COMMUNITY RESILIENCE TO CLIMATE CHANGE THROUGH DISASTER RESILIENT HOUSING PRACTICE IN COASTAL AREA: A CASE STUDY OF DACOPE UPAZILA IN KHULNA

BY

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A Thesis by

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APPROVAL

The thesis titled '**COMMUNITY RESILIENCE TO CLIMATE CHANGE THROUGH DISASTER RESILIENT HOUSING PRACTICE IN COASTAL AREA: A CASE STUDY OF DACOPE UPAZILA IN KHULNA**' submitted by Md. Rayhanur Rahman, Roll No.: 1017282021 P, and Session: OCTOBER-2017, has been accepted as satisfactory in partial fulfillment of the requirements for the degree of M.Sc. in Water Resources Development on August 13, 2022.

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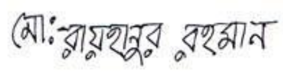
It is hereby declared that this thesis or any of it has not been submitted elsewhere for the award of any degree or diploma.



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Md. Rayhanur Rahman

Dedicated to

PARUL

In every second of my life, you will be missed.

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ABSTRACT

Every year natural disasters, specially, cyclonic storm surges disrupt the lives and livelihood of people in the coastal area of Bangladesh. Since 1990s, activities like the construction of cyclone shelters, cyclone warning, and awareness building program play important roles to reduce the fatalities and damages due to such disasters. Though the actions were effective to reduce the human fatality rate, still many houses and their related amenities are damaged on a regular basis due to cyclones and their associated storm surges. Several studies have highlighted the need for more contextual approaches to make the community resilient against cyclone-induced storm surges. Disaster Resilient Housing would be an alternative approach in the Disaster Risk Reduction (DRR) through adopting it in the strategy of pre-disaster recovery. The study aimed to develop and implement a disaster resilient house through involving the community for an area where tracks of the cyclones are observed frequently. To achieve the purpose, two villages in the Kamarkhola Union of Dacope Upazilla in Khulna district were selected for developing and implementing prototypes of disaster resilient houses as this union which was the worst victim by devastating Cyclones SIDR and AILA. To understand the causes for vulnerabilities of the community, primary data was collected using Participatory Rural Appraisal (PRA) tools including social and resource mapping, Focus Group Discussions (FGDs), group discussions, individual interviews, and Key Informant Interviews (KIIs). To evaluate the performance of the implemented design in the study area against storm surges with associated high-speed winds and surge height, Likert Scale was used to collect perceptions from the selected beneficiaries. The Cyclone Classifier Model (CCM) was used to collect the damage information of the locally build housing structure in a large scale to compare the results with observed design performance. Secondary data on real-time cyclones such as cyclone tracks, windspeeds, landfall locations, tidal condition were used in CCM. The study found that the formal supports such as cyclone shelter and warning systems and awareness development activities, which are generated at the national level for community resilience against cyclone-induced hazards, are not properly operational and not easily accessible to community people. Up to 84% of respondents have faced problems understanding warning information and 76% of respondents didn't evacuate to the cyclone shelter due to lack of water, food, and sanitation facilities after listening to warning signals. Results found that 52% of respondents were considered their own house as a safe place rather than moving into a cyclone shelter. After the implementation of the participatory design, it is found that the development of disaster-resilient housing is possible when combination of scientific knowledge and local wisdom are integrated. This concept reduced extra cost for the structures as well as enhanced effectivity of community people. This finding is also evaluated with the performances of the houses against consecutive cyclones, like Bulbul and Amphan. It is found that up to 34% of the conventional houses were fully damaged against cyclone Bulbul and Amphan respectively, while the implemented houses with participatory design sustained without collapsing its main structures.

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ABBREVIATIONS AND ACRONYMS

AHP	Analytic Hierarchy Process
BBS	Bangladesh Bureau of Statistics
BCCSAP	Bangladesh Climate Change Strategy and Action Plan
BDT	Bangladeshi Taka
BDP	Bangladesh Delta Plan
BMD	Bangladesh Meteorological Department
BNBC	Bangladesh National Building Code
BoB	Bay of Bengal
BRAC	Bangladesh Rural Advancement Committee (Former name)
BUET	Bangladesh University of Engineering and Technology
BWDB	Bangladesh Water Development Board
CARIAA	Collaborative Adaptation Research Initiative in Africa and Asia
CBA	Cost Benefit Analysis
CCM	Cyclone Classifier Model
CDMP	Comprehensive Disaster Management Programme
CEGIS	Center for Environmental and Geographic Information Services
CGI	Corrugated galvanized iron
CI	Corrugated Iron sheet
CPP	Cyclone Preparedness Program
CRR	Cyclone Risk reduction
DECCMA	Deltas, Vulnerability & Climate Change: Migration & Adaptation
DFID	UK Government ‘s Department for international Development
DMB	Disaster Management Bureau
DRR	Disaster Risk Reduction
DRH	Disaster Resilient Housing/Habitat
FGD	Focus Group Discussion
GO	Governmental Organization
GI	Galvanized iron
HH	Household
HRA	High-Risk Area
IDRC	International Development Research Centre
IPCC	Intergovernmental Panel on Climate Change
IWFM	Institute of Water and Flood Management
IWM	Institute of Water Modeling
IWTC	International Workshop on Tropical Cyclones
JJS	Jagrata Jubo Sangha
KII	Key Informant Interview
LEED	Leadership in Energy and Environmental Design
MCSP	Multipurpose Cyclone Shelter Programme
MPCS	Multipurpose Cyclone Shelter
MIROC	the Model for Interdisciplinary Research on Climate
NGO	Non-governmental Organization

PAR	Pressure and Release
PVC	Polyvinyl chloride
PRA	Participatory Rural Appraisal
PSF	Pond Sand Filter
PWD	Public Works Department
RCC	Reinforced Cement Concrete
SATREPS	Science and Technology Research Partnership for Sustainable Development
SLR	Sea Level Rise
SSNP	Social safety net programs
SSI	Semi-Structured Interview
SST	Sea Surface Temperatures
STEEPER	Steering and Persistence
STP	Storm Track Prediction
SWC	Storm Warning Center
TC	Tropical Cyclone
UNO	Upazila Nirbahi Office
WB	World Bank

CHAPTER ONE

INTRODUCTION

1.1 Background and Rationale of the Study

Climate change has already had diverse adverse impacts on human systems, including on water security and food production, health and well-being, and cities, settlements, and infrastructure (IPCC, 2022). During the last two decades, the greatest number of natural disasters related deaths and associated losses and damages took place in Asia (Cropper and Sahin, 2009). It is reported that Bangladesh, China, and India are most likely to experience the greatest number of natural disasters in Asia due to their geographical locations (UNEP, 2002). According to IPCC (2007), Bangladesh which is predominantly a floodplain country is recognized as one of the most vulnerable countries when impacts of global warming and climate change are considered. Unique geographical features, high density of population, low elevation from sea level, and geomorphological issues make this country more susceptible to climatic hazards (Rahman et al. 2021).

The coastal zone of Bangladesh has about 710 km long coastline and is one of the most dynamic deltas in the world (BWDB, 2013; Hossain and Selvanathan, 2013; Nicholls, et al., 2020). The coastal zone of Bangladesh is characterized by a wide network of river and canal systems, a dynamic Ganges-Brahmaputra-Meghna estuary shared with India, Nepal, Bhutan, and China. Unluckily, the Bangladesh coast is well-known for severe cyclones and storm surges (Blaikie, et al., 1994; Ali, 1999; Paul, 2009). This country experiences 40% of the total cyclone-induced storm surge events of the world (Murty & El-Sabh, 1992). Every year minimum of 1 and a maximum of 7 cyclones and depressions cross the coast of Bangladesh of which one is severe every 3 years (Alam, et al., 2003; Quader, et al., 2017; Ahammad, et al., 2013). Since 1970, the country has experienced 36 cyclonic storms resulting in over 450,000 deaths and a huge economic loss (UNDP 2010). Literature shows that several catastrophic cyclones hit the Bangladesh coast in 1822, 1876, 1961, 1965, 1970, 1991, and 2007 (Blaikie, et al., 1994; Dube, et al., 1997; GOB, 2008). During the cyclones of 1970, 1991, and 2007 about 500,000, 138,000, and 3,406 people were killed respectively (Ali, 1980; Haider, et al., 1991; GOB, 2008; Paul, 2009). Although the number of casualties caused by recent major cyclones has decreased since 1991, the probability of human loss due to future cyclones remains significant (Mallick, et al., 2011). Deaths and destruction during the cyclones in Bangladesh are primarily attributed to storm surge (Chowdhury, et al., 1993). The trend of cyclonic disasters hitting the coast of

Bangladesh is very alarming and increasing at the rate of 1.18 per year from 1950-2000 (Islam and Peterson, 2009). Several studies anticipate the increasing number of disastrous events in Bangladesh in the future changed climatic conditions (IPCC, 2007; WB, 2010).

In the last decades, the most disastrous events were Sidr in 2007 and Aila in 2009, which mostly affected the housing sector. According to GoB 2008, a total of 2.3 million households were affected to some degree by the effects of Cyclone Sidr, and about 1 million households were seriously affected. The impact of Aila on the housing sector was severe, as it destroyed an estimated 243,191 houses and damaged a further 370,587 houses (UNDP, 2012). Khulna and Satkhira districts were amongst the most severely impacted of the eleven affected districts (UNDP,2012), with damage to between 90 and 100 percent of houses in the four worst affected Upazilas of these two districts (Dacope and Koyra Upazilas in Khulna; Ashasuni and Shyamnagar Upazilas in Satkhira) (UN, 2010). The cyclone destroyed about 49,000 houses in Dacope Upazila (PIOD, 2009). The destruction rate of housing due to cyclones is very high because of illiteracy and lack of an idea of a modern house. Coastal people of Bangladesh built their non-engineering houses by using locally available woodcraft, artesian using wood, bamboo, tin, and thatches for living somewhat only (Zisan et al., 2013). Housing destruction during an extreme climatic disaster is inevitable due to the vulnerable structure of the existing houses in the coastal rural region. Therefore, when another cyclone strikes, the coastal population will lose their non-durable houses again. So, climate-resilient housing is a long-term solution for reducing the loss of disasters. Ideally, loss of lives and destruction could be greatly avoided if houses and infrastructure in coastal areas were strengthened to withstand cyclones and storm surges.

'Resilient Housing' is an alternative approach in disaster risk reduction targeting the most vulnerable communities. Designing and constructing a resilient built environment demands an in-depth understanding of the expertise and knowledge of avoiding and mitigating the effects of threats and hazards and that the most influential disciplines that can affect the resilience of the built environment are the design, engineering, and construction discipline (Bosher et al., 2007). Therefore, careful architectural planning and construction practices can develop resilient housing in disaster-prone areas where the communities are most at risk of losing their homes. The use of disaster-resilient materials and structures should be considered which can help minimize severe damage and loss. The idea of creating disaster-resilient communities, which are quickly able to return to normal lives after a disaster, has resulted in the concept of the Disaster Resilient Habitat (DRH) (Mallick and Rahman 2007). This uses community skills and knowledge of technical personnel like engineers and architects, to develop the "Building for Safety" options (Seraj and Ahmed 2004) to design and construct houses and infrastructure that are resilient to cyclones and storm surges.

Many factors related to DRH, such as hazard-resistant capacity, functional and spatial organization, or livelihood development have been addressed in several previous studies and projects (Boen and Jigyasu, 2005; Barenstein, 2006; Alexander et al.,2006; Steinberg, 2007; Minamoto, 2010; DWF, 2010). But the relationship between these factors and community consultation and how to address this relation in planning and implementation is rarely mentioned. The limited communication and consultation between local and external actors, the lack of technical input from built-environment professionals in developing housing designs, and the absence of resilient housing designs for low-income people, act as the key drivers of such problems. With this view of points, this study attempts to develop and implement a participatory housing design with the collaboration of local people to stakeholders and evaluate its performance against real-time natural hazards.

1.2 Objectives

The goal of this study was to understand the way to enhance resilience of a cyclone prone community and to develop a housing design through participatory approach. This study also aimed to implement the design on the study area and evaluate its performance against cyclones The specific objectives of the study were:

i. To develop a participatory disaster resilient housing design that would be used in housing practices to reduce community risk in the selected coastal areas.

ii. To implement the participatory housing design in selected coastal area involving indigenous knowledge on sustainable natural materials.

iii. To evaluate the physical performance of the implemented housing caused by flood actions during storm surge with associated high-speed winds.

1.3 Scope of the Study

This study will reveal a disaster resilient participatory housing design with minimal costing and its evaluation of performance against coastal flood actions during storm surge with associated high-speed winds. This would provide significant information to the policymakers and relevant officials for improving the policy on sustainable housing resilience for the vulnerable communities in the coastal area of Bangladesh.

1.4 Limitations of the study

The limitations of the study are as follows:

- The study results were given based on only two housing prototypes which was designed and implemented in two villages, which may be inadequate to portray further scenario of the coastal housing.
- There are very limited literature and secondary data were available on the community perceptions of housing, shelter, and warning systems. So, collecting data from the local people, were the only primary data source.

1.5 Organization of the Thesis

This thesis is organized in eight chapters described in brief as follows:

Chapter One provides with the background and rationale of the study and the specific objectives with which the study was conducted. It also provides the scope and limitation of the study and the organization of the thesis chapters.

Chapter Two delivers the review of relevant literatures on impact of climate change on the coastal area of Bangladesh, brief description of major cyclonic events and its vulnerabilities due to intensity, current cyclone forecasting system in Bangladesh, cyclone classifier model (CCM), concept of resilience, community resilience in disaster risk reduction (DRR) context, disaster risk reduction (DRR) perspectives in Bangladesh, present housing conditions in coastal area, concept of disaster resilient housing (DRH), importance of mainstreaming DRR in housing practices and challenges of mainstreaming DRR in resilient housing practices

Chapter Three contains brief description of study area including location, demography, socio-economic condition, climate, housing structure and previous storm surge hazard impact etc.

Chapter Four includes brief description of models, tools and techniques, formulas and procedures used in this study.

Chapter Five describes the problems that need to be considered in disaster risk reduction context for establishing a disaster resilient housing design in the study area.

Chapter Six includes detailed process about the implementation of the disaster resilient participatory housing design in the study area.

Chapter Seven provides the results of housing performance against real time cyclones using Cyclone Classifier Model and its cost benefit analysis with evaluation from user’s feedback.

Chapter Eight concludes the thesis with the major findings of the study along with some recommendations for further research on these issues.

CHAPTER TWO

LITERATURE REVIEW

2.1 Introduction

The study focuses on developing community resilience to climate change through disaster resilient housing practice in Dacope upazilla of Khulna district which is known as Cyclone Aila affected area.

In this chapter, an attempt has been made to review the most relevant literature of the studies regarding climate change scenario in Bangladesh, coastal community risks and vulnerabilities due to climate change, concepts of resilience, disaster resilient housing and disaster risk reduction approach, vulnerabilities, and impacts of disasters on housing and importance of mainstreaming DRR in Housing Practices.   The following topics will be helped to understand the importance and existing gaps of disaster resilient housing in global frameworks, policies, goals etc. developed for disaster risk reduction.

2.2 Concept of Climate Change

Literally 'Climate Change' refers to a statistically significant variation in either the mean state of the climate or in its variability, persisting for an extended period typically decades or longer. (Raman et al.2012) As the climate on earth has changed on all time scales even since long before human activity could have played a role in its transformation (IPCC,2007). But United Nations Framework Convention on Climate Change (UNFCCC 1994) defined Climate Change as "a change of climate which is attributed directly or indirectly to human activity that alters the composition of the global atmosphere and which is in addition to natural climate variability observed over comparable time periods". However, the IPCC definition of Climate Change includes change due to natural variability alongside human activity (UNFCC,2011). Australian Government's Department of Climate Change and Energy Efficiency (DCCEE, 2012) in its website described Climate Change- 'our climate is changing, largely due to the observed increases in human produced greenhouse gases. Greenhouse gases absorb heat from the sun in the atmosphere and reduce the amount of heat escaping into space. This extra heat has been found to be the primary cause of observed changes in the climate system over the 20th century'. Thus, in the environmental discourse different stakeholders have characterized Climate Change as mainly the change in modern climate augmented by human activities. And the adverse human activities for example burning fossil fuel, deforestation etc. are considered likely to bring change in some climatic respects. Like Foresight (2011), defined 'climate change' as, "The change of climate which is attributed directly or indirectly to human activity that alters the composition of the global atmosphere and which is in addition to natural climate variability observed over comparable time periods." And (IPCC, 2013) mentioned in AR5 report, Climate change includes both the global warming driven by human emissions of greenhouse gases, and the resulting large-scale shifts in weather patterns (IPCC,2013).

2.3 Coastal area of Bangladesh

In common parlance 'coast' is the interface or transition area between land and sea, including large inland lakes (Velmurugan et al, 2019). Unlike watersheds, there are no exact natural boundaries that unambiguously delineate coastal areas (FAO 1998a). Because of the dynamic nature of interactions and alteration by human, the coastal areas are defined in different behaviors depending on the need, purpose, scale, and availability of data for delineation. To understand the coastal areas relevant terms is described with a schematic representation of coastal areas which is shown in Figure 2.1

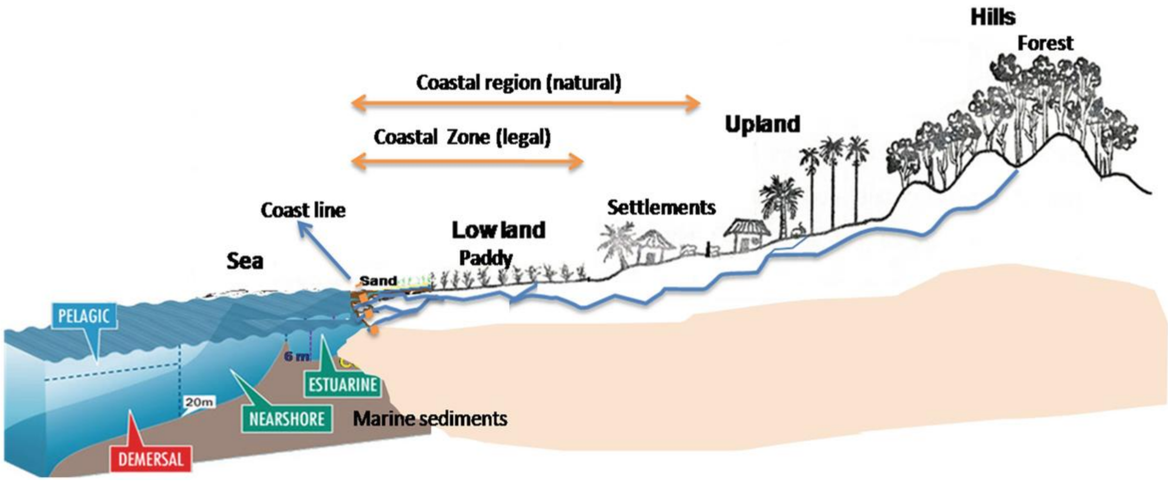

Figure 2.1: Schematic representation of coastal areas (source: Velmurugan et al, 2019)

A *"coastline"* or seashore is the area where land meets the sea or ocean or a line that forms the boundary between the land and the ocean or a lake (The Merriam-Webster Dictionary, 2000; The American Heritage Dictionary of the English Language, 2008). A precise line that can be called a coastline cannot be determined due to changes in tidal level. In many countries it is described with reference to the high tide line (Velmurugan et al, 2019). Nelson (2007) defines a "*coastal zone*" as a dynamic region where the interactions between sea and land are occurred. The terms 'coast' and 'coastal' are used interchangeably to describe a geographic location, e.g. New Zealand's coast, Coastal Bangladesh etc. *"Coastal area."* is a notion, which is geographically wider than the coastal zone, the borders of which need a less strict definition. This conception indicates that there is a national or sub-national recognition that a distinct transitional environment exists between the ocean and terrestrial domains (Abu M, Kamal U, Rob K, 2003).

The coastal area of Bangladesh covers of 47,201 km^2, 32% of the country (Khan & Awal, 2009), being the landmass of 19 districts these are Jessore, Narail, Gopalganj, Shariatpur, Chandpur, Satkhira, Khulna, Bagerhat, Pirozpur, Jhalakati, Barguna, Barisal, Patuakhali, Bhola, Lakshmipur, Noakhali, Feni, Chittagong, and Cox's Bazar (Abu M, Kamal U, Rob K, 2003). In geo-morphological point of view the coastal area of Bangladesh is divided into three different parts (Figure 2.2) (a) The eastern zone, (b) The central zone, (c) Western zone ((MCSP, 1993; Thomas et al 1992; Abu M, Kamal U, Rob K, 2003,). The western region known as Ganges tidal plain, comprises the semi-active delta and is crisscrossed by numerous channels and creeks. The central region is the most active and continuous processes of accretion and erosion. Meghna river estuary lies here in this zone. The eastern region is covered by hilly area that is more stable (Thomas et al 1992). Furthermore, 48 upazilas in the 12 coastal districts are defined as the exposed coast due to their high exposure to the sea and the remaining 99 upazilas are termed as interior coast (Abu M, Kamal U, Rob K, 2003). The coastline is 710 km long which is composed of the interface of several ecological and economic systems, including mangroves (world largest mangrove forest covers 6,017 km2), tidal flat. estuaries, sea grass, about 70 islands, accreted land, beaches, a peninsula, rural settlements, urban and industrial areas, and ports (Hossain, 2001; Iftekhar, 2006). The coastal area of Bangladesh consisting around 35 million people, and representing 29% of the total population (Ahmad, 2019) livelihood primarily depends on agriculture, fishery, forestry, near shore transportation, salt farming etc.

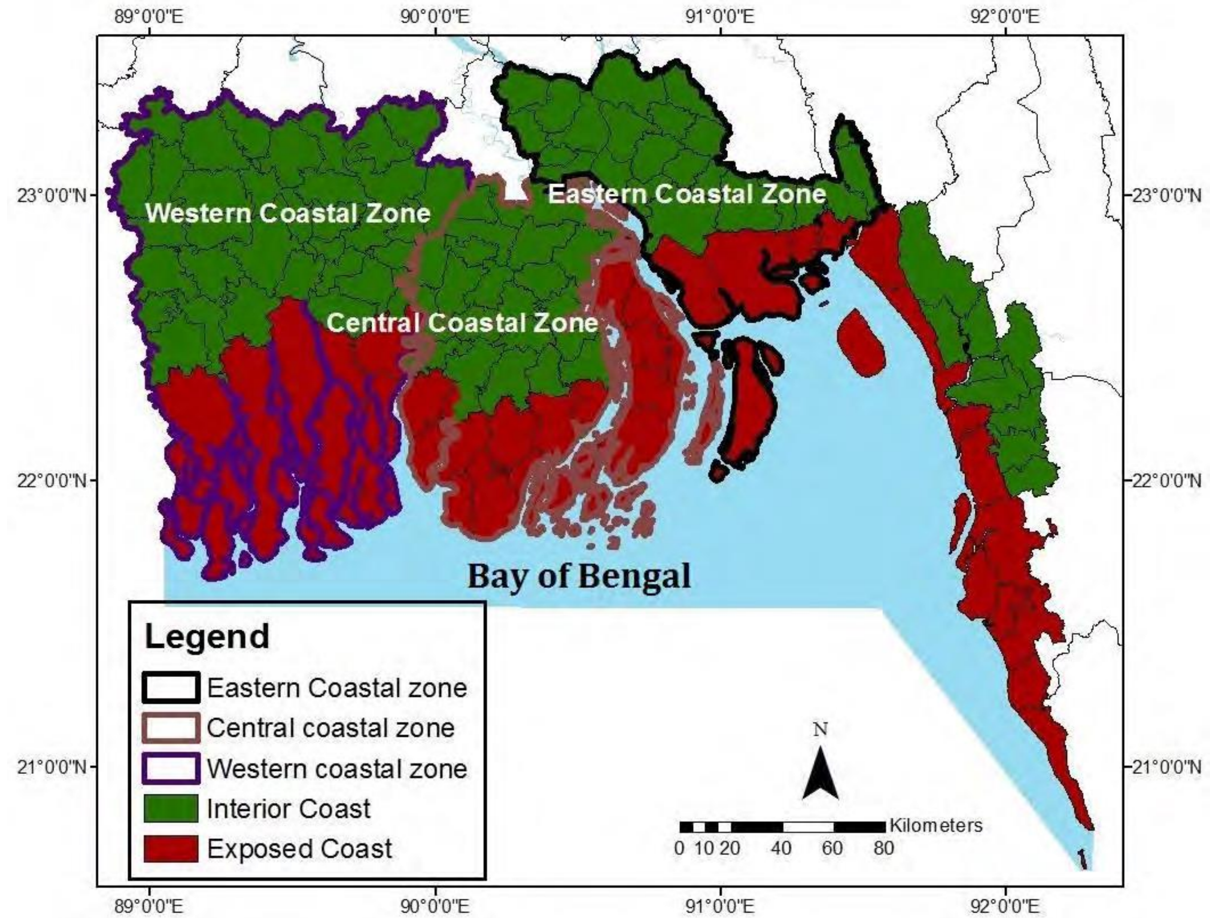

Figure 2.2: Coastal zone of Bangladesh (data source: IWFM, BUET)

2.4 Impact of Climate change on the Coastal Area of Bangladesh

Human induced climate change threatens ecosystems and human health on a global scale (IUCH, 2010). Climate change will have its greatest impact on those countries, who are already the poorest in the world (The Lancet, 2011). Climate change and its associated impacts are experienced through changes in temperatures, precipitation, and sea levels; and changes in the frequency and severity of climate extremes (IPCC 2014). According to the United Nations High Commissioner for Refugees (UNHCR) in 2010 about 42 million people around the world were forced to flee their homes because of natural disasters. What is alarming is that the number of internally displaced people because of natural disasters almost doubled between 2009 and 2010. Like among the IPCC's other findings in 2007 was that storms and cyclones have become more intense over the past 30 years specially in the tropics and sub-tropics (Nicholls et al., 2007). And geographically, Bangladesh is located in the tropical region (FAO, 2011) which is in the lower part of the Ganges–Brahmaputra–Meghna River catchment, consisting of 1.5 million km^2 area. Bangladesh comprises only 7.5% of this catchment area (Brammer 1990). The coastal area of Bangladesh is characterized by a low-lying flat land surface, wide rivers, canals, and estuarine areas, which permit sea surges to propagate quickly and to inundate far inland (As-Salek 1998; Barua 1991; Talukder et al. 1992). These elements are some of the major causes of disastrous storm surges flooding this region (SMRC 1998). That's why a severe tropical cyclone hits Bangladesh, on average, every three years (MoEF, 2009). The IPCC's Fourth Assessment Report known colloquially as AR4 (2007) indicated that due to climate change, cyclone activity has already increased and predicted that it would continue to increase in coastal areas of Bangladesh (Nicholls et al., 2007:320). A study by Unnikrishnan et al. (2006) predicted an increase in both the frequency and magnitude of tropical cyclones in the Bay of Bengal by 2050, resulting in heavy precipitation in the coastal region of Bangladesh. However, due to climate change, increasing the intensity and frequency of tidal flood, sea level rise, salinity, water-logging and other natural calamities in recent years in the coastal area creates a devastative impact on lives and livelihood. Detailed discussion of climate change impact on some major natural events is described below.

2.4.1 Cyclone

Tropical cyclones have frequently devastated large areas, taken numerous lives, and caused extensive damage to property in coastal and the island areas of the northern Bay of Bengal, which include the east coasts of India, Bangladesh, and Myanmar (SMRC 1998). A tropical cyclone is a cyclic wind that forms over tropical oceans and is mainly powered by heat transfer from the ocean (Emanuel 2003). Tropical cyclones are formed when SSTs remain above 26 °Cover an ocean depth of 60 m for a period (Gray 1978). Tropical cyclone genesis occurs in an oceanic environment where weak vertical shear of the horizontal wind and relatively large cyclonic low-level vorticity prevail (Gray 1978). Other conditions that favor genesis of cyclones are larger values of the Coriolis parameter, the heat content in the upper ocean, and the relative humidity of the middle troposphere (Gray 1978). In the southern Bay of Bengal, tropical cyclones form through a combination of all favorable genesis factors in early summer of the month from April-May or late rainy season from November- December (Choudhury, 1992; Wisner et al., 2004; Ali 1999; Paul, 2009; Farukh and Baten, 2015). During these two periods, SSTs remain constantly over 28 °C (Kikuchi and Wang 2010; Yokoi and Takayabu 2010). The effects of tropical cyclones vary based on their location of origin and place of landfall (Lal et al. 2012; Fig. 6.3). For example, just 5% of global tropical cyclones originate in the Bay of Bengal, but the adjacent countries (i.e., Bangladesh, India, and Myanmar) experience more than 75% of the global casualties (Chowdhury 2002). About 60 percent of the cyclone-related deaths that occurred worldwide between 1980 and 2000 were in Bangladesh (Nicholls et al., 2007). It's because, a severe tropical cyclone hits Bangladesh, on average, every three years (MoEF, 2009). Bangladesh's vulnerability to cyclones is exacerbated by the shape of the coastline and low, flat terrain combined with high population density and poorly built infrastructure (World Bank, 2000). Major cyclone tracks in Bangladesh are shown in Figure 2.3

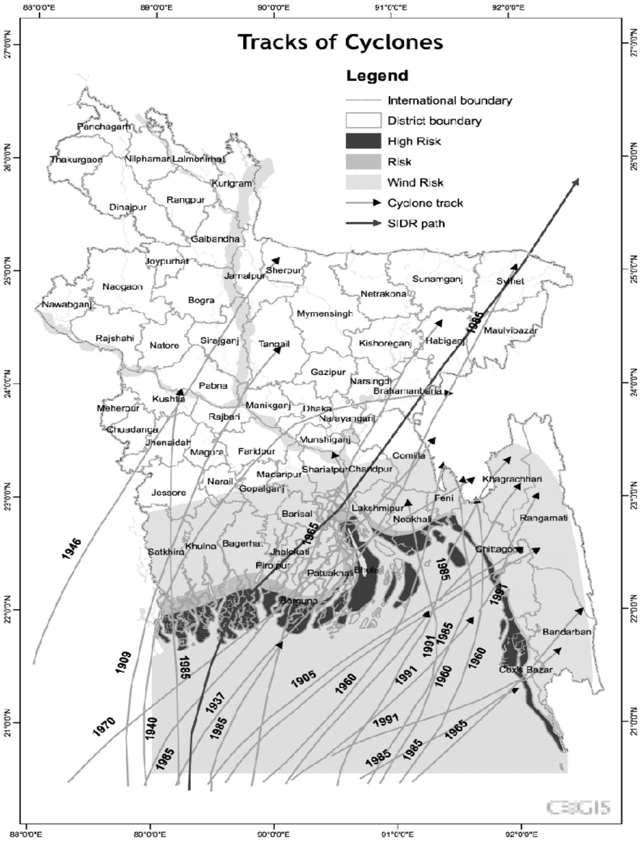

Figure 2.3: cyclone trajectories in Bangladesh *(Source: MoE, 2009)*

The global distribution of cyclones shows that only 1 % of all cyclones that form every year strike Bangladesh; but unfortunately, the fatalities they cause account for 53 % of the global total (Ali, 1999). According to the Multipurpose Cyclone Shelter Programme report, 6.4 % of the country is considered High Risk Area where the surge height may exceed 1 m.

2.4.1.1 Major cyclonic events

Several cyclones have devastated Bangladesh causing hundreds of thousands of human deaths. Apart from the human casualties, cyclones have caused substantial damage to properties, which include physical infrastructure, livelihoods mean and various direct tangible/intangible and indirect tangible/intangible items. The strength of a cyclonic disaster mainly depends on rain, strong wind, and storm surges (Dube et al., 2009). When tropical cyclones are associated with storm surges, they cause severe damages. For the formation of cyclone, the effective temperature is about 27 to 29^{0}C which is responsible for category 1 to category 5 cyclone in the context of Bangladesh (Kumar et al., 2011; Khan, 2012). Every year, 7 cyclones and depressions cross the coast of Bangladesh (Alam et.al., 2003). In the coastal areas of Bangladesh, 1 cyclone hits in every year (Quader et. al., 2017) and at least one severe cyclone hits in every 3 years (Ahammad et. al., 2013).

Historical evidence shows that, Bangladesh experiences about 40% of the total cyclone-induced storm surge events of the world (Murty & El-Sabh, 1992). At least 70 major cyclones hit the coastal belt of Bangladesh from the past 200 years including more than 900000 people died owing to catastrophic cyclone throughout the last 35 years (Islam, 2004). several catastrophic cyclones hit Bangladesh coast in 1822, 1876, 1961, 1965, 1970 and 1991 (Blaikie et al. 1994; Dube et al. 1997). During the cyclones of 1970 and 1991 about 300,000 and 138,000 people were killed respectively (Ali 1980; Haider et al. 1991). More than 50% of total deaths of the world due to cyclones and induced surges occurred in Bangladesh (Ali 1999; GOB 2008). A table representing the partial list of severe cyclonic events that caused heavy death toll and damages is given in Table 2.1

Recently, due to climate change the cyclonic activity in the Bay of Bengal has become more frequent (MoEF, 2009). Among the recent events, Sidr (2007) and Aila (2009) were the most catastrophic. Sidr, with a maximum wind speed of 240 km/h, tidal waves up to five meters high, and storm surges at a maximum of 10 meters in some areas, struck the southwest coast of Bangladesh on 15 November 2007 (GoB 2008). Due to this impact, killed almost 3000 people, injured 50000, destroyed 1.5 million homes and affected livelihoods of over 7 million people (BDMIC, 2007; UN, 2007). On the 25th of May 2009, Cyclone Aila affected coastal districts of Bangladesh, especially Khulna and Shatkira with an average speed of 120 kilometers per hour (IFRC, 2009; Khatun et al., 2018). Cyclone Aila brought heavy rains and storm surges which combined with high tides to breach flood protection embankments (IFRC, 2009) and caused 155 persons was reported dead, 10 missing, 7,108 injured. During the event, about 8,01,602 families were affected and 36,06,116 people became homeless (DMB, 2009). IFRCRCS, 2009, reported that 2,40,000 homes were fully destroyed, and 3,70,000 homes were partially destroyed. A short description of recent cyclonic events that caused heavy damages is shown in Table 2.2.

Table 2.1: Historical cyclonic events and their impact in the coastal area of Bangladesh.

Date/Month/Year	Affected Area	Type of Disturbance	Damages	References/ Source of Information
1582	Barisal and Patuakhali	Severe Cyclonic Storm with a core of Cyclone winds.	200,000 people	Bengal District Gazetteer, 24 Parganas.
1699	Sundarban	Severe Cyclonic Storm	50,000 people	Daily Ittefaq, 5 May 1991
1767	Barisal	Severe Cyclonic Storm	30,000 people	Daily Ittefaq, 5 May 1991
1822 (May-June)	Barisal	Severe Cyclonic Storm with a core of Cyclone winds	50,000 people 100,000 Cattle killed	Journal of Asiatic SOC. of Bengal
1831 (31st October)	Barisal	Severe Cyclonic Storm	22,000 people 50,000 > Cattle killed	BMD; Bengal District Gazetteer, Balasore
1847	Various locations in Bengal coast	Cyclonic Storm	75,000 people	Dipankar C. Patnaik & N. Sivagnanam.
1876 (27 October-1 November)	Patuakhali, Noakhali and Chittagong coast	Severe Cyclonic Storm, Maximum wind: 220 km/h	200,000 people	F. Henderson; D.V. Nalivkin; Journal of Asiatic SOC. of Bengal

		Surge height: 3–13.6 m (10–45 ft)		
1897 (24 October)	Chittagong and Kutubdia island	Cyclonic Storm	14,000 people	The Mercury (Hobart, Tas. 1860 - 1954)
1911 (April)	Teknaf	Cyclonic Storm	120,000 people	Khan S. R.
1919 (September)	Barisal	Cyclonic Storm	40,000 people	Khan S. R.
1941 (26 May)	Eastern Meghna estuary	Cyclonic Storm	7,000 people	Murty et al., 1986.
1958 (21-24 October)	Noakhali and West Meghna estuary	Cyclonic Storm	12,000 people	Khan S. R
1960 (30-31 October	Chittagong coast.	Severe Cyclonic Storm; Maximum Wind:210 km/h Surge: 4.5–6.1 m	10,000 people Casualty: 27,793 cattle Losses: 568,161 houses destroyed	Khan S. R
1961 (6-9 May)	Meghna estuary	Severe Cyclonic Storm; Maximum Wind:161 km/h Surge height: 2.44-3.05 m	11,468 people Casualty: 25,000 cattle	Murty et al., 1986
1961 (27-30 May)	Chittagong & Noakhali coast.	Cyclonic storm w=95 to 145 km/h and total water level was 7m	10,466 people	Murty et al., 1986
1962 (26-30 October)	Feni & Chittagong	Severe Cyclonic Storm Maximum Wind:161 km/h Surge height:2.5-3m.	50,000 people	Murty et al., 1986
1963 (28-29 May)	Noakhali-Cox's Bazar Coast	Severe Cyclonic Storm Maximum Wind:203 km/h Surge height:4.3-5.2 m	11,520 people Casualty: 32,617 cattle. Damages: 376,332 houses	Khan S. R
1965 (11-12 May) Barisal Cyclone	Barisal-Chittagong coast	Cyclonic Storm Wind speed was about 160 km/h Surge height: 3.7-7.6 m	19,279 people	Dhaka Tribune. Khan S. R
1970 (7-13 November)	Khulna-Chittagong coast	Severe Cyclonic Storm Maximum Wind:222 km/h Maximum Surge:10.6 m.	300,000 people loss of cattle:1 million, more than 400,000 houses.	US Embassy of Bangladesh. Dhaka Tribune
1971 (28-30 November)	Sunderban coast	Cyclonic Storm Wind Speed:97–113 km/h	11,000 people	Khalil, M.G., 1992

		Surge height:1 m		
1985 (24-25 May) Urir Char Cyclone	Noakhali-Cox's Bazar coast	Severe cyclone wind speed:154 km/h and 3.0-4.6m storm surges	11,069 people 94,379 houses were damaged	The Independent, Bangladesh. Dhaka Tribune
1988 (29-30 November)	Sunderban	Severe cyclonic storm, wind speed:162 km/h Surge height: 4.5 m	5,708 people	The Independent, Bangladesh. Dhaka Tribune
1991 (29 April)	Patuakhali-Cox's Bazar coast	Catastrophic cyclone	138,000 people damage of around $1.5 billion	The Independent, Bangladesh. US Embassy of Bangladesh. Dhaka Tribune.

Table 2.2: Recent cyclonic events and their impact in the coastal area of Bangladesh.

