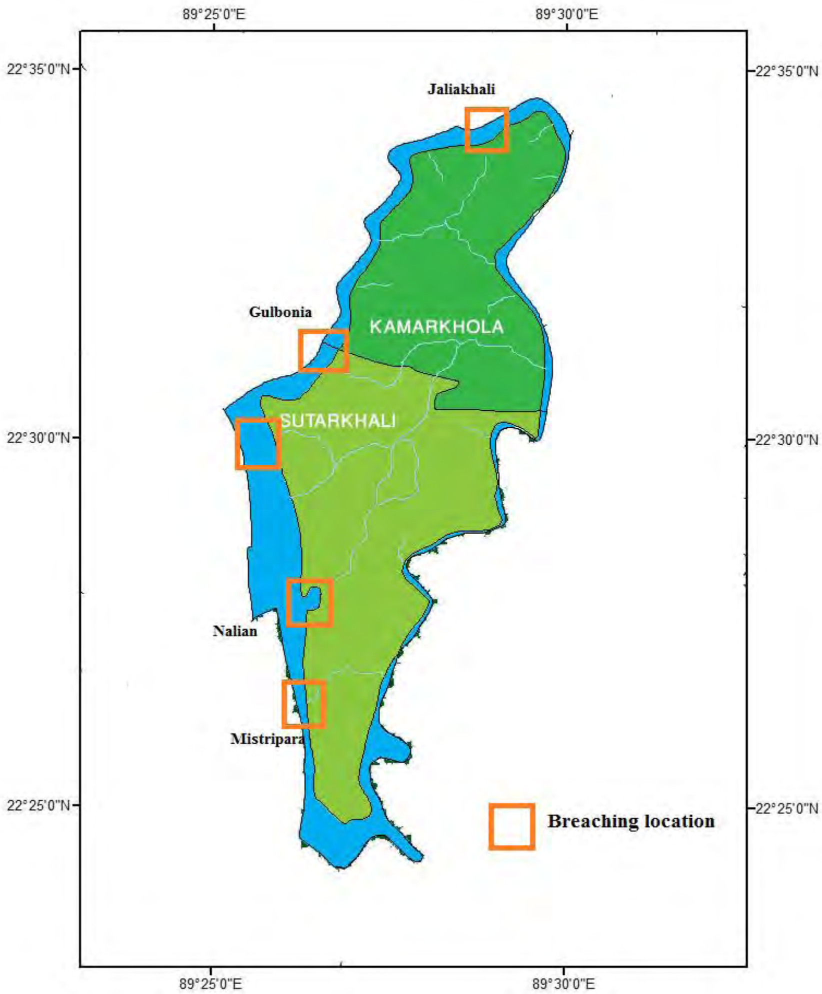


Figure 5.2: Polder breaching locations

Exact mechanism of failure at the breaching locations remains uncertain. During field visit, it was found that, the mouths of former tidal channels blocked by the embankments were previously weak to some extent. When the Aila hit the coastal area, these already vulnerable locations could not withstand the high velocity of surge water, leading to breaches. Also, all breach sites had experienced 50 to 200 m of riverbank erosion in the decade before the storm, as analyzed by Auerbach *et. al.*(2015). Within months after the storm, repairs by local people had closed several of the breaches, but inadequate construction led to nearly complete failure again in early 2010 (Auarbach et. al., 2015). Local people informed that, immediately after a month after Aila, people made temporary embankment at some breaching locations to save their settlements and agricultural lands from being inundated. But the temporary embankments were not sufficient to counteract the regular tidal wave action twice in a day. Thus consecutive failure occurred at that locations and continued the inundation of the area.

Photo 5.1: Breach locations (Sutarkhali on the left and Kamarkhola on the right)

5.2.3 Erosion at breach mouths and internal drainage canals accelerating inundation

Comparison of the inundation map in Figure 5.1 and the breach location map in Figure 5.2 reveals that the areas surrounding the breach locations were found to be of higher inundation depth and duration. Also, when compared with the Digital

Elevation Model (DEM) map as shown in Figure 5.3, it is clear that there were some places that are in higher elevation but were subjected to higher depth of inundation. For example, some parts of Jaliakhali were faced greater depth of inundation with longer duration, despite of being in higher elevation. On the other hand, Gulbonia, which is at a relatively lower elevation, also experienced greater depth of inundation. Field investigation revealed that these areas, being adjacent to the polder, experienced substantial scouring as a result of breaching in the polder (such location is shown in photo 5.2). Substantial scouring at the toe of the polder and erosion at the breach mouth made large depression near the breach locations; the process was enhanced by continuous inundation of the area through the breach points twice a day for regular tidal action. The DEM map also suggests that except the higher elevation areas there were some natural depressions, which where water logged for more than a year.

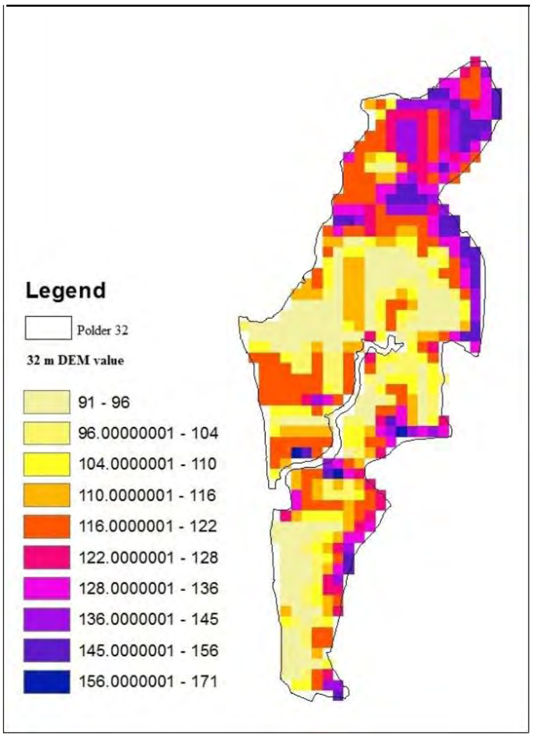


Figure 5.3: DEM map of the polder 32 (Source: CEGIS)

Photo 5.2: Erosion at breach location leading to continuous inundation after embankment damage

Field information and interview with the local people revealed that 18 to 24 months had passed before most of the breaches were soundly repaired. During the roughly 2-year period before repairing of the embankment, much of the poldered area was submerged on each high tide twice in day. Regular scouring of earthen embankment caused erosion of the bed materials which caused the enlargement of the breach sites. Although the breaching locations were mended by constructing closure, the consecutive failure of the closures made these areas even weaker and accelerated further breaching and inundation.

Besides scouring of the aforementioned breaching locations, there was substantial scouring at the both banks of the Nalian river, and the huge tidal action caused enlargement of the mouths of a few channels connected to the Nalian river. This secondary breaching caused the blockage of the inner khals (small canals) which disrupted the drainage functions of the canals. This was also found to be a major reason behind the persistent inundation at left bank of the Nalian river.

5.2.4 Widening of breaching width

From the interview with the key informant from BWDB, it was found during the study that as the time elapsed, with the post storm erosion responses, the breaching location enlarged up to 6 times the initial width (Table 5.1). The table also shows rapid widening of the mouths of the channels connected to the Nalian river, the main drainage canal inside the polder. Situation worsened, while the scouring at the toe of the polder accelerated and deepened the breaching location. Beside this aforementioned fact, human intervention like inserting pipe for saline water intrusion caused the weakening of the geological formation of polder which caused accelerated breaching. Also, variations of breaching width also found due to the inconsistency of polder geological features at different locations. Later on, it became more difficult to rehabilitate or reconstruct any water control structure at that place. As a consequence, people suffered from inundation of the human settlements for more than six months, inundation of agricultural land by salt water for more than 2 years, reduction of net cultivable land of 850 hectares due to erosion at the breaching locations. Agricultural lands were submerged for longer duration of time. The submergence of agricultural lands increased with the rehabilitation time that significantly reduced the access of the people to productive resources (land). Until the infrastructural renovation fully settled the restoration of the productive use of the land like crop cultivation and livelihood activities were not possible.

Table 5.1: Enlargement rate of breaching widths

Breaching	Initial Width(m)	Width During Repairing(m)
Vitevanga	20	120
Jaliakhali	60	80
Nalian	10	60

5.2.5 Silting up of drainage canals

The continuation of the inundation of the polder caused the sedimentation and the siltation within the polder and in the bed of the internal drainage channels. The sediment came with the regular tidal flow along with the eroded materials from the embankment was deposited at the bed of the channels. The Kamarkhola canal is one of the main canals for drainage of Kamarkhola union (Figure 5.5). This canal was blocked at its tail end. Thus the entire Kamarkhola village was under water as the tidal water entered into the polder and logged in the depressions. Also, before Aila the drainage performance of the canals was not satisfactory. But after Aila, the area remained open for tidal inundation by the breaching at Kamarkhola canal, conveying sediment-laden water into the polder. With the greater frequency and depth of inundation caused by the polder's low elevation, accelerated sedimentation rates led to an average of 37 cm of deposition in the two years following the storm, with many sites as high as 60 to 70 cm (Auerbach, et. al., 2015). The high rates of sedimentation following embankment breaches also blocked some other major canals that restricted the normal drainage of storm water. Nalian is the major river that passes through the middle of the Sutarkhali union connecting with others drainage canals of this area and act as major drainage for Sutarkhali. But river bank erosion of Nalian and the resulting sediment deposition and blockage at the connecting channels (Clozerer canal) rendered the drainage system inoperable as shown in photo 5.3 and figure 5.5. Also, Figure 5.4 shows the inundation by sediment laden water until the embankments were not rehabilitated. Substantial accumulation of the sediment in the floodplains did not happen immediately; rather it took a number of years.