Date/Month/Year	**Affected Area**	**Type of Disturbance**	**Damages**	**References/ Source of Information**
2007 (15 November) Cyclone Sidr	Coastal belt of Bangladesh	Cyclonic Storm wind speed :240km/hour Surge height: 10 m	3,363 people destroyed 1.5 million homes	GoB 2008
2008 (8 May) "Cyclone Nargis"	Coastal belt of Bangladesh	Cyclonic Storm	3500 people	US Embassy of Bangladesh
2009 (25 May) Cyclone Aila	Khulna, Satkhira & Southwestern Part of BD	Cyclonic Storm wind speed of 120km/hour	155 people 2,40,000 homes completely & and 3,70,000 homes were partially destroyed.	DMB, 2009 IFRCRCS, 2009
2013 (16 May) "Cyclone Mahasen	Chittagon	Cyclonic Storm	17 people Wind speed 85 km/hour	The Independent, Bangladesh
2016 (21 May) Cyclone Roanu	Chittagong	Cyclonic Storm	26 people, around 40,000 houses were damaged	The Independent, Bangladesh
2017 (28 May) Cyclone Mora	Cox's Bazar	Cyclonic Storm	7 people	The Independent, Bangladesh
2019 (4 May) Cyclone Fani	Coastal belt of Bangladesh	Cyclone with the strongest storm	12 people	The Independent, Bangladesh
2019 (11 November) Cyclone Bulbul	Khulna, Bagerhat	Cyclonic Storm	25 people More than 19000 houses destroyed	The Independent Bangladesh
2020 (21 May) Cyclone Amphan	Patuakhali, Satkhira, Pirojpur, Bhola and Barguna	Cyclone with the strongest storm Wind speed:85 km/h	18 people fisheries worth Tk 1 million and crops across 200 acres of land were inundated	Dhaka Tribune
2021 (26 May) Cyclone YAAS	Khulna, Satkhira, Patuakhali, Barguna, Jhalokathi	Cyclonic Storm	2 people More than 50,000 houses destroyed	Dhaka Tribune

2.4.1.2 Spatio-temporal changes of cyclone landfall location

According to Nasher et. al. 2022, There is a spatial and temporal changes of cyclones are observed in the last century. It is found that the numbers of cyclones are increased, although the numbers of cyclones are fewer in 2001–2020 which probably presents that the landfall of cyclones in the Indian regions. Last few cyclones (e.g., Tauktae, Yaas, Amphan, Fani, Bulbul) strikes on Indian coast. In the late nineteen century, the western coast experienced most of the cyclones. In the early, middle and late twenty century all over the coastal region experienced cyclones. The number of cyclones strikes on the Bangladesh coast dramatically decreased in the early 21st century. There is a spatial distribution of cyclone landfall in pre monsoon period over the last century. The western was most vulnerable in the last 19th century. The total coastal areas were vulnerable in the early and middle 20th century. In the last 20th century and early 21st century, the eastern coast became more vulnerable to cyclones. In the post monsoon period, there is a spatial variation of cyclone landfall also observed where Satkhira, Bagerhat, parts of Barguna, and Patuakhali districts have had the maximum number of cyclones in the last 137 years, according to landfall statistics (Figure 2.4) (Nasher et. al. 2022).

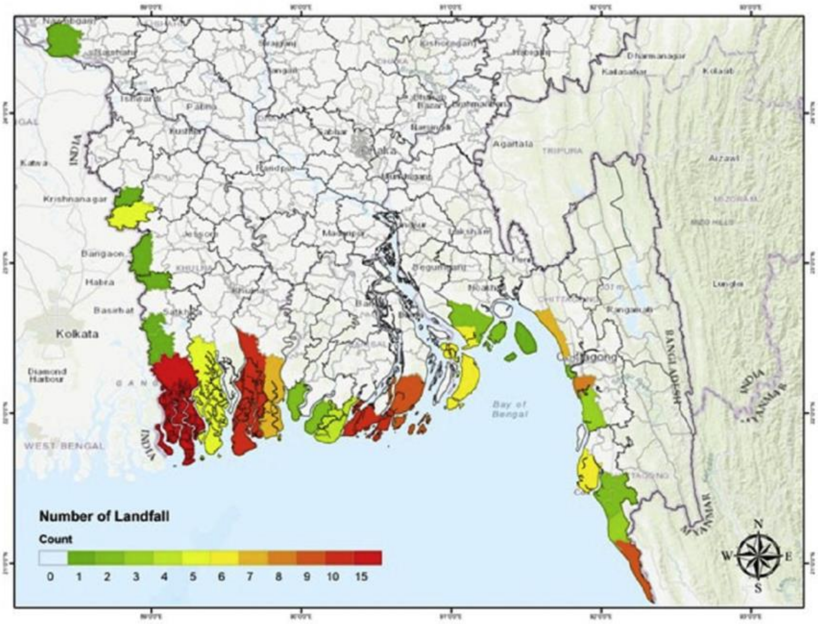

Figure 2.4: Spatial distribution of cyclone striking regions in last 137 years on the Bangladesh coast. (Source: Nasher et. al. 2022)

The eastern half of the country (Chattogram and Coxs Bazaar) was spared the brunt of the cyclone. More curiously, cyclones impacted various inland districts (for example, Jessore and Jhinaidah) in Bangladesh followed by West Bangal, Indian coast.

From 1877 to 1907, the middle and eastern costs were most vulnerable to cyclones strikes. In the early 20th century, both the eastern and western costs experienced cyclone simultaneously. From the middle to late 20th century, the total coastal region was uniformly vulnerable to cyclones. From 2001 to 2020, the western coast was most vulnerable to cyclone strikes statistics (Nasher et. al. 2022) and among the years, cyclone Aila in 2009 was the worst.

2.4.1.3 Socioeconomic impact of cyclones in the coastal community

Several disaster heat on the coastal region of Bangladesh, among them cyclone was most powerful and devastating. Among the devastating cyclone in Bangladesh the 1970, 1988, 1991, 2007 and 2009 were most destructive. Death, economic loss, property loss and damages were large amount over the country (Ahmed et al., 2012; Hofer and Messerli, 2006). Among physical, social, economic, environmental and infrastructural assets of the coastal communities were all of the assets increasing and decreasing with community's capacity. Aftermath of SIDR 2007 and Aila 2009, peer support was significant increasing but now a day's loan facility, homestead gardening, microcredit's, roads, market and market access were significant increase. But rice farming, soil and roads were significant decrease aftermath of SIDR and Aila. The destructive sector was found agriculture, this because of agricultural components would not tolerate the cyclonic storm and its duration. Livelihoods and economy are also related with agriculture. A livelihood is very important for each people well living and fulfill his/her fundamentals right. Coastal region of Bangladesh is most vulnerable for climate change as well as its destructive effects e.g., cyclone and storm surge. Cyclone can destroy people's livelihoods and their lifestyle. Migration is normal phenomena in the coastal area of Bangladesh (Saroar et al., 2015). In the context of Bangladesh, natural disasters play a significant role in forcing people to migrate to large urban centers and cope with shocks (Rayhan and Grote, 2007). However, Aila in 2009 is the best example of socio-economic impacts in the coastal community of Bangladesh. Cyclone Aila struck the coastal districts during the spring tide. The cyclone's effects lasted 15 h (approximately) with wind speeds up to 120 km/h (75 mph) and tidal surges up to 6.5 m (Islam et al. 2016). Although the intensity of the cyclone was relatively low, it inundated 350,000 acres of cropland (UN, 2010). About 1742 km of coastal polders (embankments) were washed away by the tidal surge from the cyclone, and saline water inundated large parts of the southern districts of Khulna and Satkhira (46% of croplands) for up to two years (UN, 2010; Islam et al. 2010). The full moon worsened the effects of the cyclone. It was also reported that Cyclone Aila damaged around 38,885 hectares of shrimp fields (ghers), as well as sweet fishponds (UN, 2010; Nishat et al. 2013). Fully damaged also were 445 educational institutions, 2233 km of road, and 157 km of bridges/culverts (DMIC, 2009). The cyclone struck at a time when people were trying to recover from the losses following Super Cyclone Sidr (Category 4), which battered the districts in 2007 (merely 18 months before). These two events illustrate both rapid and slow-onset climate events; however, the consequences of Cyclone Aila differed from those of Super Cyclone Sidr. While Aila was a Category 1 cyclone, the losses and damages it caused were widespread; in fact, the recovery after Sidr was much more rapid than that after Aila. The recovery from Cyclone Aila remained a challenge because the coastal people could not fully recover from the effects of Cyclone Sidr (2007) (UN, 2010). Almost two years after Aila (in 2011), many parts of Aila-affected areas remained underwater, where the land was unproductive and trees died due to saline intrusion in the soil, and people faced severe water and food shortage, as well as unemployment. The coastal people were mostly dependent on natural resources for their livelihood. The two major occupations of the coastal people, farming and fishing, were severely affected by Cyclone Aila (UN, 2010). Post Aila, prolonged waterlogging resulted in the increase in salinity in both water and soil (Nishat et al. 2013;

Mallick, 2014). Due to prolonged waterlogging, about 90% of the livelihood options of southwestern coastal communities were damaged (Jahan, 2012). It is a fact that the consequences of a disaster are not the same in the affected households even those from the same community. In general, vulnerable poor people have limited abilities in terms of socioeconomic condition, social network, and access to information, education and technology to adapt themselves to a severe situation, forcing them to migrate abruptly. In contrast, people in a comparatively better position in terms of human and social capital, migrated in a planned way, while relatively poor women and dependent members were trapped and stayed in affected areas (Shamsuddoha et al. 2012; Rahman & Akter, 2011).

Nevertheless, the consequence of cyclone Aila was much different from other cyclones as Aila was a Category 1 type, cyclonic storm formed in the Indian Ocean, with a slow onset but long-term consequences. For instance, it induced the migration of around two million people (Islam et al. 2016). Another main difference between cyclones Aila with other cyclone is that it led to three other extreme events or climatic events, flood, storm surge, salinity, and waterlogging, viewed as new forms of calamities in the southern coastal districts (Neelormi et al. 2007). Although Cyclone Aila was a slow onset event that did not cause a significant loss of life or property, its impact was prolonged. It reduced land productivity, so households required external assistance to cope with loss of incomes. As Cyclone Aila continued to directly threaten the source of income of the coastal communities several years after it struck, many people migrated to reduce their hardship; in particular, male members of the affected households moved out to look for income opportunities (Roy et al. 2009). The shock resulting from climatic events also affected the socio-economic conditions of coastal communities that were dependent on natural resources in various ways such as a loss of assets and livelihood options, reduced income, food shortage, and water scarcity (Mehedi et al. 2016). Disaster preparedness response strategies such as an early warning system and the construction of a cyclone shelter reduced the death tolls in years, but the impacts on the socio-economic conditions of the affected people remained substantial.

2.4.2 Sea level Rise

Many scientific researchers consider sea level rise as the main variable of climate change in context of Bangladesh. The reasons for sea level rise on Bangladesh coast are global sea level rising, ice cap melting and the subsidence of the Ganges Delta (Haque, 1998; Mohal et al., 2007; SMRC, 2003; Unnikrishnan et al., 2006). Studies of sea level rise along the Bangladeshi coast have generated different forecasts. According to Ahmed and Alam. (1999) and World Bank (2000), the average change in temperature for Bangladesh over a 100-year period will be as high as 3.6^0C based on Global Climate Models (GCM) - driven scenarios. Besides, analyzing 22 years of data (1977–1998), the South Asian Association for Regional Cooperation (SAARC) Meteorological Research Centre (SMRC) (2003) showed that relative sea levels in the Bay of Bengal have risen by 4.0 mm/year and by 7.8 mm/year along the western and eastern coasts. A study (Agarwala et al., 2003) predicted the range 30-100 cm by 2100, while IPCC projected 25-69 cm global SLR under scenario A1F1 (Meehl et al., 2007) and NAPA estimated possible sea level rises for Bangladesh of 14, 32, and 88 cm by 2030, 2050, and 2100, respectively (MoEF 2005). Scientists suggest that the speed of wave propagation will be increased with the increase in sea water depth. It will amplify the tidal wavelength. The height of the storm surges is also expected to increase. The shoreline is expected to retreat toward inland as a result of sea level rise enhancing the travel distance of the cyclonic storm surges. The Bangladesh Climate Change Strategy and Action Plan (BCCSAP) apprehended that if the projected sea level rise occurred, this would lead to submergence of low-lying coastal areas and intrusion of salt water into coastal rivers and groundwater aquifers (MoEF 2009). However, a sea level rise of 0.5 m over the last 100 years has already eroded 65% of the landmass (250 km^2) of Kutubdia, 227 km^2 of Bhola, and 180 km^2 of Sandwip. Over the past 100 years, this once 1000 km^2 island has been reduced to a small 21 km^2 landmass (Islam et al. 1999). In the event of any further sea level rise, islands such as these and the entire coastal area would be hit hard, resulting in billions of dollars of losses in GDP; an economic downturn; ecological damage; and lost livelihoods, assets, and options (Singh 2001).

2.4.3 Storm Surge

Storm surges are atmospherically forced oscillation of the water level in a coastal or inland water body. The surges are generated mainly by wind stresses and, to a lesser extent, falling atmospheric pressure that produces a rise in water level at the rate of approximately 1cm per hPa fall in pressure (McInnes et al.,2002). This process is called "inverted barometer effect" also known as "sucking effect". Wind force implies tangential stresses on the water surface. This tangential stress is responsible for the generation of storm waves (Huang et al, 2005). Storm surges combined with high tides can rise sharply and sweep away a whole region (Burroughs, 2003). The funnel shaped coastline and particularly the low topography of Bangladesh make the coastal area subject to high surge associated with cyclones. The country's topography is extremely low and flat with two-thirds of its land area less than 5 m or 3 m above sea level. (Dasgupta et al, 2014; Alam and Jabed, 2015). As a result, lives, and property in lower-lying coastal districts along the Bay of Bengal are highly vulnerable to inundation from cyclone-induced storm surges (Dasgupta et al, 2014). Especially the western coastal zone is mostly susceptible to surge submerging due to its low-lying land and very poor defenses against surge waves.

It has been estimated that Bangladesh is on the receiving end of about two-fifths of the world's total impact from storm surges (Murty and El-Sabh, 1992). The reasons for this excessively large impact include the re-curvature of tropical cyclones in the Bay of Bengal; the wide, shallow continental shelf, especially in the eastern part of the country; the high tidal range; the triangular shape at the head of the Bay of Bengal, which helps to funnel sea water pushed by the wind toward the coast, causing further surge amplification; the nearly sea-level geography of the coastal land; and the high-density population (1116 people/ sq. km. Islam, 2020) and coastal protection system (Ali, 1999). The Multipurpose Cyclone Shelter Programme (MCSP) report (BUET-BIDS, 1993) also identified several factors responsible for differentiated risk along the coastal areas prone to cyclonic storm surge flooding; they are:

- Storm surge height at the coast
- Angle of the storm track with respect to the coastline
- Tidal condition
- Offshore and near-shore bathymetry

- Slope of the land
- Curvature of the coastline
- Width and depth of river-mouth through which the surge will travel
- Presence of islands and chars
- Land topography and
- Land use and surface resistance including presence of forest.

Based on these factors, the MCSP report identified the area prone to storm surge flooding as the Risk Zone which was further subdivided into High-Risk Area (HRA). The HRA, where surge height may exceed 1 m, consisted of an area equaling 9,182 km^2 (6.4 % of the country) (BUET-BIDS 1993) where people are likely to be killed from drowning unless they moved to shelters.

2.5 Vulnerabilities of Coastal Area Due to Further Climate Change

People with vulnerabilities are more susceptible to the immediate, medium, and long- term effects of disasters such as loss, injury, social dislocation, and economic hardship. People who require special or significant assistance to mitigate against, prepare for, respond to and recover from a disaster should be considered vulnerable (Enam, 2015). Vulnerability is also human dimension of disasters and result of the range of economic, social, cultural, institutional, political, and psychological factors, including- social group, age, gender, design, and construction of buildings, inadequate protection of assets, lack of public information and awareness, limited official recognition of risk, and preparedness which make people isolated, insecure and defenseless in the face of risk (PreventionWeb, 2015; ODPM, 2013; IFRCRCS, 2019). At the same time, to discuss vulnerability, we must know the process of vulnerability. 'Pressure and Release (PAR) model: the progress of vulnerability' is a process of making vulnerability which has shown how the vulnerability is created to disaster (see Figure 2.5). Although this approach has contained a lot of disasters the cyclone induced storm surge is one of them.

The root causes, dynamic pressure, and unsafe condition are vulnerability, which makes risk with the help of hazards. Those people are secure who are free from the above conditions. So, eradicating the above factors must be needed to reduce the intensity of vulnerability. Though disasters affect everyone, often the impact disproportionately falls on poor communities and the poor and marginalized people within. The effects of natural disasters can be persistent for the poor, especially when they lose both of income and assets (Noy, 2009). Poverty restricts these community people from having alternate or diversified livelihood options. They have limited or almost no access to funding or financial assistance for which they are usually dependent on one kind of livelihood which when damaged by a disaster event becomes difficult to recover. Household assets are the important assets which include land, livestock, productive assets, appliances, and non-productive assets. The poor and vulnerable do not have the assets necessary to generate stable income and maintain a healthy quality of life. Only very few rural households own agricultural land. Vulnerable and highly vulnerable households are overwhelmingly landless. Therefore, their household assets are vulnerable to any natural hazard and once they are damaged, they can hardly recover the loss.

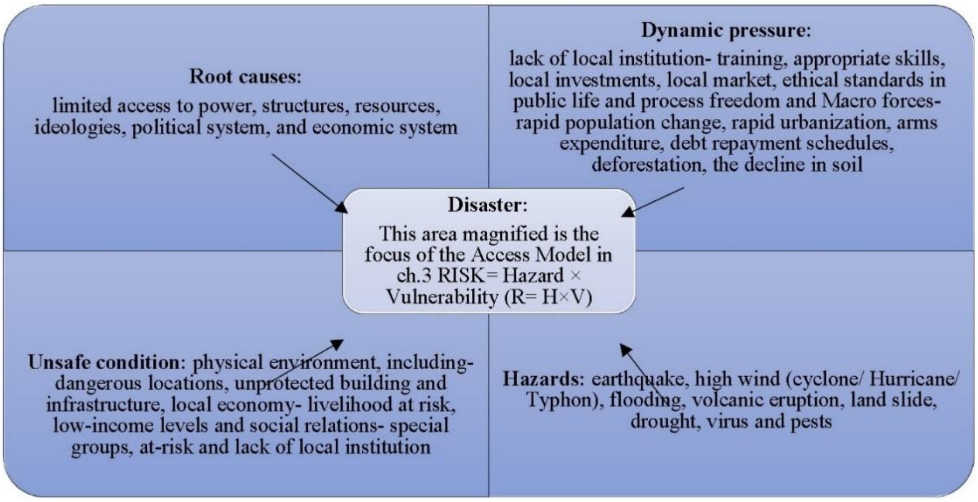

Figure 2.5: Pressure and Release (PAR) model: the progress of vulnerability *(source: Wisner et al. (2004)*

2.5.1 Vulnerabilities due to Intensity of Tropical Cyclones

Disaster is the product of natural hazards on vulnerable people who are living in disaster-prone areas (Cannon, 2008). Bangladesh is situated at a vulnerable location because of geographical and geomorphological conditions. Among all inhabitants of coastal areas, women are more affected by disasters because they depend on local natural resources and have limited decision-making power and access to resources (Sharmin & Islam, 2013). Poverty rises vulnerability during the disaster in the coastal areas of Bangladesh. To reduce vulnerability, the dwellers must make disaster resilience building which will be possible when poverty can be removed from those affected people (Chaudhury, 2017). Without poverty, several phenomena rise vulnerability, such as- unplanned settlements, dependency on dangerous and problematic places which are far away from cyclone shelters and transportations. Most of the people in those areas increase religious activities to satisfy their God. Some people can't go to cyclone shelters and take shelter in the thatched-roof house and big branches trees, and women and children are more affected by cyclone (Alam & Collins, 2010). On the other hand, vulnerability can be reduced through three ways, such as- forecasting and warning, community preparedness, and land use planning (Bisson, 2012).

However, climate change, Sea Surface Temperatures (SST), and the intensity of tropical cyclones are interrelated phenomena (Emanuel, 2005). The theory and modeling suggest that observed increases in SSTs, which are thought to be associated with climate change, have led to increases in tropical cyclone intensity (Emanuel et al. 2008; Hoyos et al. 2006; Knutson and Tuleya 2004; Solomon et al. 2007; Webster et al., 2005). Usually, a warmer ocean is likely to intensify cyclone activity and heighten storm surges (Knutson & Tuleya, 2004). The effects are catastrophic when they are escorted by strong winds. An increase in SST is probable to increase the wind speed because of convective instability triggered by increased SST.

But according to Kumar and Sankar (2010), to understand the relative changes between SSTs and tropical cyclone activity did not find any significant relationship in the Bay of Bengal. Further, it suggested that some atmospheric parameters such as low-level vorticity, mid-tropospheric humidity, and vertical wind shear play significant roles in the genesis and intensity of tropical cyclones in the Bay of Bengal.

Furthermore, in the Bay of Bengal, the evidence of changes in the frequency and intensity of tropical cyclones is contradictory (Table 2.3). Because the trend between the overall tropical cyclone activity and intense tropical cyclones may not be reliable, because of recent improvements in detection that have resulted in more intense tropical cyclones being recorded (Klotzbach 2006; Landsea et al., 2006).

Table 2.3: Contrasting evidence of changes in the frequency and intensity of tropical cyclones in the Bay of Bengal. (Compiled by Alam et al, 2018)

Frequency and intensity of tropical cyclone	Sources	Data period	Comments
Observed increase in frequency of tropical cyclones	MoEF (2009)	-----	The MoEF made a general statement about an increase in tropical cyclones without referring to any data period.
	Webster et al. (2005)	1975-1989	The period of data analyzed was relatively short
	Singh et al. (2001)	1990-2004 1877-1988	Tropical cyclone frequency mainly increased in May and November
Observed decrease in frequency of tropical cyclones	Mandke and Bhide (2003)	1901–1998	Storm frequency has decreased on a decadal scale since the 1980s despite Kumar and increasing SSTs
	Kumar and Sankar (2010	1951–2007	
Likelihood of increase in frequency of future tropical cyclones	MoEF (2009) Unnikrishnan et al. (2011)	2071–2100	The MoEF made a general statement about increases in tropical cyclones without referring to any data period
Likelihood of decrease in frequency of future tropical cyclones	Murakami et al. (2013)	2075–2099	Reduction of 31% in the frequency of tropical cyclones
Observed increase in intensity of tropical cyclones	Elsner et al. (2008)	1981–2006	Analysis of satellite imagery for 2097 tropical cyclones around the globe suggested a significant increase in the intensity of tropical cyclones
	Webster et al. (2005)	1975–1989 1990–2004	
Likelihood of increase in intensity of future tropical cyclones	MoEF (2009) Unnikrishnan et al. (2006)	2041–2060	The MoEF predicts an increase in wind speed of tropical cyclones and associated storm surge heights

For example, the intensity of tropical cyclones was underrated as recently as in the 1980s. The November 14, 1984, Bay of Bengal tropical cyclone was considered category 3 or less, but reanalysis of this cyclone by satellite revealed that it could have been category 3 or 4 (Landsea et al. 2006). Contrary to the suggestion of some recent scientific studies showed that, increase in the frequency and intensity of tropical cyclones in the last 35 years happened due to the consequences of climate change (Webster et al., 2005; Bengtsson et al., 2006). A study (WB, 2010) showed that a 10-year return period cyclone with an average wind speed of 223 km/h covers 26% of the vulnerable zone which is likely to cover 43% by 2050 due to intense global warming. Webster et al. (2005) also suggested that the frequency of category 4 and 5 tropical cyclones increased by 17% between the periods of 1975–1989 and 1990–2004.

According to Dasgupta et al. (2010) and other scientific evidence, vulnerability of Bangladesh to cyclonic storm surges may increase even more because of climate change and increased sea surface temperature. Some studies predict an increase in the frequency and intensity of cyclonic storm surges due to climate change such as increasing SST, sea level rise, and vertical wind shear etc. the coast of Bangladesh will experience amplified storm surges (Emanuel, 2005; Webster et al., 2005; Bengtsson et al., 2006). The International Workshop on Tropical Cyclones (IWTC) has recently proposed that if the projected rise in sea level due to global warming occurs, then the vulnerability to tropical cyclonic storm surge and flooding will increase and experience a 3-5% increase in wind speed per degree Celsius increase of tropical sea surface temperature (WMO, 2006).

2.5.2 Vulnerabilities due to Future Storm Surge Height.

In Bangladesh, the maximum value of storm surge has been reported to be as high as 13m (SMRC, 1998). Surges that make landfall during high tide are even more devastating. In general, it has been observed that the frequency of a 10-m high wave (surge plus tide) along Bangladesh coast is about once every 20 years, while a wave with a 7-m height occurs about once in 5 years (Dasgupta et al, 2014). In addition, wind-induced waves of up to 3.0 m in height may also occur under unfavorable conditions (MCSP 1993).

The IPCC AR4 indicates that future storm surges and related floods in Bangladesh will likely become more severe as future tropical cyclones increase in intensity (IPCC, 2007). Recently, IPCC AR6 revealed that, between 2010–2020, human mortality from floods, cyclones and storm surges was 15 times higher in highly vulnerable regions like Bangladesh, compared to regions with very low vulnerability (IPCC, 2022). Climate change and its effects on the intensity of tropical cyclones and increases in storm surge height may be coupled with possible sea level rises. It is predicted that rises in the mean sea level (MSL) and increases in the intensity of tropical cyclone wind speed will increase the depth of inundation along the Bangladeshi coast by more than 3 m and increase the exposed areas by 69% in size (Dasgupta et al., 2010). Increases in SST of up to 2 °C will increase the height of storm surges by 23% and increase areas of inundation to 1.26 times the present levels of inundation (Ahmed and Alam 1999; Karim and Mimura 2008; MoEF 2005). A study using dynamic, Regional Climate Model (RCM)-driven simulations of current and future climates indicates a significant increase in the frequency of highest storm surges for the Bay of Bengal, despite no substantial change in the frequency of cyclones (Unnikrishnan et al. 2006). Emanuel (2005) projects increased intensity of tropical storms by 2100 for the North Indian Ocean, as measured by the percent change in landfall power using the Model for Interdisciplinary Research on Climate (MIROC) General Circulation Model (World Bank and United Nations 2010).

According to World Bank, (WB, 2000b) about 10 cm of sea level rise will inundate approximately 2% of the country, while 25 cm and 1 m SLR will inundate approximately 4% and 17.5% of the country. Ali (1996) showed that increase of surge height from 7.6 m to 9.2 m increases the inundation area by about 13% and an increase from 7.6 m to 11.3 m increases inundation by about 31%. Another study quantified that about 11% additional area of the south-west region is likely to be inundated due to 88 cm where about 84% of the Sundarbans area becomes deeply inundated due to 32 cm SLR, and for 88 cm SLR Sundarbans will be lost (PDO-ICZMP, 2005). A study of IWM and CEGIS (2007) showed that about 44% people will be exposed to additional flooding due to sea level rise of 15 cm in 2080 under scenario B1. Under scenario A2, in 2050 (SLR 27 cm) and 2080 (SLR 62 cm) about 47% and 51% people may be victims of coastal storm surge flooding.

2.5.3 Vulnerabilities due to further salinity intrusion due to climate change

The coastal area of Bangladesh, in the Bay of Bengal, experiences frequent tropical cyclones and their associated storm surges; that flood areas with saline water (Dasgupta et al., 2010). Bangladesh was hit by 154 cyclones between the years 1877 and 1995, many of them included storm surges that went more than 7minland (Dasgupta et al., 2014). More recently between the years 2000–2020, there have been eight major cyclones, including Cyclone Sidr in 2007 and its associated storm surge, that affected around 3.45million people (Hossain and Mullick 2020). Approximately 37% of arable seaside land is currently impacted by fluctuating degrees of soil salinity due to these surges (Dasgupta et al., 2014). Furthermore, 1.02 million hectares (about 70%) of this arable land on the coast is affected by varying degrees of soil salinity in general. The increase in soil and water salinity causes problems within the coastal ecological setting, affecting the cultivation of crops, thus decreasing food security and increasing the shortage of drinking water by significantly reducing the quality of freshwater (Brammer 2014). This situation can potentially subject more than 20 million people to the harmful effects of excess salt through food and water resources (Haldar et al., 2017). According to the Intergovernmental Panel on Climate Change (IPCC) report, saltwater intrusion in low-lying coastal areas, river deltas and estuaries has increased, leading to salinization of groundwater, surface water and soil resources (Oppenheimer et al., 2019). Excessive groundwater Mining has lowered the groundwater level, and rising sea levels have caused seawater to invade coastal aquifers from the ocean, leading to longterm salinization in southwestern Bangladesh (Salehin et al., 2018). During the dry season, the flow of the lower Ganges becomes low, and seawater pushes inland saltwater into rivers and canals, through vertical filtration or infiltration into nearby land, resulting in salinization of groundwater and soil, which lasts until the onset of the rainy season (Lam et al., 2021; Salehin et al., 2018). Floods and storm surges caused by severe tropical cyclones such as Sidr (2007) and Aila (2009) are also responsible for the long-term salinization of soil and surface water (Kabir et al., 2016; Salehin et al., 2018). This affects agricultural activities such as plant germination, biomass production and yield, and people’s livelihoods (Lam et al., 2021).

Another important driving factor increasing soil and water salinization over the previous half-century is climate change (Daliakopoulos et al., 2016; Gorji et al., 2019). This is because soil and water are closely associated with the atmospheric and climatic schemes through carbon, nitrogen and hydrological rotations. Therefore, the changing climate will impact soil and water processes. Low-lying semi-arid and arid areas are even further exposed to soil and water salinity due to declining groundwater quality and rainfall shortages (Kurylyk and MacQuarrie 2013). In these areas, irrigation-based cultivation is indispensable, despite causing the salinization of soil and water which can lead to land degradation (Baumhardt et al., 2015). Following rigorous irrigation, soil salinity affects around 40–45% of the Earth's land and leads to immense economic harm to a universal extent (Oo et al., 2013). One such example is in the Jaffna Peninsula in Sri Lanka where 32.8% of the land and 45% of paddy land have been impacted by salt (Gopalakrishnan and Kumar 2020). The global average surface temperature in the latter part of the current century (2081–2100) is forecasted to go beyond 1.5–2°C (IPCC, 2014; Talukder et al., 2018). Around 70% of the global coastal areas are predicted to undergo remarkable sea level rise. Climate change impacts would lead to the increased river and groundwater salinity in Bangladesh especially in Southwestern coastal regions by 2050 (Brammer 2014). At least 2.9 million poor people are affected by a drinking and irrigation water deficit in the region (Bannari and Al-Ali, 2020).

2.5.4 Interconnections among Climate risks

Climate risks may ripple through sectors in the present interdependent world, posing a challenge ahead of us to maintain the resilience of the system (Helbing, 2013). The risks of climate change can be transmitted and amplified through multiple direct and indirect pathways (Liu et al., 2015; Pidgen et al., 2003). A combination of interacting processes across a wide range of spatial and temporal scales can result in extreme impacts (Leonard et al., 2014).

The magnitudes of risks may be significantly underestimated if we fail to consider their interconnections (Challinor et al., 2017). The fourth report for the assessment of climate change impacts and vulnerability in Europe (Lung et al., 2017) reviewed the ways in which the impact of climate change in one sector affects other sectors across the continent.

According to Yokohata et al. in, climate risks are connected across various sectors. The risks in each sector are caused directly by changes in the climate system (Figure 2.6) as well as by risks in other sectors. Climate drivers tend to be a cause of inter sector risk interconnections, and most sectors tend to be both a cause and effect of inter sector linkage. The health sector has the largest proportion of inter sector effects, indicating that this sector tends to be the end of the causal relationships. Figure 2.6 indicates an overall structure of climate risk interconnections: Changes in the climate system impact the natural and socioeconomic systems, ultimately influencing human security, health, and wellbeing. Figure 2.6 also shows the definition of natural and socioeconomic systems (upper rectangle, water, food, energy, industry, and infrastructure and ecosystem sectors), and the human system (lower rectangle, disaster, security, and health sector) (Yokohata et al. 2019).

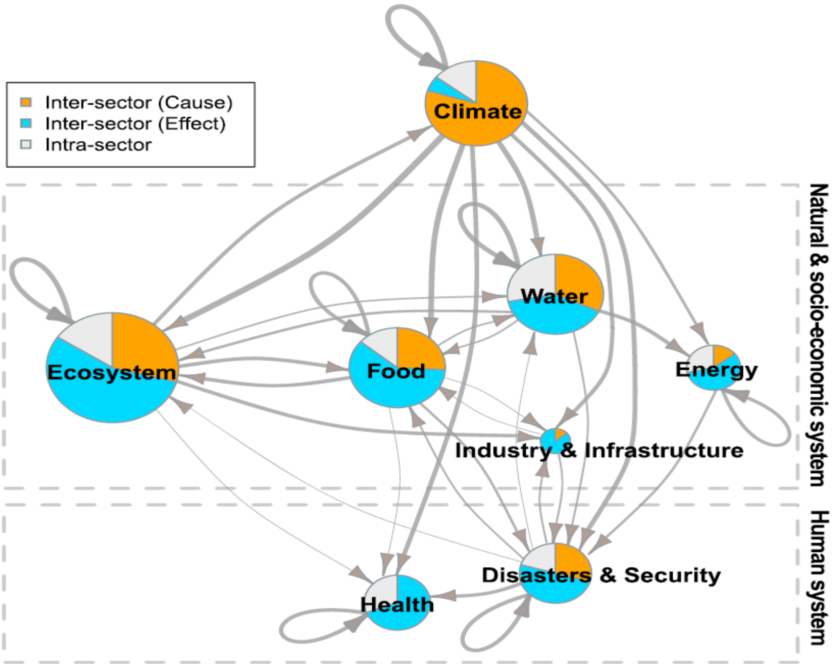

Figure 2.6. Climate risks and their cause–effect relationships shown at the sectoral level. *The arrow thickness indicates the number of risk interconnections represented. Arrows connecting different sectors indicate intersectoral causal relationships, and those looping back to the same sector represent the causal links within the sector. The node size also reflects the number of risks identified within the sector. The colors of nodes indicate the portion of inter sector cause (orange), effect (blue), and intra sector cause and effect (gray). For example, in a linkage between "increase in flooding" (water) causing "increase in damage to agricultural land" (food), the former is an inter sector cause, and the latter is an inter sector effect. This linkage is represented by an arrow from the water to food sector. In a linkage such as "change in food distribution" (food) leading to "destabilization of food supply" (food), where both are an intra sector cause and effect. This linkage is represented by an arrow starting and looping back to the food sector. The upper and lower dashed gray rectangles encompass sectors related to the natural and socioeconomic systems and the human system, respectively. (Source: Yokohata et al. 2019)*

2.6 Current Cyclone Forecasting System in Bangladesh

The exposed districts of coastal area of Bangladesh are currently the home of around thirty and a half million people (BBS, 2011). To ensure the safety of residents in the coastal areas, the Bangladesh government is investing considerable effort into developing a suitable approach to manage cyclone emergencies (Haque et al., 2012; Paul, 2009; Paul et al., 2010). The Storm Warning Center (SWC) is a specialized unit of Bangladesh Meteorological Department (BMD) and is responsible for forecasting and issuing warnings for cyclones in Bangladesh. BMD collects meteorological data through 35 ground-based, 10 weather balloon, 5 radar, and 3 radiosonde stations. In addition, BMD receives weather satellite data, ocean-buoy-recorded meteorological, and sea surface data, and numerical-model-generated weather forecasts from other national and regional meteorological offices, as a member state of the World Meteorological Organization (Akhand, 2003; Obasi, 1994; RSMC, 2013). Currently, BMD employs two techniques: (a) Storm Track Prediction (STP), and (b) Steering and Persistence (STEEPER) for cyclone forecasting (ADRC, 2005; Debsarma, 1999). Technically, neither STP nor STEEPER is sufficiently advanced, and therefore cannot produce forecasts with good accuracy for more than 12 hours ahead (Debsarma, 1999). However, the cyclone warning system is well known in Bangladesh. Warnings include the following information. i) Position of storm center. ii) Direction and rate of movement. iii)Area likely to be affected specifying upazillas (administrative unit in Bangladesh) of the district if possible. iv) Approximate time of commencement of gale winds (speed more than 32 km/h or 52 km/h). v) Maximum wind speed expected. Vi) Approximate height of storm surge/tide and areas likely to be affected. To produce a tropical cyclone warning, predictions of the following are required: i) Tropical cyclone location and motion ii) Tropical cyclone wind field. iii) Storm surge. Current cyclone warning systems in Bangladesh are described in Table 2.4 & 2.5

Table 2.4: River Port Signals

Cautionary Signal No. 1	The area is threatened by squally winds of transient nature, expecting nor'-westers and storms. -river ports are to be alerted, but communication will not stop.
Warning Signal No.2	A storm is likely to strike in the port area, with wind velocity of 51-61 km/h. - all vessels and boats (up to 65 feet length) are to seek shelter immediately.
Danger Signal No.3	A storm will strike port area soon, with wind velocity of 62-87 km/h. - all vessels and boats will seek shelter immediately.
Great Danger Signal No.4	A violent sea storm will strike port area soon, with wind velocity more than 87 km/h, but no nor' -westers. - all vessels and boats will take shelter immediately.

Table 2.5: Sea Port Signals

Distant Cautionary Signal No. 1	There is a possibility of squally weather in the distant sea where a storm may form. - wind velocity: maximum 50 km/h
Distant Warning Signal No.2	A storm has formed in the distant sea. -wind velocity: 51-61 km/h
Local Cautionary Signal No.3	The sea port is threatened by a squally weather. -wind velocity: 51-61 km/h
Local Warning Signal No.4	The port is threatened by a storm, but it does not appear that the danger is yet sufficiently great to justify extreme precautionary measures. - wind velocity: 62-87 km/h
Danger Signal No.5	The port will experience severe weather from a storm of slight, or moderate intensity that is expected to cross the coast to the South of Chittagong/Cox's Bazar port, or East of Chalna port. - wind velocity: 88-117 km/h

Danger Signal No.6	The Port will experience severe weather from a storm of slight, or moderate intensity, that is expected to cross the coast to the North of Chittagong/Cox's Bazar port, or to the West of Chalna port. - wind velocity: 88-117 km/h
Danger Signal No.7	The port will experience severe weather from a storm of slight, or moderate intensity that is expected to cross Over, or Near the port (Chittagong, Cox's Bazar, Chalna). - wind velocity: 88-117 km/h
Great Danger Signal No.8	The port will experience severe weather from a storm of great intensity that is expected to cross the coast to the South of Chittagong/Cox's Bazar port, or to the East of Chalna Port. -wind velocity: 117-250 km/h
Great Danger Signal No.9	The port will experience severe weather from a storm of great intensity that is expected to cross the coast to the North of Chittagong/Cox's Bazar, or to the West of Chalna Port. -wind velocity: 117-250 km/h
Great Danger Signal No. 10	The Port will experience severe weather from a storm of great intensity that is expected to cross Over or, Near the port (Chittagong, Cox's Bazar, Chalna). -wind velocity: 117-250 km/h
Failure of Communication Signal No. 11	Communication with the meteorological warning center has broken down and the local officers consider that a devastating cyclone is following.