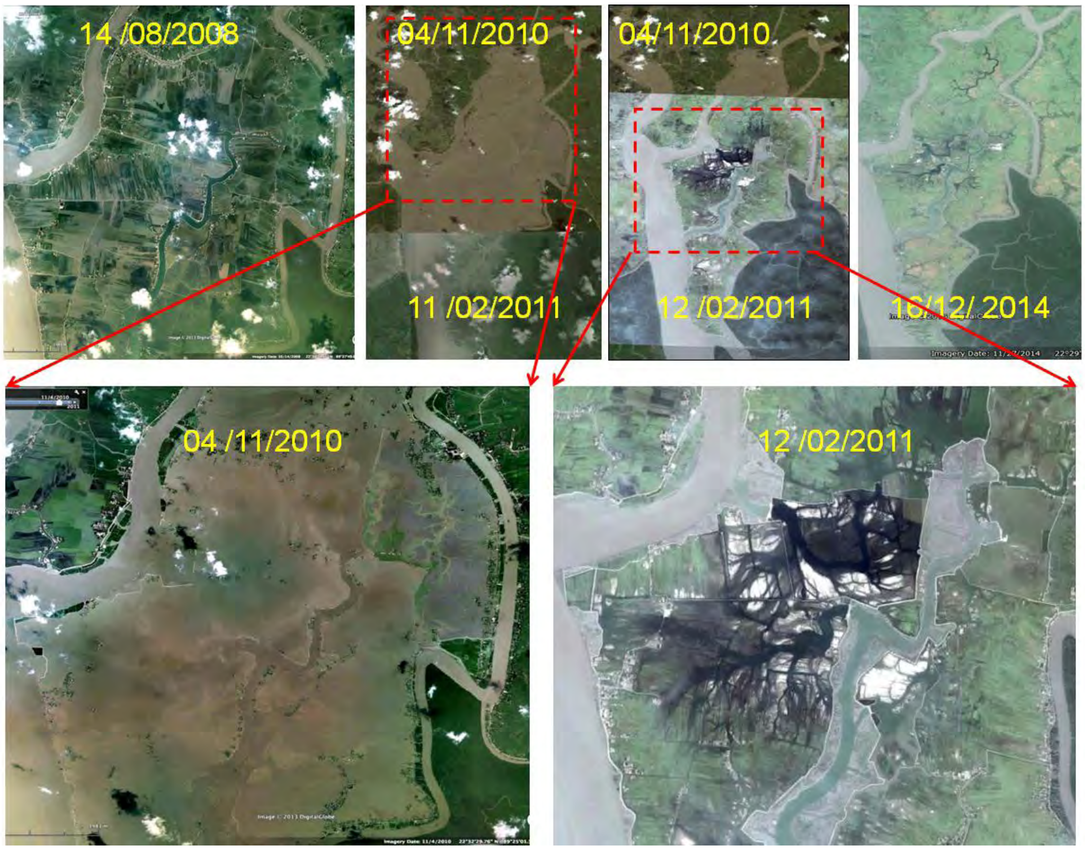


Figure 5.4: Satellite images of polder 32 for different time period (pre and post Aila)

Photo 5.3: Blockage of drainage sluice gate at Kamarkhola

Figure 5.5: Drainage canals of polder 32

5.2.6 Man-made interventions leading to enhanced inundation

The diversified land use practices, including crop cultivation, fish cultivation, and shrimp cultivation along with some man made interventions on the existing embankment had a combined effect on the prolonged inundation at a few locations of the polder. The agricultural land was used for sweet water fisheries beside crop cultivation. Also, there were some lands which were only used for shrimp cultivation. Those lands are normally lands with low elevation. Because of the delayed rehabilitation of the polder and the embankments the lands were regularly inundated and the water got logged in the depressed areas. It was observed from the inundation maps of different years (Figure 5.1) that, the areas that had been used as shrimp ponds were subjected to longer duration of inundation. As drainage condition of the internal channels deteriorated, the monsoon rain water was also locked in the depressed areas. Mostly the Sutarkhali union of the study area had the highest number of shrimp ponds and faced higher percentage of the submerged area and longer duration of the inundation [Figure 5.1 and Figure 5.7(a)].

The polder near the shrimp ponds was previously weak at a few locations as there were some human interventions on the polder to bring salt water into the shrimp ponds. Local people stated that shrimp cultivators used to cut the embankment and insert pipe for salt water intrusion which made that locations weak for resisting storm surge. After the Aila had hit, the damage and the breaching of the Polder at those locations were prolonged. Comparing the land use map and the inundation maps (Figure 5.1) reveals that the area used as shrimp ponds were inundated for longer period of time. Also areas close to the five breaching locations (Figure 5.2) were used for shrimp cultivation.

5.2.7 Delayed rehabilitation of polder aggravating inundation

Aila hit the coastal polder on May 25, 2009. Immediately after Aila the whole area remained open for continuous inundation by daily tide. As the rehabilitation and reconstruction of the polder took more than a year, areas were exposed to regular inundation during high tide and became water logged in some natural and man-made depressions. Until the water receded at a certain amount the rehabilitation process could not be started. BWDB started polder rehabilitation programme under the coastal embankment rehabilitation programme by World Bank at 2009. Polder rehabilitation i.e. the repairing of the broken embankment and the reconstruction of the sluice gate started in November of 2009. An eight vent regulator was washed away due to the breach at the mouth of the Nalian river, with rapid widening of the opening in the embankment (original location of the regulator can be seen in Photo 5.4. Construction of the sluice gate or regulator at that place was not immediately possible due to creation of deep depression at the breaching locations. From key informant interviews, it was learnt that construction of 3.2 km of retired embankment at the mouth of Nalian river was done in the first phase of the rehabilitation programme in 2009. However, by the time the retired embankment was in place, the breach location had widened 6 times the original breaching width. So having the area free from water was too difficult a task at that time. BWDB then went for constructing ring embankments at both sides of the Nalian river.

Photo 5.4: Location of 8-vent regulator which was washed away at Nalian

In the meantime, renovation of several water control structures was completed in the rehabilitation programme to improve the drainage condition of polder 32. Also six new flushing cum drainage sluices were constructed at Jaliakhali, Joynagar, Gulbonia, Gunari, Kalaboti and Sutarkhali (locations are shown in Figure 5.6; one such new sluice at Sutarkhali is shown in Photo 5.5) between 2009 to 2011 to get the area free from submergence. Despite massive reconstruction efforts it took more than a year to reconstruct and repair the damaged polder and damaged water control structures. The newly reconstructed embankments faced consecutive failures due to regular tidal exposure which made the recovery process even slower. The whole area was exposed to the tidal inundation for around two years. To completely rehabilitate this polder area from inundation during tide every day, a number of closures were constructed at the breach locations of the polder.

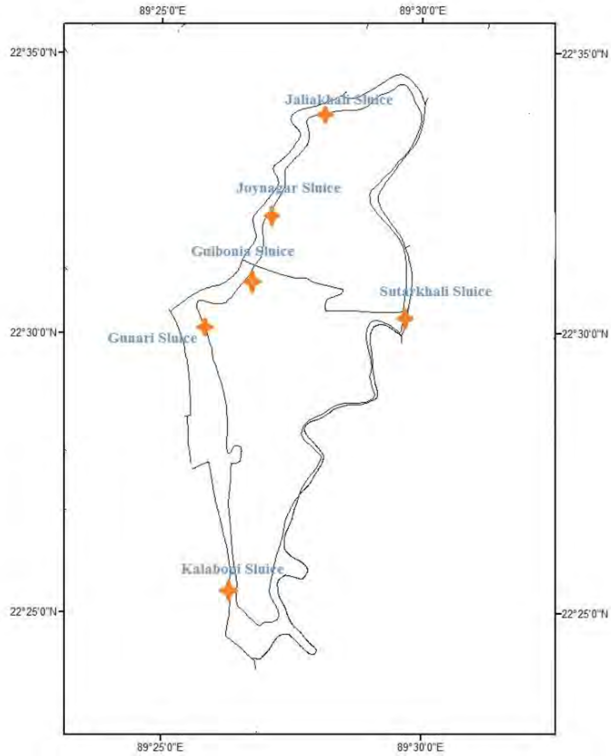


Figure 5.6: Locations of newly constructed sluice gates

Photo 5.5: Newly constructed sluice after Aila at Sutarkhali

5.3 Aila Leading to Land Use Change

From the land use map of 2014 [Figure 5.7(a) and 5.7(b)] it was observed that the shrimp cultivation was reduced compared to 2009 (before Aila). But in Sutarkhali union the shrimp cultivation increased because of degradation of quality of agricultural lands. Also there were some natural depressions in this area which encouraged the people to cultivate shrimp. There were very few places in Kamarkhola union where people cultivated shrimp previously. But after the shock of embankment failure during Aila people were discouraged to allow water in the polder for shrimp cultivation. Also the Aila induced siltation and sedimentation in the land increased the soil fertility which further encouraged farmers to cultivate crop rather than shrimp. Also before Aila i.e. before 2009, there were many shrimp ghers near both banks of Nalian River. In that time cultivation of shrimp was viable.

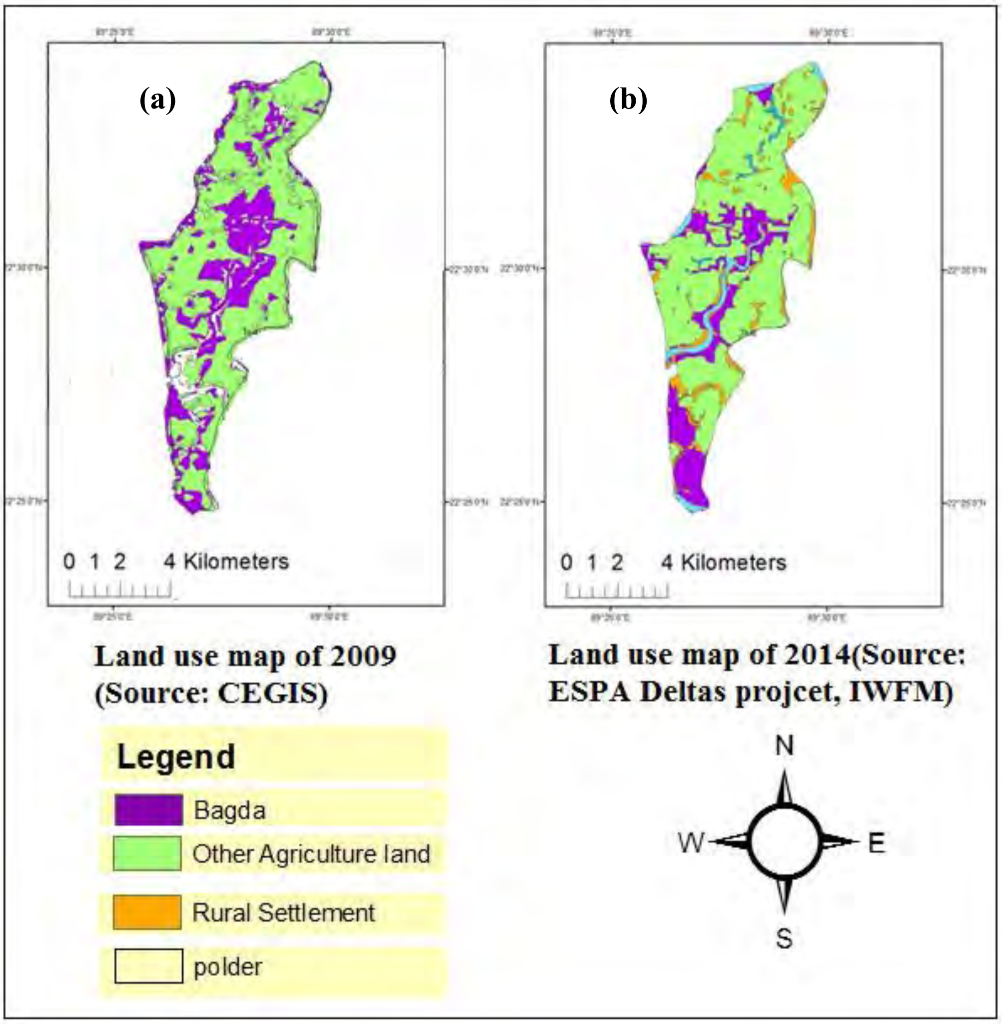


Figure 5.7: Change in Land use from 2009 to 2014

But after construction of the embankment at both sides of the Nalian river there was no provision for bringing salt water inside the polder. Also many pre-existing shrimp ghers were inundated and destroyed by the breach of the Nalian river bank. High investment cost furthermore discouraged construction of shrimp ghers in that area.

Percentages of land use changes from year 2009 to 2014 were calculated and are shown in the Table 5.2 below. It is observed that shrimp cultivation significantly decreased in Kamarkhola and increased in Sutarkhali. The reason behind the reduction of shrimp cultivation in Kamarkhola, as discussed previously, is the less provision of bringing in salt water. Many people of Kamarkhola back to agricultural practices as they faced the negative impact of embankment breach during Aila.

Table: 5.2 Land use change calculation from 2009 to 2014

Year	2009(Before Aila)		2014(After Aila)	
Union	Agriculture (%)	Shrimp (%)	Agriculture (%)	Shrimp (%)
Kamarkhola	89.15	10. 85	94.72	5.28
Sutarkhali	86.13	13. 87	83.34	16.66

CHAPTER SIX

IMPACT ON DIFFERENT VULNERABLE GROUPS AND FOOD INSECURITY

6.1 General Concepts

Due to the physical factors associated with storm surges, including area, depth and duration of inundation as represented in chapter five, some impacts are immediate in nature and some are prolonged. The impacts also vary across different vulnerable groups who experience different degrees of vulnerability to food insecurity. The impact on food security has been severe resulting from continuous inundation of agricultural fields and fish farms (e.g. shrimp ghers) for long periods with saline tidal water. Such findings are discussed elaborately in this chapter.

6.2 Vulnerable Livelihood Groups

The concept of livelihood and livelihood activities are dynamic because of the condition and composition of the livelihood resources. Due to the constraints associated with availability of different resources the livelihood systems are more diversified in the coastal areas. Field visits to different places in polder 32 and the information collected from different groups of people through a variety of PRA methods revealed that livelihood in the study area includes a range of occupation and activities, such as, farming, fishing, wage laborer, Sundarban dependent livelihood like e.g. golpata collection, crab fry collection etc. The livelihood in Kamarkhola union of the study area is mostly agriculture (crop cultivation) dominated. People of Sutarkhali union also practice crop cultivation except the most southern part, which is completely fishing dominated area. Percentage of Sundarban dependent groups are higher in the Sutarkhali union compared to the Kamarkhola union. Livelihood groups are continually being vulnerable by cyclonic storm surge and its damages. Continuation of the inundation over the years has altered the livelihood system and symphony of the study area.

6.3 Economic Activities of Different Livelihood Groups to Attain Food Security

To meet the basic requirements and household demand, different groups of people adopt different activities to secure livelihood and food all-round the year. The possible economic activities for livelihood and food security for different groups were derived from in depth interviews and focus group discussions with the people of the study area. The percentage of dependencies of different groups of people on different livelihood activities is shown in the diagram below:

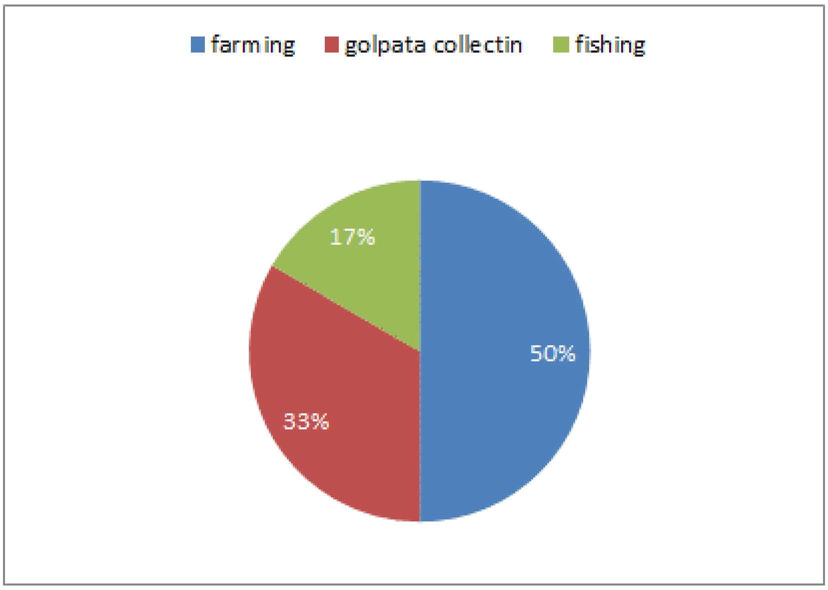


Figure 6.1: Economic activities of farmers

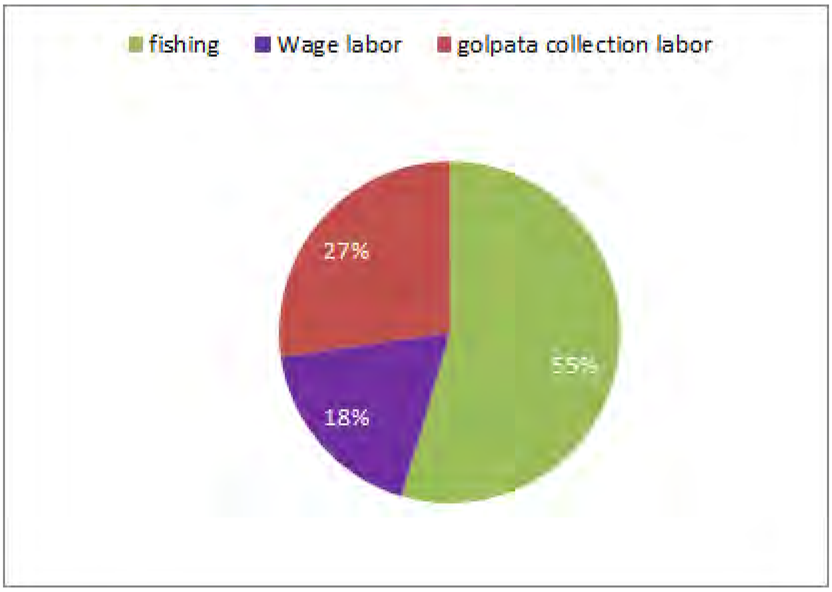


Figure 6.2: Economic activities of fishermen

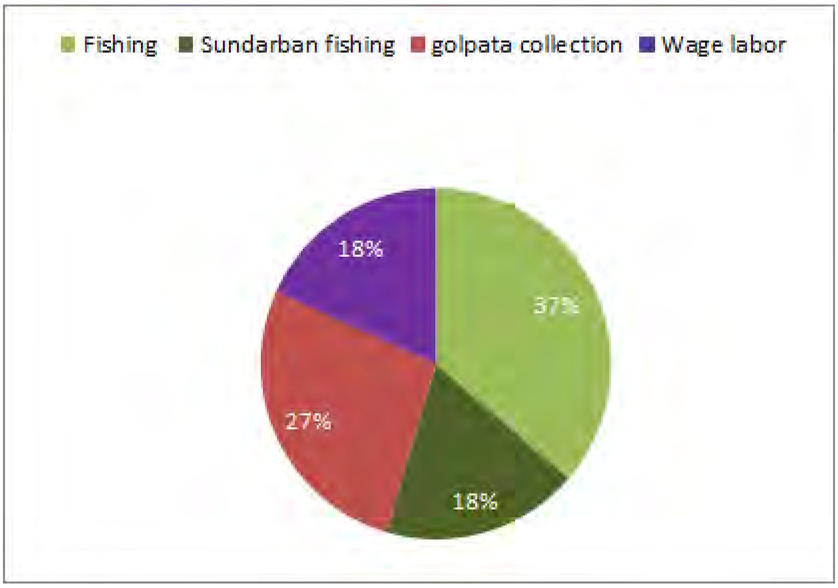


Figure 6.3: Economic activities of Sundarban dependent people

Almost 50% of the time of a year, farmers earn their livings from farming activities. The farmers mainly cultivate their lands in *Aman* season (Figure 6.1). They practice farming activities for a maximum of six months. During rest of the months of the year they depend on other livelihood activities. Mostly the large farmers have one or two fishing boats and Golpata collecting boat. From October to March is the golpata collection time in the year. Within this time, boat owners (mainly large farmers) of the Sutarkhali union use their boats for golpata collection and spend about three to four months in the Sundarbans. There are few large farmers who had income sources from business in the urban area. The marginal and small farmers constitute the majority of the golpata collectors (golpata labor) in these boats. At least four golpata loaded boats are traded in the local market. During rest of the time of the year (almost 2 months), farmers are engaged in traditional fishing activities. Besides, some small farmers have some small businesses like shops in the local market. The fishing community is mainly dependent on catching fish and selling them in the local markets. Most of the fishermen owned their individual boats before Aila. They spent almost six months in fishing activity in the river. During other times of the year they worked as wage laborers, mostly as golpata collectors for the large farmers or daily wage laborers in farm lands for two to three months. Wage earnings from golapata collection varied from BDT 6000 to 7000 per month. Also livestock rearing is a common practice in most of the livelihood groups in both Kamarkhola and Sutarkhali unions of the study area.

Most large scale shrimp collectors are not permanent residency of that area. They lease lands from the local people and cultivate shrimp. They are powerful group of people residing outside the area. But many large farmers have some shrimp ponds adjacent to the river (near Kalabogi, Sutarkhali) and they used to cultivate shrimp there. Also it was observed that, some agricultural lands fell outside the polder after reconstruction of the damaged polder due to construction of the closure inward than previous location. These lands were not suitable for crop cultivation. Few farmers cultivate shrimp by making temporary embankment outside the area. There are very few people, mostly in Sutarkhali, who are solely dependent on the Sundarbans for living. Almost all round the year, these people work in the Sundarbans for fishing, shrimp fry collection, fuel collection etc. More specifically, they depending on the Sundarbans directly almost half of the year (from October to March). For three to four months of the year they are engaged in fishing activity in the nearby river.

From the field study it was observed that, the wage laborers have no specific economic activities. Most of them work as agricultural labor in transplanting and crop harvesting time as shown in Table 6.1.