2.6.1 Limitations of Warning Signals

Technical and organizational limitations can impede accurate TC prediction at BMD:

1. Infrequent data updates over the BoB: Though storm locations are regularly available from satellite and radar images, and ground-based observations are available every 6 hours, steering wind information is only available every 12 hours. Moreover, both ground-level and upper-level atmospheric data over the BoB are often missing. In such situations, meteorologists use 12-hour old and interpolated values of wind direction and speed over the BoB as input to TC forecasting.

2. Data integration problems: BMD receives ocean buoy data and reanalysis data from the National Centers for Environmental Prediction (NCEP) (Kalnay et al., 1996). However, BMD cannot use these data to compensate for the infrequent update of data over the BoB, as the received data are often in formats that are not supported by the currently operational forecasting techniques, and the meteorologists at BMD do not have the necessary expertise to re-code the data.

3. Forecast verification: With no benchmarking technique such as CLIPER and SHIFOR (NOAA, 2012) in operation, the meteorologists are not able to verify prediction performance of the current TC forecasting technique. As a result, they cannot include the precision level of the produced forecast in the warning message.

4. Lack of expertise: BMD has access to numerical models to produce forecasts for rainfall and storm-surges. However, these models are not advanced, and the meteorologists do not have the necessary data-processing knowledge and computational skills to modify these models to produce forecasts for new atmospheric phenomena like TCs.

5. Lack of computational resources: The BMD is running forecasts on a cluster computer using 15 quad-cores running at 2.8 GHz each, with 16 gigabytes of RAM. These computational resources are insufficient for running advanced numerical models (Roy and Kovordányi, 2012; Roy and Kovordányi 2015)

2.6.2 Difficulties of BMD forecasting system in community level

The forecasts produced by BMD are not reliable for longer than 12-hour. Therefore, longer-term warnings must be based on gross estimates of cyclone intensity and motion, which renders the disseminated warning messages unreliable. As a result, residents in the coastal areas do not follow the evacuation orders due to mistrust of the warning messages- which can deter from early evacuation; and insufficient number of shelters and poor transportation possibilities- which discourages late evacuation. Moreover, the contents of a warning message might not be considered in the same way by its provider and by its receivers living in a community (Drabek, 1999). Results from recent studies conducted on the offshore islands and in the coastal regions of Bangladesh show that people often refrain from responding to the warning messages, typically for the following reasons:

- People do not receive, understand, or believe the warning, in the latter case partly because the warning messages are seen as unreliable.
- The guidelines for evacuation contained in the messages are not clear.
- The shelters are far from the residents' homes, do not have enough capacity, or are derelict due to lack of maintenance.
- Underlying causes of vulnerability to cyclone, such as lack of access to resources, lack of education and training, fragmentation in the community.

Previous research evaluating the cyclone early warning system in Bangladesh has only considered the residents' perspective: the residents' perception of risk, their vulnerability to cyclones, their indigenous coping strategies and their response to warnings (Paul, 2009; Paul & Routray, 2011; Rahman et al, 2007).

2.6.3 Introducing Cyclone Classifier Model (CCM)

In terms of human casualty and property damage, cyclone & storm surge is the dominant hazard in Bangladesh coast. Cyclone warning is considered as the non-structural mitigation measure that can reduce this damage. As mentioned above, Bangladesh Meteorological Department (BMD) issues cyclone warning which is largely criticized for its several drawbacks (Haque et al, 2019). In SATREPS project of BUET introduced Cyclone Classifier Model (CCM) that uses simple classification algorithm and is used to generate additional information (location-specific cyclone wind speed, storm surge depth, information on probability of house damage & embankment damage and hazard map) for the present warning system which is considered useful by the local people (Haque et al, 2019). Application of CCM gives location specific information for cyclone wind speed, surge depth, status of house damage, embankment damage and hazard map for the entire coast. Evacuation will be easy if all this information is used with the present cyclone warning issued by BMD (Haque et al, 2019).

2.7 Concept of Resilience.

The concept of resilience is increasingly being used in academic and policy circles related to the field of environmental health. While definitions of the concept of resilience are also increasingly diverse, when applied to people and their environments, "resilience" is most often utilized as a metaphor for the capacity of system to return to some equilibrium state after a crisis through processes of both resistance and adaptation (Norris et al., 2008). The term resilience is often used in the same manner as the notion of "bouncing back" or "build back better" that reflects its Latin root *"resilierel"* which means to "jump back" (Klein et al., 2003; Paton & Johnston, 2006). The concept of resilience is applied broadly across scales, ranging from individual characteristics supporting personal capacities for coping with stressors to entire social ecological systems that consider the integrated capacity of both communities and the environments upon which they depend to adapt to an ever-changing context (Mayer, 2019).

Into the twentieth century, the term was increasingly used in medicine, engineering, and psychology, followed by natural ecology and then human ecology. In recent decades, economics and development studies among many other fields adopted their own views of the meaning of 'resilience.' For example, Manyena (2006) and Gaillard (2007) provide background and interpretations from a disaster risk reduction (DRR) perspective. In the USA, national and local governments and research programs are increasingly call for the integration of plans to increase community resilience into disaster risk reduction policies and interventions involving planning and enhancing adaptive capacities (National academies, 2012). Internationally, policy initiatives such as the 2015 Sendai Framework for Disaster Risk Reduction have further elevated the role of resilience in academic and professional settings (Maini, et al., 2017).

For better understand the scope of resilience, Paton (2007) offers a schema that overviews resilience from the point of view of individuals, communities, and institutions. Under each of these headings, they list a series of characteristics or capacities providing the basis for 'bouncing forward' when a disaster causes disruption and loss. Of note is the recurrence of the word 'resources' in each list, reminding one of the unequal distribution of resources required for the capacities to recovery (and summarized in Figure 2.7) to materialize. The double-headed arrows suggest interaction and complex feedbacks, also noting that institutions upon which communities and individuals normally depend are likely to be disrupted by disaster. Other new institutions can be introduced, including those brought in by humanitarian actors, but their routines and cultures are different (Robinson, 2008). Also 'Resilience' is usually seen as a broader concept than 'capacity' because it goes beyond the exact behavior, strategies and measures for risk reduction and management that are normally understood as capacities. However, it is difficult to distinct the concepts clearly. In everyday usage, 'capacity' and 'coping capacity' often mean the same as 'resilience'. A focus on resilience means putting greater importance on what communities can do for themselves and how to strengthen their capacities, rather than concentrating on their vulnerability to disaster or their needs in an emergency.

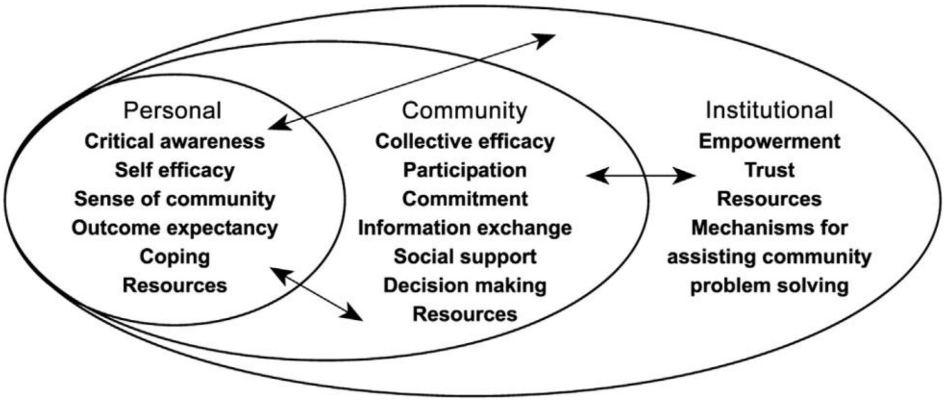

Figure 2.7: Resilience model. (Source: Paton, D., 2007).

The terms ‘resilience’ and ‘vulnerability’ are opposite sides of the same coin, but both are relative terms as argued by Manyena (2006). One must ask what individuals, communities and systems are vulnerable or resilient to, and to what extent. Like vulnerability, resilience is complex and multifaceted.

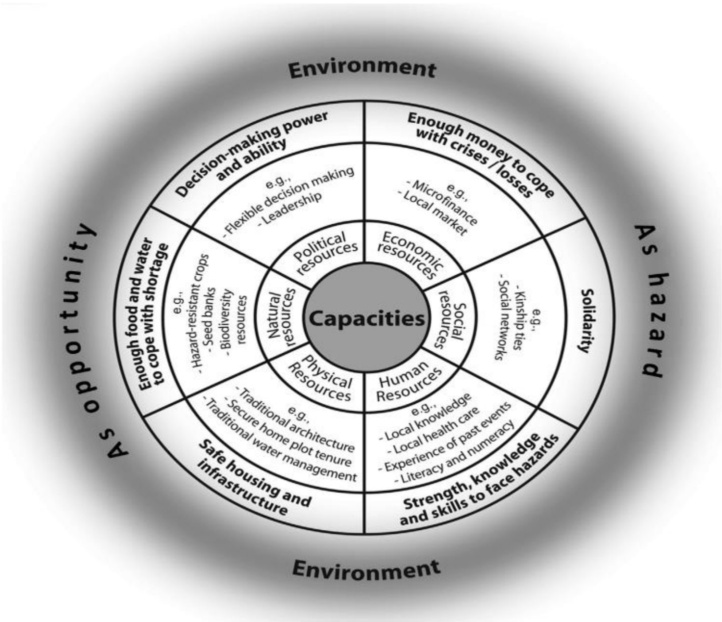

Figure 2.8: Resources and capacities for resilience. (Source: Wisner et al., 2012).

Different features or layers of resilience are needed to deal with different kinds and severity of stress. However, given the heterogeneity of subgroups within any community with people stratified in terms of decision making, capacity and vulnerability, by wealth, income and sometimes ethnicity and religion, alongside common place differences such as gender, sexual orientation, age, and ability – there are both winners and losers while and after a disaster manifest (Wisner and Kelman 2015). Often, humanitarian assistance, recovery, and reconstruction reestablish that status quo because resilience is seen as a return to the pre-disaster ‘normal,’ rather than trying to create a different community, which solves the problems that led to the disaster in the first place, frequently espoused by the tagline ‘Build Back Better.’ By returning to the status quo, vulnerability to disaster remains the same, or can even increase, while capacity and resilience can decrease, instead with those in control gaining resources, capacity, and resilience (Susman et al., 1983). With risk being an intersection of hazard and vulnerability (Wisner et al., 2004), returning to the pre-disaster 'normal' can increase risk by doing nothing about the hazard while increasing vulnerability; that is, taking a narrow view of resilience can increase risk (Wisner and Kelman 2015). Similarly, any lack of risk reduction, risk prevention, or preparedness will simply be reinstated, achieving little with regards to broader views of resilience. Instead, resilience depends on access to various kinds of resources that provide members of subgroups with a community with capacity to cope. The relationship between capacity and access to six kinds of resources is schematized in Figure 2.6 (Wisner et al., 2012).

Moreover, different scholars/organizations have defined resilience by different viewpoint. Here resilience is considered with the observation of disaster or hazard event. International Strategy for Disaster Reduction (ISDR) defines resilience as "the capacity of a system, community or society that is potentially exposed to a hazard, to adapt to it by resisting changing so that it reaches and maintain an acceptable level of functioning and structure" (Sadeka et al., 2013). UNISDR also define as "The ability of a system, community, or society exposed to hazards to resist, absorb, accommodate to and recover from the effects of a hazard in a timely and efficient manner, including through the preservation and restoration of its essential basic structures and functions." (UNISDR, 2009). USAID defined resilience as "resilience is the ability of people, households, countries, and systems to mitigate, adapt to, and recovery from shocks and stresses in a manner that reduces chronic vulnerability and facilitates inclusive growth (USAID 2012). FAO considered resilience definition based on recovery time, the said "Resilience is the ability of people, communities, or systems that are confronted by disasters or crises to withstand damage and to recover rapidly" (FAO, 2019). So, all the definitions combinedly indicates that, "resilience is an ability of individuals or communities or systems that reduce the disaster risks and mitigate the impacts and helps to recover from impacts quickly to build sustainable adaptive capacities".

The concept of community resilience from the work of Norris and colleagues, broadly captures its emerging usage as "a process linking a set of adaptive capacities to a positive trajectory of functioning and adaptation after a disturbance" that often at the scale of the community (Norris et al., 2008). Thus, the multitude of approaches to examining resilience can accommodate attention to various "adaptive capacities" that operate at a systems-level to reduce the impact of disasters, reducing recovery times and efforts, and reducing future vulnerabilities (Mayer, 2019).

As defined by Chandra et al. (2011), Community resilience involves enhancing the capacity of the community to account for its vulnerabilities and grow capabilities that support the community in preventing, withstanding, and mitigating the stress of a hazard incident; recovering in a way that restores the community to a state of self-sufficiency and using knowledge from a past response to strengthen the community 's ability to withstand the next hazard incident. It also involves the interactions among individuals, groups, and institutions that usually result in collective action to enhance the capacities for recovering from a disaster. Acts of solidarity with those in need may emerge and transformative structural change could be affected if it is to transcend individual resilience, particularly, among those who are especially vulnerable in each situation (Dominelli, 2012). Community resilience is not just about dealing with a specific disaster (or 'event' or 'shock') in space and time but is also about capacities to deal with multiple vulnerabilities and intersecting, multiple hazards leading to multiple risks and crises, any of which might be conjunctive, cascading, or coincidental (simultaneously or not). In a sense, these characterizations are the disaster(s) to which communities seek resilience (Wisner and Kelman 2015).

Furthermore, the "disaster-resilient community" is an ideal. Communities can never be entirely safe from natural and man-made hazards. It may be helpful to think of a disaster-resilient or disaster-resistant community as the safest possible community that we have the knowledge to design and build in a natural hazard context, minimizing its vulnerability by maximizing the application of DRR measures. DRR is therefore the collection of actions, or process, undertaken towards achieving resilience. The component of resilience is a broad concept and hence is divided into five thematic areas relating to resilience and DRR. The five thematic areas are based on those in the Hyogo Framework for Action and are intended to cover all aspects of resilience shown in Table 2.6 (Twigg, 2007).

2.7.1 Enabling pre-disaster recovery planning for Build Back Better in post disaster phase

Build Back Better is the use of the recovery, rehabilitation and reconstruction phases after a disaster to increase the resilience of nations and communities through integrating disaster risk reduction measures into the restoration of physical infrastructure and societal systems, and into the revitalization of livelihoods, economies, and the environment (UNGA, 2016). But build back better is highly connected to pre-disaster recovery planning. Conduct of pre-disaster recovery planning (PDRP) is considered integral to a nation's, community's, or organization's capacity to effectively and efficiently manage all recovery, reconstruction, and rehabilitation needs in the aftermath of a major disaster. It's important because post-disaster recovery benefits immensely from PDRP. Like response planning, PDRP allows some of the more difficult, time-consuming decisions to be addressed in a time-relaxed environment where ample thought and energy can be dedicated to identifying possible opportunities within the Build Back Better strategy. It also allows for deeper reflections on options and solutions and their costs and benefits (UNISDR, 2017b). Once a disaster strikes, pre-planned strategies are quickly mobilized, thereby allowing greater attention to event-specific, post-disaster recovery actions that must be performed according to prevailing conditions and newly generated data. In the absence of the coordination mechanisms and strategies established through pre-disaster recovery planning, recovery projects will often commence despite knowledge about their implications on the long-term outcomes. Pre-disaster recovery planning is not the replacement of the planning efforts required in the post-disaster setting on account of the unpredictable nature of disasters - even those that occur regularly. Rather, PDRP enables effective coordination and decision-making structures, and facilitates rapid yet informed action in an otherwise demanding and chaotic environment. It also increases the likelihood that the planning process is inclusive of all stakeholders, including vulnerable groups that are typically overwhelmed in the post-disaster environment and therefore less capable of participating under such circumstances. There are a number of organizational and policy issues that are common to almost every disaster, and across multiple hazards (UNISDR, 2017b). The payoff for addressing these foreseeable issues in pre-disaster recovery planning is significant. When the affected communities' needs are paramount for planners, government leaders, lawmakers, and the community members themselves, access to required funding may be markedly increased. Another benefit of pre-disaster recovery planning is that it greatly increases the ability of these stakeholders to recognize and harness atypical opportunities as they are presented. The problem, however, is that pre-disaster recovery planning is conducted far too infrequently. Many communities fail to recognize the value of PDRP or lack the resources or knowledge to perform the actions required. This task is also important because it seeks to establish a culture and environment wherein development of such plans becomes the norm (UNISDR, 2017b).

2.8 Community Resilience in Disaster Risk Reduction (DRR) Context

The notion of 'community resilience' is rapidly gaining ground as both a targeted process of societal development and as a research topic. Community safety and resilience has also been absorbed in long term development and millennium goals where re-building adhere to 'build better' to achieve (UN, 2015) sustainable built environments. Monday (2002) recognizes the importance of resilience in creating 'a community that can endure into the future'. This is related to the ability of a community to take control and make decisions that concern them with capacity 'to adapt to and influence the course of environmental, social and economic change' IOTWS (2007).

According to the UN (2004), the mechanism to achieve community resilience depend on four key features hazard identification, adaptations (hazard mitigation), preparedness planning and recovery and rehabilitation which is a major part of Disaster Risk Reduction (DRR) context. Community resilience has also been cleared ''as the ability of groups or communities to cope with external stresses and disturbances because of social, political, and environmental change' (Adger, 2000).

It can be both preventative (avoiding poor outcomes by developing coping strategies), or it may facilitate recovery after a traumatic event or catastrophe and is often based on a 'bottom-up' approach. In Disaster Risk Reduction (DRR) context, The International Federation of Red Cross (IFRCRCS. 2012) has identified the following criteria as characteristics of resilient communities:

- Understand the disaster risks and can assess and monitor them and take steps to protect and minimize losses.
- Able to sustain basic community functions and structures despite disaster impacts.
- Can build back after a disaster and work to ensure that vulnerabilities continue to be reduced for the future.
- Understand that building safety and resilience is a long-term, continuous process requiring ongoing commitment and the ability to adapt to future issues.
- Appreciate that being safe and disaster resilient means that development goals are more likely to be met.

The Hyogo Framework recognized the importance of awareness and preparedness in enabling communities to respond and recover from disaster, which has underpinned most Disaster Risk Reduction (DRR) initiatives over the last decade (IFRCRCS, 2012). The concept of community resilience has gained stronger as DRR has progressively moved away from a 'predict and prevent' paradigm to building the capacity of communities who face a wide range of shocks and stresses. According to Kaluarachchi, three aspects enhance community resilience combining DRR approaches (Kaluarachchi., 2018).

Table 2.6: Components of Resilience (Source: Twigg, 2007)

Thematic Area	Components of Resilience
Governance	• Policy, planning, priorities, and political commitment. • Legal and regulatory systems • Integration with development policies and planning • Integration with emergency response and recovery • Institutional mechanisms, capacities and structures; allocation of • responsibilities • Partnerships • Accountability and community participation
Risk Assessment	• Hazards/risk data and assessment • Vulnerability and impact data and assessment • Scientific and technical capacities and innovation
Knowledge and Education	• Public awareness, knowledge, and skills • Information management and sharing • Education and training • Cultures, attitudes, motivation • Learning and research
Risk management and vulnerability reduction	• Environmental and natural resource management • Health and well being • Sustainable livelihoods • Social protection • Financial instruments • Physical protection; structural and technical measures • Planning regimes
Disaster preparedness and response	• Organizational capacities and coordination • Early warning systems • Preparedness and contingency planning • Emergency resources and infrastructure • Emergency response and recovery • Participation, voluntarism, accountability

(a) Assets owned by communities including housing, agricultural and livestock that enhances livelihoods, and other income streams that increase security and independence of households.

(b) Policies, laws and Legal and institutional frameworks for disaster management and climate change adaptation and their implementation that shape the risks communities face and their capacity to adapt.

(c) Communities' knowledge, resources and actions that might strengthen their resilience to adapt. Many communities have traditional DRR knowledge and have benefited from training and capacity-building programmes run by NGOs and government authorities.

According to a global report on "Disaster Risk Reduction: A challenge for development", Bangladesh ranked as the most disaster-prone country in terms of the impacts of tropical cyclones. Cyclones related death rate was the highest in Bangladesh amongst other cyclone prone countries as 32.1 people per 100,000 have died over 100 years (UNDP 2004). Frequent cyclones (Gorky on April 29, 1991; Sidr on November 15, 2007; Aila on May 25, 2009; Mohasen in May16, 2013; Komen on July 31, 2015) gave an early indication of increasing natural calamities as well as support the latest observation of the Intergovernmental Panel on Climate Change (IPCC) that frequency of climate change induced extreme events like cyclone will increase in the future (IPCC 2012).

The magnitude of physical hazards, poor land-use decisions and unenforced public policy are the main causes of disaster related death and casualty in Bangladesh (Paton and Johnston, 2006). But lately Bangladesh has demonstrated its ability to withstand disasters and climate risks by making action and plan through DRR policies and combining infrastructure development with community-based coping practices. Formulation of the National Adaptation Programme of Action (2005), Bangladesh Climate Change Strategy and Action Plan (2009) and BDP 2100 etc. are the actions that helps to address adverse impacts of climate change and ensure long-term water and food security, economic growth and environmental sustainability while effectively coping with natural disasters, climate change and other delta issues through robust, adaptive, and integrated strategies, and equitable water governance.

However, Government of Bangladesh is now realized that disasters are the first and foremost local phenomenon where local communities are on the frontlines of both the immediate impact of a disaster and the initial emergency response capital. In the face of hazard, learning from the previous disastrous events helps to create disaster resilient community through different disaster risk reduction mechanisms. More importantly, Disaster Risk Reduction (DRR) activities begin at home throughout the local communities. It was realized that combined efforts of GO, NGO and concerned community could save lives and livelihoods of the vulnerable people.

2.8.1 Paradigm shifts towards Disaster Risk Reduction (DRR)

Because of dramatic climate changes and its massive impact, a global movement concerned with a world safer form disaster was starting to develop from late 1980s (Kyoto University and UNISDR 2010). The concept of Disaster Risk Reduction (DRR) has evolved in the last decade to a widely adapted framework to reduce the risks of natural hazards. For the last several years, Disaster Risk Reduction (DRR) has gained its strong recognition due to the increased loss and damages of human lives and economic assets caused by the impact of natural hazards (shaw. et al., 2013a). Within the UNISDR Terminology 2009, DRR is defined as "the concept and practice of reducing disaster risk through reduced exposure to hazards, lessened vulnerability of people and property, wise management of land and the environment and improved preparedness for adverse events". DRR has a broad context including governance, technical, education and awareness, infrastructure, mitigation, and preparedness issues (shaw. et al., 2013a). As Twigg (2007) considers, there are different definitions of the term of DRR in the technical literature, but it is generally understood to mean the broad development and application of policies, strategies, and practices to minimize vulnerabilities and disaster risks through society (Matsuoka 2013).

Over the past decades, the UN International Decade for Natural Disaster Reduction (IDNDR), the Yokohama Conference (1994) and the World Conference on Disaster Risk Reduction (WCDR) in 2004 have contributed to a significant shift in the understanding of disaster management towards a more comprehensive understanding of the underlying causes of hazards and vulnerability and towards the development of a forward looking and longer-term strategy for anticipating and managing risk (Enam, S., 2015).

At the end if the IDNDR, the United Nations International Strategy for Disaster Reduction (UNISDR) was formed to facilitate the implementation of the International Strategy for Disaster Reduction, as the successor mechanism of IDNDR within the United Nations to promote increased commitment to DRR and strong linkages to sustainable development.

However, towards promoting the DRR approaches, one of the two major milestones is 'The Yokohama Strategy and Plan of Action for a Safer World' that conceived at the 'World Conference on Natural Disaster Reduction' in Yokohama in 1994 (UNISDR 2004). Under this world conference, several principles, strategies, and action plan complementary to DRR were adopted by expressing the deep concern about natural hazards. Later, in 2005 'Hyogo Framework for Action (HFA)' 2005–2015 was uncovered which has added some new ideas and filled some of the gaps that the Yokohama Strategy left (UNISDR 2005). At the second UN WCDR in January 2005, Hyogo Framework for Action (HFA) 2005–2015 was adopted as the outcome document were based on the consultation process through the Inter Agency Task Force on Disaster Reduction facilitated by UNISDR (shaw. et al., 2013a). The consultation process was building on the review of the Yokohama Strategy, and it follow up has created and fostered the movement on DRR.

Several international events such as the Global Platform for DRR in Geneva 2009 and the Conference of the Parties (COP) under the United Nations Framework Convention on Climate Change (UNFCCC) in Copenhagen in December 2009 have mentioned the urgencies for the DRR plan (Birkmann and Teichman 2010). DRR policies and measures are associated with the local hazards, risks, vulnerabilities and capacities leading to planned interventions by the governments (Prabhakar et al. 2009). In March 2015, the Sendai Framework for Disaster Risk Reduction 2015–2030 (SFDRR) (UNISDR 2015) laid out a voluntary pathway for the next 15 years of disaster risk reduction, following on from the 10 years of the Hyogo Framework for Action 2005–2015 (HFA) (UNISDR 2005). The agenda of DRR is shown in Figure 2.9

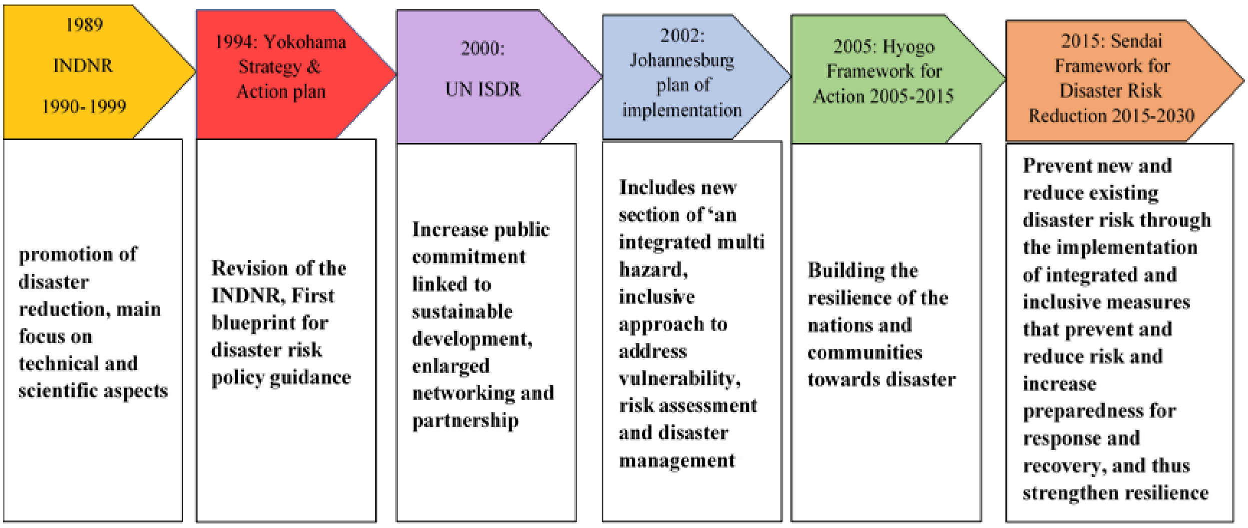

Figure 2.9: DRR agenda in progress *(Source: UNDRR, 2009; modified by author).*

2.8.1.1 Concept of DRR

The DRR community used the terms prevention, preparedness, resistance, mitigation, response and so on to describe various risk-reduction efforts (shaw. et al., 2013a). However, recently, building resilience against disasters has become one of the important concepts within DRR. According to Twigg (2007), DRR is a systematic or community-based approach to identifying, assessing, and reducing the risks of disaster. It aims to reduce socio-economic vulnerabilities to disaster as well as dealing with the environmental and other hazards that trigger them. It is the responsibility of development and relief agencies alike and it should be an integral part of the way such organizations do their work, not an add-on or one-off action. DRR is very wide-ranging, therefore, there is potential for DRR initiatives in just about every sector of development and humanitarian work (Twigg, 2007).

As Joerin (2012) pointed out, there were several scholars (Adger 2000; Allen 2006; Bruneau et al. 2003; Paton and Johnston 2001; Twigg 2007) regard the extent of people's abilities to respond to a disturbance (e.g., disaster) to be shaped by the political, economic, physical, and natural context of their environment where they are embedded in. Twigg (2007) suggested the three capacities as a system or community resilience: (1) capacity to absorb stress or destructive forces through resistance or adaptation; (2) capacity to manage, or maintain certain basic functions and structures, during disastrous events; (3) capacity to recover or bounce back after an event. Surjan et al. (2011) considers that resilience has four main elements: Redundancy, Flexibility, Capacity to reorganize, and Capacity to learn.

Disaster risk reduction (DRR) can be accelerated through using the potentials of the community people where they join hands together. So, community based DRR approach could be useful to reduce disaster risk and enhance resilience of the livelihood. Establishing social organizations such as community-based organizations (CBOs) are important tool to conduct DRR measures at local level which enhance the resilience of the community people (Pelling, 2003). Several countries have already adopted community based DRR approaches that have increased the capability of the community to deal with disaster event (UNISDR, 2007a).

2.8.2 Disaster Risk Reduction (DRR) Perspectives in Bangladesh

Disaster Management in Bangladesh had gone through a process of significant reform. After independence, the focus was limited to relief and rehabilitation activities. Following the devastating floods of 1988 and the cyclone of 1991, which created a massive destruction in the economy, the focus has been shifted towards adoption of a holistic approach that embraces processes of hazard identification and mitigation, community preparedness and integrated response efforts (Habib et al., 2012). Bangladesh initiated its actions for disaster preparedness immediately after the cyclone of 1991 (before introduction of many of the international drivers). As consequences Bangladesh has a well-structured framework for DRR. The Bangladesh Government's regulatory framework includes:

- A Disaster Management Act.
- A National Plan for Disaster Management.
- A National Disaster Management Policy.
- Standing Orders on Disasters (SOD) – guidelines for Government at all Levels.

At present Bangladesh has National Disaster Management Act-2008, National Disaster Management Policy, Standing Order on Disaster and National Plan for Disaster Management 2010–2015 as key documents guiding the disaster management works in Bangladesh (shaw. et al., 2013b). To implement the documents in ground works Bangladesh has Disaster Management and Relief Division, Disaster Management Bureau (DMB) and Comprehensive Disaster Management Programme (CDMP) under the Ministry of Food and Disaster Management (NPDM 2010). National Disaster Management Plan 2010–2015 has been prepared considering the Hyogo Framework for Action 2005–2015 and SAARC framework on Disaster Management (shaw. et al., 2013b). The plan prepared to help address the disasters in a comprehensive way. The plan is prepared with the aim to reduce vulnerability of the poor to natural, environmental, and human induced disaster to a manageable and acceptable level. To achieve the aims, the concerned authorities have adopted strategies like:

(a) Bringing a paradigm shift in disaster management from conventional response and relief practice to a more comprehensive risk reduction culture.

(b) Strengthening the capacity of the Bangladesh disaster management system in improving the response and recovery management at all levels.

Recently, for long term challenges in development outcomes presented by climate change and natural hazards, the Government has decided to formulate a long-term Bangladesh Delta Plan 2100 (BDP 2100). This plan will be implemented following DRR policies, SDG, and Sendai framework action and other promoted worldwide protocols for Bangladesh. That's why the first Specific goal of BDP 2100 is, "Ensure safety from floods and climate change related disasters" (GED, 2018). In this goal, Bangladesh government give importance on reducing the exposure that tend to be vulnerable in climate related hazards. To reduce the vulnerability of exposure housing resilience in cyclone risk reduction approach could be a key point for BDP 2100. Because in BDP 2100, it's mentioned that under the climate change scenario, the capital stock in the construction sector would be depleted by 0.05% annually and floods and cyclones will have a significant impact on rural infrastructure especially on housing sector in Bangladesh (GED, 2018). The BDP 2100 therefore comes up with an adaptive, holistic, and long-term strategic plan to steer the opportunities and vulnerabilities created by the interface of water, climate change, natural disasters, environment, ecological balance, agriculture, land use and inland water management for national development.

2.8.2.1 Cyclone Risk reduction (CRR) approach

Farsighted the impact of 1991 Chittagong Cyclone, the government of Bangladesh gave more efforts to implement the CRR approaches in the coastal area of Bangladesh. For example – ensuring the formation of Cyclone Preparedness Program (CPP), increasing number of cyclone shelter, proper development of early warning system, and several awareness building program, etc. Those actions play an effective role to reduce the fatalities and damages due to disaster in the coastal area (Rahman et al, 2019). But still a large number of properties and resources are destroyed every year due to the impact of cyclone induced storm surge. Number of barriers preventing those approaches to run properly. However, considering those barriers Government of Bangladesh have taken several approaches for cyclone induced storm surge to reduce the risk with ensuring community resilience. Description of cyclone risk reduction approaches in Bangladesh are given below.

Multipurpose Cyclone Shelter (MPCS)

The construction of designated cyclone shelters started in Bangladesh after the devastating effect of the 1970 cyclone (Mallick and Islam., 2013). Typically, MPCS facilities are multistoried, with reinforced concrete buildings that can on average accommodate 1,600 people. These shelters generally have an open ground-floor structure to avoid flooding from the storm surges and top floors (either one or two) designed to accommodate people during and after the disasters (Paul, 2009, 2012; WB, 2010). The main agency responsible for constructing and operating MPCS facilities is the Disaster Management Bureau (DMB) which operates within the Ministry of Food and Disaster Management. Under the supervision of the DMB, the hierarchical structure of shelter management is the zila (district level) disaster management committee, upazila (sub-district level) disaster management committee, union (village-unit level) disaster management committee and the MPCS management committee (MoEF, 2008).

Over the period 1972–1979, 238 cyclone shelters were constructed in various locations along the Bangladesh coast. Following the 1985 cyclone, BDRCS decided to construct 500 cyclone shelters out of which only 62 were constructed by the year 1990 because of financial constraints. That the number of cyclone shelters was inadequate was demonstrated by the casualties arising from the cyclone on 29 April 1991(Mallick and Islam. 2013). Recently, around 1.5 million people took refuge in multi-purpose cyclone shelters (MPCS) when Cyclone Sidr hit the coastal districts in 2007 (Paul et al., 2010). In present around 2,500 MPCS facilities have already been built across coastal districts as part of Disaster Risk Reduction (DRR) strategies (CEGIS, 2009). The World Bank (2010) further estimates that there is a need for 5,500 new MPCS facilities as an integral component of a disaster management strategy.

Cyclone Preparedness Program (CPP)

Central to the Bangladesh Early Warning System is the Cyclone Preparedness Programme (CPP), developed and improved through the efforts of the Government of Bangladesh (GoB), United Nations, International Red Cross and the Bangladesh Red Crescent Society (Habib et al., 2012). The ideas of CPP started in 1965 when the National Red Cross Society, now the Bangladesh Red Crescent Society (BDRCS), requested the International Federation of Red Cross and Red Crescent Societies (IFRCS), then the League of Red Cross and Red Crescent Societies, to support the establishment of a warning system for the population living in the coastal belt. In 1966 the International Federation and the Swedish Red Cross began the implementation of a pilot scheme for Cyclone Preparedness which consisted of warning equipment such as transistor radios, sirens etc. and training of the local volunteers, as the backbone of warning and dissemination activities (Mallick and Islam., 2013). In June 1973 the Government of Bangladesh approved the new program, accepted financial responsibility for recurring expenses and established joint program management through the creation of a Program Policy Committee and a Program Implementation Board.

CPP volunteers are given training on the Red Cross and Red Crescent movement, cyclones and their behavior, warning signals and their dissemination, evacuation, sheltering and rescue, first aid and relief operations, gender issues, humanitarian values and climate change issues, to maintain a high level of efficiency (Habib et al., 2012). CPP Presently covers 11 districts in the coastal area comprising 32 Upazilas consisting of 274 Unions. There are 2,845 units spread across this area each of which covers one or two villages.

Coastal Embankment

The coastal embankments along Bangladesh cost have been constructed with a view to protecting the agricultural land from salinity intrusion associated with tidal flooding. Constructed under the Coastal Embankment Project in the 1960s, these earthen embankments are not capable of withstanding the forceful surge nor are they high enough to guard against the surge. Rather the presence of these embankments created a sort of false sense of security among people; in 1991 cyclone, many people were reported to have been killed because of taking shelter on such embankments (Choudhury 1996). Recent catastrophe like cyclone Aila in 2009, about 1742 km of coastal polders (embankments) were washed away by the tidal surge from the cyclone, and saline water inundated large parts of the southern districts of Khulna and Satkhira (46% of croplands) for up to two years (UN, 2010; Nishat et al., 2013). The age-old embankments are also suffering from improper maintenance. While they are not meant to be safeguards against cyclonic surges, their damage/destruction is causing unprecedented havoc to the people (Mallick and Islam. 2013). Recently, The Coastal Embankment Rehabilitation Project (CERP) has improved planning and design methods and started development of a sustainable embankment system. The project has improved community participation in operation and maintenance schemes by introducing the Embankment Settler Scheme, where settlers are given a piece of the embankment for plantation and housing (Saari and Rahman, 2003).

Coastal Afforestation

Mangrove forests act as a guard against cyclone by minimizing wind speed as well as reducing the surge impacts; appreciating this, coastal afforestation with mangrove species was initiated along the Bangladesh coastal belt in the 1960s. The advantage of coastal afforestation programs then extended to several development agenda including protection of agricultural land against salt intrusion, protection of coastal ecosystem and environment, protection of aquatic resources and wildlife and enhancing land accretion, inter alia (Mallick and Islam., 2013). Over the last four decades the Department of Forest has brought about 148,000 ha of land under mangrove plantations distributed over on- and offshore areas mostly along the central part of the coast (Islam n.d., 2012).

Cyclone-Resilient Housing

Since 197O annually, hazards ranging from floods and cyclones to tornadoes and river erosion have been responsible for fully damaging approximately 300,000 houses and partially damaging about 500000 houses (GFDRR, 2014). Since the 1970's devastating cyclone, the government of Bangladesh has spent at least 10 billion USD for the disaster-related sector, and it is safe to assume that majority proportion of the expenditure is done for post-disaster recovery (MoEF, 2008). Cyclone shelters save lives; this is evidenced by the decline in casualties since the Multipurpose Cyclone Shelter Programme has been implemented. But destruction of houses and infrastructure continuing (Mallick and Islam. 2013). The housing destruction during an extreme climatic disaster is inevitable due to the vulnerable structure of the existing houses in the coastal rural region. Therefore, when another cyclone strikes, the coastal population will lose their non-durable houses again. So, climate resilient housing is a long-term solution for reducing the loss of disasters. Ideally, loss of lives and destruction could be greatly avoided if houses and infrastructure in coastal areas were strengthened to withstand cyclones and storm surges. This is not possible because of economic constraints, but not necessarily technical ones. The idea of creating disaster resilient communities, who are quickly able to return to normal lives after a disaster, has resulted in the concept of the Disaster Resilient Habitat (DRH) (Mallick and Rahman 2007). This uses community skills and knowledge of technical personnel like engineers and architects, to develop on the “Building for Safety” options (Seraj and Ahmed 2004) to design and construct houses and infrastructure that are resilient to cyclones and storm surges.

2.8.3 Present resilience initiatives against climate change in Bangladesh

The Government of Bangladesh earnestly strives for shifting the country’s vulnerability towards resilience. Ministry of Environment, Forest and Climate Change (MoEFCC), Ministry of Disaster Management and Relief (MoDMR), Ministry of Agriculture (MoA), Ministry of Water Resources (MoWR), along with other relevant ministries/divisions and respective agencies, are working hard to make the country climate resilient. The Government has recently adopted the Bangladesh Delta Plan 2100, a comprehensive 100-year strategic plan aimed at gradual sustainable development through adaptive delta management process. The plan targets to achieve a safe, climate-resilient and prosperous delta with a mission to ensure long term water and food security, economic growth and environmental sustainability, effectively reducing vulnerability to natural disasters and building resilience to climate change. (MoEF, 2022). Besides, The Bangladesh Climate Change Trust Fund (BCCT) has undertaken about 800 projects so far with the investment of around 480 million US dollar to implement strategic actions of the BCCSAP which mainly focus on adaptation, mitigation and climate change research. Recently, Bangladesh has accessed to resources available from Green Climate Fund (GCF), Least Developed Countries Fund (LDCF), Adaptation Fund (AF) and other bilateral and multilateral funds (MoEF, 2022). For cyclone impacts, 4,530 Cyclone Shelters have been constructed across the coast and 320 Flood Shelters have been constructed across the country with additional 393 Flood Shelters under construction. Additionally, 46,000 urban volunteers are also working for urban safety and resilience. 550 Mujib Killa, specially designed raised land, have been constructed to provide shelter for the people and livestock in coastal regions during the cyclone/tidal surge. 60 Multipurpose Rescue Boats have been built for persons with disability. A total of 66 Disaster Relief Warehouse- cum-Disaster Information Center established. To enhance climate resilience and DRR, the government has implemented 726 km river-bank protection, 2,123 km river excavation and dredging, 1,266 km embankment, excavation/re-excavation of 181 km irrigation canal and 499 km drainage canal in last 10 years (MoEF, 2022). Among all the climate resilience initiatives from the Government of Bangladesh, very few concentrations have been focused on Disaster Resilient Housing.

2.9 Mainstreaming DRR into Disaster Resilient Housing

Disaster risk reduction focuses on reducing vulnerabilities and exposure stemming from development within high-risk zones, unplanned urbanization, environmental degradation, population growth and climate change. The most cited definition of DRR is one used by UNISDR "The concept and practice of reducing disaster risks through systematic efforts to analyze and manage the causal factors of disasters, including through reduced exposure to hazards, lessened vulnerability of people and property, wise management of land and the environment, and improved preparedness for adverse events" (UNISDR, 2009). This definition means that disaster risk reduction is vital for building a more equitable and sustainable future.

There is a wide range of literature on disaster risk reduction (Wamsler, 2007; Carcellar et al. 2011; Basher, 2013), a paper by Carcellar et al. 2011, identified the ways in which government and other stakeholders can support the needs and address the vulnerabilities of at-risk communities. They noted that flash flood triggered by Typhoon Ketsana in 2009 heavily damaged many houses in poor communities. Through the support programme developed, it was proposed that building materials loans for house repairs should be paid to the affected communities. This conclusion means that, improvement on housing conditions is vitally important in risk reduction. It was noted by Wamsler in 2007 that dwellers in 15 slum communities in El Salvador cope with disaster risk and reveals the variety of strategies they must reduce risk. The strategies are based on different patterns of social behavior, with a strong focus on individualistic behavior for survival. It was concluded that the applied strategies are huge and crucial, but they are weak coping strategies and thus very difficult to protect houses from being affected by disaster and minimize disaster risk in general (Wamsler, 2007). Increasing scale of disaster occurrence and impact is a growing concern of all countries and people (Basher, 2013). Therefore, it is important to understand where and how the disaster occurs in order to deal with it. Likewise, it is important to understand knowledge of the affected communities as far as disaster is concerned and how they cope with such a situation, this in turn will make possible implementation/ improvement of DRR measures and increase resilience of such community (Basher, 2013).

Mainstreaming DRR in housing development means that all housing related interventions and disaster mitigation structures consider the effect of natural hazards that are happening and expected to happen in future. In addition, it should be noted that, once vulnerability to natural hazards on housing have been considered then disaster risk reduction measures must be adopted. For mainstreaming DRR in housing development to be followed by those who live in disaster prone areas, mainstreaming DRR must be incorporated in laws and policies of the country. This will be very helpful especially in dealing with legal enforcement and to deal with those who violate the law (Sakijege, 2019).

2.9.1 Present Housing Conditions in Coastal area of Bangladesh

The coastal areas in Bangladesh have a trend of using non-durable housing materials. The number, of disaster-resilient housing structure is inadequate. Poverty is the main burden here. According to BBS 2011, 79% of rural dwellings were made entirely of natural (kutcha) or marginal (jhupri) building materials. These materials are not durable in the face of cyclone hazards, storm surges or inundation. This percentage is higher for the most cyclone exposed coastal districts- up to 90% are built with non-resilient materials. If 8 most exposed coastal districts of Bangladesh are considered, the scenario of housing structures is found in Table 2.

Table 2.7: Distribution of population and types of housing structures in eight most exposed districts. *(Source: BBS,2011)*

District total	Population		Numbers of households	Type of Structure (%)			
	No of people living in settle households	No of people not living in settle households		Paka	Semi paka	Katcha	Jhupri
Bagerhat	1,47,160	4,420	350,357	5.1	11.8	78.3	4.8
Barguna	8,91,795	986	214,863	2.0	4.8	89.6	3.6
Bhola	1,775,689	1,106	371,799	1.7	7.6	86.3	4.5
Cox's Bazar	2,275,084	14,906	413,402	6.2	11.6	68.9	13.3
Khulna	2,316,869	1,658	540,504	18.3	23.0	56.6	2.0
Noakhali	3,106,740	1,343	590,808	7.6	7.6	80.6	4.2
Patuakhali	1,532,301	3.553	345,113	2.6	5.7	86.6	5.0
Satkhira	1,985,566	393	468,853	14.3	28.5	55.8	1.4

In Table 2.7 four types of constructions were found which are described below

Jupri (very low durability): Houses made by individuals own structure knowledge. No participation from any builder or mason. Any institutional structural design is missing. Materials are natural and organic such as bamboo, timber, grasses, and mud, and industrial products such as plastic sheet and cheap Corrugated Iron (CI) sheet. Such houses are the most vulnerable to disasters and are widespread in Bangladesh.

Katcha (Low durability): Houses made by local mason or builder. Proper institutional structural design is missing. Sometimes indigenous knowledges are used for choosing materials. Houses with a CI sheet roof and, the remaining materials natural. Bamboo mat walls and mud plinths are typical, though there is variation in walling according to region. Houses such are these are vulnerable to disaster, but it can be possible to hold on to or salvage the CI sheet for re-use.

Semi-Paka (medium durability): Houses made by local mason or builder. Proper institutional structural design is used but building codes are missing. Houses with brick walls (concrete block is rare) and flooring, and CI sheet roofing. If the walls are built properly, they can withstand hazard impacts, but the CI sheet roof is prone to damage by a strong wind; widespread application of wind-resistant CI roof construction methods are generally lacking.

Paka (high durability): Houses made by local mason or builder using a proper architectural design. Proper institutional structural design is used with maintaining building codes. Houses with brick walls and reinforced concrete (RC) roofing. Such houses are considered as highly durable and preferred, though their expense makes it a rare typology in rural areas and unaffordable to most rural residents.

2.9.2 Risk & vulnerabilities of housing due to cyclone

For generations, cyclones and tidal surges have frequently devastated lives and property in coastal areas of Bangladesh. Rural communities that are located on lowlands or in unprotected and unsheltered, low-lying coastal areas or river floodplains are mostly considered to be vulnerable to cyclones. The vulnerability of a human settlement to a cyclone is determined by its siting, the probability that a cyclone will occur, and the degree to which its structures can be damaged by it (Enam., 2015). Generally, the poor and the marginalized, who cannot afford to obtain a land in a safe area, to build a house with proper guidance and building materials and to have an alternate source of livelihood are forced to settle down in these vulnerable areas that pose serious threat to cyclones. Houses are considered vulnerable if they cannot withstand the forces of high winds. Generally, lightweight structures with wood frames, especially older buildings where wood has deteriorated and weakened the walls, houses built with temporary materials, poor joints, and bracings, without any design guidance and construction assistance are those most vulnerable to cyclones (Enam., 2015). Houses made of unreinforced or poorly constructed concrete block are also vulnerable unless they are anchored properly to the ground. The degree of exposure of land and buildings will affect the velocity of the cyclone wind at ground level, with open country, seashore areas and rolling plains being the most vulnerable. Certain settlement patterns may create a "funnel effect" that increases the wind speed between houses, leading to even greater damage (Agarwal, 2007). Factors contributing to the vulnerabilities of housing as stated in ADPC (2011):

- Poor land use planning/with poor understanding on hazards/without risk-based planning
- Lack of knowledge and incorporation of appropriate disaster resistant features during planning and construction process
- Lack of regulatory mechanism to enforce land use/building regulations
- Limited or no mechanism for accountability in case of violation of regulations
- Lack of skilled human resources in planning and execution
- Poor quality and sub-standard building materials
- Poor maintenance of structures
- Poor governance-corruption

The variety of factors, which contributes to the vulnerability of the housing stock ranges from having systems in place for proper settlement planning, appropriate technical guidance in forms of building codes, suitable enforcement mechanisms, capacity for implementation, and skilled labor as well as enabling factors such as good governance.

2.9.3 Potential damages in housing due to cyclone and storm surge

Dasgupta et al. (2010) found that, the housing sector experienced maximum damage and loss during the Sidr cyclone in 2007 and accounting by housing/ dwelling type further indicates that "semi-pucka" houses, "kacha" houses and "jhupris" were the predominant categories of damage. Analysis of the 2001 census data in Bangladesh reveals only 2.23% of rural households with $470 per capita annual income or more could afford a "paka" house, a brick house with a concrete roof in 2001. However, Bangladesh is currently experiencing and expecting 6%-8% GDP growth per year for the coming decades. It is expected that approximately 98% of the households will be living in brick houses by 2050, even after accounting for inflation. This in turn implies a significant reduction in housing damages and a substantial increase in household asset damages during cyclones over time. Projection of population in coastal regions by 2050 without and with climate change indicates that an additional 7.08 million inhabitants (i.e., an additional 1.45 million houses under the assumption of an average family size of 4.89) will be exposed to significant damages from storm surges in a changing climate. Accounting for the larger areal extent of a cyclone under climate change an additional 1.6 million houses are projected to be damaged from a 10-year return period cyclone due to climate change (Dasgupta et al., 2010). The size of a standard house in Bangladesh is assumed to be 400 sq. feet with 2,000 sq. feet of brick wall surface and approximate value of household assets is $2,143 (Tk 150,000). Under the assumption that on average 50% of the walls and 50% of the household assets will be damaged during inundation, re-plastering the houses will cost $229 million (at Tk 10/ sq. ft) and an estimate of household content damage is expected to be approximately $1.718 million.

2.9.4 Concept of Disaster Resilient Housing (DRH)

There is a strong link between housing and climate change, particularly in developing countries where housing is considered one of the most valuable assets of residents (Ahmed, 2011). Housing often represents the highest loss due to climate-related disasters associated with the decrease of national economies (Lyons, 2009). Natural hazards intensified by climate change have placed huge demands on disrupted and affected communities all over the world, in terms of the need to provide long-term resilient housing (UNEP and SKAT, 2007), particularly in developing countries. The coastal community of Bangladesh have very limited response and recovery capabilities and current housing strategies from government and aid agencies seem to lack an overall approach to long-term Disaster-resilient housing (DRH). As climate change is an ongoing process associated with the increasingly unpredictable occurrence of climate events, withstanding ongoing disturbances has more implications than just recovering from individual events (Morecroft et al., 2012). In this sense, post-disaster housing provides one of the best opportunities to improve pre-disaster fragile conditions and achieve long-term community resilience, rather than just rebuilding the destroyed or damaged parts (Archer & Boonyabancha, 2011; Schilderman & Lyons, 2011).

However, housing has close relationship to a person ‘s life, livelihood, health and overall well-being and therefore directly includes the social themes of vulnerability, social protection and livelihoods. Disaster resilient housing is not just limited to provide shelter from disaster. This housing means adequate privacy; adequate space; physical accessibility; adequate security; security of tenure; structural stability and durability; adequate lighting, heating and ventilation; adequate basic infrastructure, such as water-supply, sanitation and waste-management facilities; suitable environmental quality and health-related factors; and adequate and accessible location with regard to work and basic facilities: all of which should be available at an affordable cost.

Disaster resilient housing concept refers to those structures that is expected to not collapse or be destroyed, but may still suffer some damage which, however, can be repaired. Disaster resilient housing means to build structures and a community considering the disaster resiliency strategies and integrating the disaster risk reduction measures so that the houses can withstand the impact of any natural hazard i.e., cyclone, flood, earthquake, landslide etc. A disaster resilient housing does not only depend on the structure, material, design and construction of the houses but also depends on the socio-economic conditions, administrative and local governance of the community (Enam, 2015).

As housing reconstruction is seen one of the key interventions to building disaster and climate resilience for vulnerable communities. Many factors related to DRH, such as hazard-resistant capacity, functional and spatial organization, or livelihood development have been addressed in several studies and projects (Boen and Jigyasu, 2005; Barenstein, 2006; Alexander et al.,2006; Steinberg, 2007; Minamoto, 2010; DWF, 2010). But the relationship between these factors and community consultation and how to address this relation in planning and implementation is rarely mentioned. The limited communication and consultation between local and external actors, the lack of technical input from built-environment professionals in developing housing designs, and the absence of resilient housing designs for low-income people, act as the key drivers of such problems. Three major aspects related to the development of disaster-resilient housing provides appropriate scenario of sustainability which are (i) Community Consultation, (ii) The Role of Built-Environment Professionals, and (iii) Design Principles for Resilience. Moreover, approaches to post-disaster housing reconstruction are usually different in how they engage and consult with communities, depending on cultural and political constraints. There is no ‘best’ model for community consultation: every local context is different (Davidson *et al*., 2007; Sliwinski, 2010). Recent research findings have highlighted an increasing concern over problems related to community participation and consultation (Lawther, 2009; Davidson *et al*., 2007; Barenstein, 2006) and the effectiveness of community engagement (Sliwinski, 2010; Davidson *et al*., 2007; Pearce, 2003) in building Disaster Resilient Housing.

2.9.5. Importance of Mainstreaming DRR in Housing Practices

As stated by Bosher and Dainty in 2011:

—*Arguably a diverse range of hazards are likely to become more significant in future years and so it has become incumbent upon those responsible for planning, designing and constructing the built environment to take account of these threats as a core part of their professional activity‖ (Bosher and Dainty, 2011, p.7).*

Housing located near to the disaster-prone areas are under great threat of multiple hazards. Often these communities are the poorest and the most socially marginalized and they are likely to suffer great damage from disasters associated with natural hazards. They are more susceptible to disasters because of their housing vulnerability. Therefore, it is necessary to retrofit the existing housing for reducing the threats of impending disasters and incorporate disaster risk reduction in the planning and construction of new housing practices. Argued by Benson et al. in their paper.

—*Mainstreaming DRR into development means to consider and address risks emanating from natural hazards in medium-term strategic frameworks, institutional structures, country and sectoral strategies, and policies in the design of individual projects in hazard-prone countries‖ (Benson. 2007, p.7).*

It requires analysis of how potential hazard events could affect those policies and projects, which should lead to the adoption of related measures to reduce vulnerability, treating risk reduction as an integral part of the development process. —The lack of consideration of DRR into development process leads to bearing extra costs in reconstruction which perpetuates the conditions for unsustainable development and shifts the scarce resources originally programmed for development into relief and response‖ (Bakhtiari, 2014).

With this understanding, Mainstreaming DRR in housing would mean that all housing related interventions have considered the effect of natural hazards (current as well as future risks magnified by climate change) and of the impact of those interventions in turn, on vulnerability to natural hazards, and accordingly have adopted risk reduction measures. This would require understanding the typical vulnerabilities to hazards, analyze how these vulnerabilities interact with the existing processes of development of the sector and understanding of the actors involved in each of the processes. At a strategic level mainstreaming entails addressing or incorporating DRR measures in policies, regulations while at operational level, undertaking specific measures such as evaluation of hazards, vulnerability and risks and addressing it through appropriate mitigation measures. In case of housing, it would be important to design the structure to a minimum service level of operational or of higher order to life safety performance level (ADPC, 2011).

On the aftermath of a disaster, it is of utmost importance at the policy level for mainstreaming DRR in the reconstruction strategies to enable safe built environment and build back better. Housing reconstruction is a unique challenge and provides a window of opportunity to reduce underlying risk factors and build back better. Mainstreaming can be undertaken by enhancing safety standards, review of regulatory and planning framework such as land-use and by incorporating DRR.

Objectives of Disaster Risk Reduction Initiatives in Housing Construction:

- Ensure adherence to guidelines on hazard resilient construction in hazard prone areas.
- For successful implementation of housing, usage of land use zoning plans which takes into consideration information on risk from natural hazards.
- Introducing amendments and revisions for land sub-division process considering the natural surface drainage path, contour plans and its approval procedure.
- Utilization of national building codes that have special provisions for enhanced design standards for buildings in areas affected by natural disasters.
- Compliance and enforcement of local building laws requiring prescribed standards under natural building codes in urban hazard-prone areas.

2.9.6 Challenges of Mainstreaming DRR in Resilient Housing Practices

For resilient housing in disaster prone areas, it is very important that housing practices integrate disaster risk reduction measures to reduce threats of impending disasters. However, there are many challenges that need to be addressed for mainstreaming disaster risk reduction into housing practices, some of which are described below.

Socio-Economic Situation of the Households

Often the communities located in hazard prone areas are the poorest and most marginalized. The concept of resilience is beyond their understanding and capacity as survival is the biggest challenge to them. Economic difficulties generated by the unstable livelihood, unemployment and low paid jobs are one of the biggest obstacles to achieving resilience. It undermines the effort of housing risk reduction (Tran and Tran, 2013). Due to very limited financial capacity, houses of low-income households are the most vulnerable. The owners tend to buy the cheapest plots in hazard prone areas. In addition, their houses are very vulnerable without strong connections or bracings and often built based upon experiences of local masons without technical designs and construction supervision. Economic difficulties make them put DRR as the secondary priority behind basic needs of living such as food, healthcare, or school fees for children.

Lack of Climate-Risk Knowledge

Limited awareness of local people on climate change and the importance of climate risk reduction for a long-term development is another big challenge addressed (Thang et al., 2013). This has made them underestimate the actual danger of climate hazards and prefer immediate or short-term responses. These people often think of disaster preparedness and risk reduction when they receive announcements of a coming hazard on mass media, and then rush to using quick and measures to respond (e.g., putting sandbags on roofs, moving valuable items to safe places in house, and evacuation). They can hardly think of a permanent solution to their housing problems which would provide them with safety from the multiple hazards.

Skills and Communication of the Local Builders

The safety techniques of local builders seem inadequate and are likely to re-produce risks to future hazard in new construction (Thang et al., 2013). These builders lack proper knowledge on safe construction methods and are poorly equipped with construction techniques, equipment, and materials. Another challenge for these builders and the local people is the lack of awareness and understanding on how to properly create safe buildings with new materials (e.g., cement, brick, or steel) and new construction methods (Chantry and Norton, 2008). Therefore, in an era of climate change with the estimated increasing occurrence of climate events improper construction of houses and inappropriate material use will not help local communities avoid disaster damage and losses. Lack of communication and consultation with in-field experts and professionals (i.e., local architects and engineers) about building resilient shelters also become an issue. Currently, poor and low-income groups pursue construction on their own and lack technical guidelines or instruction for disaster resilient construction (Tran and Tran, 2013).

Applying Planning and Construction Regulations

Application of building codes and construction regulations related to DRR is another challenge. Usually building permits are not required for most local practices of housing construction in hazard prone or rural areas. Local people decide on their housing forms and construction freely based on their needs and financial capacity (Thang et al., 2013). As for poor and low-income groups, as there are neither technical supports nor regulatory requirements for safe construction given to them, many unsafe conditions can be found in their houses. DRR is faced with challenges from a lack of building codes, zoning, and planning criteria for climate risk reduction in hazard prone areas (Tran and Tran, 2013).

Lack of Local Governance

Lack of local governance is also a challenge for an environment of safe construction. This limited or no governance strongly influences housing vulnerability and may undermine efforts of building a resilient housing system to climate change. Limited governance and management are a complementary catalyst to the increase of climate risks in human society (Tran and Tran, 2013). Usually governance mechanisms for civil construction (i.e., residential houses) tend to focus on central urban districts. However, more consideration should be given to peri-urban and rural areas, the places that are more vulnerable to climate risks and natural hazards. There is no system in place that will overlook the housing system and construction methods, at the same time, the local people and the builders are not accountable to any administrative system for their housing construction. This makes the integration of DRR a challenge as the whole management process is absent.

CHAPTER THREE
STUDY AREA

3.1 Introduction

Two villages of the Kamarkhola Union were selected for this study as this area was adjoining the landfall location of Cyclone Aila. This area was one of the worst sufferers of the past cyclonic events such as Sidr (2007) and Aila (2009). Many cyclones concerted in the Bay of Bengal left their tracks in the study area through the failure of embankments, intrusion of saline water into the polders, loss of household properties, agricultural damages, disruption of traditional livelihoods, etc. Since this study area, Kamarkhola Union represents the sign of cyclone Aila impacts in the southwestern region, the outcome of this study will help understand the storm surge propagation and damages caused by the cyclone. This understanding will be useful to the policymakers for more pragmatic investment in infrastructure development to attenuate the damages due to any further Aila-like disasters in the coastal region. In this chapter demography of the study area, land use pattern, socio-economic condition, climate conditions and relative hazard impact, etc. will be discussed.

3.2 Location

The study was conducted in one of the Union of Bangladesh namely Kamarkhola, which is in Dacope Upazila of Khulna district. Dacope (located at 22.5722°N and 89.5111°E), has a total area of 991.85 km2, and is bounded by Batiaghata Upazila on the north, the Pashur river on the south, Rampal and Mongla Upazilas on the east, and Paikgachha and Koyra Upazilas on the west. There are 3 polders in the Upazila namely Polder 31, 32, and 33. Polder 32. The total area of the Kamarkhola union is 29.2 km2. It is bounded by Polder 31 on the north, the Sundarbans on the south, Polder 33 on the east, and Polders 10, 11, 12, and 23 on the west. The Union is surrounded by the Bhadra River on the north and east sides, the Dhaki river on the north-west, the Sibsa (Passur) on the west, and the Sutarkhali (Bhadra) on the south. Kamarkhola union has two Mouzas (Smallest Boundary of Bangladesh) namely Kamarkhola mouza- JL-16 and Kalinagar-Sreenagar mouza-JL-15. Two mouzas are consisting of 13 Villages which are Kamarkhola, Channir Chak, Jaliakhali, Rajnagar, Rekhamari, Fakirdanga, Jaynagar, Shibnagar, Parjaynagar, Vitavanga, Kalinagar, Satgharia, Shaharabad, and Sreenagar. Among them Jaliakhali (Located at 22°558957°N and 89°47307°E) and sreenagar (22°304479"N and 89°292690"E) villages are selected as a study area which is shown in Figure 3.1.

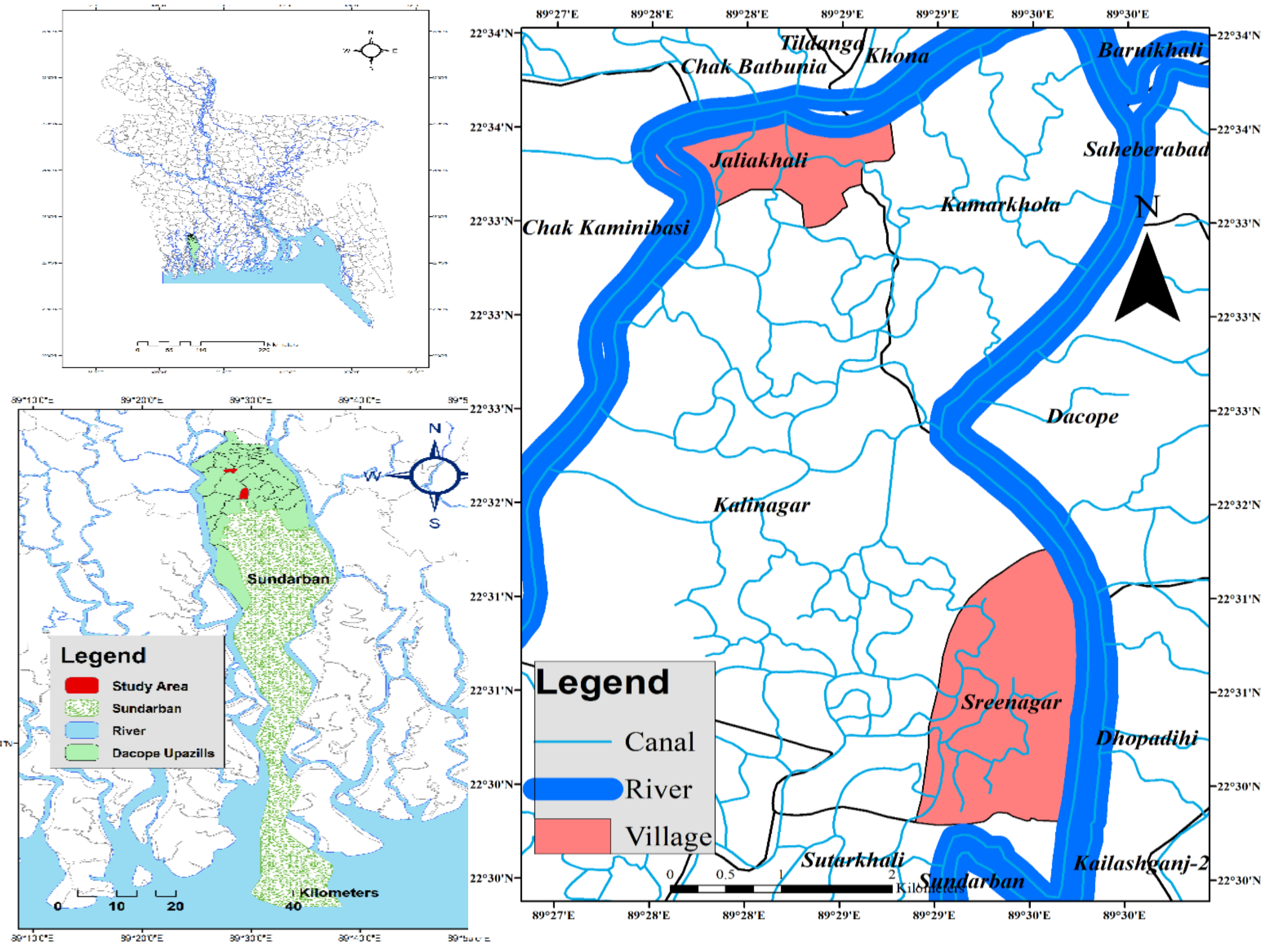

Figure 3.1: Study area location.

3.3 General Information

3.3.1 Demography

Demographic information is a controlling factor in the preparation of damage calculations. The estimated population in Dacope Upazila is about 1,52,000 of which 76,000 are male and 76,000 are female. In Dacope Upazila, approximately 56% of the total population are Hindu, 42% are Muslim and 2% are Christian. There are 36,597 households in the Upazila (BBS, 2011). Kamarkhola Union has a total population of 15,407, of which 51% are male and 49% are female (BNP.2013). The proportions of religious views in the Kamarkhola union are 50% Muslim, 48.6% are Hindu and 1.4% are Christian (See Table 3.1). Population densities in Kamarkhola are 965 per km2 (BBS, 2011). The average size of households in Kamarkhola is 3.9.

Table 3.1: Demographic information on the study area (source: BBS, 2011; BNP, 2013).

Demographic information	Kamarkhola
Total population	15,407
Male	7,858
Female	7,550
Population density (per km2)	965
Muslim	7,704
Hindu	7,488
Christian	216

3.3.2 Literacy status

In the study area, the rate of literacy, defined as the percent of the population able to write any letter in any language, was assessed for the population of 7 years and above. There are 17 educational institutions are found in the Kamarkhola union. Among them, the number of Govt. primary schools is 6. Non- Govt. primary school is 7, Secondary school is 4, and the number of Junior Secondary schools is 1 (BNP,2013). The overall literacy rate in the Kamarkhola union is 58.1% where this rate is 65.9% in males and 50.1% in females (BBS, 2011). The literacy rate has increased from 50.5% to 58.1% in the Kamarkhola union over the period 2001-2011. The population aged between 6-10 years attending school and not attending school in Kamarkhola Union are 1,225 and 243 (BBS, 2011).

3.3.3 Livelihood pattern

The livelihood pattern in an area normally depends on the resources available at the household level, and local resources and opportunities. Land ownership and access are considered major factors in determining the livelihood status in the study area. Occupations that characterize the livelihood groups in this area are agriculture, day labor, shrimp gher labor, small farming, fishing, small and medium business, rickshaw/van pulling, and Sundarbans resource extraction. In Dacope Upazila, 66.07% of the population are farmers, 4.85% are non-agricultural laborers, 12.86% are businessmen, 1.72% are transport and communication-related job holders and 4.10% are service holders. The main income source of the Kamarkhola union’s people is agriculture. 65% of the total population are farmers, 5% of the total population are fishermen, 2% of the population are involved in the honey collection (BNP, 2013) and other percentages are involved in a different profession.

3.3.4 Land use pattern

The land use of Dacope Upazila is dominant in agriculture. Other land uses/cover categories include shrimp culture, settlements with homestead forest, waterbody, river/canal, and infrastructural development (Table 3.2). Though the area is rich in aquatic and terrestrial resources, it is vulnerable to cyclones, storm surges, and salinity intrusion. The diversity in land use and resources creates conflicts among the users. The net cultivable land of the Kamarkhola union is 19.0 km2, which is 65% of the respective total area. The permanent fallow land is 0.40 km2, while the temporary fallow land cover is 0.40 km2 in this union. Of the 2,824 farmer families, 25% are sharecroppers in Kamarkhola. The area of irrigated land is 22% of the total land in the Kamarkhola Union, and boro rice is cultivated on a very small-scale using surface water irrigation. Major crops are T. Aman, boro, sweet potato, pulses, and different types of vegetables along with fisheries. The cropping intensity is 104% in the Kamarkhola Union, which indicates the dominance of single cropped areas (BBS, 2011).

3.3.5 Infrastructure

In Dacope Upazila, there are 1 health center/ hospital, 3 family welfare centers, 9 health and family planning centers, and 1 mother and child welfare center. In Kamarkhola Union 21 educational institutions are found including 4 Madrasha. 1 community clinic, 1 UP office, 1 BWDB office, and 1 Land office are also found respectively. There are 6 cyclone shelters and

5 school cum cyclone shelters are established in this union. All cyclone shelters are currently functioning. Paka road length of this union is only 1 km, 7 km road is made by bricks and other 100km road is still earthen. Two markets are found in this union. The length of the embankment surrounding this union is 45 km. There are 18 sluices, inlets, and outlets within the polder. The total number of drainage channels within the polder is 26 including 2 rivers. About 8km2 area is under social forestry development and only 3% of people of the area have electricity connection (BNP,2013).

Table 3.2: Land use pattern of the study area (source: MoL, 2011).

Land use pattern	Kamarkhola
Total land area (ha)	2921
Net cultivable area (ha)	1900
Agriculture (%)	65
Settlement (%)	13
Water body (%)	15
Fisheries: Bagda and White fish (%)	8
Sundarbans	-

3.3.6 Socio-economic condition

The complete socio-economic condition of the study area can be defined multi-dimensionally by poverty, which controls them from enjoying a minimum standard of living and the basic requirements of life. The visible results of poverty in the study area are malnutrition, ill health, poor housing condition and illiteracy. The disadvantaged people are distressed with unemployment and a lack of access to resources, which restrict their opportunities to income and make them even poorer. The male-dominated clarifications of social and religious norms have placed the women in even more controlled situations as they get very limited ownership and access to resources. There is, however, a strong social coherence shaped by the relationships and networks among the nuclear and extended families, and within and among different communities and groups (Kibria, 2016).

3.3.7 Housing Structure

worst situation. Their socioeconomic status collapsed just in one moment. Among 36369 households only 2.9% of paka houses were found in the people census 2011. In the Kamarkhola union there are 3540 households are found among them 2.4% of houses are paka, 2.8% of houses are semi paka, 94.7% of houses are katcha. and 1% of houses are jhupri (BBS, 2011). Only 36% of these total households have water-sealed sanitation systems and the rest of households have no water-sealed facilities or have no sanitation. The scenarios of the selected two villages' housing conditions are worst. Jaliakhali and Sree nagar villages have 227 households and 378 households respectively, among them only 0.4% houses are paka, 1.3% of houses are semi paka, 98% of houses are katcha. and 0.3% houses are jhupri in Jaliakhali village and only 2.6% houses are paka, 2.9% of houses are semi paka, 94% of houses are katcha. and 0.4% of houses are jhupri in Sreenagar village (BBS, 2011). (BBS, 2011). Only 0.4% houses of have proper sanitation system and 66% houses don’t have any sanitation facilities in jaliakhali village and 14.6% houses of having a proper sanitation system and 41.8% of houses don’t have any sanitation facilities in Sreenagar respectively (BBS, 2011).

3.4 River System

In 2009, due to cyclone Aila, the people of Dacope Upazila had faced the worst situation. Their socioeconomic status collapsed just in one moment. The area is enhanced with natural ecosystems consisting of rivers, khals, beels, etc., which are sources of local living opportunities in numerous ways. The area is bounded by the Dhaki river on the north, the Bhadra and the Sutarkhali on the east, the Sibsa on the west, and the Sutarkhali river on the south (BNP, 2013). There are several small rivers and canals within the polder area such as the Nalian river, Mankiriver, Golbunia Khal, Jaliakhali Khal, Kamarkhola Khal, Mistripara Khal, Chuna Khal, Oramukhi Khal, and Jugra Khal, Bishanbari Khal, Mara Pashur River, etc. These rivers and canals are important for local communication, agriculture, and sources of income.

3.5 Climate of the Area

The study area is in a subtropical monsoon climate with moderate rainfall. There are four main seasons, which are pre-monsoon (March-May), monsoon (June-September), post-monsoon (October-November), and dry season (December-February) (Kibria, 2016). The pre-monsoon season is characterized by high temperature, high evapotranspiration, and cyclonic storm surges. The monsoon appears with heavy rainfall, high humidity, and cloud cover. The post-monsoon is characterized by hot and humid weather, occasional thunderstorms, cyclones, and storm surges. The dry season is characterized by cool, dry, and sunny weather. Climatic data of 2013 collected from the Bangladesh Meteorological Department (BMD) shows that the monsoon varieties from late May, averaging 183 mm of rainfall to October, averaging 159 mm of rainfall. The peak rainfall occurs in August averaging 445 mm of rainfall. Rainfall is quite rare in the dry season. The yearly average rainfall is 1,764 mm. According to the data collected from the meteorological station in Khulna in 2013, the relative humidity varieties from 18% to 100%. The maximum temperature occurs in April and the minimum temperature in January. According to the data from the meteorological station in Khulna in 2013, the maximum temperature was 38.8 degree Celsius in April, and the minimum temperature was 11.7 degree Celsius in January.

3.6 Storm Surge Hazard

Geographically, the study area is very near to the Bay of Bengal and, therefore, is uncovered to the cyclonic storm surges and tidal surges. Historical records designate that the wind speed during Cyclone Sidr reached up to 223 km/h, which was escorted by heavy rainfall and causes tidal inundation up to 7 m (Haq et al., 2012). There is evidence that since 1770 to date, at least 25 major cyclones associated with storm surges have hit the general area (MoL, 2011). The super cyclone Sidr hit this area on 15 November 2007, causing enormous loss of lives and properties. Due to the lack of adequate funding and efficient planning, essential rehabilitation of the economy and infrastructure could not take place in time. Just one-and-a-half year after Sidr’s attack, another distressing cyclone, Aila, hit the area. This time, high storm surges washed away polders, human settlements, and properties resulting in prolonged sufferings of the populations of the study area. Additionally, the riverine (tidal) floods and their consequences have always been a matter of concern in this coastal belt. The major devastating floods in this region occurred in 1978, 1981, 1987, and 1988 (MoL, 2011).

3.7 Damage Due to Aila, 2009

On 25 May 2009, Cyclone Aila hit this coastal belt, including the study area. The constant wind speed reached up to 120 km/h. The cyclone sustained over the polder for 2-3 hours, and the associated storm surge overtopped the embankment at several places and caused 3 major breaches. The cyclone destroyed the communication networks, and harshly affected human settlements, lives, and properties. Saline water intruded vigorously and washed away the homestead properties and agricultural lands (Kibria, 2016). The population of the affected areas took shelter on the roadside embankments, schools, cyclone shelters and other raised platforms. Many people left behind their domestic animals such as cows and goats and somehow managed to survive. The number of immediately displaced people in the Kamarkhola Union was about 12,000. The sum of destroyed households in the area was estimated as 2,950. The total number of affected people was about 31,000 with 700 acres of crop damage, 600 dead or missing livestock, and 450 shrimp gher damage (USS, 2009). In addition to the instant impact, Aila inflicted a prolonged impact on waterlogging that subsequently affected agricultural production for three-four years.

CHAPTER FOUR
METHODOLOGY

4.1 Introduction

This study was planned based on different primary and secondary data collection on location-specific cyclone wind speed, storm surge depth, thrust force that hit the coast of Bangladesh in previous years. The study investigated possible losses and damages as well as the performance of the implemented disaster-resilient household design in the study area through the Cyclone Classifier Model (CCM). Both quantitative and qualitative data were collected for the study and then implemented disaster resilient housing design in the study area. Although several previous studies worked on housing resilience in the coastal region of Bangladesh, very few studies investigated the cost-effective resilient housing approach in a participatory way. This study offered a cost-effective participatory housing design approach where the community played both roles of implementer and user. Information was gathered from scientific literatures, several visits to the study area, and relevant organizations. This study provides a noteworthy message to the policymakers regarding the cost-effective disaster resilient housing in the coastal area and the local people about the importance of disaster-resilient housing for mitigating the cyclone impact. The steps of this study are shown in the methodological framework (Figure 4.1) designed for this research.

4.2 Steps of the Study

4.2.1 Literature review

Tropical cyclones, cyclonic storm surges, and other natural disasters are familiar phenomena in the coastal belt of Bangladesh that experience 40% of the total cyclone-induced storm surge events of the world. IPCC reports and other scientific research predict that in the future, both the intensity and the severity of the events may increase due to climate change-related issues. The impacts caused by cyclones may be multiplied by some scales in future events if proper policy and strategies are not maintained. To mitigate the impact of climate change, Disaster resilient housing (DRH) played a very important role in community based DRR approaches. Since the Disaster risk reduction (DRR) developed many countries adopted the DRH theme under this concept. Currently, Bangladesh govt. takes several initiatives of policymaking on Disaster resilient housing concept. Many stakeholders, researchers, NGOs, and other officials became very concerned about the Disaster resilient housing issue after the Sidr and Aila event. Several official and unofficial reports on the impact of cyclonic events on housing sector, long term scenarios of damages and impacts of Aila and Sidr on housing patterns and several national international journals, reports, books, etc. on the importance of resilient housing against a hazardous event, the evolution of DRH in community based DRR approach were critically reviewed during this study.