Table 6.1: Seasonal calendar of economic activities of different livelihood groups

Livelihood groups	%	Dec	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov
Large farmers	8.0 %	Golpata Collection business				Fishing or other business		Aman Cultivation					
Medium and Small farmers	16 %	Small business						Aman Cultivation					
Marginal and Landless farmers	21 %	Fishing						Crop cultivation and wage labor in other lands					
Fishermen	20 %	Fishing and Golpata collection in Sundarban				Sundarban fishing		River Fishing					
Wage labor	21 %	Golpata labor		Labor in Crop harvesting			No job	Agriculture labor		No job		Golpata labor	
Sundarban dependent	14 %	Golpata collection (labor)				Sundarban fishing		Fishing				Crop harvesting labor	

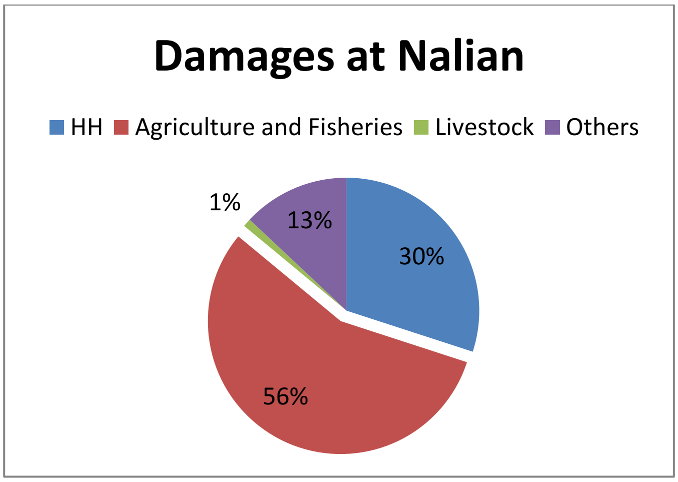
In addition they sell labor for a maximum of four months in golpata collection. Around three months of the year they remain unemployed with no definite source of income. It was observed during the field study that the farmers are completely dependent on the local resources for their livelihood and hence for food security. For fishermen, access to livelihood bases, e.g. fishing boats and nets was also important to continue regular livelihood practices.

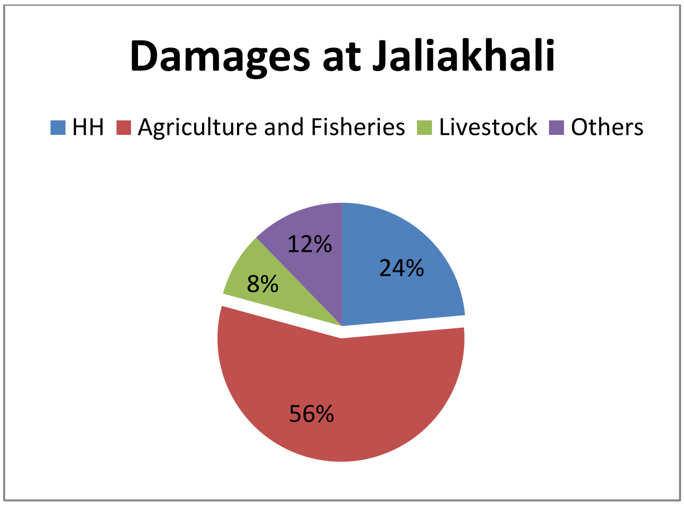
6.4 Immediate Impacts of Inundation on Different Vulnerable Groups

The dreadful force of "Aila" breached and overtopped polder 32 at several places and inundated 5000 ha of land of the polder by saline water (Figure 5.1). Immediately after "Aila" had hit, all human settlements except very few houses at Kamarkhola union were washed away by the surge water. People, who escaped from death, left their residence and took shelter over the embankment. The situation of Sutarkhali union was worse, with all households damaged and about 5000 households completely damaged by the surging water that entered into the polder by breaching of an 8 vent regulator at Nalian River (UN 2010). The local communities lost all the household resources and capital. All the agricultural fields were inundated all in a sudden. Almost 450 shrimp ponds were ruined resulting in huge economic losses to the shrimp cultivators as they lost all export quality shrimps in a day. Communication facilities were severely disrupted due to broken embankments. About 2856 number of families of Kamarkhola and 4840 number of families of Sutarkhali had to live over the embankment for more than one year and were only dependent on aid for food from several agencies (Action Aid, 2009). Each affected household saw their income decreased by approximately 44% as a result of immediate impacts of Cyclone Aila (UN 2009). Also due to submergence of the areas, access to safe drinking water was lost and people suffered from many water borne diseases.

6.4.1 Loss and damages in household asset

From field observations it was found that most of the houses of the study area were earth-made. These earthen houses are very much sensitive to water submergence and even more so to saline water. As a result, most of the houses failed in the first thrust of Aila causing a huge immediate loss in this sector (Figure 6.4). From the information collected from the local people, it was found that 75% of the damages of household assets were immediate, meaning in the early periods of the event.





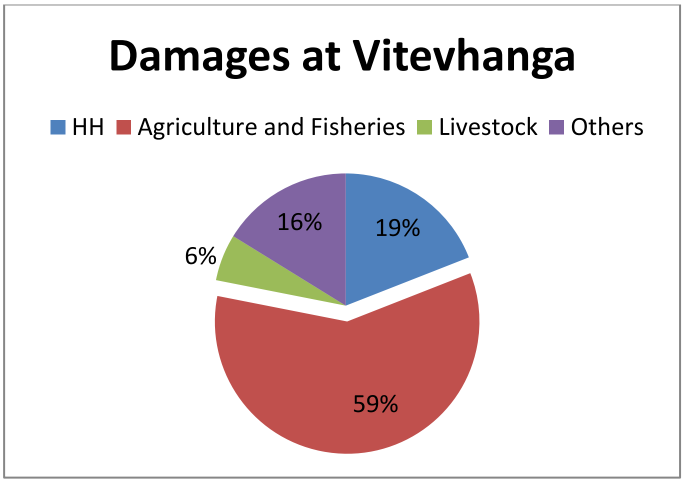


Figure 6.4: Comparative analysis of damages at different locations of the study area

In addition to this, the local people confirmed that the earthen houses which somehow survived the first phase, could not stand tall for more than few weeks. During the first few months after Aila, the houses were continuously submerged under approximately 0.5 m depth even during low tide depending on the house location.

As a result, most of the houses failed or broke and became unsuitable for further living. In addition to this, 90% of the people of the area lost their houses along with their daily essentials like cooking utensils, furniture, etc. (Kibria et al.,2016). Many of the household furniture and daily accessories were washed away by storm water. Some people were in such a rush during the first stage of Aila that they could barely think about their household resources and were running for a safe shelter.

Based on the interviews of the affected people, Figure 6.4 shows agricultural damages compared to other sectors in the three major damaged locations of the study area, Nalian, Jaliakhali and Vitevanga, where polder breaching caused the worst impacts.

Compared to total damages, percentage of damages to agriculture and fisheries sectors (crops and fishing ponds) were substantial, and in the range of 56 to 59 percent of the total damages at different locations of the study area. Damages to households were also substantial, with 30%, 24% and 19% out of the total damages in Nalian, Jaliakhali and Vitevanga, respectively.

6.4.2 Comparison of short term damages and long term damages

Short term damages refer to the damages within few months after Aila. The impacts on households were mostly immediate or short-term, as discussed in the previous section. About 75% of the total damages of household and household assets were immediate while the immediate damages to agricultural crops were 35%. Agricultural damages were mostly due the long term inundation of agricultural lands and subsequent impacts. About 52% of the total damages to agricultural sectors were the long term impacts (Figure: 6.5) because of prolonged inundation, loss of consecutive monsoon cropping seasons and long term agricultural unproductivity.

Short term damages of agriculture sector was around 13%, which is quite less compared to long term damages.

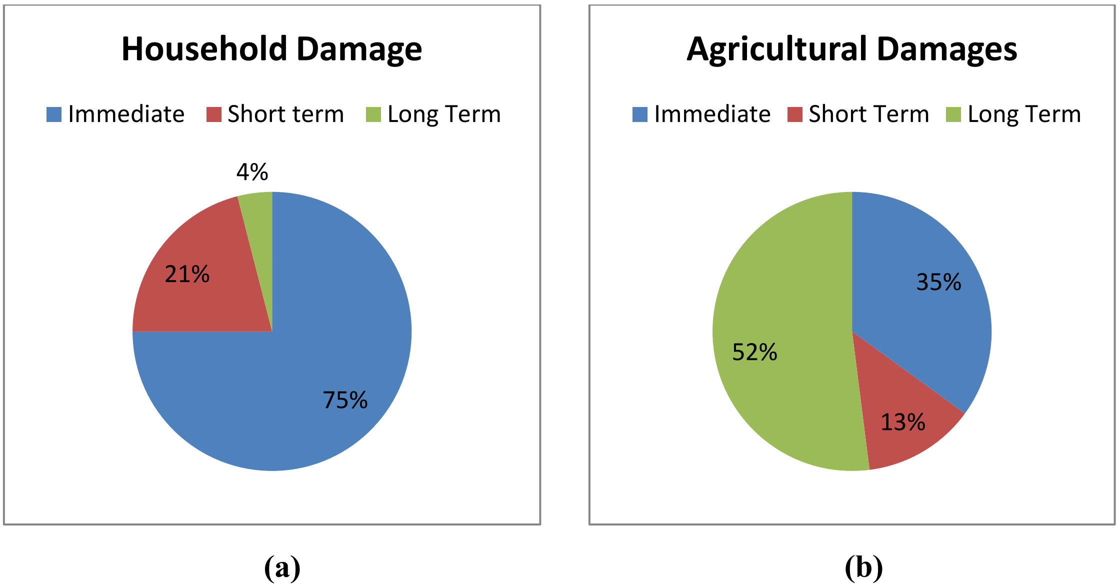


Figure 6.5: Comparison of short term and long term damages at different sectors

6.5 Prolonged Impacts of Inundation on Different Livelihood Groups

Inundation over prolonged periods was the main reason behind the persistent suffereings of people even after the physical systems were rehabilitated. Local communities were impacted by the storm surge hazard immediately after the Aila; however, the differential impacts depended largely on the duration of inundation and the subsequent degradation of soil quality.

From the previous analysis it was observed that agricultural lands, fishing and golpata collection boats are the main livelihood resources. Also some other natural resources and social resources are important for usual livelihood practices. Based on the land use map (Figure 5.7) and PGIS-derived inundation maps (Figure 5.1), it was found that agricultural lands, fish (shrimp) ponds beside households and human settlements were subjected to prolonged duration of inundation. Duration varied from one to more than two years at different locations. Percentage of inundation area also varies across different land use categories. These are presented in Table 6.2. It is notable that the inundation of the agricultural lands in Sutarkhali was prolonged compared to that in Kamarkhola. Kamarkhola union recovered from inundation a year before Sutarkhali. Percentage of inundation of shrimp pond was also higher in Sutarkhali than in Kamarkhola.

Households and the agricultural lands were the main resources on which most of the farmers depended for their livelihood. Also the fish ponds were regularly inundated for more than a year. Also inundation induced degradation of the resource quality had negative impacts on livelihoods.

Table 6.2: Percentage inundated area for different land use since Aila in 2009

Union	Percentage of inundation								
	2009 after Aila			2010 (Up-to August)			Mid-2011		
	Agri-cultural land(%)	Shrimp Pond (%)	Human Settlement (%)	Agri-cultural land(%)	Shrimp (%)	Human Settlement (%)	Agri-cultural land(%)	Shrimp (%)	Human Settlement (%)
Kamarkhola	100	100	100	91.1	100	50	0	68.9	0
Sutarkhali	100	100	100	100	100	100	75.4	95.7	0

The major vulnerable groups, viz. farmers, shrimp cultivators, fishermen, wage labor and sundarban dependent group, as identified through field reconnaissance survey, experienced different degrees of impact and vulnerability as the livelihood system was completely paralyzed due to longer duration of inundation.

6.5.1 Impacts on farmers

Agriculture was the worst affected sector by the cyclone Aila. How the farmers have been affected by the hazard with different duration of storm surge inundation is shown schematically in Figure 6.6. The degree of impact on the farmers' livelihoods and in turn on income depend on a number of factors, including capital loss, access to land resources, soil quality and access to social resources (including roads, markets and other infrastructure). All these factors are function of duration of inundation. Field investigation clearly revealed that most farmers were severely impacted as they lost all access to natural and household (land) resources that restricted agriculture based livelihood, as well as loss of capital that restricted their opportunities of alternateive livelihoods to earn their livings. Not only the access to household resources was disturbed but also less access to social resources and infrastructure like roads and markets for long time diminished the opportunities of livelihood alternatives and consequently the income of the small and marginal farmers.

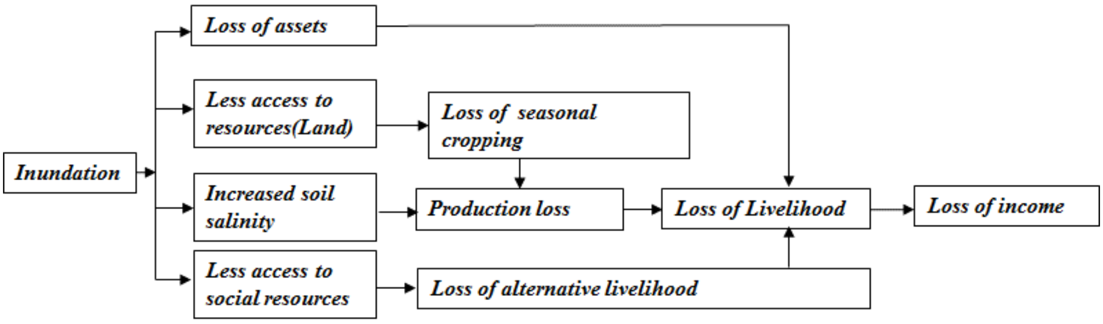


Figure 6.6: Impacts of Aila on farmers

All cultivable lands (about 1900 ha) of Kamarkhola union were inundated for a year up-to August 2010 (Figure 5.1). As a result, farmers had no access to land directly due to submergence of lands during this time period. Although water started to drain out in September 2010 and all agricultural lands were free from water logging (with water remaining only in the natural depression areas) in mid-2011, farming was also not possible in 2011 by the farmers because of poor soil quality as soils became highly saline due to prolonged salt water inundation. It was reported that in some places of Kamarkhola union (dry season) soil salinity increased to about 50 dS/m after Aila from 39 dS/m before Aila (MoL, 2011). The salinity build-up in soils was high enough such that salinity was not flushed out sufficiently by rainfall to allow Aman cropping. Consequently, farmers in Kamarkhola area missed three (2009, 2010 and 2011) consecutive cropping years due to water logging followed by adverse condition of land and soil quality. This meant 100 percent production loss, which is equivalent to 7,20,000 mounds of rice production, in three years. While monsoon (Aman) cropping was possible in 2012, yield was reduced due to increased soil salinity to 90 to 95 mound/ hectares while it was 120 to 140 mound/ hectares before Aila. The major sufferers from the aforementioned impacts were the small and marginal farmers as they constitute about 50% of the farming community. The impacts on the landless (about 30% of farmers) were even more compounded because loss of capital due to inundation did not allow majority of them to lease land from the large farmers in 2012.

The impact on farmers in Sutarkhali union was more severe since the duration of duration of submergence and water logging was three years compared to two years in Kamarkhola union. Unlike in Kamarkhola union, many parts of agricultural lands (about 2500 ha) in Sutarkhali union was still waterlogged till August 2011; all agricultural lands were free from water logging in Sutarkhali in the subsequent year 2012 (with water remaining only in the natural depression areas) (Figure 5.1). This means that farmers in Sutarkhali union missed four consecutive Aman cropping seasons. Marginal and small farmers were the major sufferers as they constitute the majority of the farming community and most of them live below the poverty line, and depend on domestic production for household food production. Landless farmers were the worst sufferers like in the Kamarkhola union; the numbers of landless farmers are much more in Sutarkhali union than in Kamarkhola union. Also due to less access to communication facilities as well as markets because of deterioration of all internal roads, people suffered more as they faced difficulties in finding any alternative livelihood opportunities. Livelihood system thus became brittle with no or very limited access to alternatives. The ultimate impact on the farmers was food insecurity and loss of income, leading to increased poverty.

6.5.2 Impacts on fishermen and shrimp cultivators

Cyclone Aila impacted about 60% of the people who are directly dependent on small scale shrimp and sweet water fish farming in Kamarkhola and Sutarkhali unions. How the shrimp and sweet water fish cultivators were affected by the hazard with different duration of storm surge inundation is shown schematically in Figure 6.7.

Salt and Sweet water fisheries was not possible for more than 2 years because of continued inundation of the sweet water fish ponds and shrimp pond (*ghers*) due to broken embankment and prevailing saline water logging induced by Aila. Shrimp cultivation mostly in Sutarkhali union faced massive losses for more than two years. Normal river fishing for the fishermen were also difficult due to loss of fishing boat which cost BDT 20,000 to purchase a new one.

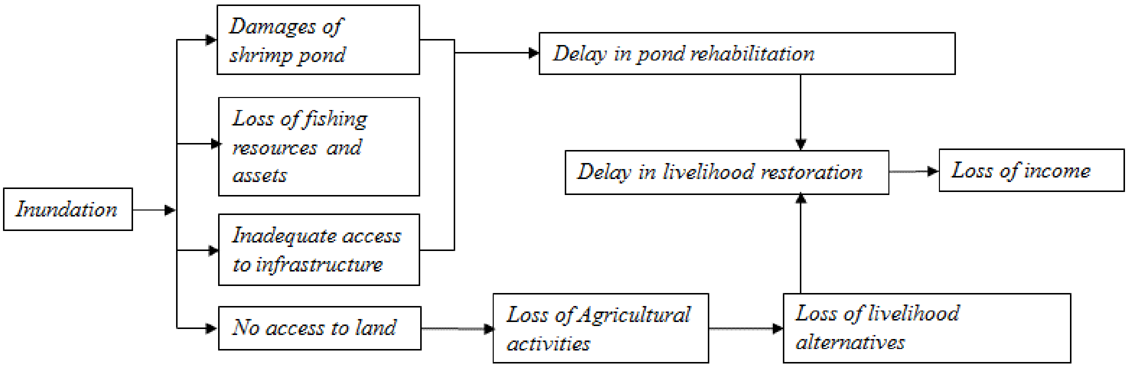


Figure 6.7: Impacts of Aila on local Shrimp and sweet water fish cultivators

It was reported that almost 300 shrimp ponds at Sutarkhali and 150 in Kamarkhola were damaged by sudden thrust of water during Aila (Kumar, 2010). But sufferings of the shrimp cultivators increased due to continued effects extending to 2 to 2.5 years of salt water inundation. The loss of shrimp production in Sutarkhali union was 60,79,590 kg/year causing loss of income and livelihoods of the dependent groups. Another study also reported that after Aila production of shrimp was reduced from a normal year‟s 2,350.14 kg/ha to 470.03 kg/ha (CPRD, 2013). To restart shrimp farming and sweet water fisheries, it demands rehabilitation of the polder and sluice gates besides high capital investment. According to shrimp farmers, it needs an investment of BDT 40,000 to restart shrimp cultivation. Thus dependent livelihood groups (shrimp farmers and labourers) are hugely vulnerable to expected losses as recovery is too costly. As employment opportunity and alternatives were lost for more than two years for prolonged inundation, it restricted the scope of capital investment in restoration of shrimp ponds. Some of the shrimp farmers went back to crop farming in areas where shrimp cultivation was practiced formerly; however, they got low yields of rice compared to other agricultural lands. Also inundation of resources like households and agricultural lands for more than two years made them too poor to restart any livelihood alternatives.

6.5.3 Impacts on Sundarban dependent people

Forest livelihood includes collection of *Golpata* (forest leaves), honey, fodder, timber, fish and crab. As people lost boats and tools during Aila, they faced difficulty in entering and working in the forest. The Sundarban dependent people were used to work in the Sundarbans for 4 months for golpata collection only.

Except large farmers there were very few people who had large collecting boats. As Aila damaged all their belongings, it was not possible for them and others who worked on golpata collection boats to continue their regular livelihood practices. Again reduction of income generating opportunities forced them to switch livelihoods. Rickshaw pulling and working as day labor in crop harvesting season are such activities that people adopted as they lost their usual livelihood opportunities. The local people said that already some of them migrated to the cities for seeking income opportunities.

6.5.4 Impacts on wage laborers

About 30% of the population of the area earn their living by working as wage labourers. Most of them work in crop fields during the harvesting time as well as in shrimp ponds (ghers) as day labourers. These groups of people were completely unemployed due to continuous inundation. The main reason for income loss is the fall in agricultural and fishing activities which significantly affected the labor market and subsequently diminished employment opportunities. Casual laborers found only 7-10 days‟ work per month, compared to 20-25 days per month in a normal year. This situation continued for the laborers of Kamarkhola for almost one year and more than one year in Sutarkhali. Also poor condition of infrastructure like polder, embankment and connecting roads prevented them from migration. Day laborers (mostly female) and small traders who used to be involved in collecting shrimp from the farms and selling to mainland wholesalers were seriously affected.

6.6 Impacts on Food Security

Food security is determined by four dimensions i.e. availability, access, utilization and stability. Crop production, crop loss, food availability from household production, flow of income and family size are some related issues that are interlinked with the above mentioned food security indicators. The aftermaths of inundation as described in the earlier part of this chapter have some direct and indirect impacts on the indicators of food security. The study indicated that the duration of the storm surge inundation has direct impacts on the resources and livelihood bases of different livelihood groups. Continuous inundation and prolonged submergence has negative impacts on the natural resources, household resources, human capital and other resources as well. The negative impacts on natural and household resources and reduced access to those resources has direct impacts on their household food availability. Similarly, the impacts on other resources in turn impacted the human capital and the livelihood alternatives that people may adopt to fulfill their household food and other basic requirements.