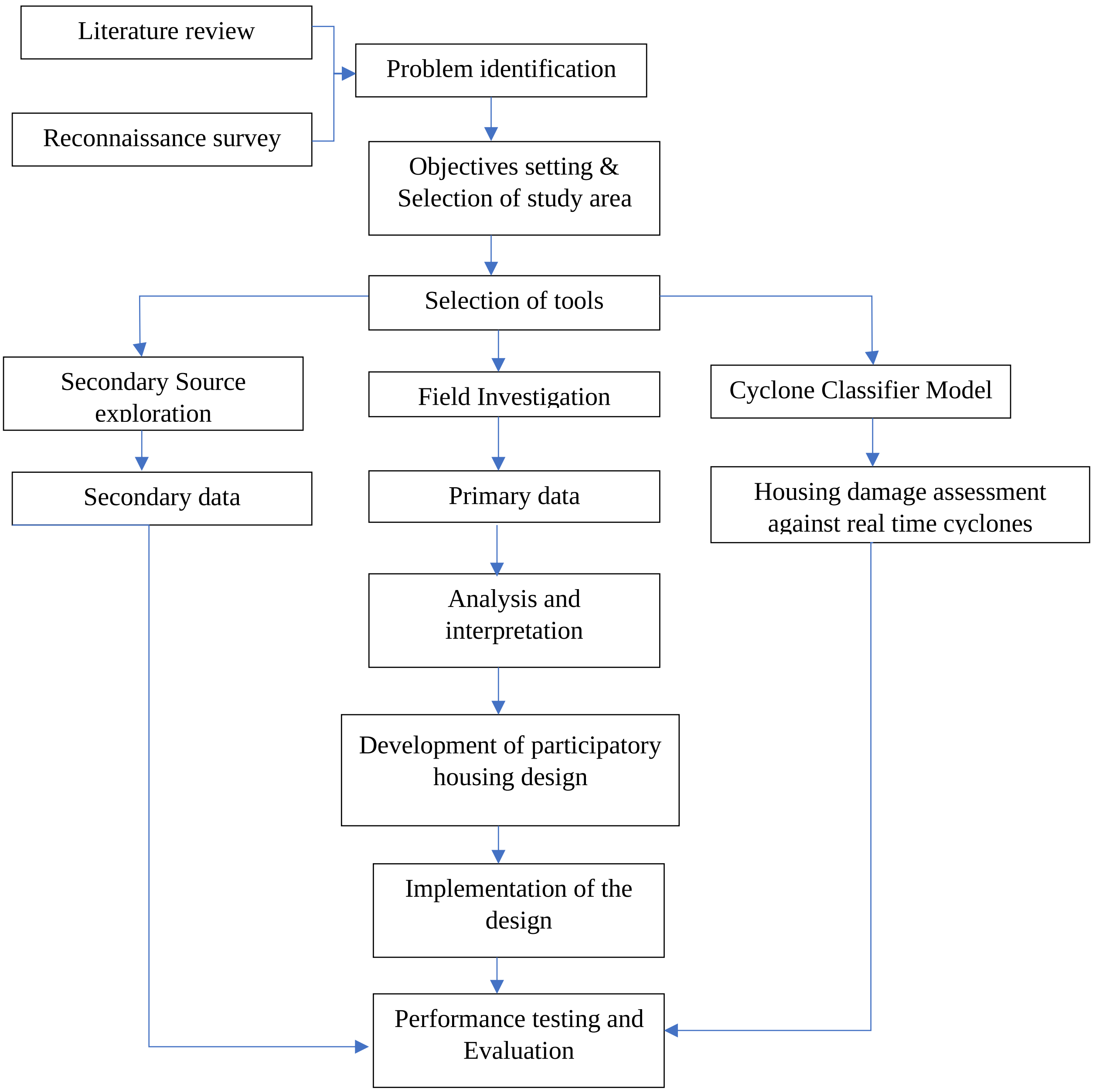

Figure 4.1: Methodological framework of the study

4.2.2 Reconnaissance survey

Due to cyclone Aila, most of the losses and damages were caused by massive embankment failures in Dacope Upazilla, Khulna. Impacts of Aila included damage to individual households, embankment failure, loss and injury of human lives and livelihoods, damage to crops and fisheries, loss of livestock, etc. Impacts on the household sector are the major issue that still trying to recover. To identify a representative affected area, a reconnaissance survey was carried out during February of 2017 in Dacope Upazila of Khulna district. During the survey, local people were interviewed to share their experiences of Cyclone Aila, its impacts on the housing sector, and their current housing status. They defined the cyclone Aila as mostly affected housing and agricultural sector due to embankment failure. Some affected locations were preliminarily visited, which were damaged during Aila. Some group discussions and Key Informant Interviews (KIIs) were conducted during the reconnaissance survey.

4.2.3 Understanding problems

In recent years, frequent disasters have caused extra burden for the marginal people of the country and jeopardized its economic growth. At the same time, the environment is also under threat as people are compelled to live in disaster-prone areas and damage the surrounding natural resources. Dacope Upazilla of Khulna district experienced both instant and long-term impact due to Cyclone Aila. Several literature reviews indicate that number of sectors such as household, agriculture, and fisheries were well affected severely though not equally. Specifically, the housing sector faced the major impacts of cyclone Aila. About 10,750 houses were destroyed and 52,000 people become displaced immediately (USS, 2009). During the reconnaissance survey affected people claimed that in any past events the losses and damages in this specific area were less as the embankments did not fail as they did during Aila. The high tidal surge caused more devastation than Sidr. After eight years of the Aila attack, the situation of the Aila-affected areas is still recovering from the impacts. Till now local people are struggling to get access to food, pure drinking water, shelter, and sanitation. The number of affected people are staying on thatches made housing or in makeshift tents as their living places are still difficult to make for poverty. The problems related to the incidence of Cyclone Aila in the housing sector were recognized through reviews of different scientific, non-scientific research works on Aila and its results along with extensive field visits to the affected areas. Key informative Interviews with the officials from different line agencies related to the rehabilitation and development of the study area in the post-Aila period also helped to identify the difficulties that enhanced the devastating impact in the housing sector in the study area.

4.2.4 Defining objectives

After studying several literatures on cyclone impacts in the housing sector and the reconnaissance survey to the cyclone Aila affected areas, it was possible to identify the problems. It facilitated to make the research questions more precise. The overall aim of the study was selected to reduce coastal community risk through a participatory housing design, ensuring its implementation in a cost-efficient way, testing its performances through the cyclone classifier model, and evaluating its effectiveness from the user level. The specific objectives which were defined for this study are:

i. To develop a participatory disaster resilient housing design that would be used in housing practices to reduce community risk in the selected coastal areas.

ii. To implement the participatory housing design in the selected coastal area involving indigenous knowledge on sustainable natural materials.

iii. To assess the physical performance of the implemented housing caused by flood actions during storm surge with associated high-speed winds.

The first objective aimed to ensure community participation from local beneficiaries to stakeholders for a new design approach, the second objective included activities of design development involving local wisdom on sustainable housing materials, and the third objective included the evaluation of design performance through both scientific social methods.

4.2.5 Selection of the study area

Cyclone Aila, a category-1 cyclonic storm, was the second tropical cyclone hit in 11 southwestern coastal districts in Bangladesh on 21 May 2009. Around 3,928,238 people and 948,621 households were affected by Cyclone Aila (UN,2010). Cyclone Aila also adversely affected the socio-economic conditions of the coastal communities in terms of assets, incomes, livelihood options, and food consumption. Among the affected districts, the Khulna district was one of the severely affected areas. According to different official reports on Cyclone Aila Koyra, Dacope, Paikgacha, and Batiaghata Upazilas of Khulna district were the worst affected (USS, 2009). Among them, Koyra and Dacope Upazila of Khulna district are also among the most severely affected areas from outrageous Aila. The study areas were selected using two criteria: the area with the highest loss and damages in the housing sector from cyclone-induced storm surges and the area with the prolonged impacts from a disaster compared with other affected areas. According to relief web (2009), in 11 districts approximately 600,000 unplanned thatched homes were damaged or destroyed due to cyclone Aila-induced storm surge. Only in Dacope Upazila of Khulna district, 29,832 households were completely or partially damaged (UN,2010). In addition, according to the local people and other officials from different government and non-government organizations (LGED, BWDB, Agriculture office, Fisheries department, forest department, JJS, CODEK, BRAC, etc.), Aila not only broke down the overall social harmonization but also resulted into a chaotic situation in this Upazila. Now around 40% of people are still fighting against the rampant effect of slow poisoning of Aila. As mentioned earlier, Cyclone Aila was a slow onset event that did not cause a significant loss of life or property, its impact was prolonged and reduced land productivity, so households required external assistance to cope with the loss of incomes. Subsequently, cyclone Aila continued to directly threaten the source of income of the coastal communities several years after it struck, (Mallick and Vogt, 2014; Roy et al. 2009) that producing several homeless and jobless people in Dacope Upazilla. Besides impacts on a polder, crop agriculture and fishery were far-reaching and continued for a prolonged period. Having focused on those criteria, this Kamarkhola Union of Dacope Upazilla was selected as the study area.

4.2.6 Sampling and Sample size

The primary unit of analysis was affected households due to any cyclonic hazard are considered as a unit. In addition, this research considered households who were also affected by Aila but could not cope with their situation. Therefore, at least one section of an affected household such as drinking options, sanitation, main body, kitchen, storage options, etc. was considered. A total of 3,559 households are found in the Kamarkhola union (BBS,11) and a total of 950 households were fully damaged by Aila (USS, 2009). According to local NGO JJS, there are 1570 households partially or fully damaged by any cyclonic hazards in recent years. Among 400 households in Jaliakhali and 424 households in Sreenagar village, the number of affected households in both villages are 160 & 162 respectively (Field Census, 2017).

The sample size was determined following the formula of Kothari (2004).

$$n = \frac{p(1-p)z^2}{d^2} \times design\ effects \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots \text{(1)}$$

Here,

n = sample size

p = indicator percentage

z = value of normal variation with 95% confidence interval

d = relative error margin

design effect = 1.345

Based on 50% indicator percentage (proportion of households affected by any sort of cyclonic hazards), 95% confidence interval, 5% precision, and highest response distribution with an assumed design effect 1.345, it is found that at least 114 targeted households for Jaliakhali village and 115 households for Sreenagar village are required for maintaining the data accuracy. Combining 229 households were surveyed through semi-structured questionnaire interview in both villages.

4.2.7 Tools for the study

For testing the performance of implemented housing design Cyclone Classifier Model (CCM) has been used. The result of the CCM model provided the probability of detailed scenarios about housing and polder performance against a real-time or simulated cyclone-induced storm surge. Different results are produced by CCM in a different tidal situation. The generated impact maps and detailed results in different cyclonic hazards at the selected location were used to test the performance of the houses. ArcGIS 10.2 (open source) was used to generate hazard maps, location maps. Google sketch was used to draw necessary structural drawings.

Likert scale (1932) is used to measure the effectiveness of the current warning system through the participants and the effectiveness of implemented housing design against cyclone-induced storm surges through the user of the houses.

For the selection of users, the current housing status and damage scenario of the study area were collected from several field visits through Participatory Rural Appraisal (PRA) tools. PRA tools included transect walk, social mapping, Focus Group Discussions (FGDs), Key Informant Interviews (KIIs), group discussions, individual interviews, etc. (Appendix B). Two semi-structured questionnaire approaches were followed to collect all information. One questionnaire for discussion-related information and another is for individual household basis perceptions of respondents.

4.3 Problems Consideration

4.3.1 Primary data

Different primary data on cyclone warning systems, shelter options, housing options, livelihoods, etc. were collected from the affected people for assessment of the problems. Detailed data on housing such as current land use pattern, housing types, status, problems, requirements, drinking water source, sanitation status, etc. were collected from two different villages of the study area. A brief discussion on the primary data collection process is given below.

4.3.1.1 Transect walk

Two transect walks were conducted with a group of stakeholders such as local NGO members, local representatives, and local peoples in two selected villages for initiating discussion about the available resources in the study area. The transect walks were conducted during reconnaissance visits for a better understanding of the geography and geomorphological conditions of the selected villages. A route was chosen between two points through the chosen villages. The chosen route was passed through as many of the different physical areas, land-use zones, and social statuses of the community. During the walk, the number of different stops set up and conversations have been made with participants along the way by sharing the purpose and opportunity to focus people's observations and conversations on public assets, hazards, livelihoods, cropping pattern, housing status, etc. of the community. After the walk, facilitated the group to compile a diagram of the main features observed through the walk such as a list of present vulnerabilities, embankment length, shelter options, way of communications, individual housing status, cropped area, etc. The developed diagram was used as a guide for the overall scenario of the study villages.

4.3.1.2 Social and resource mapping

These mapping tools were used to get information about the social and resources of the study area more precisely. Positions of social institutions such as schools, madrasa, mosques, temples, cyclone shelters, etc.; along with infrastructures, marketplaces were identified through the social map. Cropping area, crab, and shrimp gher, homestead vegetation, pond, and other wetland, etc. were identified through the resource map. For understanding the current scenario of the two villages, the probable social institutions, and resources of the villages were needed to be identified which were likely to be damaged due to a cyclonic event. The objectives of the resource mapping process were shared with the local people. Then the resources were identified through the discussions with the local people. Participants, including women, farmers, and other livelihood holders helped to draw the maps. At first, we originated the sketch, and then the engaged people percept their opinions on drawing the map. Two maps were prepared for two study villages Jaliakhali and Sreenagar respectively. These maps also helped to understand the damages that the local infrastructures and resources had experienced during Aila and other cyclonic events.

4.3.1.3 Group discussion

For saving time, group discussions were conducted rather than individual interviews to gather the required information. Several group discussions were conducted during five field visits in the study area (Table). A major number of group discussions were conducted casually in the field. During the reconnaissance visit, two group discussions were held for understanding the overall scenario of the study area which included problems related to livings, households, safe drinking sources, and sanitation. After that six group discussions (3 on each village) were conducted during field visits with a proper semi-structured questionnaire for gathering information related to the current amount of damaged or lost lands, types of crops they currently grow, the available amount of cropland currently they have and the number of livestock they had lost. In both study villages, people were living in different places without considering the socio-economic classes. Several times they had to shift their house because of polder breaching. So, stratification according to caste, religion, livelihood, economy was insignificant during the group discussions. Generally, group discussions were location dependent. During field visits, four major group discussions were conducted at four points which are the direct victim of cyclone Aila and rather two group discussions held at the breaching points of the polder. The usual members in each group discussion were 7-10 (ensuring at least one-third of women) depending on the availability of the people. For model validation, another 16 group discussions were conducted in the study areas to gather field data. After design implementation, 4 real-time cyclonic events were considered for the model. For all cyclonic events, 8 group discussions were held in Jaliakhali and 8 were held in Sreenagar. The group discussions were conducted through a check box in a short duration. Only Yes/No data were considered for household damages due to cyclones. The usual members in each group discussion were 20-28 depending on the availability of the people. Table 4.1 & 4.2 shows the scheduled group discussions in the study areas.

Table 4.1: Schedule of group discussion

Date	Location	No. of Participants	Types of Participants
16-02-2017	Jaliakhali	8	Small Farmer, landless farmer, boatman, fisherman, woman
16-02-2017	Sreenagar	7	Small Farmer, day laborer, woman
11-02-2017	Jaliakhali	10	Small businessman, fisherman, small farmer, woman
11-02-2017	Jaliakhali	10	Farmer, boatman, woman
11-02-2017	Jaliakhali	8	Farmer, fisherman, woman
03-03-2017	Sreenagar	10	Small farmer, fisherman, small businessman, woman
03-03-2017	Sreenagar	9	Small businessman, fisherman, small farmer, woman
03-03-2017	Sreenagar	9	Farmer, fisherman, woman

Table 4.2: Schedule of model validation group discussions

Date	Location	No. of Participants	Types of Participants
01-06-2017	Jaliakhali	20	Farmer, boatman, fisherman, woman
01-06-2017	Sreenagar	23	Farmer, boatman, fisherman, woman
01-06-2017	Jaliakhali	27	Farmer, boatman, fisherman, woman
01-06-2017	Sreenagar	26	Farmer, boatman, woman
28-05-2019	Jaliakhali	21	Farmer, fisherman, woman
28-05-2019	Sreenagar	20	Small farmer, fisherman, small businessman, woman
28-05-2019	Sreenagar	24	Small businessman, fisherman, small farmer, woman
28-05-2019	Jaliakhali	20	Farmer, fisherman, woman
28-11-2019	Jaliakhali	23	Farmer, boatman, fisherman, woman
28-11-2019	Sreenagar	21	Small businessman, fisherman, small farmer, woman
28-11-2019	Jaliakhali	25	Small businessman, fisherman, small farmer, woman
28-11-2019	Sreenagar	24	Farmer, fisherman, woman
08-06-2020	Jaliakhali	20	Farmer, fisherman, woman
08-06-2020	Sreenagar	20	Farmer, fisherman, woman
08-06-2020	Jaliakhali	26	Farmer, fisherman, woman
08-06-2020	Sreenagar	20	Farmer, boatman, fisherman, woman

4.3.1.4 Focus group discussion

Focus Group Discussions (FGDs) were conducted among the individuals who are affected by any kind of cyclonic hazards. The information was gathered on different sectoral damages such as impacts on their living, household, sanitation, drinking water source, livestock etc. A formatted semi-structured questionnaire was followed to collect information among diverse livelihood groups including farmers, fishermen, day laborers, etc. 8 Focus Group Discussions (FGDs) were conducted in both villages (4 in Jaliakhali and 4 in Sreenagar). The target groups for FGDs were selected based on the following criteria

- ✓ Victim of cyclonic hazards.
- ✓ Similar in gender
- ✓ Age is considerably similar
- ✓ Identical with respect to habitat
- ✓ Livelihoods similar
- ✓ Comparable in social status
- ✓ Economically almost similar

The participants for FGDs were contacted prior to the meeting through a field facilitator to ensure their presence at the scheduled time. The groups were formed of 10-12 homogenous members. Separate gender basis group were formed for avoiding biases. The discussions were held for one hour or less to manage time. The discussions were held in a common place like institutional ground or fallow land. The schedule of FGD is given Table 4.3.

Table 4.3: Schedule of FGD

Date	Location	Participants	Age	Target Group
05-04-17	Jaliakhali	10 Male	(45-60)	Farmer
05-04-17	Jaliakhali	11 Male	(50-65)	Day labor
05-04-17	Jaliakhali	10 Male	(40-55)	Fisherman
05-04-17	Jaliakhali	8 Female	(35-60)	Housewife
06-04-17	Sreenagar	10 Male	(45-60)	Farmer
06-04-17	Sreenagar	12 Male	(50-65)	Day labor
06-04-17	Sreenagar	10 Male	(40-55)	Fisherman
06-04-17	Sreenagar	10 Female	(35-60)	Housewife

4.3.1.5 Semi-Structured Interview (SSI)

The semi-structured interviews (SSIs) were conducted among the households which are the victim of cyclonic hazards. Especially, the household affected by cyclone Aila and still struggling to manage the impacts are got prioritized. The questionnaire of the semi-structured interview was based on the Likert Scale (1932) which helped respondents to answer the questions more precisely. Through the semi-structured interviews (SSIs) respondents gave their perceptions on the effectiveness of the current early warning system, cyclone shelter, communication systems, housing options, and its related segments like safe drinking water sources, sanitation systems, storage systems, etc. Besides, information on their accessibilities, barriers, opinions, etc. was collected through semi-structured interviews (SSIs). In both study villages, affected households must shift, repair, or fully construct several times due to any cyclonic hazards. So, random households were selected for interviews based on the breadwinner’s occupation. Generally, the head of a household attend the interview and shared their thoughts, feelings, and beliefs. Total 229 interviews were held in the study area for fulfilling a pre-determined sample size. 114 households were surveyed through semi-structured questionnaire interviews in Jaliakhali and 115 households for Sreenagar village respectively.

4.3.1.6 Key Informant Interview (KII)

The information of an individual may differ from person to person and from place to place due to the variance of their perceptions and understandings. But Key Informant Interview (KII) is a suitable tool to collect the reliable and correct information. It helps to confirm the field data. KII was conducted with selected persons from different organizations who were related to the preparedness, mitigation, rehabilitation, recovery, and development program from the beginning to the end. Initial contacts were made with the key informants prior to the meeting to make the schedule. The participants of the KII are mentioned in Table 4.4

Table 4.4: Participants of Key Informative Interview

Serial No.	Designation
1	Upazila Nirbahi Officer, Dacope
2	Upazila agriculture Officer, Dacope
3	Upazila Fisheries Officer (UNO), Dacope
4	Sub-Assistant Engineer, BWDB, Khulna
5	Executive Engineer, BWDB, Khulna
6	Executive Engineer, LGED, Khulna
7	UP Chairman, Kamarkhola Union
8	Project Manager, HEED Bangladesh
9	Manager, JJS
10	Project Officer, JJS
11	Manager, BRAC
12	UP Member, 7 no. Ward
13	UP Member, 1 no. Ward
14	Secretary, DRR committee
15	Volunteer, DRR committee

4.4 Development of Participatory Design Workshop

4.4.1 Selection of beneficiaries

4.4.1.1 Individual Interviews

After conducting 8 Focus Group Discussions (FGDs) in both villages, 6 respondents were selected from the group based on their livelihood options, income level and current housing status for individual interview. During the interview a structured questionnaire was followed to avoid misconceptions. The interviews focused on the habitat type, land use, livelihood, livestock, etc.

Among 6 recipients, finally two respondents in both villages were selected as beneficiaries based on following criteria.

- Have ownership of land but lost their house completely due to cyclone Aila.
- Didn’t have income options for reconstruction
- Didn’t have proper source of drinking water
- Didn’t have proper sanitation system.
- Didn’t have rice/seed storage options.
- Didn’t have kitchen.
- Didn’t have livestock place

Considering all the criteria and proper cross checking with local representative's annotations, one respondent from Jaliakhali village and another from Seenagar village were selected as beneficiaries of further implemented housing design.

4.4.2 Participatory methods (PMs)

Participatory methods (PMs) were used to develop a participatory design workshop. Participatory methods (PMs) include a range of activities with a common thread: enabling ordinary people to play an active and influential part in decisions that affect their lives. This means that people are not just listened to, but also heard and that their voices shape outcomes. During the workshop session, a team was formed involving stakeholders; the beneficiaries (both male and female members), local masons, craftsmen, builders, community leaders, architects, architecture students' engineers, and so on. Through this session, participants shared their thoughts, opinions, experiences, indigenous knowledge, expectations, opportunities, problems on possible design development. After the session, a possible design model was developed which would be more resilient during any natural calamity events.

4.5 Testing design performance in large scale

To test the performance of the local housing structure in large scale area, Cyclone Classifier Model (CCM) was used. CCM was one of the outputs from SATREPS project that implemented by IWFM, BUET (2014-2019). Through this model the output CCM in the form of location specific data of cyclone wind speed, surge depth, house damage, embankment damage and hazard map (Haque et al. 2019).

4.5.1 Cyclone Classifier Model (CCM)

To develop CCM, a total of 170 pseudo-cyclones are generated to create the database of CCM. Numerical model Delft3D, analytical model DFM, structure model ETAB, and embankment model PLAXIS 2D are applied to simulate cyclone wind speed, surge depth, thrust force, house damage, and embankment damage for all the 170 pseudo-cyclones. CCM is executed by creating a database with all the pseudo-cyclone simulation results. One typical simulation result of these parameters for one of the pseudo-cyclones is shown in Figure 4.2. The output of CCM from Figure 4.2 shows the result of a pseudo cyclone which has a landfall location in 21.885 latitude and 89.903 longitude, maximum wind speed of 213 km/hr, and landfall time during high tide. The CCM output shows the location-specific (division, district, Upazila) impact of this cyclone in terms of wind speed, surge depth, embankment (polder) damage, structure damage, and a hazard map for the entire coast. For testing the design performance, several real-time cyclonic events were simulated through CCM to measure the real-time impact of those cyclones on the housing design and measure the performance of the houses. Required data for cyclone simulation such as previous cyclone landfall location, wind speed, surge height, and tidal situation, etc. were collected from Bangladesh Meteorological Department (BMD) and other secondary sources like journals, articles, newspapers, etc.

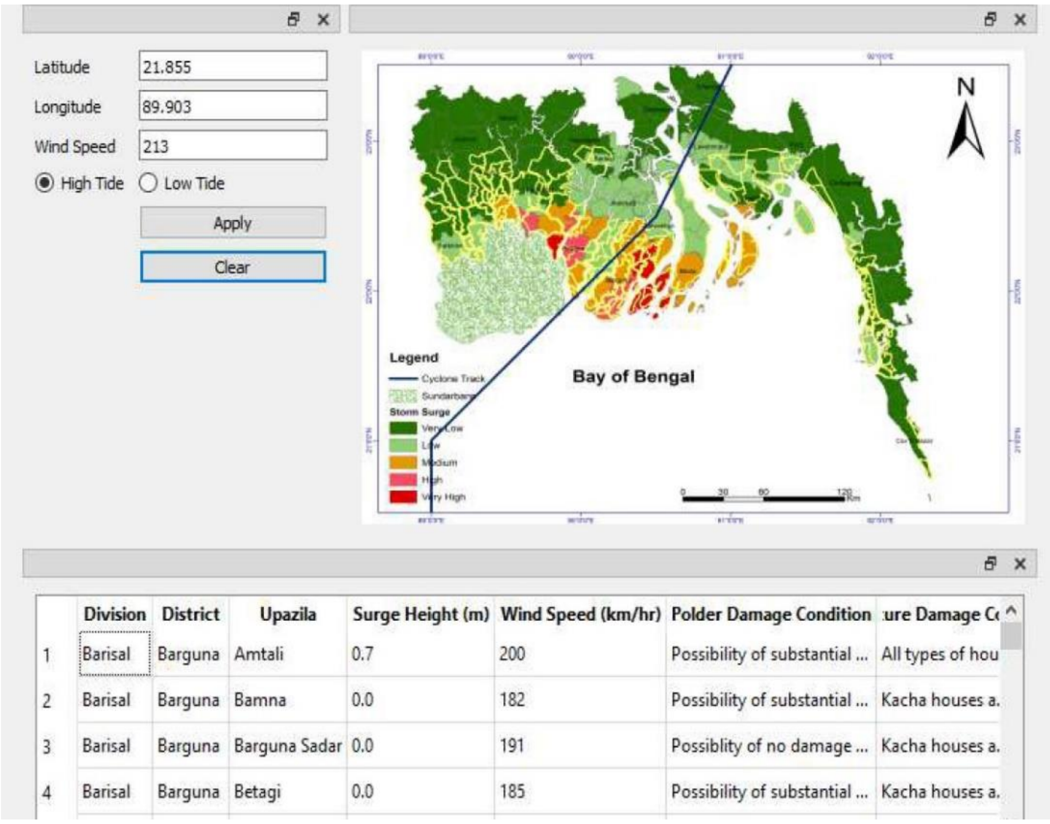

Figure 4.2: simulation results of a pseudo cyclone in CCM (Source: Haque et al.2019)

4.6 Data analysis methods

4.6.1 Evaluation of the design performance

Later evaluation of the implemented design performance was also done as an outcome evaluation process using the Likert scale (1932) from both beneficiaries of the study area. A semi-structured questionnaire was used using the Likert scale to collect perceptions of the beneficiaries on design performance. As selected beneficiaries are the user of the design scheme, their real-time using experiences helped to evaluate the design performance against real-time natural calamities they had experienced. Through the semi-structured questionnaire, beneficiaries gave their perceptions on the resilience of the house after a natural event such as damage information, repairing costs, required time, availability of repair materials, etc. Besides, information on housing comfort, the performance of established drinking water options, sanitation system, storage option, lack of the design, problems for repair or reconstructions, etc. were also collected. Finally, a five-point Likert scale was used for scoring each perception of the beneficiaries on design performance. Every member of both households was asked to select one of the five options given below to describe the effectiveness of each variable from their insights.

1 = Unknown, 2 = Very Low, 3 = Low, 4 = High, 5 = Very high

The level of effectiveness or the options of Likert scale are defined as (Islam et al, 2019):

Unknown- Respondents unknown about the options or a large extent of problems or lacking. As a result, the outcomes are far away from that of expectation.

Very low- Respondents are getting very few benefits, but the level of usefulness is below expectation level. In other words, the benefits are outweighed by problems, but this gap is not very much.

Low- Respondents are getting some benefits or confused to rate the measure as the advantage and disadvantage seems to be unclear. Benefits come along with moderate problems or lacking.

High- Respondents are getting good benefits that can be considered as satisfactory. Although there are some problems within the functions of each sector, but the level of benefits is outweighed by problems or lacking.

Very high- Respondents are getting very good benefits from every sector that can be considered as highly satisfactory. However, minor problems can be found within the functions of the measures, which is negligible.

4.6.2 Assessment of respondent perceptions

Respondents' perceptions of effectiveness on present cyclone warning system, and cyclone shelter were also assessed through Likert scale (1932) Index Score

Index

The following indexing formula was developed to rank respondents' perceptions and experiences on cyclone warning systems, cyclone shelters with a calculated score using percentage of frequency and weight of each Likert option

$$\text{Effectiveness Score} = \{(PU \times 1) + (PVL \times 2) + (PL \times 3) + (PH \times 4) + (PVH \times 5)\} \quad \dots (2)$$

Here, PU = percentage of Unknown, PVL = percentage of Very Low, PL = percentage of Low, PH = percentage of High, and PVH = percentage of Very High

4.6.3 Assessments of Barriers

Different types of barriers were identified during data collection in different sectors. These barriers are related to social, financial, cultural, and political which exist in the community against accessibility and adequacy of social resources. Such as cyclone warning system, present housing structure, shelter, communication system, etc. These barriers affect community resilience against a disaster. From community perspectives, the notation of each identified barrier is given below.

Social barrier

The social barrier is a term that is used to point at the inequalities that exist between different. The discrepancies are caused because of several reasons, for instance, socioeconomic status, religion, race, ethnicity, and gender.

Financial barrier

Financial barrier refers that the shortage or lacking resources of a community or individuals to fulfill their needs or requirements certainly. The shortage of resources caused because of disaster impacts, losing livelihoods, poverty etc.

Cultural barrier

Cultural barrier refers that the differences of norms, values, and beliefs that exist between different individuals in a society. The differences are communication way, religious view, physiological theme, traditional beliefs.

Political barriers

Political barriers are those that necessitate larger societal change to be overcome. Of these, political and electoral cycles present perhaps the greatest challenge to effective community processes, often constraining public dialogue and limiting decision-making effectiveness.

These barriers are internally dependent on each other, i.e., they are mutually not exclusive. An individual may face one or more barriers at a time. Probabilistic analysis is made to assesses the impact of barriers. Probabilistic scores are calculated as:

$$Probability\ that\ people\ facing\ one\ barrier = \frac{Number\ of\ people\ facing\ one\ barrier}{Total\ population\ of\ the\ study\ area} \quad (1)$$

$$Probability\ that\ people\ facing\ two\ barriers\ at\ a\ time = \frac{Number\ of\ people\ facing\ two\ barriers\ at\ a\ time}{Total\ population\ of\ the\ study\ area} \quad (2)$$

$$Probability\ that\ people\ facing\ three\ barriers\ at\ a\ time = \frac{Number\ of\ people\ facing\ three\ barriers\ at\ a\ time}{Total\ population\ of\ the\ study\ area} \quad (3)$$

$$Probability\ that\ people\ facing\ four\ barriers\ at\ a\ time = \frac{Number\ of\ people\ facing\ four\ barriers\ at\ a\ time}{Total\ population\ of\ the\ study\ area} \quad (4)$$

$$Probability\ that\ people\ facing\ at\ least\ one\ barrier = Probability\ that\ people\ facing\ one\ barrier - Probability\ that\ people\ facing\ two\ barriers\ at\ a\ time + Probability\ that\ people\ facing\ three\ barriers\ at\ a\ time - Probability\ that\ people\ facing\ four\ barriers\ at\ a\ time \quad (5)$$

The interpretation of barriers notations is given in Table 4.5

Table 4.5: Interpretations of notations

Probabilistic impact of various barriers	Interpretations
$P(S \cap F)$	The probability that people facing social and financial barriers at a time
$P(S \cap C)$	The probability that people facing social and cultural barriers at a time
$P(S \cap P)$	The probability that people facing social and political barriers at a time
$P(F \cap C)$	The probability that people facing cultural and financial barriers at a time
$P(F \cap P)$	The probability that people facing political and financial barriers at a time
$P(P \cap C)$	The probability that people facing political and cultural barriers at a time
$P(S \cap F \cap C)$	The probability that people facing social, financial, and cultural barriers at a time
$P(S \cap F \cap P)$	The probability that people facing social, financial, and political barriers at a time
$P(P \cap F \cap C)$	The probability that people facing political, financial, and cultural barriers at a time
$P(S \cap P \cap C)$	The probability that people facing social, political, and cultural barriers at a time
$P(S \cap F \cap C \cap P)$	The probability that people facing social, political, financial, and cultural barriers at a time

4.6.4 Analytic Hierarchy Process (AHP)

AHP is a method of MCDA developed by Thomas Lorie Saaty in the late 70s (Saaty, 1977, 1980). To date, there are many AHP applications to problems of assessment in various industries, and several studies are dedicated to AHP application to occupational safety problems (Caputo et al., 2013; Podgórski, 2015; Zheng et al., 2012). AHP is used to determine the relative importance of a strategy set, which may be made up by different elements as actions, alternatives, criteria, securities. Its greatest characterization is that it structures any problem in a hierarchical way, even if it is complex, multi-person, multi-period, or multi-criteria. The AHP can be used to determine the benefit/cost of a project, when this cannot be evaluated exclusively in terms of monetary benefits (Saaty, 1980, 1990; Saaty and Kearns, 1985). Among the most important steps of the AHP decisional analysis and basis of the procedure is the criteria selection.

In this research, AHP is used to develop a causal relation network to show interrelationship among different indicators that impede housing resilience in the study sites. Multiple circles with arrow directions in the causal relation show relationships among the factors. Depending on the connectivity in the network, each of the indicators is assigned a specific weight. This weight is calculated by Analytical Hierarchy Process (AHP) method. The AHP method performs pairwise comparisons to measure the relative importance of elements at each level of the hierarchy and evaluates alternatives at the lowest level of the hierarchy to make the best decision among multiple alternatives (Sipahi and Timor, 2010). Increased weight of an indicator means increased sensitivity of the indicators within the network.

4.6.5 Venn diagram

Venn diagram is constructed by overlapping geometric shapes and used to describe the complex relationship among different dependent variables. Venn diagram is an effective visual tool for an easy interpretation and understanding of this complex relation. In this study, Venn diagrams are constructed for respondents' barriers on accessibility and adequacy for public and individual resources and where each of the circle shapes represents one of the four barriers identified through the data collection – social, cultural, financial, and political. In this study, four different colors have been used for these four barriers. Intersecting domains of the circle shapes represent the probabilistic score for multiple barriers.

4.6.6 Cost benefit analysis

Cost-benefit analysis (CBA) is an established tool for determining the economic efficiency of development interventions. CBA compares the costs of conducting such projects with their benefits and calculates the net benefits, or economic efficiency (Kull et al., 2013). In this study, cost benefit analysis is done to evaluate the economic return of the implemented Disaster Resilient Housing Design and locally built housing against the cyclones that occurred from 2017-2020. The purpose of the cost benefit analysis is to compare the economic return of both houses for further implementation in the study area. To do this, this study uses the results of the architectural housing design that implemented in the study area. Main characteristics of cyclone resilient housing include (i) Interconnection of all key structural components in the house structure; (ii) Anchoring of roofing materials, particularly lighter ones made of corrugated iron with roof angles designed to deflect wind and reduced eves; (iii) Increasing wall thickness from the common in low-income housing (iv) Inclusion of a reinforced ring beam at window level – mid way up most walls; (v) Strategic placement of pillars to strengthen walls; (vi) Establishment of safe rooms within houses in case walls fail; and (vii) Avoidance of courtyards, verandas, setback entryways and other features that concentrate wind pressures differentially. It will be helpful to policy makers to choose which design will be most benefited on the large scale.

4.6.6.1 Assessment of benefits

In a typical CBA of investment projects, benefits are the further outcomes generated by the mediation project (e.g., resilient housing measures) as compared with the situation without the project. In the disaster risk reduction case, benefits are the risks that are reduced or avoided (Mechler, 2005). Benefits of resilient housing processes are defined as the escaped damage and loss or the increased benefits following the implementation and application of resilient housing measures (Tran et al. 2015). Avoided damage (benefits) is the variation in damages and losses under two conditions: with and without commencing the resilient housing measures. It is noted that this study does not incorporate specific types of costs, such as the cost of fatalities or grievances or the cost of social interruptions within a group or community. Cyclones lead to significant community disruptions, human causalities, and so forth, but due to the complexity of measuring these economic costs, the study does not incorporate them in the overall analysis. In addition, as mentioned by some focus group discussion's participants that the most benefit of a resilient house is adding peace of mind during the cyclone season; building a resilience house could also carry in some socio-economic paybacks to the owner such as he/she is satisfied of new house and easier to access credits and loans. These benefits can be considered as non-monetary ones and complicated to measure. This study mainly focuses on economic benefits of resilient house.

4.6.6.2 Assessment of costs

Associated costs of both housing designs include (1) major investment cost for building a resilient house (construction cost) and (2) operation and maintenance expenses for the house incurred over time (O&M cost). The study focuses on the extra costs incurred by a standard non-cyclone resistant local house as compared to a cyclone-resistant house.

Finally, economic efficiency is assessed by comparing benefits and costs. Three economic instruments were used to measure the overall economic returns to resilient housing. They include (1) net present value (NPV), (2) benefit-cost ratio (BCR), and (3) internal rate of return (IRR).