6.6.1 Food security of farmers

Farmers are the most vulnerable community that experienced the effects of continuous inundation and submergence. As mentioned earlier, the agricultural lands were inundated for almost two years in Kamarkhola union and more than two years in Sutarkhali union. Also percentage of area submerged had an impact on the crop production. The large farmers whose land is around 15 to 45 hectare/person, used to cultivate the land for Aman rice. The production they received was normally utilized for fulfilling the household food requirements. They used to sell the additional amount to the local market. For the large farmers the scope for savings was more. As farmers lost access to agricultural land for three to four years, they had to bear a production loss as mentioned earlier. Also most large farmers had boats for goalpata collection so that they could earn approximately BDT 30000 to 40000 as profit from each goalpata collector boat. From October to March, they would visit the Sundarbans twice and fill up nearly four boats with golpata, which would be sold in local markets. Some large farmers of Sutarlkali union also cultivated shrimp seasonally. Although the impact of hazard was more for large farmers as they had to bear large amount of loss of crop production, they had adequate alternative income sources within the area and outside the area. But the small and marginal farmers have less than 1.5 hectares of land. The amount of crop they produced was not sufficient for their household food requirements. Most marginal farmers had 1 to 1.5 hectares of land. They barely managed food for six months from their own production. During rest of the time of the year they depended on other livelihood options. Their family expenses were around BDT 15000 per month for a family size of 7 members. One year after Aila, the income reduced to BDT 5000 per month, which was too small amount for them to manage three meals in a day. As an alternative of crop cultivation they went for fishing. During these three years of inundation of agricultural land, small and marginal farmers were only dependent on fishing and Sundarban resources. People of the southern part of the Sutarkhali union mainly depended on fishing all year round. Eventually, to survive with the lost livelihood and reduced income they had to take single meal in place of three meals a day. Also the degradation of the food quality was persistent as they were having food with lower calorie and less nutrition value.

6.6.2 Food security of fishermen

The fishermen of the study area suffered as they lost their fishing boats and nets. Aila took away all their fishing belongings and compelled them to depend only on relief for almost one year. Although the traditional fishermen were not the direct sufferers of the prolonged inundation, most fishermen of the Jalaiakhali and Nalian lost their dwellings. They were the worst sufferers as they had no alternatives left for livelihood. They could not manage to get back to fishing until they could manage to buy a new boat. For more than one year they were completely dependent on food aid from different agencies. Their food quality was already below standard before Aila. But due to sudden shock of Aila they had to starve in some cases. Their percentage of expenditure on food was previously the maximum when compared to that for farmers and shrimp cultivators. After Aila it increased to nearly 100 percent. This adverse situation led them to take less number of meals than the requirements. Also, the areas where fishermen lived had problems with availability of safe drinking water, which further deteriorated their health status and hampered food utilization. Besides, they had to compromise with the dietary diversity to counterbalance the impact of lower income.

6.6.3 Food security of Sundarban dependent people

The Sundarban dependent people of the study area were mainly depended on fishing near the Sundarbans, shrimp fry collection and golpata collection. From the study it was found that about 80 percent of the Sundarban dependent people work on goalpata collector boats that are owned by few large farmers who are hardly 10 percent of the total community. The wage earnings from this activity were around BDT 5000 to 6000 per month which was quite a small amount in comparison to their needs to have adequate monetary access to food. Most of the households dependent on the Sundarbans were unemployed after Aila for more than one year and hence were completely dependent on the food Aid for nearly one year. Furthermore, involvement of women in income generating activities increased from year 2010 to cope up with less income and less food. Also, they had to change their food consumption behavior; they had to reduce their consumption. Degradation of the nutrition level of food added to their problems. From this study it was found that they were not able to take even two meals a day for almost one year. It was evident that they faced acute food insecurity due to lack of livelihood opportunities and income.

6.6.4 Food security of wage laborer

The wage laborers of the study area mainly worked as agricultural laborers in crop harvesting seasons. Also they worked on golpata collector boats as labor in during the collection time as mentioned earlier in Table 6.1. Almost for two months they found no work in their own village. The incomes they would normally receive from their usual economic activities were found to be very less to meet the household food requirements. From the study, this group of people were found to be food insecure prior to Aila having less availability of and access to food. But Aila induced short term and prolonged inundation and damages made the food insecurity more severe than earlier. Reduction of working opportunities because of less agricultural activities within the study area significantly reduced the income opportunities for these people. Besides, limited access to Sundarban resources also impacted their income opportunities. Thus, these people suffered from having less economic access to food. Fewer numbers of meals in a day were needed for them to cope with this crisis situation. Also, these people had to compromise with the nutritional quality of food they consumed.

6.7 Synthesis of Food Security Dimensions

6.7.1 Percentage of income and expenditure to food

Percentage of income and expenditure is compared for different livelihood groups and shown in Figure 6.8. From the study, it was found that about 60 % of the income of the large farmers were reduced due to the loss of three to four consecutive cropping seasons within three to four years after Aila and the resulting loss of production. Two years after Aila, they needed money to rehabilitate and to restart usual livelihood practices, they had to spend most of their income in purchasing food. As there was no household production, the large farmers had to spend almost 70% of their income to purchase food. Similarly, percentage of income loss is also high for medium farmers. But the small farmers had some livelihood alternatives in nearby villages and cities and their percentage of income loss was less than that for large and medium farmers. However, expenditure for food for medium and marginal farmers increased substantially after Aila. They spent almost 80 to 90% of their income as food expenditure. They can be considered to be food insecure as they spent more than 70% of their income as food expenditure (Sylvia et al., 2015). For fishermen, livelihood opportunities were there but they lacked livelihood resources. After one year many fishermen managed to buy fishing boats by virtue of financial aid and loan from different GOs and NGOs. But their net income was reduced as they had to pay back their loans. Eventually their percentage of expenditure for food increased.

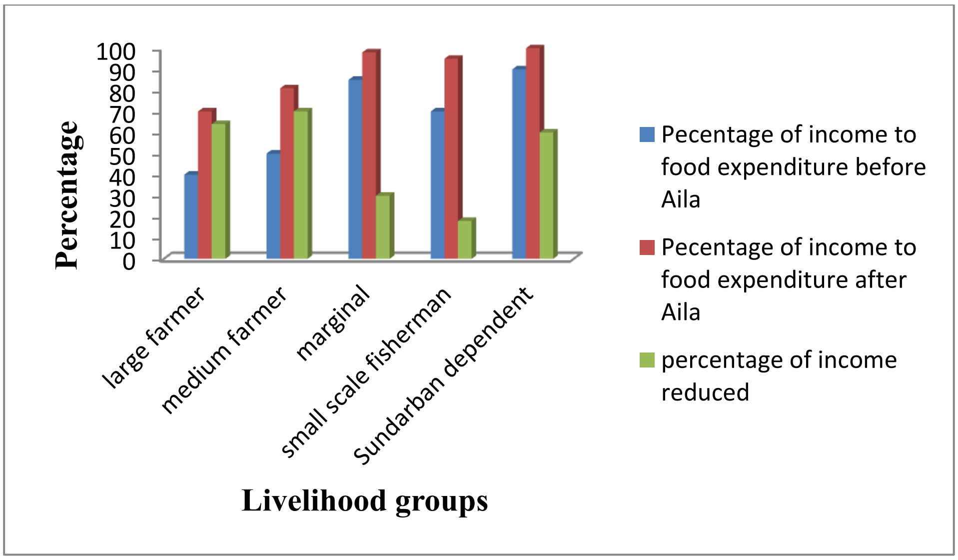


Figure 6.8: Percentage of income and expenditure for food before and after Aila

6.7.2 Percentage of food consumed from household production

Figure 6.9 shows the percentage of household food consumption from own production for different livelihood groups. It was found that, large farmers consume almost 100% of food (staple food rice) directly from household production while the percentage of food consumption from household production vary from 40 and 60% for small and medium farmers. So, the inundation induced loss of crop production has serious impact on the farmer‟s community for having less food availability. From field observation it was found that many traditional fishermen and Sundarban dependent people had no large boats of their own for fishing activities.

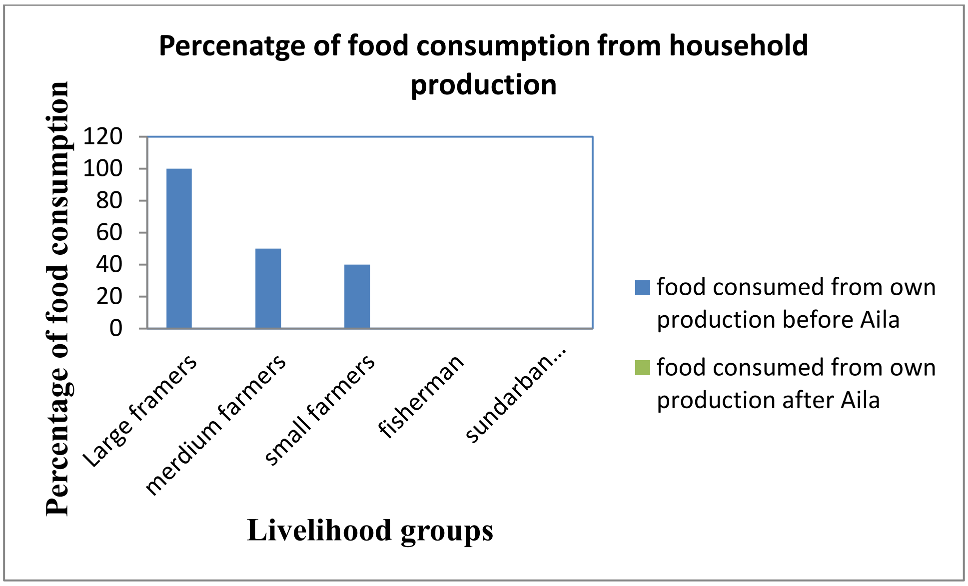


Figure 6.9: Percentage of food consumed from own production

6.8 Summary and Discussions

Based on the previous discussions about the impacts on food security of different vulnerable groups, the governing factors that linked the food security dimensions i.e. availability, access, stability and utilization are discussed below.