Net Present value (NPV)

NPV is generally Costs and benefits arising over time are discounted and the difference taken, which is the net discounted benefit each year. The sum of the net benefits is the NPV. A fixed discount rate is used to represent the opportunity cost of using public funds for a given project. If the NPV is positive, then a project is considered desirable. The following equation is used to calculate the NPV

$$NPV = \sum_{t=0}^{N} \frac{Rt}{(1+i)^t} \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots \text{(6)}$$

Here,

NPV	=	net present value
Rt	=	net cash flow at time t
i	=	discount rate
t	=	time of the cash flow

Benefit-Cost Ratio (BCR)

The BCR is a variant of the NPV, with the benefits divided by the costs. If the ratio is greater than 1, a project is considered to add value to society. The following equation is used to calculate the BCR

$$\text{BCR}=\frac{PV\ of\ Expected\ Benifits}{PV\ of\ Expected\ Costs} \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots \text{(7)}$$

Internal Rate of Return (IRR)

Whereas NPV and BCR use a fixed discount rate, this criterion calculates the interest rate internally. This represents the return on investment in the project. A project is rated desirable if the IRR surpasses the average return of public capital as determined beforehand. The following equation is used to calculate the IRR

$$0 = \sum_{t=1}^{N} \frac{CFn}{(1+IRR)^t} \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots \text{(8)}$$

N = Total number of time periods

n = Time period

CFn = Net cash flow at time period

IRR = Internal rate of return

CHAPTER FIVE

PROBLEMS CONSIDERATION IN THE STUDY AREA

5.1 Introduction

The biophysical and socio-economic condition of Dacope Upazila in Khulna District is extremely vulnerable and almost every year this region is being affected by natural disasters and climatic stress like cyclones, floods, waterlogging, salinity intrusion, storm surge, riverbank erosion, etc. Though there are 83 cyclones center the community peoples of this area lose their lives and livelihoods due to cyclones within a regular interval of time. Since the last decade, several numbers of the cyclone were struck in the coastal area of Bangladesh. Among them, cyclone Sidr in 2007 and cyclone Aila in 2009 created devastating situations for the community peoples of this area. After 10 years of cyclone Aila, the number of people of Dacope Upazilla is struggling to get back to their normal life. In the study area, people are still facing salinity in soil and until 2012. They were not able to cultivate any crops on their land. This long-term impact on livelihoods creates local people incapable to reconstruct or repair their affected houses due to extreme poverty. Still, in 2017, a large number of people are currently living on polder by making thatches somehow only. Those mentioned factors and the continuous impact of natural depressions frequently hindering to achieve affected people's resilience against Aila impact. In this chapter problems with present early warning systems, existing cyclone shelter options, present household situations of cyclones affected people, and its related segments like safe drinking water sources, sanitation systems, storage systems, livestock place, etc. will be discussed. Besides, the effectiveness of each segment, barriers, accessibility, etc. will be measured through the perceptions of respondents.

5.2 Cyclone Warning Systems

Although communities are never homogenous and some households and communities always have fewer options than others (Cannon, 2008), Bangladesh's community-based efforts vary from expectations in much literature about the nature of warning systems. The traditional technical structure of warning systems is top-down. Peripheral institutions provide information about a looming hazard followed by command-and-control instructions guiding response. Research, policy, and practice have challenged this construct, from evidence regarding the importance of unofficial warnings (Parker and Handmer, 1998) to the United Nations' people-centered warning systems (Basher, 2006). As illustrated by these studies correspondingly, most periodicals countering the top-down view of warning systems are either empirical or theoretical. Few interpret people's perceptions of and actions for warning in the context of theories of warning systems as social processes, even though some foundational work (e.g., Mileti et al., 1975) advocates for this agenda. Warning message languages, community's understanding, the ability of message interpretation, response time, perceptions, and participation, etc. are the determiner of a successful cyclone warning system. In this section, respondents' sources for receiving signals, warning message interpretation results, response to warning signals, the effectiveness of cyclone management systems during preparedness program, problems, and barriers are discussed.

5.2.1 Cyclone Warning Sources

Since the cyclone Aila event has occurred, people of both study villages are quite aware of the cyclone warning signals nowadays. In both villages, receiving multiple information sources is common and media are by far the most popular source. Particularly radio in mobile phones, TV, and transistors is commonly used to get cyclone warning signals. At present, about 59% of respondents in Jaliakhali village and 67% of respondents in Sreenagar village are related to media respectively. As internet is not listed because respondents are not familiar withonline. The next most popular sources in the study villages are word-of-mouth, coming from friends and relatives. Currently, 39% of respondents in Jaliakhali village and 30% of respondents in Sreenagar village are receiving information of cyclone warning signals from their friends, neighbors, or relatives. As 80% of people in both villages have a Hindu religious view, the number of mosques in both villages is rare considering other villages of the Kamarkhola union. The formal cyclone warning systems such as CPP volunteers, NGO initiatives, Union Disaster Management Committee, etc. are least informative, mainly due to the village's remoteness, poor transport accessibility, and the lack of personnel to cover all villages. Jaliakhali displayed some differences from Sreenagar, where communication and development played a major role in this variation. Figure 5.1 provides the respondent's cyclone warning sources in both study villages.

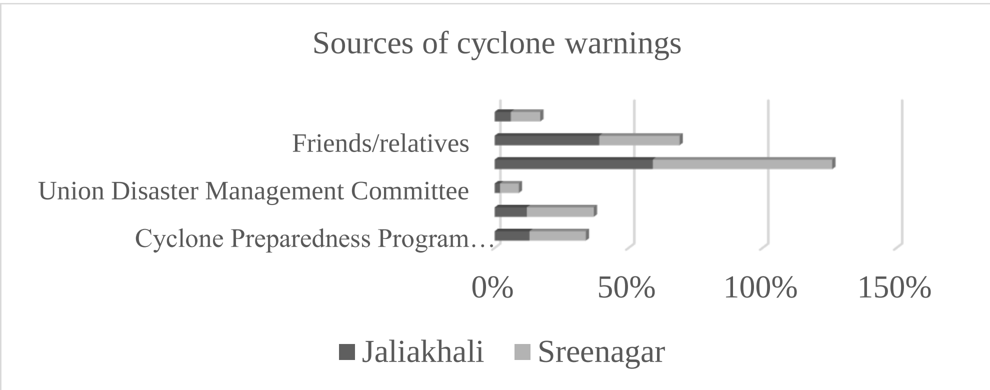

Figure 5.1: Sources of cyclone warnings (n=229). (Sources: Household survey, 2017)

(Respondents could select more than one answer)

Table 5.1: Number of sources that respondents have access (n=229) (Sources: Household survey, 2017)

Number of sources for received warnings	Jaliakhali	Sreenagar
No Access	28%	17%
At least one Source	40%	48%
Two Sources	22%	20%
Three sources	10%	15%

As mentioned earlier, media is the main source to respondents for receiving information on cyclone signals. But the number of people still don't have any access to any types of warning signal sources. Table 5.1 shows that 28% of respondents in Jaliakhali village and 17% of respondents in Sreenagar village have no access to warning signals sources in the last four cyclone events. Not even from any formal cyclone warning systems. The main reasons are poverty block them to access media service, living in a remote place, and poor communication system prevents formal warning systems to disseminate the signals. Currently, these respondents are using their traditional knowledge on weather forecasts before a cyclone. Some of them are moved to safe places and rather are stayed their own houses. At present, 40% and 48% of respondents of respected villages have access to at least one source, 22% and 20% of respondents have two sources, and 10% of respondents in Jaliakhali village and 15% of respondents in Sreenagar village (Table 5.1) have three sources to get signal updates. Technological evolution makes the dissemination of the cyclone warning sources easier. But in the study area poverty blocks respondents' access to this technology.

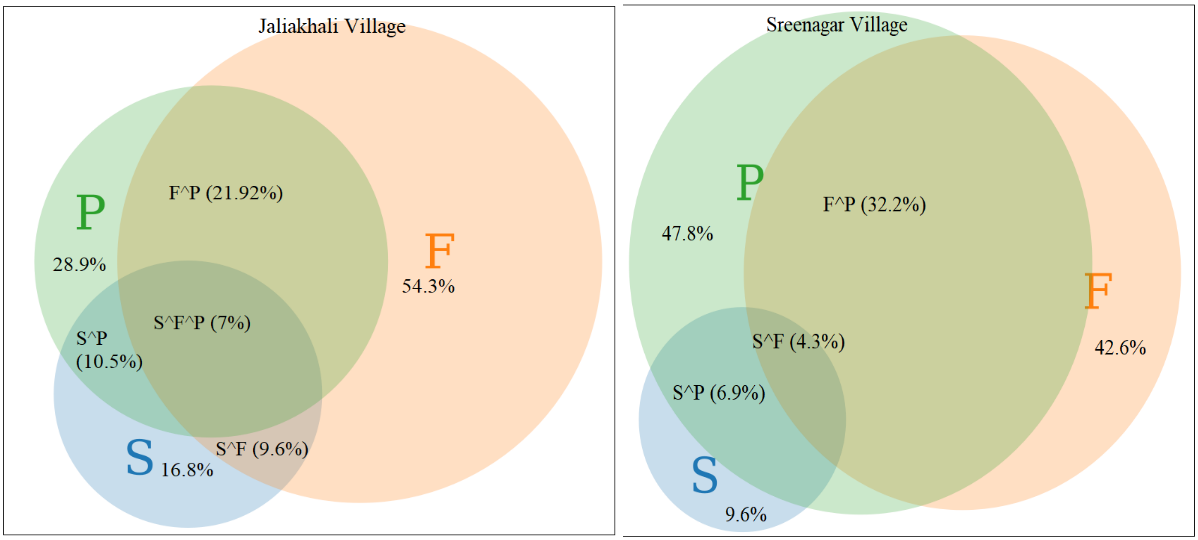

Figure 5.2: Venn diagram of barriers for accessibility to the cyclone warning sources in the study villages (mutually inclusive). *Here, S= Social Barriers, F= Financial Barriers, P= Political Barriers. Various combinations of S, C, F, represent multiple barriers. For example, SP=Social and Political barriers, SF= Social and Financial barriers, SFP= Social, Financial and Political barriers. Sample size: Jaliakhali =114; Sreenagar= 115.*

In Jaliakhali village 54% and Sreenagar 42% of respondents claimed about the financial problem for getting access in any media coverage such as TV, Radio, Cell phone, Newspaper, etc. The basic needs of these people become important rather than affording technological objects. Local representatives of government could fill this gap of cyclone warning sources by disseminating signals through CPP volunteers, miking, or personal initiatives. But 29% of respondents in Jaliakhali village and 47% of respondents in Sreenagar village are not able to touch up with these formal sources of government (CPP volunteers, miking, or personal initiatives). Because of either they are living in a marginalized place or formal sources have a lack of interest to contact them. Respondents (16% and 9%) in both villages are claimed about social barriers as signal information sometimes came from relatives, friends, or neighbors. Besides, the number of respondents has faced more than one barrier at a time to access the signal sources. For example, 22% of respondents in Jaliakhali and 32% of respondents in Sreenagar have faced both financial and political barriers at a time. The percentage of facing multiple barriers in jaliakhali and Sreenagar respectively: both social and financial barriers

(9%, 4%), both social and political barriers (10%, 7%), and all three barriers social, financial, and political (7% only in Jaliakhali) have found (Figure 5.2).

5.2.2 Warning message interpretation

Through the semi-structured questionnaire survey, respondents claimed that they become very concerned about warning signal messages after the cyclone Aila event. As warning message contents typically vary depending on the tropical cyclones' forecasted track and intensity, it is important for the respondents to identify these variations for their safety. To understand the cyclone response-ability of the respondents through warning messages in the study area, four prerecorded major cyclones (cyclone Aila, cyclone Mahasen, cyclone Komen, cyclone Roanu) warning messages are delivered to respondents which results are presented in Table 5.2 for Jaliakhali and in Table 5.3 for Sreenagar Village.

Tables 5.2 & 5.3 show that most of the respondents could extract most of the information contained in the warning messages correctly. Misinterpretation rates were high for information on: "cyclone movement direction", "landfall time", and "surge height" (highlighted bold and highlighted in the tables) compared to other information. However, the interpretation rate of other information like current location, ports/area likely to be affected, wind speed, guidance for fishing boats, and danger level, etc. were very high. That's because respondents know these terms for their fishing profession, easily recognizable and familiar. The results of proper cyclone warning message interpretation are quite similar for both villages.

Table 5.2: Interpretation of proper cyclone warning message by the respondents in Jaliakhali ***(n=114)*** (Sources: Household survey, 2017)

Jaliakhali Village								
Information in the Warning messages	Cyclone Aila	Change in info	Cyclone Mahasen	Change in info	Cyclone Komen	Change in info	Cyclone Roanu	Change in info
	Special bulletin No. 31 on 26 May. 2009		Special bulletin No. 23 on 15 May. 2013		Special bulletin No. 25 on 28 July. 2015		Special bulletin No. 27 on 20 May. 2016	
Current location	94%	64%	96%	51%	95%	49%	97%	53%
Cyclone Movement direction	**44%**	**34%**	**43%**	**32%**	**42%**	**31%**	**45%**	**39%**
Danger level	92%	57%	89%	53%	93%	52%	95%	58%
Ports/Area likely to be affected	82%	73%	87%	73%	89%	72%	92%	77%
Landfall time	**54%**	**46%**	**49%**	**43%**	**55%**	**47%**	**56%**	**42%**
Wind speed	88%	92%	86%	81%	93%	84%	92%	90%
Surge height	**45%**	**28%**	**43%**	**29%**	**42%**	**30%**	**49%**	**31%**
Guidance for fishing boats	77%	81%	86%	84%	83%	82%	91%	94%

Table 5.3: Interpretation of proper cyclone warning message by the respondents in Sreenagar ***(n= 115)*** (Sources: Household survey, 2017)

Sreenagar Village								
Information in the warning messages	Cyclone Aila Special bulletin No. 31 on 26 May. 2009	Change in info	Cyclone Mahasen Special bulletin No. 23 on 15 May. 2013	Change in info	Cyclone Komen Special bulletin No. 25 on 28 July. 2015	Change in info	Cyclone Roanu Special bulletin No. 27 on 20 May. 2016	Change in info
Current location	93%	57%	92%	50%	94%	43%	98%	49%
Cyclone movement direction	**41%**	**35%**	**47%**	**33%**	**42%**	**29%**	**48%**	**41%**
Danger level	95%	52%	93%	56%	95%	49%	98%	54%
Ports/Area likely to be affected	92%	83%	86%	76%	91%	75%	95%	82%
Landfall time	**46%**	**36%**	**48%**	**42%**	**53%**	**43%**	**57%**	**48%**
Wind speed	93%	91%	89%	84%	94%	92%	96%	94%
Surge height	**43%**	**29%**	**41%**	**27%**	**40%**	**32%**	**41%**	**32%**
Guidance for fishing boats	85%	86%	87%	89%	92%	87%	98%	94%

5.2.3 Identified problems related to cyclone warning signals

There are several problems are identified during the survey for recognizing proper warning messages. Especially, when the information of one bulletin changes in the next update, respondents couldn't recognize the variations correctly (68%). Several numbers of warning signals (82%), the meaning of each signal, and differences among signal messages (84%) create complexity among the respondents to understand. Besides, a forecasted message of a cyclone warning provides upcoming cyclone-related information. There is no information about possible cyclone impacts on households, polders, infrastructure, or other live-saving properties. That's why incomplete instructions are obtained by CPP volunteers, and the process creates confusion among the respondents to or not to leave their houses. 73% of respondents claimed about warning signals don't provide any information on infrastructure or properties. Furthermore, other problems related to cyclone warning signal such as forecasted language (67%) creates difficulties for women, children, and the elder group to understand. Other problems related to signals like respondents have faced several false warning signals (55%) before, terminology like surge velocity, high-low tide, landfall (53%) creates difficulties to understand the meaning, female respondents didn't get enough time for preparation (57%) and appropriate news and instructions, respondents have dependent on expensive conventional sources (47%), etc. are shown in Table 5.4.

Table 5.4: Percentage of respondents who have faced problems related to cyclone warning signals in the study villages. (Multiple selections are allowed for respondents) ***(n= 229)*** (Sources: Household survey, 2017)

Problems	Percentage of respondents
Forecasted language problem	67%
False warning signals	55%
Several signal numbers	82%
Used terminology are not understandable	53%
Variations in warning update messages	68%
Incomplete instructions	49%
Lack of information on properties	73%
Difficult to differentiate information among the signals	84%
Not enough time for preparation	57%
Must depend on conventional sources	47%

5.2.4 Response to cyclone warning signals.

According to the DRR committee of the Kamarkhola Union, 23% of the people evacuated during Aila (2009). This number increased to 28% during Mahasen (2013), 32% during Komen (2015), and 34% during Roanu (2016). This means that about half of the respondents did not follow the evacuation orders even after receiving cyclone warnings. Considering 229 sample size in the study villages, the results show that 37% of respondents during Aila (2009), 23% of respondents during Mahashen (2013), 19% of respondents during Komen (2015), and 16% of respondents during Roanu (2016) did not receive any warnings during the Cyclones. Compared to Sreenagar village the evacuation rate was greater among respondents in Jaliakhali (26% during Aila, 28% during Mahasen, 31% during Komen, and 34% during Roanu) (see Table 5.5).

There are 6 operational cyclone shelters or school cum shelters that have been found in Kamarkhola Union of Dacope Upazilla. In Jaliakhali village 38% of the respondents live within 1 km of a shelter. Despite this, 41% of the respondents in Jaliakhali did not follow the evacuation orders during the four cyclones, and an additional 74% did not evacuate during one of the cyclones. In Sreenagar, 33% of the respondents live within 1 km of a shelter, 44% of the respondents did not follow the evacuation orders during the four Cyclones, and 81% did not follow the orders either during any of the cyclones mentioned above. Respondents who evacuated during cyclones were mostly from middle-sized families (having 4 to 6 family members) and had jhupri or katcha houses. During the cyclone Roanu, 76% of those who evacuated in Jaliakhali were from middle-sized families and 92% had jhupri or katcha houses. Whereas among those who evacuated in Sreenagar during Roanu, 72% were from middle-sized families and 80% had jhupri or katcha houses.

Table 5.5: Respondents' responses to evacuation orders of last four tropical cyclones. (Sources: Household survey, 2017)

Tropical Cyclones	Both Villages		Jaliakhali (n=114)		Sreenagar (n=115)	
	Didn't receive warning signals		Evacuation rate		Evacuation rate	
	Number	Percentage	Number	Percentage	Number	Percetage
Cyclone Aila (2009)	86	37.55	30	26.31	29	25.21
Cyclone Mahashen (2013)	53	23.14	32	28.07	28	24.34
Cyclone Komen (2015)	45	19.65	36	31.57	29	25.21
Cyclone Roanu (2016)	37	16.15	39	34.21	31	26.95

5.2.5 Effectiveness of cyclone management system activities

CPP is a mechanism that relies on technical skills and volunteers' commitment to ensuring that all potential victims of an approaching cyclone are given sufficient warning to 20 million coastal people to enable them to move to safe- sites including cyclone shelters and safe buildings. The system starts with the collection of meteorological data from the Bangladesh Meteorological Department (BMD), which issues bulletins including the designated warning signals of an approaching cyclone. When the situation turns serious the GOB passes the Order for evacuation. The volunteers implement the order and advise and help people to seek safety in cyclone shelters or other available safe places. After the cyclone is over the volunteers rescue the injured and marooned people, provide first aid to the injured, send serious cases to the local hospital and assist in post-cyclone emergency relief operation launched by BDRCS. The whole activities determine successful cyclone management from preparedness to rehabilitation. The effectiveness of cyclone warning system activities in the study areas is measured based on four indicators are related to providers' instructions for cyclone management. The indicators are:

- Activities of CPP- (Dissemination of signals, Miking, Raising flags, Emergency medical support, etc.)
- Rescue and evacuation- (Evacuate vulnerable people like elder, children and disable people)
- Support to human life- (Ensure food, water, and medicine)
- Support to public and private properties (Support vulnerable housing, livestock place, maintenance of polders)

Table 5.6 provides the effectiveness score of each activity through respondents' perceptions. Activities of CPP (effectiveness score is 349) such as dissemination of signals, raising flags, emergency medical support, etc. are effective in both study villages. According to respondents' perceptions, the scenario of these activities changed after the Aila impact in 2009. The government became very concerned about the implementation of CPP programs. Rescue and evacuation programs also have a good position in table 1. About 35% of respondents identified it effectively implemented in the study villages with 298 effectiveness score. Respondents changed their perceptions when they gave opinions on the other two indicators. A successful cyclone management system ensured people's basic needs before or during a cyclonic event. But in both study villages respondents claimed that present cyclone management activities are only related to disseminating signals and ensuring evacuation to shelter (still the number of shelters are insufficient).

Table 5.6: Effectiveness of present cyclone warning activities in the area (Sample:229) (Sources: Household survey, 2017)

Indicators		Unknown	Very Low	Low	High	Very High	Total
Activities of CPP	Rank	1	2	3	4	5	**1**
	Number	33	32	36	44	84	229
	%	14.41	13.97	15.72	19.21	36.68	100%
	Effectiveness Score	14.41	27.95	47.16	76.86	183.41	**≈349**
Rescue and evacuation	Rank	1	2	3	4	5	**2**
	Number	36	47	62	52	32	229
	%	15.72	20.52	27.07	22.71	13.97	100%
	Effectiveness Score	15.72	41.05	81.22	90.83	69.87	**≈298**
Support to human life	Rank	1	2	3	4	5	**3**
	Number	128	53	30	18	0	229
	%	55.90	23.14	13.10	7.86	0.00	100%
	Effectiveness Score	55.90	46.29	39.30	31.44	0.00	**≈172**
Support to public and private properties	Rank	1	2	3	4	5	**4**
	Number	199	30	0	0	0	229
	%	86.90	13.10	0.00	0.00	0.00	100%
	Effectiveness Score	86.90	26.20	0.00	0.00	0.00	**≈113**

Support to basic needs such as food, water, sanitation, medicine, etc. before or during a cyclone is missing. That's why the effectiveness score of support to human life is 172. Another important indicator is supporting public and private properties before or during a cyclone. Here, the present cyclone management system in the study areas has no activities. Respondents of both study villages asserted that there is no information is available to get support on live-saving properties such as a house, livestock, embankments. CPP volunteers are not trained to advise people about any vulnerable public or private properties before or during a cyclone. For this reason, several respondents are not interested to participate in the evacuation program by leaving their vulnerable properties in front of a cyclone. About 86% of respondents are unknown to any curriculum from the union disaster management committee for giving support to their house, livestock, or embankments which protect them from saline intrusion. The effectiveness score of this indicator is 113 that suggests the lack of cyclone management activities in the study areas.

5.3 Single Purpose Cyclone Shelter (SPCS) or Multi-Purpose Cyclone Shelter (MPCS)

Cyclone shelters play an important role during disasters in ensuring successful adaptation steps and in preventing the loss of human lives, for those living in the coastal areas of Bangladesh. These shelters are fortified with concrete multistoried buildings raised several meters from the ground to withstand storm surges. The government planned to construct 2,000 cyclone shelters in the late 1960s. However, they could only construct 132 shelters at that time due to financial difficulties (Haque and Blair, 1992; Haider and Ahmed, 2014). After the impact of the Bhola cyclone in 1991, the government and NGOs accelerated cyclone shelter construction, the number of construction of shelters reached 3,976 by 2007. Unfortunately,1,576 out of 3,976 shelters are not in use due to the local people's poor management and maintenance (Paul, 2009b). In Jaliakhali village only one school cum cyclone shelter is available with 500 actual population capacity. The distance of other cyclone shelters such as Channir Chawk Primary School (2 km far from village) and Poschim Joynogor Primary School (2.5 far from village). On the other hand, Sreenagar village also has one school cum cyclone shelter with 650 actual population capacity. The radius of another cyclone shelter from this village is quite extended like Uttar Kamarkhola Govt. Primary School (4.7 km far from village), Sutarkhali high school cum cyclone shelter (6.6 km far from village). During a cyclone, the smallholding capacity of each cyclone shelter forced people to search for alternative ways or take a risk to stay at their own house. Besides, distance from the house, inadequate space, food and water problem, gender issues, socio-cultural norms, and political barriers, etc. prevents respondents' accessibility to cyclone shelter. For this reason, evacuation to a cyclone shelter becomes more difficult before a cyclone. Problems related to cyclone shelter, evacuation behavior of respondents before a cyclone, and overall effectiveness of cyclone shelter in the study areas are discussed below.

5.3.1 Evacuation Behavior of Respondents

Previous studies mentioned that evacuation proportions can be different between areas. For example, 39.1% of the population of the three most vulnerable unions of Kutubdia (Uttar Dhurung, Ali Akbar Deil, and Kaiyarbil) moved to public cyclone shelters or places designated as shelters by the authorities, while only 16.8% of the three most vulnerable unions of Maheshkhali (Dhalghata, Matarbari, and Kutubjom) did so during Cyclone Viyaru. Likewise, for the same three unions in each Upazila, 36.4% in Kutubdia and 16.3% in Maheshkhali moved to public cyclone shelters or places designated as shelters by the authorities during Cyclone Komen (Saha and James, 2017). This differentiation of evacuation proportions is also found in study areas which are shown in Table 5.5 of section 5.2.4. In the 5.2.4 section, it was mentioned that 74% of respondents in Jaliakhali and 81% of respondents in Sreenagar didn't evacuate during one cyclone out of four. Three out of the top five reasons for not evacuating were related to cyclone shelter which is: long distance of cyclone shelter; lack of drinking water, light, and toilet facilities in the cyclone shelter; Poor communication and transport system to cyclone shelter; Mistrust in cyclone warnings; fear of burglary due to absent of presence at home. Besides several behavioral reasons for not evacuating during a cyclone are shown in Table 5.7. Almost all (98%) of the non-evacuee respondents of both villages (n = 174) cited more than one reason for not moving to any place other than their own house.

A lack of facilities in the cyclone shelter discourages people from evacuation and taking refugees (Saha and James, 2017; Ahsan et al. 2015; Paul, 2010). This frequency also found in the field, Table 1 shows that about 58% (n=101) of the non-evacuee households considered a lack of food, drinking water, lights, and toilets in the cyclone shelter as a reason for not taking shelter in any place other than one's own house. While a major number of the female respondents claimed about this issue. There is a big difference of percentages are found between two villages. This is because of the newly built primary school-cum-cyclone shelter in adjacent village Channirchak and the newly built school-cum-cyclone shelter in Jaliakhali village which are used as a shelter by many people in part of the village, have at least water and toilets inside the shelter building. Solar or lighting is missing due to management and maintenance. On the other hand, the school cum cyclone shelter in Sreenagar is relatively backdated, marginalized, and has a lack of facilities. Although it was repaired by an NGO after Cyclone Aila, it does not have lights, and the tube well and toilets are located outside the building.

Table 5.7: Reasons for not evacuating during cyclone (multiple responses possible). (Source: Household survey, 2017)

Reasons	JaliaKhali (n=83)		Sreenagar n= (91)		Overall (n=174)	
	Number	%	Number	%	Number	%
No cyclone shelter	0	0.00	2	2.20	2	1.15
False warning received at previously	21	25.30	26	28.57	47	27.01
Mistrust in cyclone warnings	36	43.37	48	52.75	84	48.28
Distance of cyclone shelter	27	32.53	59	64.84	86	49.43
Inadequate space in the cyclone shelter	20	24.10	33	36.26	53	30.46
Male members were not at home	29	34.94	31	34.07	60	34.48
Poor communication and transport system to cyclone shelter	56	67.47	22	24.18	78	44.83
Lack of livestock place in cyclone shelter	27	32.53	35	38.46	62	35.63
Consideration of own house as a safe place	38	45.78	52	57.14	90	51.72
Abuse and Violence	24	28.92	28	30.77	52	29.89
Living in a pucca (masonry) house	2	2.41	12	13.19	14	8.05
Lack of food, water, and sanitation	32	38.55	69	75.82	101	58.05
Not understanding instructions in the warning message	35	42.17	20	21.98	55	31.61
Better space is reserved for political family in cyclone shelter	12	14.46	21	23.08	33	18.97
Fear of burglary	9	10.84	7	7.69	16	9.20
Others	6	7.23	12	13.19	18	10.34

The distance to the adjacent cyclone shelter also acts as an important thought for not evacuation in a safe place. About 32% (n=27) of the respondents in Jaliakhali and 65% (n=59) of respondents in Sreenagar mentioned that this was one of the reasons for not moving into a shelter (See Table 5.7). Previous studies suggest that the closest cyclone shelter should be located within 1 km or 1–2 km of residences, as people do not have sufficient time to reach the cyclone shelter by that time, they decide to leave their house (Saha and James, 2017; Ahsan et al. 2015; Paul 2014; Paul, 2010). However, the analysis of qualitative data shows that although the extended distance between the cyclone shelter and residence prevents evacuation, too little distance does not itself ensure taking shelter in a cyclone shelter. In both villages, many of the people who live near to the cyclone shelter do not go to it as they enthusiastically think that they can easily go there if the storm becomes violent. Roy et al. 2015. also observed this fact. However, some of the people who are far away from the cyclone shelter do go to the shelter as they are afraid that they will not be able to reach the shelter if any problem occurs. The optimistic mindset of people who live close to a shelter is dangerous. During Cyclone Aila, many people staying close to the cyclone shelter or safe building could not reach them by the time they left their house, as the village became swamped very quickly

Poor communication and transport system to cyclone shelter was a reason for 45% (n = 78) of respondents for staying at home. Most of the part of Jaliakhali village was not well connected to the cyclone shelter because road damage by Cyclone Aila was not repaired at the time of fieldwork in 2017. A part of Sreenagar village also has the same situation. People in both the villages usually take to walk to the shelter and transport their belongings as the roads are not suitable for other transportations. Although motorbikes and vans use the roads on sunny days, most of the roads in both the villages become muddy and impassable if there is rain.

Furthermore, 52% (n=90) of respondents considered their own house as a safe place during a cyclone. Although consideration of houses as safe places discourages people from moving to safe places, the consideration of houses as safe places can also protect ‘ontological security and hence the mental health of people at risk (Paul, 2010. People renounce the representation of houses as safe places when they experience hazardous events such as cyclones damaging their houses. While some may react to the loss of representation of houses as safe places by taking protective actions, others may lose their ‘ontological security’ and as a result, may experience mental distress. Thus, the mental suppression of the awareness of the risk by people in harm’s way can protect their ontological security and hence their mental health (Paul, 2010).

Previous studies found mistrust in the warning as one of the major factors for not evacuating to shelter (Paul, 2012; Haque et al. 1992). For instance, Paul’s study in 2012 on Sidr found that about 19% of the non-evacuees did not believe the warnings. Likewise, Haque et al, 1992 study found that of household heads who stayed home after receiving warnings, 53.2% of urban household heads and 58.9% of rural household heads mentioned disbelief in the warning as one of the reasons. In study villages, 48% (n=84) of the respondents have issues with a warning. That’s because respondents who cited false warnings received on previous occasions as one of the reasons for not taking shelter but took precautionary measures after receiving the warnings. Thus, although the cyclone did not hit on previous occasions, they believed the warnings. Otherwise, they would not have taken precautionary measures after accepting the warnings. People’s trust in warnings contempt not taking shelter might be explained by their encounter with Cyclone Aila and the widespread training inhabitants of both the villages received on disaster preparedness from the government and NGOs in the post-Aila period. Both the villages were under danger signal number 7 during Cyclone Aila, and people from both the villages overlooked the warnings. However, they experienced a disastrous situation contrary to their expectation. After that, the government brought both the villages under CPP coverage and trained some of the villagers to serve as CPP volunteers. Excepting those, Table 5.7 provides several other reasons such as inadequate space in the cyclone shelter (30%), Male members were not at home (34%), lack of livestock place in cyclone shelter (35%), abuse and violence (30%), not understanding instructions in the warning message (31%) etc. are dominating to thwart evacuation procedures in the study villages.

5.3.2 Effectiveness of existing cyclone shelter in the study area

The importance of cyclone shelter is well-known as an effective measure at the community level that significantly reduces human casualty during the storm surge (Rahman et al. 2021). It is well known that Bangladesh Government is very successful to fulfill the cyclone shelter's purpose of saving human life. But nowadays several studies suggested that people are not interested to move into the shelter as they were before. Rahman et al. 2021. found in their study in Galachipa, Patuakhali that, 27% of respondents identified cyclone shelter as a planned adaptation measure was highly ineffective and 37% of respondents identified ineffective. So, half of the cyclone-affected people preferred to stay at home instead of moving to an ineffective cyclone shelter. The effectiveness of cyclone shelter in this study was measured based on the following indicators.

- A lifesaving structure for human
- A lifesaving structure for livestock
- Adequate space for living
- Facilities of water, food, and sanitation for people
- Available facilities for disabled people
- Socially safe for female respondents
- Gender friendly
- Politically unbiased and properly managed.

It has been mentioned in section 5.2.4 that 41% of respondents in Jaliakhali and 44% respondents of Sreenagar didn't follow any evacuation order in any cyclones. Excepting those, an average of 57.5% of respondents in both villages followed evacuation orders in one cyclone out of four. Respondents of both villages gave the perceptions of effectiveness on selected indicators based on their experiences related to cyclone shelter. Considering study villages, combined results of existing cyclone shelter's effectiveness are shown in Table 5.8.

The perception of evacuee respondents on effectiveness indicates that making the purpose of cyclone shelter is fully served. It reduced human causalities from 138,866 (Bhola cyclone, 1991) to 30 (Cyclone Roanu, 2016). As a 'lifesaving infrastructure,' it plays a very effective role to a community. In the study villages, about 84% of evacuee respondents claimed, cyclone shelter's effectiveness is high to very high for saving human life and the calculated effectiveness score is ≈473 with rank 1 (see Table 5.8). But the differences were found when respondents gave their perceptions on other indicators. The difference of effectiveness score from ranked 1 indicator (effectiveness score ≈473) to ranked 8 indicators (effectiveness score ≈148) is ≈325. Even the differences from ranked 1 indicator (effectiveness score ≈473) to ranked 2 indicators (effectiveness score ≈268) is 205. That's because the relationship between saving life and cyclone shelter is lucrative whether no relationship is stable between cyclone shelter and other indicators.

Rahman et al 2021 identified in their study the effectiveness of a cyclone shelter as a planned adaptation concluded by several indicators such as distance from individual's household, road communication, capacity compared to the total population, space adequacy, availability of livestock place, shelter management, gender discrimination, and water and sanitation facilities, etc. (Rahman et al. 2021). In the study villages, it has been found that available basic needs of human life such as ‘food, water, and sanitation system’ (Ranked 8) in existing cyclone shelter is inadequate during a cyclone. Especially 60% (n=79) of evacuee respondents are unknown about the availability of food and water in shelter. They had to carry their food and water from their house for an uncertain journey. Sanitation is available with an inadequate number, without water and hygiene facilitates.

Facilities for disabled people’ (Ranked 7) such as wheelchair, sloping stairs, separate latrine etc. are unavailable in cyclone shelters of study villages. Evacuees who had a handicapped in family normally were not willing to move into shelter expect the condition is too serious. The calculated effectiveness score of this indicator is ≈182 (Table 5.8).

Effectiveness of existing cyclone shelters based on ‘Gender friendly’ and ‘social safety for female’ ranked 6 (effectiveness score ≈184) and 5 (effectiveness score ≈192) respectively. Here ‘gender friendly’ indicates that available facilities such as common room, separate sanitation system for women, open space, lighting system for children and separate room, emergency medical support for vulnerable people. In the study area, 66% (n-89) of respondents were perceived from unknown to very low on this indicator. ‘Social safety for female’ indicates that how much a cyclone shelter is safe from sexual violence and social abuse. As in the study area, no cyclone shelters have a separate room for both males and females. Sexual violence and social abuse often create a haphazard situation for the widow or young female individuals. 74% (n=99) evacuee respondents especially females have identified the effectiveness of this indicator from unknown to very low which means most of the female members are not safe from social abuse in cyclone shelters during a cyclone.

Effectiveness based on ‘politically unbiased and proper management’ indicator ranked 4 with effectiveness score ≈203. It determines the management and maintenance of the cyclone shelter. In Jaliakhali the established school cum cyclone shelter is relatively new with better facilities and maintenance options considering Sreenagar. But respondents of both villages have claimed about political bias. Local representatives like UP members and the political person charged better room in cyclone shelter before a cyclone. About 61% (n=82) of respondents identified that existing cyclone shelters have political power practice for better space during a cyclone. The effectiveness score of ‘lifesaving structure for livestock’ (≈268) and ‘adequate space for living’ (≈234) is relatively nearby as they have connected each other. The rank of these indicators in Table 5.8 are 3 and 4 respectively. Livestock is the most common and valuable property for respondents in the study villages.

Table 5.8: Effectiveness of existing cyclone shelters in the study area (n=132) (Source: Household survey, 2017)

Indicators		Unknown	Very Low	Low	High	Very High	Total
A lifesaving structure for human	**Rank**	1	2	3	4	5	**1**
	Number	0	0	8	19	105	132
	%	0.00	0.00	6.06	14.39	79.55	100.00
	Effectiveness Score	0.00	0.00	18.18	57.58	397.73	**≈473**
A lifesaving structure for livestock	**Rank**	1	2	3	4	5	**2**
	Number	12	41	56	23	0	132
	%	9.09	31.06	42.42	17.42	0.00	100.00
	Effectiveness Score	9.09	62.12	127.27	69.70	0.00	**≈268**
Adequate space for living	**Rank**	1	2	3	4	5	**3**
	Number	8	76	42	6	0	132
	%	6.06	57.58	31.82	4.55	0.00	100.00
	Effectiveness Score	6.06	115.15	95.45	18.18	0.00	**≈234**
Water, food, and sanitation facilities	**Rank**	1	2	3	4	5	**8**
	Number	79	42	11	0	0	132
	%	59.85	31.82	8.33	0.00	0.00	100.00
	Effectiveness Score	59.85	63.64	25.00	0.00	0.00	**≈148**
Facilities for disabled people	**Rank**	1	2	3	4	5	**7**
	Number	68	32	19	13	0	132
	%	51.52	24.24	14.39	9.85	0.00	100.00
	Effectiveness Score	51.52	48.48	43.18	39.39	0.00	**≈182**
Socially safe for female	**Rank**	1	2	3	4	5	**5**
	Number	46	53	30	3	0	132
	%	34.85	40.15	22.73	2.27	0.00	100.00
	Effectiveness Score	34.85	80.30	68.18	9.09	0.00	**≈192**
Gender friendly	**Rank**	1	2	3	4	5	**6**
	Number	64	25	43		0	132
	%	48.48	18.94	32.58	0.00	0.00	100.00
	Effectiveness Score	48.48	37.88	97.73	0.00	0.00	**≈184**
Politically unbiased and properly managed.	**Rank**	1	2	3	4	5	**4**
	Number	41	54	28	9	0	132
	%	31.06	40.91	21.21	6.82	0.00	100.00
	Effectiveness Score	31.06	81.82	63.64	27.27	0.00	**≈203**

As poverty amalgamated after cyclone Aila, several respondents are currently dependent on livestock for a living. Saving the life of livestock before a cyclone becomes a major issue for them, Ground floor of the cyclone shelter would be an option but surge water and inadequate space for people sometimes made this option complicated. However, 17% (n=23) of respondents mentioned high effectiveness for available livestock place in the shelter as they are living near cyclone shelter. Besides, 4% (n=6) of respondents found adequate space for living in the shelter, whether they are living close to the shelter or politically influenced.

5.3.3 Influential barriers on effectiveness of cyclone shelter

As most of the cyclone shelters in Bangladesh are the government's property, political involvement is a major concern since it became established. Management and maintenance of a cyclone shelter are done by local representatives or volunteers of the DRR committee at the union level. This continuous involvement of a political person with this public property makes him treat it like his own resource. SPCS or MPCS management committee members are currently chosen by local government representatives at their discretion instead of being elected by the community (Nateque et al 2014; Rahman et al 2021). According to Rahman et al 2021, this nepotism of political leaders is considered a political barrier that plays a major role to influence the effectiveness of a cyclone shelter. In the study area, social and cultural barriers are also found along with political barriers. Social and cultural barriers that respondents have faced included: social status of a woman, woman's decision-making ability, male dominancy, sexual harassment and abuse, inadequate space in cyclone shelter, responsibilities for the family members, livestock maintenance, responsibility to collect food, religious diversity, etc. Similarly, the notable political barriers on cyclone shelters are favoritism of local leaders and political benefits to determine the location of cyclone shelters, lack of maintenance and management, etc. Most of the evacuated respondents have faced more than one barrier at a time during a cyclone in the study villages. The summary of all barriers that identified by respondents in both villages for taking shelter in the study area is combinedly shown in Figure 5.3. Where about 51% of evacuee respondents had faced social barriers, about 41% cultural barriers, and 36% political barriers by staying at a cyclone shelter during a cyclone.

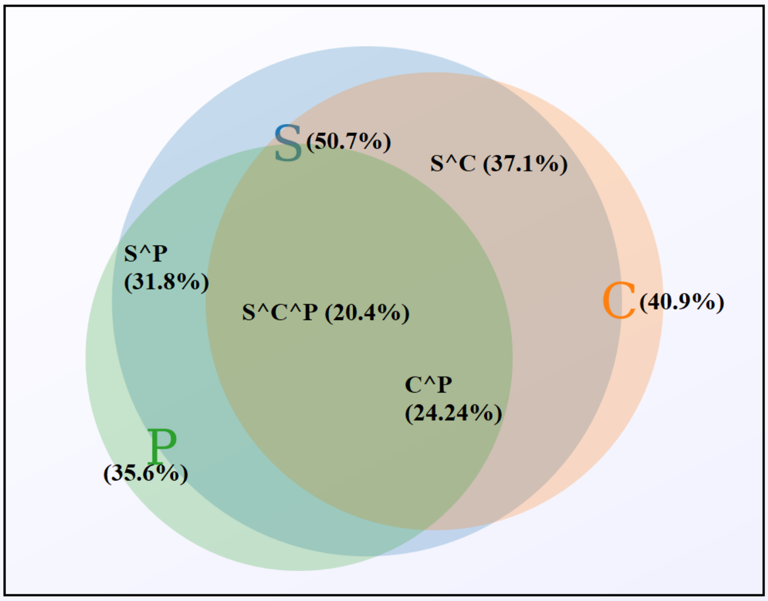

Figure 5.3: Venn diagram of barriers that have faced by evacuee respondents in cyclone shelter of the study villages (mutually inclusive). *Here, S= Social Barriers, C= Cultural Barriers, P= Political Barriers. Various combinations of S, C, P represent multiple barriers. For example, SP=Social and Political barriers, SC= Social and Cultural barriers, SCP= Social, Cultural and Political barriers and so on. Sample size: n=132*

Respondents who were younger females and widowed women generally claimed about social barriers. Rahman et al 2021 have. found similar results for cyclone shelter in their study at Galachipa Upazilla. They identified social (57%) and cultural (48%) barriers that have a very high impact on cyclone shelters to adopt it as an adaptation measure whether in their study 50% of the respondents were female. So, the effectiveness of cyclone shelters is always influenced by several barriers at the community level of Bangladesh. Moreover, evacuee respondents in study villages have faced more than one barrier for cyclone shelter including both social and cultural barriers (37%), both social and political barriers (31%). both cultural and political barriers (24%) and three barriers social, political, and cultural at a time during a cyclone.**5.4**

5.4 Individual Housing

Like food and clothing, shelter is one of the basic needs of human persistence. Everyone has the right to suitable housing for health and well-being. Housing has a close relationship to a person 's life, livelihood, health, and overall well-being and therefore directly includes the social themes of vulnerability, social protection, and livelihoods. Often housing is the sector severely impacted by disasters. The impact of Aila on the housing sector was severe, as it destroyed an estimated 243,191 houses and damaged a further 370,587 houses (UNDP, 2012). Disaster event interrupts day to day on life and leaves the families without shelter and consequences in a lack of access to basic needs such as water and sanitation. In addition, micro, small and medium-sized businesses found in those homes are equally affected ultimately and the family could also be bereaved of the opportunity to be qualified for loans since one of the key properties or collateral is demolished, making it hard for them to convalesce from the loss. Experiences from past events have shown susceptible groups face various protection-related problems aftermath of disaster events. With inadequate resources and options, recovery processes of individual households are conditional upon their coping capacity and external support. Further, the community also suffers as the local economy is hard hit, and the responsibility to support those made homeless by the natural disasters can place an extra burden on the dwindling economy (ADPC, 2011). Disasters have an undesirable impact on individual housing as the financial inadequacy of the relegated community people makes them incapable of building back better by themselves.

5.4.1 Present housing conditions

The people of Dacope Upazilla are comparatively poor and marginalized rather than other coastal communities. Since, the cyclone Aila events occurred, poverty raised and prolonged massively. Still, numbers of people couldn't afford a resilient house after the Aila impact and. currently living on the embankment by making thatches somehow only. Continuous impacts of major cyclones like Mahashen, Roanu, Komen prevent the resilience below the line. Jaliakhali and Sreenagar have faced the massive impact of cyclones on the housing sector. From the selection of 229 surveyed cyclone-affected households in both villages, 96% of houses are Katcha made of bamboo, mud, grass, reed, stones, thatch, straw, leaves, unburnt bricks, etc. Present housing conditions in the study areas are shown in Appendix B.

Figure 5.4 provides the present housing types of the respondents in the study areas. It shows that respondents of both villages are not familiar with masonry houses (paka house).

Respectively, 79% of respondents in Jaliakhali and 77% of respondents in Sreenagar village are currently living in katcha houses. Those katcha houses are not formally instructed and are not maintained by any building code from BNBC. Another housing type called 'Jhupri' is found in the study villages which are structurally less stable than Katch house. People who are extremely poor, marginalized, widowed, and more vulnerable living this type of house. About 19% of respondents in Jaliakhali and 10% of respondents in Sreenagar are live in 'Jhupri'. This house is made of grass, straw, poly sheets, or leaves without any bracing of wall and roof. Combinedly 12% of respondents in both villages have access to Semi-paka (half masonry) houses.

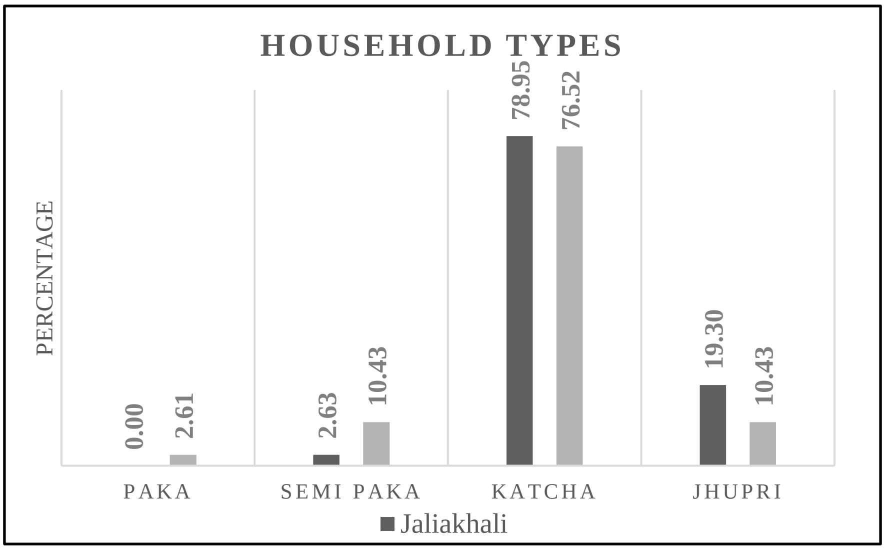

Figure 5.4: Household types of respondents in the study areas. (n=114, n=115)

Source: Household survey, 2017

However, considering the only main body of a household is not enough to define 'resilient housing'. A resilient housing also ensures wash and sanitation, a safe drinking source, granary, and livestock place. In both study villages, only 2% of respondents have all those amenities with their houses. Even some respondents who have masonry houses in the study area were not able to maintain all those facilities at a time. Most of the jhupri and katcha households' sanitation system is open, didn't have access to easy and safe drinking sources, granaries are missing, and livestock place is open spaced. An oriented description of these amenities related to housing in the study areas is discussed below.

5.4.1.1 Safe water drinking sources

Safe drinking water is the most essential item in human life. In general, the availability of drinking water sources is established near the household for easy access to human necessities. But in the study area available safe drinking water is tail-end due to high salinity in both ground and surface. As the study villages are surrounded by polder 32 which protects salinity to enter sweet water sources. But due to Aila, the polder was breached in multiple sections and saline water from surrounded river destroyed the major sources of sweet water such as a pond, canal, and other water reservoirs. The scarcity of safe drinking water sources is still a major problem in the study area. Figure 5.5 shows that 90% of respondents in Jaliakhali and 80% of respondents in Sreenagar are highly dependent on Pond Sand Filter (PSF) respectively. The established PSFs in both villages are situated near organizational places such as UP offices, Mosques, and Temples, etc. So, every day respondents had to walk around 2-3 km for collecting water from PSFs and especially female persons of the family did this job. However, harvesting rainwater for drinking purposes was also found in the study villages. About 58% of respondents in Jaliakhali and 46% of respondents in Sreenagar respectively harvested rainwater for drinking. But respondents who have harvested rainwater also claimed that collected rainwater is not sufficient for drinking all over the year. Respondents who have collected rainwater in a tank or other big jar could use it for 6-8 months and other respondents who have collected rainwater considering small jars like mud pots, empty bottles, etc. could use it only for 1-3 months. For the rest of the months, they had to collect water from PSFs. The usages of drinking water are also dependent on the number of family members.

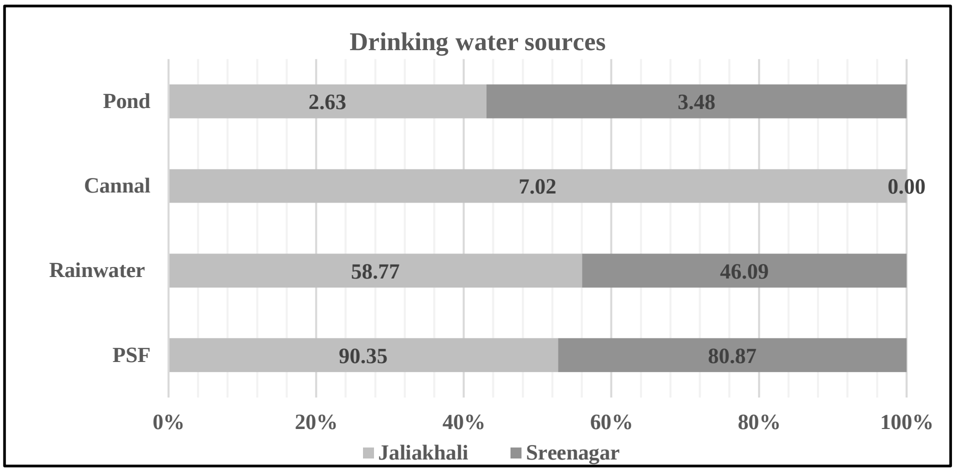

Figure 5.5: Safe drinking water sources in the study areas (n=114, n=115)

(Multiple responses possible). Source: Household survey, 2017

5.4.1.2 Sanitation System

Like drinking water sources, sanitation is another important part of a household. It ensures the health, hygiene, and protection of family members. In the study area, sanitation problems remained since before the Aila occurred that's because this facility of a house comes with a financial matter.

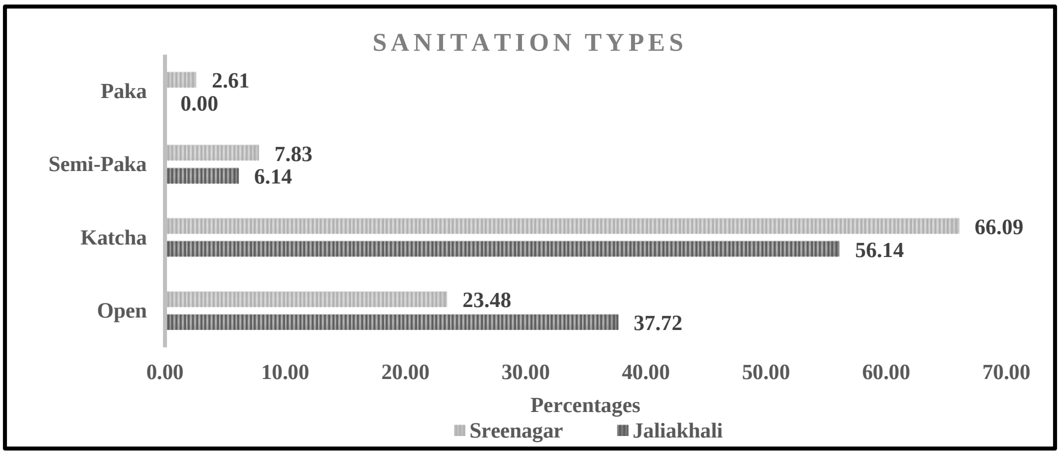

Figure 5.6: Sanitation systems in the study areas (n=114, n=115)

Source: Household survey, 2017

As the people of Dacope Upazila are the poorest and victims of continuous cyclonic processes, investing separately in the sanitation system is a burden for them. Besides awareness of a safe and hygienic sanitation system is ambiguous to respondents. The present conditions of the sanitation system in the study areas are shown in Appendix B.

Figure 5.6 shows the present types of sanitation systems that respondents have access to. About 38% of respondents in Jaliakhali and 23% of respondents in Sreenagar didn't have a sanitation system with their house. They use open space as a toilet or a ring slab as a toilet without having a wall and roof. These respondents lost their land as well as households due to cyclone Aila and currently living on embankment somehow only. They didn't have enough financial ability to reconstruct the housing or sanitation system. Other 56% of respondents in Jaliakhali and 66% of respondents in Sreenagar have katcha toilet included their houses made by tin, ring slab, straw, and bamboo, etc. Some of these katcha toilets didn't have a roof, water, and seal facilities with a high chance of collapse against a cyclonic wind or surge velocity. Combinedly 13% of respondents in both villages have the semi-paka toilet in their houses made by RCC slab and wall. Even some of these semi paka toilets didn't have proper water and seal facilities relatively more stable against a cyclone. Only 2% of respondents in Sreenagar have paka (masonry) toilets in their houses with proper water, seal, and hygiene facilities. There is no paka toilet found among the respondents of Jaliakhali village.

5.4.1.3 Granary and livestock place

A granary is a storehouse or room in a barn for threshed grain or animal feed. Ancient or primitive granaries are most often made of pottery. Granaries are often built above the ground to keep the stored food away from mice and other animals and floods. Since the 1960s polders were constructed in the study areas to protect farmers from saline water intrusion and tidal floods, amount of agricultural production has been raised to its peak. Many people have changed their livelihood and become a farmer because of high crop production. But in both study villages, the crop production scenario has been changed after the Aila impact. Polder breached due to Aila and almost 95% of a farmer lost their crop in the land. They didn't have any options or storehouses to secure their production. Furthermore, losing crops during Aila is not the only event, through the FGD among the farmer respondents it was identified that even any cyclone 77% of the farmer have lost their crops, 45% of farmers claimed that they didn't have enough time to harvest crops or crops were immature and 89% of a farmer identified that they didn't have enough space or storing options to store crops in their houses.

Similarly, through the semi-structured household survey, it was identified that 96% of the respondent was the owner of at least one livestock and among them only 13% of respondents have livestock place in their house. Other 87% of respondents kept their livestock in front of their house or kitchen or their living room. The damage data on crops, granary and livestock place is shown in Appendix A.

5.4.2 Influential factors for impeding disaster resilient house in the study area

Inappropriate housing solutions together with poorly constructed houses have been known as one of the main sources of risks to climate hazards (Tran et al., 2012). If the houses are not well built using appropriate structures, materials, proper design, and construction methods catering to the need to reduce disaster risk then, the houses will be highly vulnerable to adverse impacts of natural hazards. For understanding the fact, several factors have been identified which impeded respondents to build a proper resilient housing structure against a cyclone.

5.4.2.1 livelihood activities

Socio-economic characteristics include qualities of responded households such as family status, income, occupation, earning persons, etc. In the study area, the socio-economic conditions of the responded households provide a clear vision of their vulnerability against a cyclonic hazard. Among them, the relation of livelihood activities of the respondents with natural hazards played a major role in impeding disaster resilient housing structure in the study area. Livelihoods of individuals or households 'comprise the capabilities, assets, and activities required for means of living' (Scoones, 1998). It needs to be stated that people apply livelihood strategies in hazardous contexts for achieving beneficial livelihood outcomes, including higher material welfare, increased wellbeing, and reduced vulnerability. A livelihood strategy encompasses activities that generate the means of household survival (Ellis, 2000). The results in Table 5.9 show that mentioned major livelihood options of the responded households in the study areas are not enough to reduce vulnerability because they relate to cyclonic hazards vice versa. For example, Table 5.9 shows that the main livelihood activities of the responded households in the study areas are a farmer (39% in Jaliakhali and 32% in Sreenagar) and sequentially 22% of responded households in Jaliakhali and 20% of responded households in Sreenagar earned their livings from labor ship. And in section 5.4.1.3 it was mentioned that previously 77% of the farmer have lost their crops because of breached polders due to cyclonic events that occurred in the last decades. Also, 89% of responded labor households claimed that there is no work or opportunities were available for earnings during pre- to post-cyclone situations. Similarly, livelihood activities such as fishermen (12% in Jaliakhali and 11% in Sreenagar) become earn less due to bad weather and lacking fishes, households which were involved in small business (7% in Jaliakhali and 13% in Sreenagar) had to shut off their activities, diver (4% in Jaliakhali and 10% in Sreenagar) and boatman (3% in Jaliakhali and 2% in Sreenagar) become jobless because of restricted activities and losing properties due to a cyclone. So. more than 97% of households' livelihood activities (except GO/NGO services) in the study area are somehow affected by cyclone impacts which creates a major drawback for achieving resilience.

5.4.2.2 Income

The financial ability of a household determines how quickly a family could recover from impacts of hazards and able to achieve resilience against impacts. In the study area, major portions of the responded households were poor and marginalized. According to World Bank (2016), the poverty line definition is based on purchasing power parity basis, at $1.9 (BDT 160) per day. The household equivalent of $1.9, assuming two consumption units and one-earner is BDT 5814.35/ household/ month ($68/month). But the monthly income of 47% of responded households in Jaliakhali and 36% of responded households in Sreenar is less than 5000 BDT/month (less than $58/month) (Table 5.9). These extremely poor people are the first victim of cyclone's impact, and their level of income is not enough to choose a safe place for living with proper housing materials. Besides the major portions of their income have been expended for basic needs like food, clothes, and medicine. It was difficult for them to invest a portion of their income in the reconstruction or repair of houses and other facilities in the rehabilitation or recovery phase. Only 11% of responded households in Jaliakhali and 16% of responded households in Sreenar have income more than BDT 15,000/month (more than $175/month). These responded households also have a problem with recovery in the meantime but at least they could maintain wash, hygiene, and health. Considerably which was completely absent in poor to lower-income households.

5.4.2.3 Family size and number of earning

According to Thornton and Kim, family income should be an important factor in deciding to have a child (Thornton and Kim, 1978). Thornton and Kim showed their results based on the economy of a developed country but in a developing country like Bangladesh, the practice of this concept is completely absent because of poor literacy rate, socio-economic norms, and culture. In the study areas, family planning of responded household members is culturally developed without knowing the facts.

Table 5.9: Socio-economic profile of the responded households in the study area. (Source: Household survey, 2017)

Livelihood activities	**Jaliakhali (%) n=114**	**Sreenagar (%) n=115**
Farmer	38.60	32.17
Fishermen	12.28	11.30
Boatman	3.51	2.61
Small Business	7.02	13.04
Day labor	22.81	20.87
Driver	4.39	10.43
Service	1.75	2.61
Others	9.65	6.96
Monthly income (BDT)	**Jaliakhali (%)**	**Sreenagar (%)**
Less than 5000	47.37	36.52
Between 5000-10000	28.07	32.17
Between 10000-15000	13.16	14.78
More than 15000	11.40	16.52
Family size	**Jaliakhali (%)**	**Sreenagar (%)**
Less than 4	10.53	15.65
Between 4-6	75.44	72.17
More than 6	14.04	12.17
Earning Person	**Jaliakhali (%)**	**Sreenagar (%)**
1	81.58	74.78
2	15.79	20.00
More than 2	2.63	5.22
SSNP	**Jaliakhali (%)**	**Sreenagar (%)**
Yes	17.19	22.17
No	82.81	77.83

Table 5.9 shows that combinedly more than 73% of responded households in both villages (75% in Jaliakhali and 72% in Sreenagar) is the middle-sized family with 4-6 family members. And combinedly more than 13% of responded households (14% in Jaliakhali and 12% in Sreenagar) have more than 6 family members. Against this large percentage, only 15% of responded households in Jaliakhali and 20% of responded households in Sreenar have found two earning persons in their family. The major issues of this large family size with fewer earing persons accompanied by exposure to hazard, prolong resilience period and financial burden after a cyclonic event. Responded households that are large-sized expended 50% more than small-sized families in the study areas. Extra expenses increased their vulnerability during a cyclonic event and impeded resilience duration during the post-cyclone phase. Taking loans in the rehabilitation phase is also a common phenomenon that was identified among the large-sized households which affected for achieving resilience in meantime. However, responded large-sized households were highly exposed to hazards especially the gender groups rather than small or middle-sized households. There are 7 fatalities had been occurred due to cyclones in the last decade in the study areas, among them, 6 of the fatalities were from large-sized responded households.

5.4.2.4 Access to SSNP

Social safety net programs (SSNP) consist of non-contributory assistance existing to improve the lives of vulnerable families and individuals experiencing poverty and destitution (World Bank, 2018). For examples of SSNPs are previously contributory social pensions, in-kind and food transfers, conditional and unconditional cash transfers, fee waivers, public works, and school feeding programs. As the major number of respondents are living below the poverty line, formal assistance through SSNPs could play a vital role to achieve resilience after a cyclone in the study areas. Though there are several activities are found in SSNP, but in the study areas aiding a certain amount of money to the gender group such as widow, senior citizens, handicapped, etc. is identified during normal time. Ration card for a fishing family during prohibitory order of fishing was available but not familiar as an allowance to senior citizens. However, the amount of allowance money for the widow, senior citizens, handicapped is only 1500-3000 BDT/month ($17-$33/month). Considering the situation and impacts of hazards in the study area this little amount of money isn't enough for a person or family to build resilience against a cyclonic hazard. Moreover, the accessibility of respondents to allowance depended on their age, economic conditions, health, social status, and vulnerability. That's why only 17% of responded households in Jaliakhali and 22% of responded households in Sreenar have access to existing SSNP (see Table 5.9).

5.5 Relationships among the assisting and impeding factors for housing resilience

The objective of this chapter is to understand the existing problems that protracted the community to achieve resilience against cyclone-induced storm surge hazards. As the study areas are frequently the victim of natural calamities, resilience is often disrupted by cascading impacts, poor socio-economic conditions, and lack of adaptive capacity. Especially the households which are currently living below the poverty line, achieving resilience against a cyclone is difficult for them. Formal supports for the affected households come in a shared way such as cyclone warnings or cyclone shelters where people love to think about it individually.

Unfortunately, the government can’t help each of the family members of a household due to resource limitations but initiatives for working with the community could change the scenario. Previously formation of CPP, cyclone warning systems, and cyclone shelters saved millions of lives but still, the whole initiative is facing problems to save people's livings and properties. Besides, formal supports are not equally distributed to the community. Several barriers are identified for having access to formal supports such as having access to early warning systems that need technological gadgets which are influenced by financial barriers of the people. Similarly, cyclone shelters that saved thousands of lives because of socio-cultural barriers gender groups are not attracted to adopt this support.

However, during a cyclone, the most prioritized thing is shelter and included facilities such as food, water, and sanitation. If one of these facilities is not playing well the shelter couldn’t tell as a resilient structure. Though the shelter from the government gives protection from wind due to its masonry structure still several people in the study areas didn’t get all facilities in the shelter at a time. For this instance, individual housing could be the key for bringing the community on track of resilience but poverty, lack of land, cascading impact of cyclones, and lack of resilient knowledge for housing impeded the procedures prolonged.

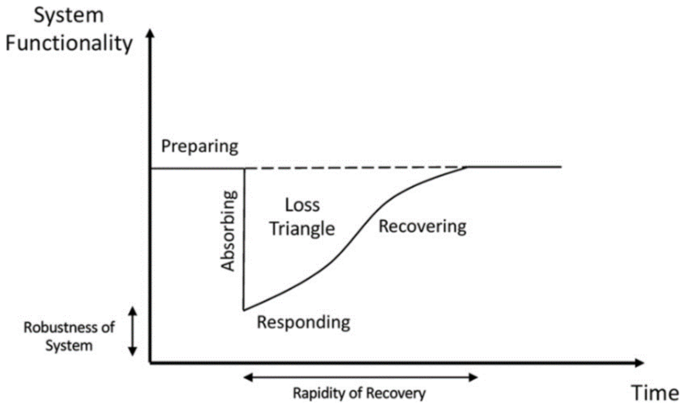

Figure 5.7: The Resilience Triangle (Tierney and Bruneau, 2007)

If the housing system is considered for resilience against a cyclone, the resilience triangle as discussed by Tierney and Bruneau (2007), can be used to illustrate the loss of functionality of a system over time due to disruptions, as well as the pattern of restoration and recovery (see Figure 5.7). The resilience triangle represents a measure of both the loss of functionality of a system after a disaster and the amount of time it takes for the system to return to normal performance levels.

In the context of this discussion, housing resilience to disasters can thus be thought of as the ability of a housing system to (1) absorb the shocks of such disruptions, (2) respond to consequences of those disruptions once they occur, and (3) reduce the time to recover normal performance. The resilience triangle provides a simple, high-level means of representing the performance loss of a housing system, together with the time to recovery. Following this criterion there is a causal relationship has been found among assisting and impeding indicators which is already mentioned in sections 5.4.1 and 5.4.2. For understanding the relationship among the indicators, a summary of causal network and weighted score calculated by AHP is shown in Table 5.10.

Table 5.10: Weights of assisting and impeding indicators calculated by AHP

Assisting Indicators	AHP weight	Impeding Indicators	AHP weight
Structured Body	0.42	Cascading cyclone impact	0.36
Facilities	0.25	Losing households	0.27
Sustainable Livelihoods	0.21	Losing Livelihoods	0.19
Formal Supports	0.12	Daily needs	0.1
		Household size	0.08

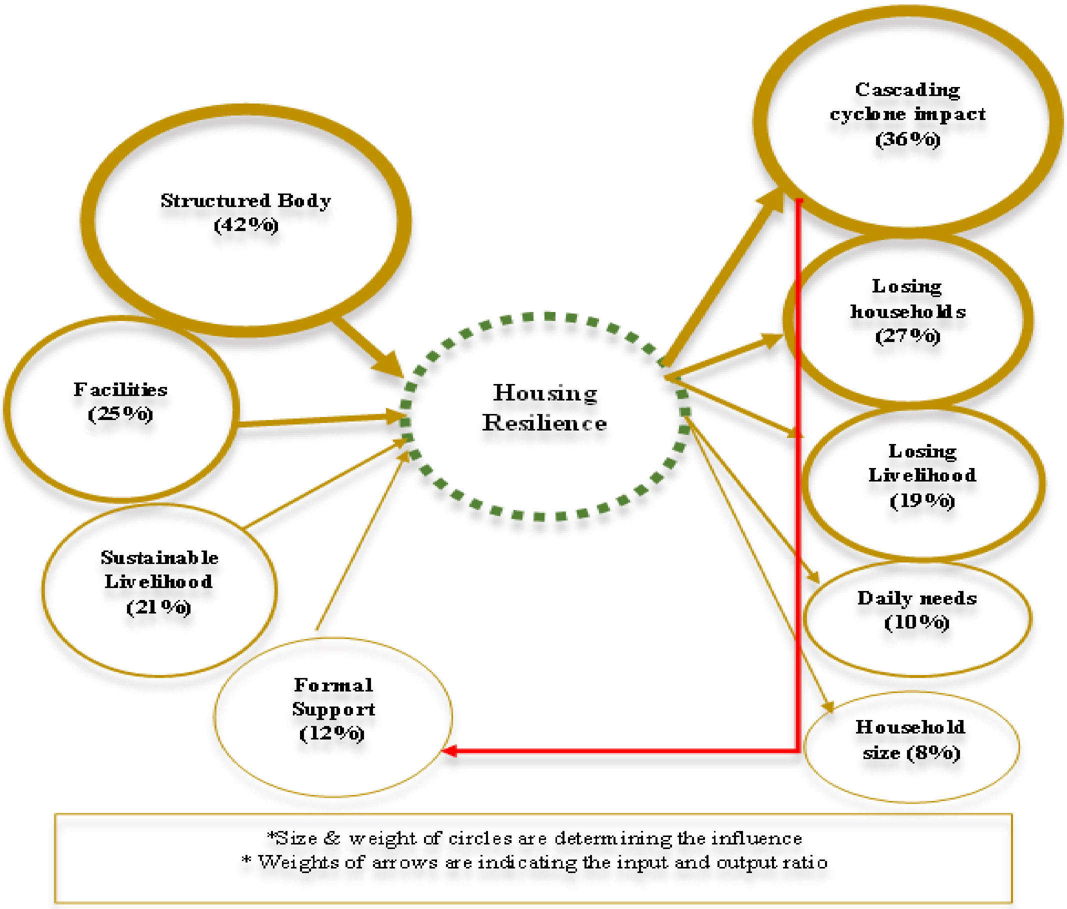

Figure 5.8: Causal Relationship among the indicators for assisting and impeding housing resilience

Figure 5.8 shows how people in the study area could achieve resilience through housing and what will be the concerning issues for further augmentations. When a community could achieve resilience against cyclones through properly structured housing and its included facilities with sustainable livelihoods, mega infrastructures like shelter or community infrastructure will reduce its necessity. Besides, individuals' perceptions earlier suggested that people are more interested in a sustainable individual shelter instead of public property. But impeding indicators like cascading impact of the cyclone, losing land, or livelihoods could be prolonged the recovery time of resilience. In these circumstances, formal supports like assisting for repair or reconstruction, managing livelihoods, food, and family education could be the responders for making up the duration of recovery against a cyclone.

CHAPTER SIX

DEVELOPMENT AND IMPLEMENTATION OF A PARTICIPATORY DISASTER RESILIENT HOUSING DESIGN

6.1 Introduction

After understanding the problems in the study area there is a gap identified between the formal agencies and community people. Supports from formal agencies are generally bounded by non-structural and relief based. Few structural supports like cyclone shelter or construction of the house are found but there is no effective design and technology available for this construction of low-cost houses (kutcha house). When a GO or NGO implemented a post-disaster program, most of the time, the focus is on providing approaches for giving a shelter only, rather than in enabling strategies to help people to access knowledge, which will help them to build on their own and more resilient houses. This is important to consider, as each community has its construction techniques and materials for low-cost houses. Some of them are very effective and scientific. These are sometimes overlooked and so, there is a gap in understanding the local knowledge for having effective design and technology for the construction of katcha houses. There is a necessity for bridging this gap, by learning from the people and then, transferring the improvement back to them, through disseminating this know-how to responding agencies. There is no doubt that the input of local people, local artisans, and a strong understanding of local culture and general context should be considered for sustainability. In this chapter by including the participation of local people, local engineers, organizational stakeholders, and architectural personnel a participatory housing design was approached and implemented through indigenous materials with a cost-effective budget.

6.2 Development of a participatory disaster resilient housing design

Before developing a participatory disaster resilient housing design, two beneficiaries have been chosen considering the facts mentioned in section 4.4.1 by a local NGO named Jagrata Juba Shangha (JJS) and local elected members of the Union Parishad. Both beneficiaries lost their home during cyclone Aila and couldn't rebuild their homes due to a lack of capital and resources. Bikash Roy being a farmer from Jaliakhali and Bipul Mondol being a fisherman from Sreenagar got chosen for the cause. The previous housing conditions of both beneficiaries are shown in Figure 6.1 (a) (b). Both structures were vulnerable against the minimum lateral force as materials got decay and weak which is shown in Figure 6.1 (c) (d). They lack adequate spaces to accommodate their family members properly as well. Both families live below the poverty line and couldn't afford to rebuild the home themselves as did not have enough savings. After selecting beneficiaries design workshop team was established for the development of a housing model through a participatory knowledge sharing session.

(a) (b)

(c) (d)

Figure 6.1: Previous housing conditions of beneficiaries. (a) Bikash Roy and Shobita Roy in front of their previous home (b)Bipul Mondol and Lolita Mondol's previous home structure. (c) Bikash Roy and Shobita Roy's home's interior and exterior showing poor physical and spatial conditions. (d) Bipul Mondol's previous home 's interior and weak structure.

6.2.1 Design workshop team establishment

For the development of a housing design, a team was formed involving stakeholders; the beneficiaries (both male and female members), local masons, craftsmen, builders, community leaders, architects, architecture students, local engineers, and so on. This team spent the whole day being involved in a participatory design and mapping workshop to learn about the socio-economic condition of Bikash Roy and Bipul Mondol, prevailing resilient concept, available materials to build homes. The team went through rigorous brainstorming and discussion

Figure 6.2: Bikash Roy and Shobita Roy's home's Participatory workshop

sessions to design and select appropriate spatial profiles and physical structures which would be more resilient during any natural calamity events (see Figure 6.2 and 6.3).

Figure 6.3: Bipul Mondol and Lolita Mondol home's participatory workshop

During the session, the beneficiaries are agreed to ensure their participation by providing their land and labor. Local masons, craftsmen, builders suggested the structural design for lateral forces of wind also suggested the types of natural and modern material for buildings. Community leaders were agreed to participate in the collection and gathering of materials cost-effectively. And local engineers, architects, architecture students developed a kutcha housing model by maintaining National Rural Development Policy in 2001. Major suggestions that were considered from the participatory workshop are given belowHouses should be established near the livelihoods place. Previously many examples were found ineffective.

- Houses should be established in the inner areas of the polder.
- Minimum plinth height should be 2 feet.
- Plinth should be fully stabilized.
- Cross bracing should be established with appropriate materials and process.
- In case of precast components, transportation should be ensured.

6.2.1.1 Working model and workshop outcome

Through the workshop, several factors such as landscape and climate, availability of materials, purchasing power, local building, and living practices and cultural preferences, etc. were considered for design development. Unfortunately, the BNBC doesn't provide any building code for kutcha houses. But the policy developed by National Rural Development in 2001 was adopted in workshop output. The policy centers on all activities of rural development with a view of alleviating poverty, improving the quality of life of the poor, and economic development of landless and marginal farmers. The housing section of the policy aims primarily on resettlement of families who become landless, displaced or shelter-less due to natural disasters. Considering the terms and available resources, attended workshop members were agreed to develop housing with available natural materials. A preliminary bamboo-based model was developed through a trial-and-error process. Developed working model during the participatory workshop is shown in Figure 6.4.

Figure 6.4: Developed working model during participatory workshop.

The outcome of the workshop went through a scrutiny phase to mitigate the limitations of the developed design by the experts. The developed model and workshop outcome was presented to research experts and NGO leaders to get their valuable feedback and suggestions for further moving. After their suggestions, another working model workshop was arranged to let know all the local stakeholders about the building and structure design which would be used as a reference during the implementation phase.

For the implementation phase available resources are gathered in a participatory way during the workshop session. All the participants shared their knowledge and experiences for listing the available resources for the implementation of the design. Table 6.1 provides the list of resources for implementation phase.

Table 6.1: List of available resources for design implementation. (Sources: Author, 2017)

Resources	Description
Community	Includes owners, communities, construction professionals, managers, and policy makers to take up their role of improving the housing design line with their respective experience and expertise.
Skills	It includes local construction labor, skills to material production and supply, architecture and engineering practice and research, social mobilization and communication skills and governance and coordination to improve the housing design.
Information	Includes the knowledge inherent in traditional building cultures to the practical knowledge of housing implementers in the field along with the more theoretical knowledge of research and teaching institutions.
Budget	This includes the savings or lending that owner take on for their housing, and the financial support offered by DECCMA-BUET participation project Proper and effective utilization of available funds, on all levels, complements the optimal use of people, skills, and knowledge.
Materials	Includes from home-grown materials to materials available on the local markets, newly introduced materials, or materials in development.
Land	Includes the available beneficiaries land for design implementation.

6.2.3 Selection of housing materials

For the implementation of housing design, both homegrown materials to materials available on the local markets are selected. It was needed to take care of available materials market price. High costing materials such as bricks, stone, steel, cement weren't selected because of affordability of repair and reconstruction issues after a cyclone. Natural and homegrown materials such as bamboo and palm leaves were selected due to their easy availability and affordability. As the whole housing scheme was designed as a resilient feature, repair, reconstruction time, easy access to materials, and affordable price was considered. Besides, gender groups of the households can also have easy access to repair materials. So, the selected materials for housing implementation are highly gender-friendly, easy to gather, low costing, and resilient against a cyclone-induced storm surge. The selected materials for implementation are shown in Figure 6.5.

6.2.3.1 Materials for house

***Bamboo*: ** Bamboo was selected for the construction of the main body structure of the house such as pile, purlin, bracing, and structural buttress, etc. There is a misconception about its structural strength, but it's scientifically proved that some bamboo species have the same strength ratio as steel and almost twice the compression ratio of concrete. Besides it is easy to cut, handle, repair, reposition and maintain, without the need for sophisticated tools or equipment. It can be used in combination with other types of construction materials, like reinforcing materials for foundations.

***CGI sheet**:* CGI sheet was selected for the installation of outer portion of the roof as well as for rainwater harvesting. CGI sheet is a low-cost material rather than steel but durable with long lasting capacity. Generally, CGI sheet is light wight and can move easily from one place to another.

Palm leaves: Feathery leaves of the palm (Nypa fruticans) were selected for thatched roof material which will be installed at the inner portion of the house. Palm leaves also selected for warping inner portion of the wall with combination of bamboo matt. Generally, weight of palm (Nypa fruticans) leaves is varied from 6-30 kg in different species. As a heavy natural material palm leaves will give extra protection against lateral wind force. Beside this material is naturally grown in coastal area which is very cost effective and easily accessible.

Bamboo matt: Strong bamboo matt was selected for outer portion of the main structure's wall with combination of palm leaves for gathering weight.

Wood: wood was selected for clamping.

Mud: Mud or soil was selected for plinth work and creating basement for the housing design.

Jute rope and steel wire: Jute rope and heavy still wires were selected for bending the structure.

Figure 6.5: Selected materials for design implementation phase. (a) bamboo (b) CGI sheet (c) palm leaves (d) mud (e) jute rope (f) steel wire (g) bamboo matt (h) tank (i) PVC pipes (j) bricks (k) Concrete Block (l) 14 CFT wood. Source: Author and web.

6.3.2.2 Materials for Granary

Bamboo: Bamboo was selected for main structure of the granary

***CGI sheet*:** For roof installation of the granary CGI sheet was selected

Bamboo matt: Strong bamboo matt was selected for granary wall.