Availability

Household food availability was found as the function of crop production and crop diversity. Also access to resources and livelihood bases significantly affected the crop production at household level. Moreover, the discussions from the previous sections in Chapters 5 and 6 suggested that storm surge induced biophysical factors like inundation area, depth and duration significantly reduced the food availability of different size of farmers by affecting household crop production. For instance farmers were found to be the most vulnerable community affected by persistent inundation and submergence in terms of availability of food. As discussed earlier farmers lost a number of consecutive cropping seasons and suffered significant amount of agricultural production loss. As a consequence, household food availability from own production was found to be inadequate to meet the dietary requirements. Food security of other livelihood groups, i.e. fishermen, Sundarban dependent people and wage laborers were also impacted by less availability of food for household. As discussed earlier, it was evident that amount of income was significantly reduced for farmers as well as for all other livelihood groups. Availability of and access to food were found to be interlinked with one another. Most of the farmers were considered to be food insecure after Aila. Reduction of number of meals and consumption of less nutritious food were found as coping mechanisms with less availability and access to food.

Access to food

Access to food was found to be an important dimension and functional unit of food security resulting from loss of livelihoods and income. The previous discussions suggested that for securing access to adequate amount of food, access to livelihood resources and alternative resource bases were important for all livelihood groups. Access to agricultural lands impacted the income generating activities of farming dependent people like medium and small farmers, wage laborers etc. Reduction of food purchasing power considerably affected the access to food. Moreover, spending more percentage of income for food expenditure after Aila was evident for all livelihood groups. Income of fishermen, Sundarban dependent people and wage laborers were reduced by significant amounts. Fishermen and shrimp cultivators were facing more difficulties in livelihood restoration process that hindered the ways of getting access to adequate amount of nutritious food. Unlike farmers these people were spending higher percentage of income to food expenditure. Wage laborers and Sundarban dependent people were considered to be food insecure prior to Aila. The situation worsened for them after Aila. Reduced access to Sundarban resources due to loss of the resource bases caused Sundarban dependent people to be food insecure. Together with the Sundarban dependent people, wage laborers were considered to be the most vulnerable in terms of getting income to secure access to food.

Stability

Stability was another important dimension of food security that was impacted in different ways through the associated factors of inundations as explained in previous chapters. Food supply system is mostly dependent on the local resources. Production losses for consecutive years, yield variations due to degraded soil quality and income uncertainty associated with inadequate alternative livelihood options were found to be the governing factors that affected stability of the food supply system. Farmers, fishermen, wage laborers and Sundarban dependent people were facing uncertainties in securing food all around the year because of slower rehabilitation of the agricultural system and delayed and difficult livelihood restoration processes. It is also notable from earlier discussions that physical difficulty in rehabilitation process, rehabilitation time and speed of rehabilitation process also had significant impacts on the consecutive losses of agricultural productivity and therefore food stability.

Utilization

Utilization is mostly associated with the access to safe drinking water and sanitation facilities. As discussed earlier, slower rehabilitation and the resulting impact on access to adequate quality of drinking water and sanitation impacted utilization of food value. Moreover, inadequate infrastructural facility and lack of safe drinking water and sanitation acted as major contributing factors in relation to less utilization of food value. Fishing communities in fishermen dominated areas were mostly lacking access to safe drinking water and sanitation facilities. As a result, poor utilization of food value was prevalent.

CHAPTER SEVEN
CONCLUSION AND RECOMMENDATION

8.1 Conclusions

The study was performed to assess the physical factors of cyclonic storm surge Aila, the immediate physical impacts, prolonged inundation impacts and the resulting implications for food security of different livelihood groups in polder 32 of Dacope upazila following an interdisciplinary research methodology. While the storm surge caused a number of immediate physical damages, which made thousands of people homeless and put them in tremendous hardship, the prolonged impacts due to continued tidal inundation for several years meant that people could not recover quickly and mostly falling into food insecurity. The specific conclusions drawn from the study are summarized below:

- Participatory GIS method proved to be a useful technique in mapping storm surge duration in terms of depth and duration.
- Embankment failure in the form of breaching and overtopping caused substantial inundation and damages within the polder immediately, resulting in the inundation of human settlement, agricultural lands and shrimp and sweet water fish ponds. About 80% of the polder was found to be inundated; Nalian, Gulbonia and jaliakhali were three major breaching locations in the polder.
- While the exact mechanism of failure at breaching locations remains uncertain, the pre-existing weak condition of embankment, lower height with significant prior river bank erosion seem to have played major roles.
- There were a number of reasons for continuation of inundation. Slow infrastructure rehabilitation process, scouring of the major breaching locations, widening of the width of breaching, siltation of drainage channels along with some man made depressions were found to be the major reasons for prolonged inundation. For example, scouring of the mouth of the Nalian river and siltation of two major canals named Kamarkhola canal and Clozerer canals aggravated the water logging condition. It took two years for

Kamarkhola union to get fully free from inundation, while it took almost three years for Sutarkhali union for the same.

- Farmers, traditional fishermen, shrimp cultivators, wage laborers and Sundarban dependent people were found to be the major livelihood groups who were affected by immediate storm surge (Aila) inundation and prolonged tidal inundation.
- Practice of diversified economic activities by different livelihood groups was found to be present in the study area. Examples are golpata collection activity of large farmers for a significant period (four months in a year) and traditional fisherman working as wage laborers in crop harvesting time (18% time of the year). However, more diversified activities were found for Sundarban dependent people: fishing and golpata collection for four months and river fishing in the fishing season.
- Agricultural lands, fishing boats and nets, golpata collection boats and Sundarban are the main livelihood bases which were found to be seriously affected due to short term and long term inundation caused by storm surge.
- Consecutive loss of three to four cropping years happened due to water logging followed by adverse condition of land and soil quality (it took substantial time for the salts in soils to get flushed out), which were prominent as long term effects to farmers. Farmers in Kamarkhola union missed three complete cropping seasons, which was equivalent to 7,20,000 mounds of rice production, while the impact on farmers in Sutarkhali union was more severe as a result of loss of four cropping seasons.
- While monsoon (Aman) cropping was possible after water receded, yield was reduced in the first year in Kamarkhola due to increased soil salinity to 15 to 16 mound/bigha while it was 20 to 22 mound/bigha before Aila. Loss for the farmers of Sutarkhlai was even severe with 2500 ha of agricultural lands remaining fallow for four years.
- Impacts on small and marginal farmers were severe, as they were solely dependent for food from household production.
- About 60% of the people directly dependent on small scale shrimp and sweet water fish farming suffered from deterioration of fish ponds. Also, to require

high amount of money (about Tk. 20,000) to purchase a small fishing boat made the livelihood restoration of fisherman even more difficult.

- The loss of shrimp production in Sutarkhali union was 60,79,590 kg/year causing loss of income and livelihoods. Also, reduced production from 2,350 kg/ha to 470 kg/ha was a major source of income loss to shrimp cultivators.
- As Aila damaged all the belongings (fishing and golpata collection), the Sundarban dependent people suffered a significant loss of livelihood activities. Also the wage laborer, 30% of the total population, found only 7-10 days‟ work per month, compared to 20-25 days in a normal year.
- About 30 to 60% reduction in income resulted for marginal to large farmers, while income reduced by 20% for small scale fishermen and 50% for the Sundarban dependent people.
- Large farmers were found to spend almost 70% of their income as food expenditure after Aila while it was 80 to 90% for medium and marginal farmers and small and medium farmers.
- Large, medium and small farmers were consuming almost 100%, 60% and 40% food (staple food rice) from own household production. But they were considered to be food insecure for spending more than 70% of their income as food expenditure after Aila.
- A conceptual framework for food security assessment for different vulnerable groups was formulated linking inundation and food security indicators. Based on the study, some interrelated factors were identified that linked inundation directly to the indicators of food security.
- Cropping season loss, access to resources, quality of resources, and loss of resources seemed to be important factors that linked inundation to the availability of food. Access to land, income opportunities, condition of alternative livelihood base along with infrastructural facility for securing or restoration for supporting livelihood activities were found to be important for linking inundation with the access to food. Some other factors like, year to year yield variations, income uncertainty, loss of cropping season as a consequence of direct inundation of the agricultural fields and others

resources were found to be significant that linked inundation with stability of food.

8.2 Recommendations

The following recommendations are made based on the study:

1. The food security assessment framework for different vulnerable groups can be used to assess and link food insecurity to physical factors of storm surge i.e. depth and duration of storm surges for similar cases. Comprehensive quantitative analysis can be done in future to make statistical relationships among inundation and food security indicators. This will allow framing a systems dynamics model for food security assessment.
2. The study was carried out in one coastal polder. Similar study can be carried out in other places too, to interlink storm surge, physical damages, inundation and food security with more quantitative relationships.

REFERENCES

Action Aid (2009). In-depth Recovery Needs Assessment of Cyclone Aila Affected Areas, UK.

Agrawala, S., Ota, T., Ahmed, A.U., Smith, J., and van Aalst, M. (2003). Development and Climate Change in Bangladesh: Focus on Coastal Flooding and the Sundarbans. Organisation for Economic Co-operation and Development (OECD).

Alam, M.M. (2011). Poverty alleviation through improved water management in a deltaic tidal plain. Unpublished Ph.D Thesis, Institute of Water and Flood Management, Bangladesh University of Engineering and Technology (BUET), Dhaka, Bangladesh.

Ali, A. (1999). Climate change impacts and adaptation assessment in Bangladesh. Climate Research, vol. 12, pp.109-116.

Antwi, E. K., Boakye-Danquah, J., Barima Owusu, A., Loh, S. K., Mensah, R., Boafo, Y. A., & Apronti, P. T., (2015). Community vulnerability assessment index for flood prone savannah agro-ecological zone: A case study of Wa West District, Ghana. Weather and Climate Extremes, 10, 56–69. http://doi.org/10.1016/j.wace.2015.10.008

Auerbach, L. W., Goodbred Jr, S. L., Mondal, D. R., Wilson, C. a., Ahmed, K. R., Roy, K., Ackerly, B. A., (2015). Flood risk of natural and embanked landscapes on the Ganges–Brahmaputra tidal delta plain. Climate Change, 5(2), 153–157. http://doi.org/10.1038/nclimate2472

BBS, (2001). Information on Khulna and Satkhira District, Community Series, Bangladesh Bureau of Statistics, Dhaka, Bangladesh.

BCCSAP (2009). Bangladesh Climate Change Strategy and Action Plan 2009.

Bengtsson, L., K. I. Hodges, and E. Roeckner, (2006). Storm tracks and climate change. Journal of Climate, 19(35), pp.18-43.

BIDS (2006). Natural disasters, risks, vulnerability and persistence of poverty: an analysis of household level data. PRCPB Working Paper No. 15, Programme for Research on Chronic Poverty in Bangladesh (PRCPB), Bangladesh Institute of Development Studies (BIDS), Dhaka.

BWDB (2013a). Coastal Embankment Improvement Project, Phase-I (CEIP-I), Detailed Design of Five Polders, Volume III: Environmental Impact Assessment, Part A: Polder No 32, Bangladesh Water Development Board.

BWDB (2013b). Coastal Embankment Improvement Project, Phase-I (CEIP-I), Final Report, Volume I: Main Report, Bangladesh Water Development Board.

BWDB (2013c). Coastal Embankment Improvement Project, Phase I (CEIP-I), Resettlement Action Plan (RAP), Polders 32, 33, 35/1, 35/3 & 39/2C, Volume II: Resettlement of PAPs in Polder 32, Part A: Bangladesh Water Development Board.

BWDB and WARPO (2004). Southwest Area Integrated Water Resources Planning and Management Project, Main Report, Bangladesh Water Development Board, and Water Resources Planning Organization, Prepared by Halcrow Group Ltd.

CCC (2009a). Characterizing Country Settings: Development of a Base Document in the Backdrop of Climate Change Impacts. Climate Change Cell, Department of Environment, Ministry of Environment and Forests, Component 4b, Comprehensive Disaster Management Programme (CDMP), Ministry of Food and Disaster Management, Bangladesh.

CEGIS, (2004). Vulnerability Analysis of Major Livelihood Groups in the Coastal Zone of Bangladesh, Final Report, FAO supported study, CEGIS, Dhaka.

CFPR (2013). Local Perspective on Loss and Damage in the Context of Extreme Events: Insights from Cyclone affected Communities in Coastal Bangladesh. Centre for Participatory Research, Bangladesh.

Chowdhury, J.U., Rahman, M.R. and Salehin, M. (1997), Flood Control in a Floodplain Country Experience of Bangladesh, prepared at IWFM, BUET, Legal No:1276/97, ISESCO, Rabat, Morocco.

Dasgupta S, Kamal FA, Khan ZH, Choudhury S, Nishat A (2014) River salinity and climate change: evidence from coastal Bangladesh. The World Bank. http://econ.worldbank.org/external/default/main

Dasgupta S., B. Laplante, C. Meisner, D. Wheeler and J. Yan. (2009). The impact of sea-level rise on developing countries: A comparative analysis. Climatic Change, Vol. 93, No. 3, pp. 379- 388.

DFID (2009). "Participatory Geographical information System: Environmental Mainstreaming Initiatives", Paper No 7.

Emanuel, K., (2005). Increasing destructiveness of tropical cyclones over the past 30 years. Nature: 436, 686-688.

Emanuel, K., R. Sundararajan, J. Williams., (2008). Hurricanes and Global warming: Results from Downscaling IPCC AR4 Simulations. Available at ftp://texmex.mit.edu/pub/emanuel/PAPERS/Emanuel_etal_2008.pdf

FAO, IFAD, WFP, (2013). The state of food insecurity in the world 2013: The multiple dimensions of food security. Food and Agriculture Organization of the United Nations (FAO), International Fund for Agricultural Development (IFAD) & World Food Programme (WFP), Rome, p-56.

GoB (2008). Cyclone Sidr in Bangladesh: Damage, Loss, and Needs Assessment for Disaster Recovery and Reconstruction. Government of the People"s Republic of Bangladesh.

GoB (2009). Bangladesh Climate Change Strategy and Action Plan 2009. Government of the People"s Republic of Bangladesh.

Habiba, U., Shaw, R. and Takeuchi, Y. (2011). Drought risk reduction through a socio-economic, institutional and physical approach in the northwestern region of Bangladesh, Environmental Hazards, 10: 121-138.

Hossain, M. N., & Paul, S. K., (2015). Simulation of physical and socioeconomic factors of vulnerability to cyclones and storm surges using GIS: a case study. Geo Journal, http://doi.org/10.1007/s10708-015-9668-9

IPCC (2007). Climate Change 2007: Synthesis Report, Intergovernmental Panel on Climate Change (IPCC), WMO-UNEP, Geneva, Switzerland, pp. 20.

IPCC (2014). Climate change 2014: synthesis report, summary for policy makers. Fifth Assessment Report, Intergovernmental Governmental Panel on Climate Change.

Islam, A.K.M.S., Haque, A. and Bala, S.K. (2010). Hydrologic characteristics of floods in Ganges-Brahmaputra-Meghna (GBM) delta, Natural Hazards, 54: 797-811.

Islam, A.M.Z. (1985). A brief account of bank erosion, model studies and bank protection work in Bangladesh, Proceedings of the workshop on the impact of riverbank erosion and flood hazards in Bangladesh, REIS, JU, Dhaka.

Islam, K.M.N (1996). Linkages and Flood Impacts at Macro Level – A Case Study of Bangladesh, Research report No. 146, BIDS, Dhaka.

Islam, M. B., Ali, M.Y., Amin, M., Zaman, S. M., (2011). Climate variations: farming systems and livelihoods in the high barind tract and coastal areas of Bangladesh. Climate change and food security in South Asia, Springer.

Islam, M. F., Parveen, S., (2004). Food Security in the Face of Climate Change, Population Growth, and Resource Constraints: Implications for Bangladesh. Environmental Management , Volume 34, Issue 4, pp 487-498.

Jayasinghe, A., Mahanama, P. K. S., Senanayake, L., Bandara1, L., Seifert, I., (2013). Participatory GIS (PGIS) as a Tool for Flood Mapping in Climate Change Adaptation: A Study of Batticaloa City, Sri Lanka. European Climate Change Adaptation Conference (EECA), Norwegian Institute for Water Research (NIVA), Norway.

Johansson, R., Luebehusen, E., Morris, B., Shannon, H., & Meyer, S., (2015). Monitoring the impacts of weather and climate extremes on global agricultural production. Weather and Climate Extrmes, 10, 65-71.
http://doi.org/10.1016/j.wace.2015.11.003

Mallick, F. and Rahman, A. (2013). Cyclone and tornado risk and reduction approaches in Bangladesh, In: Disaster risk reduction approaches in Bangladesh, Shaw, R, Mallick, F. and Islam, A. (eds.), pp. 91-102, Springer.

McCarthy, J.J., Canziani, O.F., Leary, N.A., Dokken, D.J., White, K.S. (Eds.) (2001). Climate Change 2001: Impacts, Adaptation, and Vulnerability. Cambridge University Press, Cambridge.

MoEF (2005). National Adaptation Programme of Action Multi-purpose Cyclone Shelter Project (MCSP) 1993. Summary Report, Ministry of Environment and Forest, Government of the People‟s Republic of Bangladesh.

MoEF (2008). Bangladesh Climate Change Strategy and Action Plan 2008. Ministry of Environment and Forest, Government of Bangladesh, Dhaka

MoEF (2009). Bangladesh Climate Change Strategy and Action Plan 2009. Ministry of Environment and Forests, Government of the People‟s Republic of Bangladesh.

MoL (2011). Land Zoning Report, Dacope Upazila, Khulna District, Ministry of Land, Government of the People‟s Republic of Bangladesh.

MoWR (2005). Coastal Zone Policy (2005). Ministry of Water Resources, Government of the People‟s Republic of Bangladesh.

Murty, T. S., & Neralla, V. R., (1992). On the recurvature of tropical cyclones and the storm surge problem in Bangladesh. Natural Hazards, vol 6(3), pp. 275–279. http://doi.org/10.1007/BF00129512

Murty, T.S., and El-Sabh, M.I., (1992). Mitigating the Effects of Storm Surges Generated by Tropical Cyclones: A proposal, Natural Hazards 6(3), pp. 251-273.

Nicholls, R. J. (2003). An Expert Assessment of Storm Surge "Hotspots". Final Report (Draft Version) to Center for Hazards and Risk Research, Lamont-Dohert Observatory, Columbia University.

Paul, S. K., & Routray, J. K., (2011). Household response to cyclone and induced surge in coastal Bangladesh: Coping strategies and explanatory variables. Natural Hazards, 57(2), pp. 477–499. http://doi.org/10.1007/s11069-010-9631-5

PDO-ICZMP (2004). Where Land Meets The Sea. Edited by M.R. Islam, Program Development Office for Integrated Coastal Zone Management Plan Project. Water Resources Planning Organization, Ministry of Water Resources, Bangladesh; Published by University Press Limited, Dhaka.

Poppy, GM., Chiotha, S., Eigenbrod, F., Harvey, C. A., Honzak, M., Hudson, M. et al, (2014). Food security in a perfect storm: using the ecosystem services framework to increase understanding. Philos Trans R Soc B Biol Sci. (doi:10.1098/Rstb.2012.0288)

Rahman, M., and Ahsan, M. (2001). Salinity Constraints and Agricultural Productivity in Coastal Saline Area of Bangladesh. In Soil Resources in Bangladesh: Assessment and Utilization. Proceedings of the Annual Workshop on Soil Resources, pp.1-14, Soil Resources Development Institute, Dhaka.

Rahman, R. and Salehin, M. (2013). Flood risk and reduction approaches in Bangladesh, In: Disaster risk reduction approaches in Bangladesh, Shaw, R, Mallick, F. And Islam, A. (eds.), pp. 65-90, Springer.

Saha, C. K., (2014). Dynamics of disaster-induced risk in southwestern coastal Bangladesh: an analysis on tropical Cyclone Aila 2009. Natural Hazards, 75(1), 727–754. http://doi.org/10.1007/s11069-014-1343-9

Shameem, M. I., Momtaz, S., Rauscher, R., (2014). Vulnerability of rural livelihoods to multiple stressors: a case study from the southwest coastal region of Bangladesh. Ocean Coast Manag, 102, p 79–87.

Sikder, R. and Xiaoying, J., (2014). Climate Change Impact and Agriculture of Bangladesh. Journal of Environment and Earth Science, Vol.4(1).

UN (2009). "Cyclone Aila joint UN Multi-sector Assessment & Response Framework: In-depth Recovery Needs Assessment of Cyclone Aila Affected Areas." The United Nations.

UN (2010). Cyclone Aila joint UN multi-sector assessment & response framework. In-depth Recovery Needs Assessment of Cyclone Aila Affected Areas.

UO (2010), Cyclone Aila: One Year on Natural Disaster to Human Sufferings. Unnayan onneshon, Bangladesh.

WB (1986). Poverty and Hunger: Issues and Options for Food Security in Developing Countries, World Bank, Washington DC.

WB (2008). Poverty Assessment for Bangladesh: Creating Opportunities and Bridging the East-West Divide, Bangladesh Development Series, Paper No. 26, Poverty Reduction, Economic Management, Finance & Private Sector Development Sector Unit, South Asia Region, the World Bank Office, Dhaka.

Webster, T. L., Forbes, D. L., MacKinnon, E., Roberts, D., (2006). Flood-risk mapping for storm-surge events and sea-level rise using lidar for southeast New Brunswick. Canadian Journal of Remote Sensing: Journal canadien de télédétection, Volume 32, Issue 2, p 194-211.

WB (1986). Poverty and Hunger: Issues and Options for Food Security in Developing Countries. World Bank. Washington DC.

Khalil, G. (1992). Cyclones and Storm Surges in Bangladesh: Some Mitigative Measures. Natural Hazards. Vol. 6, pp 11-24