6.3.2.3 Materials for Water Harvesting system

Three layers blow molded tank: 1500-liter three-layer blow molded tank was selected for rainwater storage.

PVC pipes: Polyvinyl chloride pipes were selected for gathering rainwater.

6.3.2.4 Sanitation system

Brick: Brick was selected for making wall of the toilet.

Aerated Concrete Block: Aerated concrete block was selected for sanitation basement.

***CGI sheet**:* CGI sheet was selected for roof of the toilet.

6.3 Implementation of disaster resilient housing design

In this section implementation of disaster resilient housing design is discussed. From plan generation to installation of sanitation system, all phases are described briefly for understanding implementation procedures.

6.3.1 Plan Generation

According to Agarwal (2007) Simple, compact, symmetrical housing shapes are best against cyclones. The square plan for a constructed house is allowed high winds to go around them.

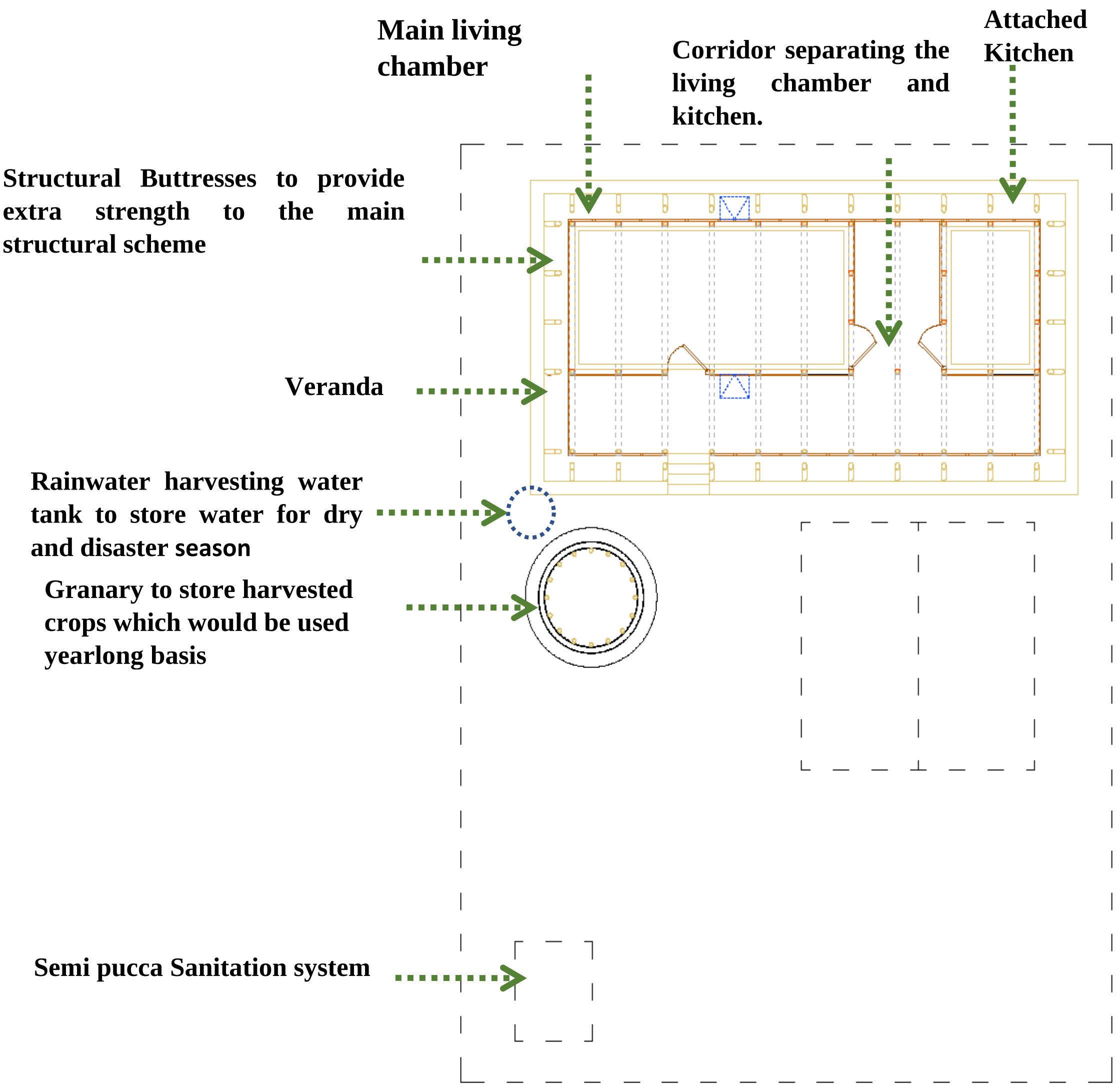

Figure 6.6: Proposed plan for the disaster resilient housing design

But from the viewpoint of functional efficiency, a rectangular shape is commonly used. Which is not compact as symmetrical shape but is better than the L-shaped plan. For functional efficiency, the design plan was generated as rectangular shaped for construction with as much compact as symmetrical shape. The proposed design (Figure 6.6) consisted of 9-8”x 10’-9” one main living chamber, one 3’-0”x 10’-9” corridor separating the living chamber, and a 6’8”x 10’-9” kitchen would work as a dining space and wind tunnel to release the strong wind coming from the southern side including one 18’8”x 4’-9 separated veranda to protect the living chamber and would work as a living and activity space. Besides one 4’8”x 6’-9-cylinder-shaped granary established to store harvested crops. A rainwater harvesting water tank was established to store water. A semi-pucca sanitation system was installed in front of the house.

6.3.2 Housing materials collection and preparation

Both homegrown and market available materials were collected in a participatory way. Local NGO representatives lead the team with selected local mason, craftsmen, beneficiaries, and local UP members. Materials such as bamboo, wood, palm tree, and ropes were bought from the local hat. Industrial materials such as CGI sheets, water tanks, bricks, blocks, and pipes were bought from the city market. Boat and van were used for materials transportation. Total 212 bamboo, 14 & 11 CFT wood, 900-1000 kg palm leaves, 2 water tank, 84 muli bamboo, 20 CGI Sheets, 6 packet cement, 200 bricks, 60 blocks, 2 ring slabs, 2 pans were bought for two houses. Before using natural materials like bamboo and palm leaves, seasoning and preparation were needed to increase their longevity. The procedure of seasoning and preparation of natural materials are shown in Figure 6.7.

6.3.2.1 Treatment of Fresh Bamboo

Curing*:* The freshly felled bamboo was kept upright, with branches and leaves intact for a few days (10-15 days) when the nutrient and moisture used by the parenchyma cells in bamboo itself. The duration of curing was estimated by drying up of the bamboo. Continue to live for some time the results in bamboo with significantly less quantity of nutrients and moisture and therefore less attractive to biodegrading agents.

Storage in Water*:* Some of the Bamboos were kept in water bodies like pond, rivers etc. for a period of a month or two for the preservative action to occur. During this process the soluble nutrients leaches out of the bamboo besides such treatment may also imbue some microbes which gives it a protective covering against some rotting fungi.

lime coating: After dried up the whole of bamboo was coated with lime to enhance its durability. The cuts ends and openings after removal of branches usually serves as the entry points for the bio-degrading agents and application of such coatings serves as an impenetrable layer to them.

6.3.2.2 Treatment of Palm leaves

Drying: palm leaves were kept in open space for a period of a one or two weeks before roof installation for the preservation of the leaves.

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Figure 6.7: Natural material seasoning and preparation

6.3.3 Selection of location

The location of the building establishment is crucial. Though cyclonic storms always approach from the direction of the sea towards the coast, the wind velocity and direction relative to a building remain random due to the rotating motion of the high velocity. According to IFRC (2011), to protect the houses from strong winds, one of the most important ways is to build them in sheltered positions. The houses should be constructed by the shape of the land or by windbreaks, to protect them from strong winds and tidal surges in coastal areas (See Figure 6.8).

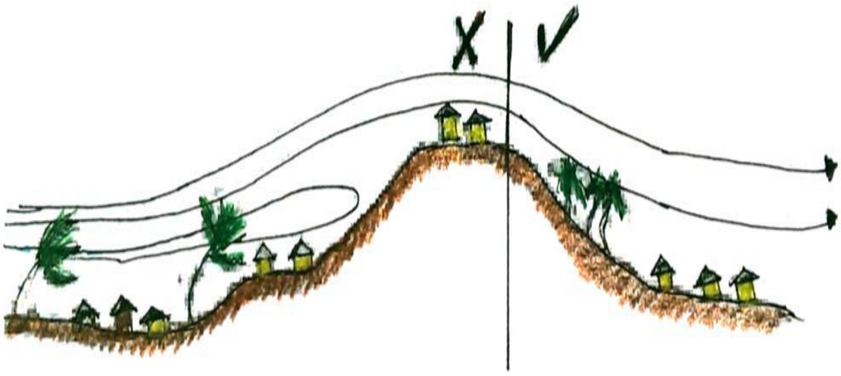


Figure 6.8: Suggested housing location against wind direction by IFRC,2011

Besides behind an earthen mound or natural vegetation should be preferred to provide for natural shielding against predominant wind and surge velocity. Both beneficiaries had to provide their land for the design construction. Bikash Roy from Jaliakhali provided his land near his previous home and Bipul mondol from Sreenagar provided his existed household land. Both housing location was inside the embankment. The embankment is newly constructed by World Bank which is 30 m elevated from the river edge. Considering the suggestions from IFRC, 2011, the houses were designed to construct against predominant wind direction and behind the embankment. The embankment will act as a shield that will reduce the wind and surge velocity from directly hitting the houses (See Figure 6.9).

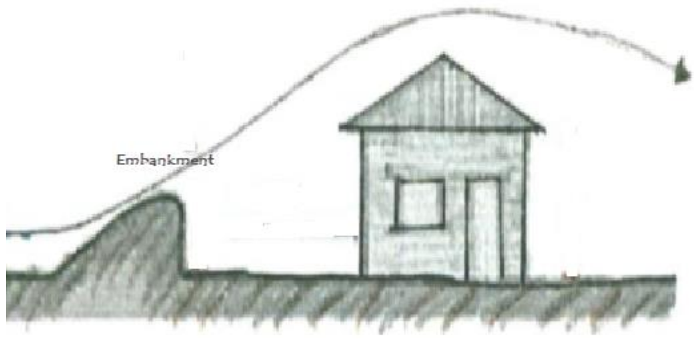
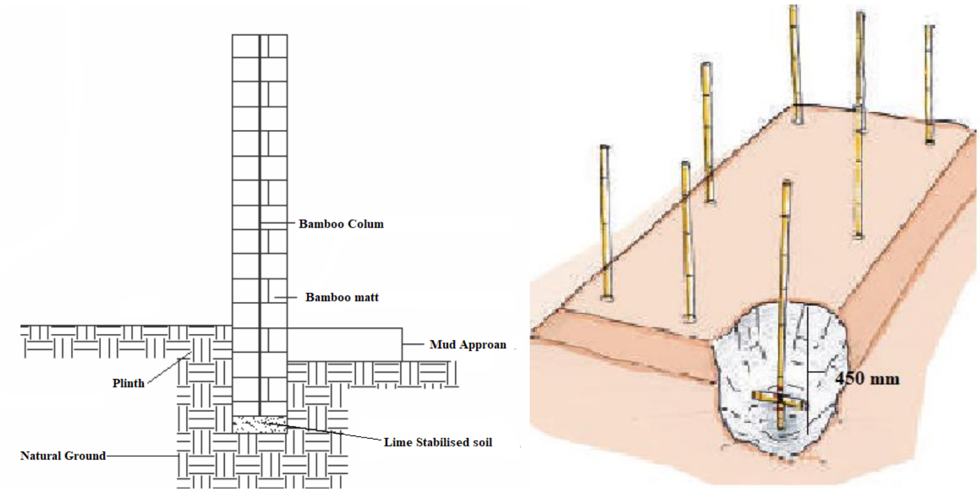


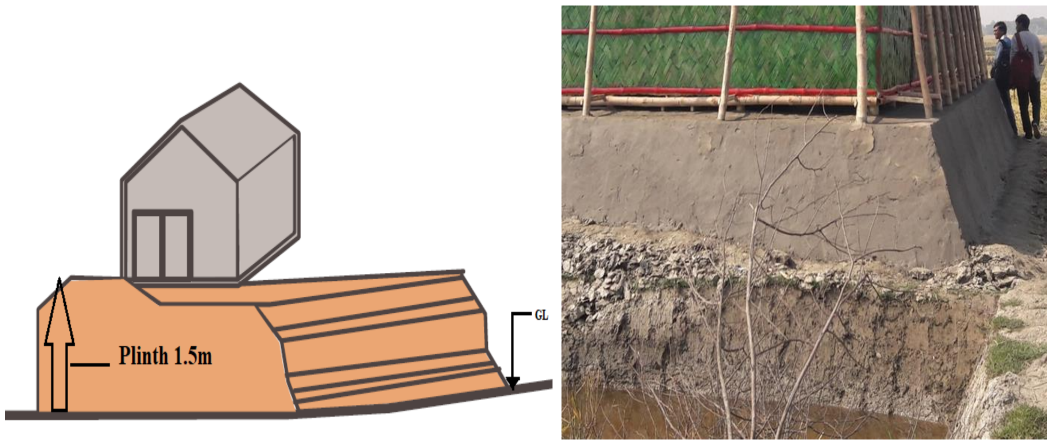
Figure 6.9: Sitting position of the implemented houses (Source: IFRC,2011 modified by author)

6.3.4 Foundation and Plinth Work

Foundation is the extensions of the base of the structures such as walls and columns that are directly supported or kept in equilibrium with the earth.



(a)



(b)

Figure 6.10: (a) Foundation and T-footing work (b) Plinth work of the implemented design.

The foundation bed is the prepared ground over which the foundation rests. It transmits the load of the structure to the soil. The basement of the houses was made by an earthen mound. Foundation's depth was 2 feet into the finished ground level with T-footing (foot is 5" by 5" by 17") with a compacted lime stabilized soil filling. After raising the plinth 1.5 m from the ground level, a ferrocement layer is used to wrap around the earthen plinth. This procedure ensures the safety of the plinth area from corrosion as well as enhances durability against surge water.

The designed structure was a raft foundation by spreading the weight over a wider area. It was needed to be considered that foundation was made in soft soils where bamboo canes should not be exposed to moisture. Using bamboo in columns with a directly earthen attach is not a good practice because the direct touch of bamboo with the soil since their durability is greatly affected. That's why lime stabilized soil was used to prevent direct touch of bamboo with soil. Therefore, the formwork was erected for the plinth course that was constructed together with the foundations. The bamboo columns were assembled in place and rooted with an extra brace (T-footing) in the plinth course about 450 mm. Figure 6.10 shows the foundation and the plinth work of the implemented housing design.

6.3.5 Wall and openings

A T-shaped two layers plan was construed where the outer layer is known as the veranda and the core layer known as the living chamber. The front veranda will reduce the wind pressure towards the hip roof over the living chamber and work as a wind tunnel. And connected corridor with a veranda which is separating the living chamber and kitchen would work as a dining space and outer wind tunnel to pass the wind. The roof of the main living chamber and veranda were built separately for the safety of the main roof. Moreover, minimum roof overhangs and low openings in the front veranda wall prevent roof uplift from wind pressure. A schematic wind load and openings pressure on housing is shown in Figure 6.11.

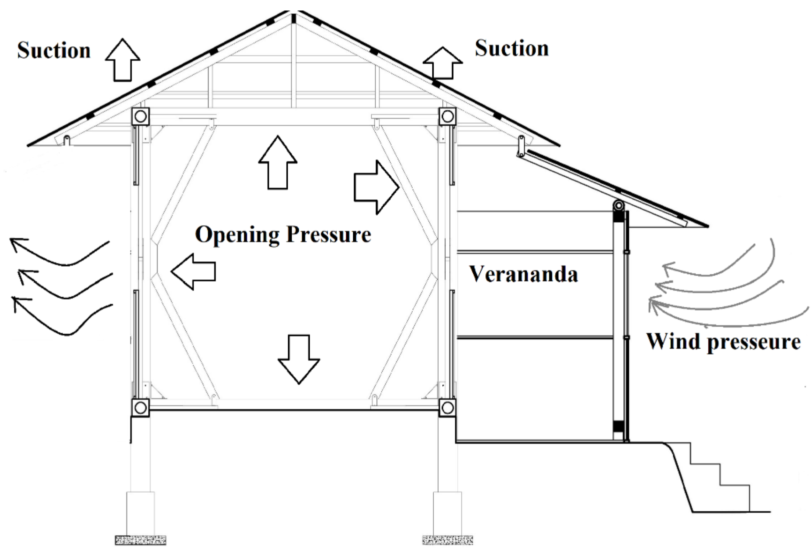
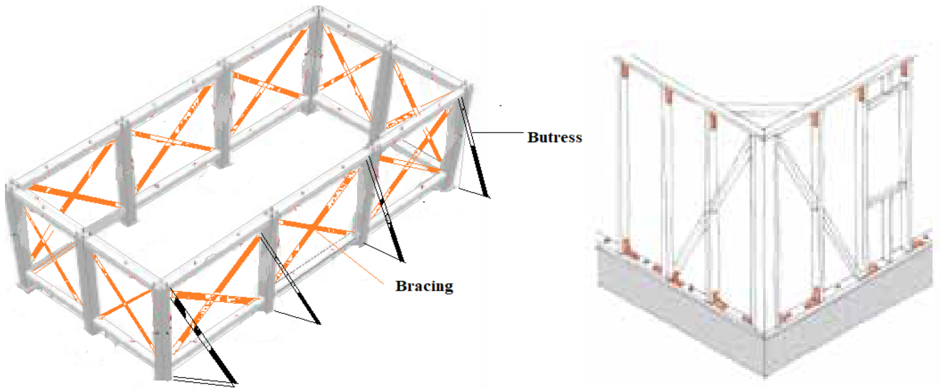


Figure 6.11: Effects of openings in the walls from the attack of winds

Figure 6.11 shows that Wind generating openings on the windward side during a cyclone will increase the pressure on the internal surfaces. This pressure, in combination with the external suction, may be sufficient to cause the roof to blow off and the walls to explode. That' s why the floors were well braced and tied firmly into the walls to strengthen both walls and floors, reducing the risk of them collapsing. Strong walls were made from bamboo matt and palm leaves (see Figure 6.13) with vertical and horizontal columns and with sufficient bracing to resist the horizontal forces of strong winds (See Figure 6.12). Ensured the bamboos were strongly fixed to each other and that the wall frame was well anchored to foundations through the buttress to avoid the building lifting off the ground (Figure 6.12 a). All structural elements were connected between each other by hurricane strap is shown in (Figure 6.12 b).



(a) (b)

Figure 6.12: Schematic wall structure of the implemented house. (a) bracing and buttress with wall structure (b) Hurricane cape

(a) (b)

Figure 6.13 Photos of constructed wall structure. (a) Inner portion of the wall consisting bracing aganist wind force and palm leaves for gathering weight. (b) Outer portion of the wall consisting bamboo matt against surge water and buttress for avoiding lifting.

Openings in general are areas of weakness and stress concentration but are needed essentially for light and ventilation. Openings just below roof level were avoided except that two small vents without shutters were provided in opposite walls to prevent suffocation in case the room gets filled with water and people may try to climb up on lofts or pegs. Since the failure of any door or window on the windward side may lead to adverse uplift pressures under the roof (Figure 6.11), studs around windows and doors should be doubled as openings weaken the structure.

6.3.6 Roof

The roof is the most vulnerable element of a house against cyclone wind. It has significant effects on the wind-induced force. Lightweight flat roofs are easily blown off in high winds. To lessen the effect of the uplifting forces on the roof, the roof pitch should not be less than 22º (Agarwal, 2007). Hip roofs are preferred to gable roofs for a non-engineering house to reduce the risk of the roof lifting off (see Figure 6.14). In our implemented design hipped roofs were used with a slope of 30 degrees as they are more cyclone-resistant than gable roofs. This roof design will reduce the effect of suction and uplift from the wind. The roof overhangs were set 20 cm be to avoid the roof being uplifted by strong winds. Veranda attached to the main building has an independent roof structure made by palm leaves for gathering heavyweight against cyclone wind force. It was safeguarded that, if the veranda's roof lifts due to high winds it does not damage the roof of the main building.

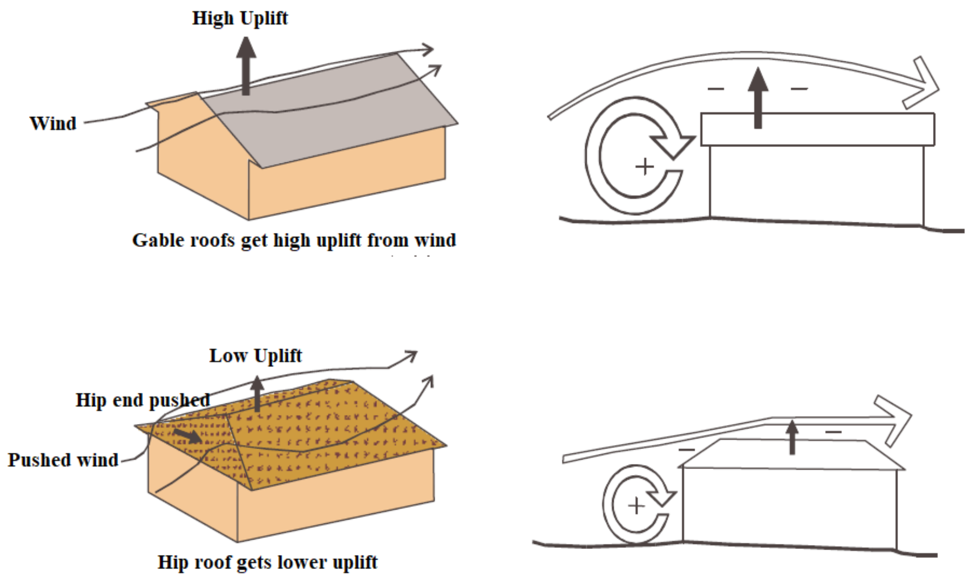
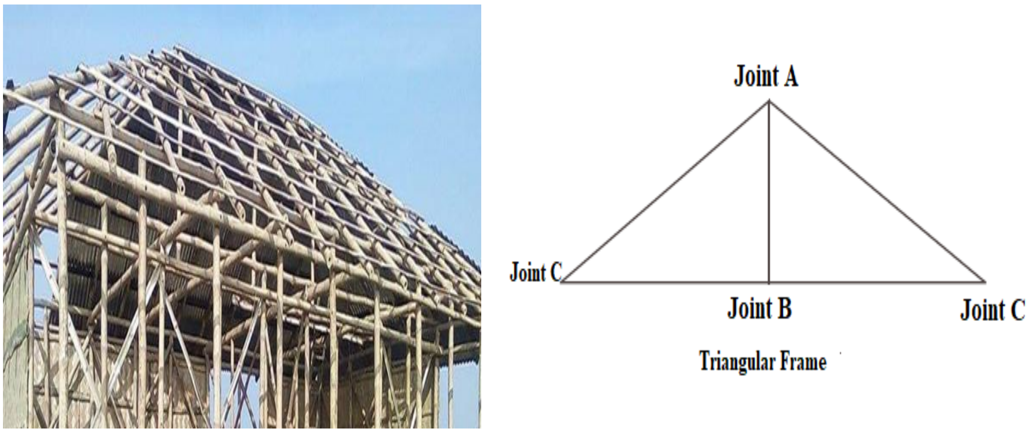


Figure 6.14: Effects of wind force on gable and hip roof

6.3.6.1 Roof framing and anchoring to walls

The connection of roof framing to the vertical load resisting elements i.e., wall or post, by providing properly designed anchor bolts and base plates is equally important for the overall stability of the roof. The mainframe and triangular frame (see Figure 6.15) were firmly connected to anchorage elements I bond beams at the level of the eaves. The anchorage elements in turn were connected to the main post of the wall using U bolts. For sloping roofs, triangular frames were located 2-meter space width with suitable connection (diagonal and square lashing) of various elements of the frame using GI wires, metal straps, bolt, and nuts for better integrity. Adequate diagonal and knee bracing were provided both at the rafter level and the eaves level on the sloped roof.



. **Figure 6.15**: Main & Triangular frame of the roof

The purlins were properly anchored at the gable end. Two bays, one at each end, were braced both in the horizontal and vertical plane to provide adequate wind resistance. Where the number of bays was more than 5, additional bracing was used in every fourth bay. Figure 6.16 shows the framing & anchoring of the roof.

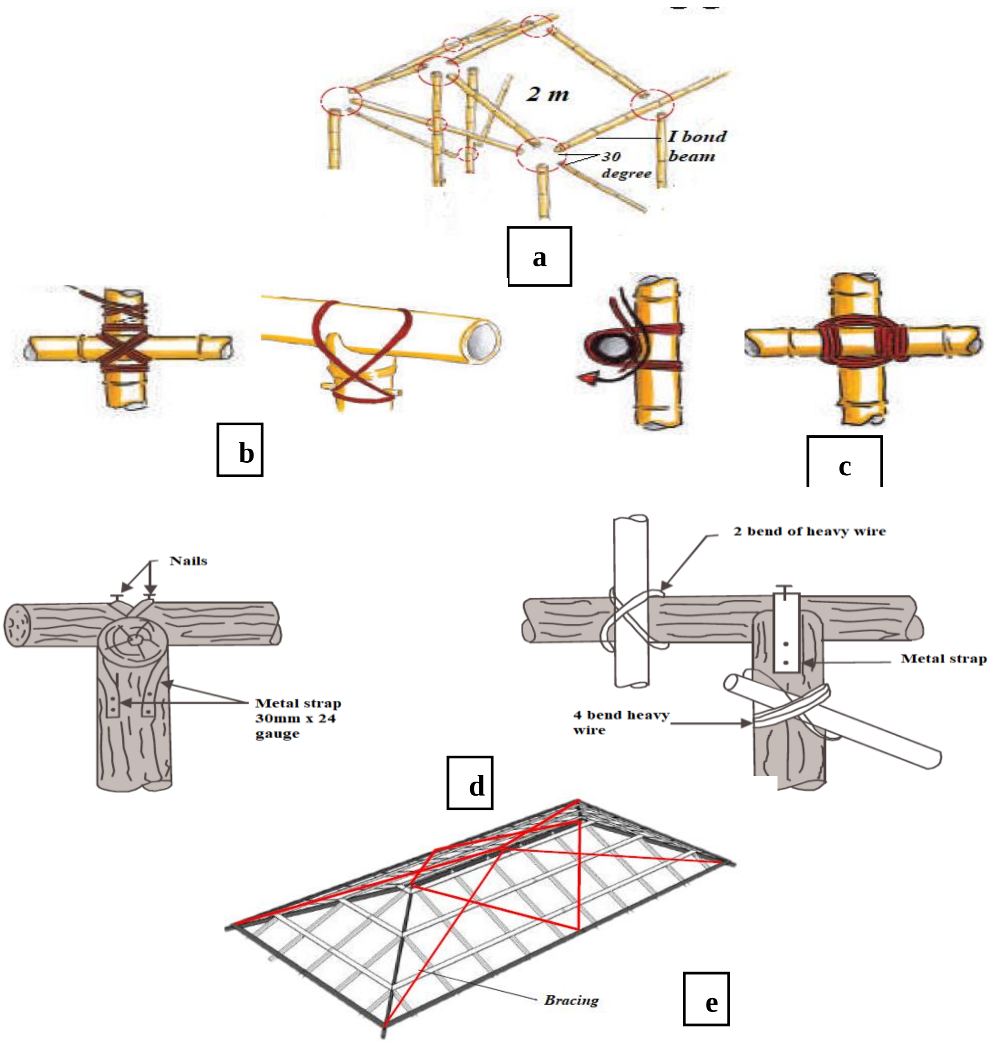


Figure 6.16: Framing & anchoring of the roof. (a) Frame joint (b) diagonal lashing using GI wires (c) square lashing using GI wires (d) Using metal straps for more stability (e) Bracing to reduce wind load.

6.3.6.2 Installation of plan leaves thatched

Palm leaves thatched are used for gathering weight at the inner portion of the roof. The designed bamboo structure, enough to support up to 20kg/m2 of thatch. This heavy thatched roof will ensure protection against roof blown off. Palm leaves must be mature and dry before they are used for thatch. After seasoning, the leaf blades were stripped from the stem and then stitched to a thin wood batten. This batten was made from palm leaf rib. Then the leaf blades were squeezed tightly and neatly together as they were stitched onto the batten. The standard mat of 600mm length was made of about 200 leaf blades. The process of laying feather-type mats resembles tiling. Mats were tied to the rafters in overlapping layers starting at the eave. The thickness of the coat, and therefore the durability of the roof depends on the size of the overlap. Approximately 60mm thickness along the length of the eave was fixed to the batten. This provided essential support for the first layer of thatch. It is sometimes suggested that palm thatch requires side lap as well as vertical overlap, but this should be unnecessary with well-made mats. This may be a positive disadvantage as the extra thickness created by each side-lap creates ridges in the surface which will lead to the formation of gulleys and more rapid decay. A steep roof with a thick thatch is more durable than a thin, shallow pitched roof. The higher cost of a steeper, thicker roof is more than offset by the increased life, but the choice is always a trade-off between cost and performance. The maximum economic life of palm thatch, using the best available materials and a skilled thatcher is 10 years. Figure 6.17 shows installation of palm leaves thatched.

Figure 6.17: Palm leaves thatched installed in the inner portion of the roof to prevent blown off.

6.3.6.3 Installation of CGI sheet

CGI sheet was installed above the thatched roof for dumping protection of palm leaves from the rain as well as for harvesting water in the tank. A 24-gauge CGI sheet was used for layering of the roof. Used fittings with a broad washer and more fixings for each sheet, tapped in the laths at closer centers, and nails closer together. Fixed every two corrugations at ridges, eaves, and overhangs. Also fixed every three corrugations by using galvanized iron flats under the fixings. Used 75 mm screws for corrugated galvanized roof sheets and was ensured that the screws go into the purlins at least fifty (50) mm. Used large washers under the screw head to prevent the roof sheets from tearing when pulled upward by high winds. For normal connections, U bolts were used but for cyclone resistant connections. Alternatively, straps were used at the edges to fix cladding with the purlins to avoid punching through the sheet. Properly connected M.S. flat was used as reinforcing band in high suction part. The corrugated sheeting was properly overlapped to prevent water from blowing under the seam. Spaces between the sheeting and the wall plate were closed to prevent the wind from getting under the sheeting and lifting it. This was done by nailing a fascia bamboo to the wall plate and rafters. Figure 6.18 shows the CGI sheet layer of the roof.

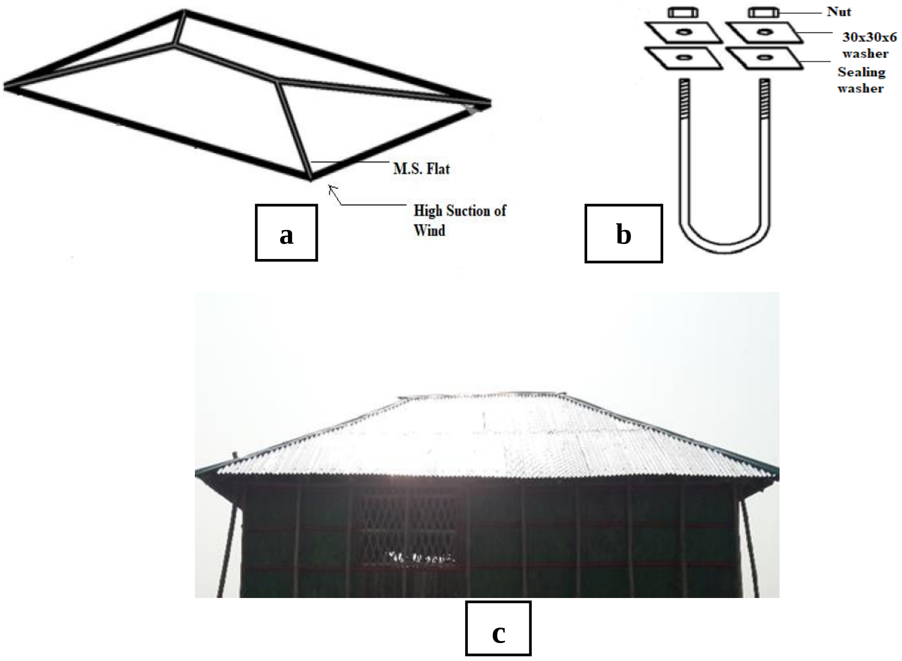


Figure 6.18: CGI sheet layer of the roof. (a) Using reinforcing bands in high suction zones (b) U bolt – cyclone connection for roof cladding to purlins (c) Completed roof layer

6.3.7 Additional features

Few additional features were added to increase the performance of the design against cyclone wind and surge velocity.

6.3.7.1 Cross Bracing

Cross bracing is a system utilized to reinforce building structures in which diagonal supports intersect. Cross bracing is usually seen with two diagonal supports placed in an X-shaped manner. Under lateral force one brace will be under tension while the other is being compressed. This method of construction maximizes the weight of the load a structure can support. It is a usual application when constructing cyclone-safe buildings. In implemented design both horizontal and vertical bracing was used in wall and roof which is shown in Figure 6.19.

Figure 6.19: Horizontal and Vertical bamboo bracing in wall and roof

6.3.7.2 Structural buttresses

A buttress is an architectural structure built against or projecting from a wall which serves to support or reinforce the wall. Buttresses are common on more ancient buildings, as a means of providing support to act against the lateral (sideways) forces arising out of the roof structures. In implemented design bamboo buttress constructed surrounding the house which will provide lateral support to the buildings. Figure 6.20 shows structural buttress of the implemented design.

Figure 6.20: Structural buttressess constructed in both implemented design

6.3.8 Reasons for selection of bamboo structure

Strength

Bamboo Living Homes are made with a special tropical clumping bamboo species. The poles used in the houses are 3 ½ inches in diameter and the wall of the bamboo pole is a ¾ inch in thickness. The exceptionally strong and flexible bamboo poles can withstand the extreme forces imposed on a house during hurricanes and earthquakes. It has twice the compression strength of concrete and roughly the same strength-to-weight ratio of mild steel. The hollow tube shape gives a strength factor of 1.9 times more than an equivalent solid wood beam. As strong as mild steel with the compression strength of concrete. Amazingly, one inch of bamboo can hold up to 7 1/2 tons of weight.

Sustainability

Sustainable design aims to provide ways of building that use a less non-renewable material, less energy, and cause less pollution and waste while still providing safe and sufficient dwellings. There is great potential for bamboo to provide long-term sustainable improvements in environmental, social, and economic wellbeing. Adopting a sustainable lifestyle is our best solution for preserving life and creating sustainability for future generations.

Economical and easy harvesting

Bamboo forests are typically harvested in a very different manner than tree forests. Bamboo culms are usually harvested 2-4 years after the shoot reaches its full height, which can take just a few months. Sympodial (tropical clumping) species will send up new shoots every year if conditions are adequate depending on rainfall, temperature, and nutrients. Bamboo can be sustainably harvested yearly. In the past, tree forests were typically harvested by clear-cutting, which is more economical and provides full sun for a newly reforested tree crop. However, clear-cutting adversely affects the local ecosystem, encourages soil erosion, and dramatically reduces the carbon sequestration rate of the forest.

Evidence of Cyclone Resistant

According to report from Best (2017), when three typhoons swept into the Cook Islands in 2005, one producing winds of 173 mph, they devoured everything in their path everything, that is, except a group of bamboo houses on the beach.

Figure 6.21: (a) Interior of both house (b) Completed house (front view).

Similarly, the bamboo Living structures held up to the incredibly strong winds of Cyclone Olaf category five while the conventionally built structures were decimated. Another evidence is the bamboo living structures performed phenomenally well when Hurricane Maria, known as the tenth-most intense Atlantic hurricane on record and the most intense tropical cyclone worldwide, hit the Caribbean in 2017.

Certification

The LEED green building certification program stands for "Leadership in Energy and Environmental Design" promotes bamboo living structure for reducing environmental disturbance and construction waste.

Considering above mentioned facts bamboo was selected for main structure of the design. After added all components together the completed house got shaped as Figure 6.21.

6.3.9 Rainwater Harvesting System

Safe drinking water source is the key element for housing resilience. To ensure that 1500-liter tanks were installed in both houses for rainwater storage. The best place to install a rainwater harvester was next to the roof drainpipe. This was the place where most of the rainwater is diverted. Then in installing the system was fixing the PCV gutters to the roof leading to the storage tank. PCV gutters were the cylindrical pipes that transport water to the storage tanks. It was ensured that PVC downpipes were firmly fixed to the wall vertically with the help of clamps. Downpipes were remained fixed in their place. The next thing was to install the washout pipe or first rain separator. This separator was basically a valve that was used while cleaning the roof or when rainwater was not collected. Also, installed a leaf trap in the downpipe to prevent blockage. For collecting clean water, a filter was installed on the storage tank. This prevents dust and other matter from entering the storage tank. A water storage tank was installed at an elevated place to prevent the growth of bacteria and to keep it from the reach of animals. Also, placed some heavy objects on top of the water tank to keep it tightly covered.

Figure 6.22: Installed water harvesting system in both houses

Finally, an overflow pipe was installed on the top of the storage tank to allow the release of excess water. The overflow pipe was the size equal to the inlet pipe. Figure 6.22 shows installed water harvesting system along the houses.

6.3.10 Installation of Granary

Granaries are made of wood and bamboo materials and most of them are built raised up on four or more posts to avoid rodents and insects. In this study, cylinder shaped two granaries were made by wood, bamboo, bamboo matts and CGI sheet for each beneficiary.

Figure 6.23: Installed Granary

The main structure of the granaries was raised 2 meter above from the ground level to avoid inundation problem. Earthen mound was used to build the basement. 11 CFT wood was used to construct deck. Main columns were made by bamboo and bamboo matts were used to warping wall protection. 14 CFT wood was used to build roof structure and CGI sheets were used for layering the roof. The complete picture of the granary is shown in Figure 6.23

6.3.11 Installation of Sanitation

Simple pit toilet with well maintenance facilitates was installed in both houses. The toilet was established 7 meters far from the main households to maintain hygiene and easy access. The simple pit latrine is the most basic type which is essentially a large hole in the ground covered by a platform in which there is a hole through which the user excretes. The platform is surrounded by a screen to provide privacy and, shelter from the weather. The details of installing sanitation system are discussed below.

Pit hole

The larger the pit, the longer it will take to fill up. The size of pits varies widely around the world. In some areas the pits are only a meter deep. These tend to fill very quickly and are usually only of a temporary nature. In other places the pit may be 10 to 15m deep and take a long time to fill. The plan size of the pit (the size looking down on the hole from above) also varies. Some are less than 0.5m wide whilst others are 2 to 3m wide. However, in this design pits were 6m deep and 1.5m wide with circular shape. There are several factors affecting the time taken to fill a pit. Especially number of family members, usage and maintenance determine the duration for filling a pit. A pit is considered full when the contents are within 0.5m of the surface. As a rule, a pit 3m deep and 1.5m square will last a family of six about 15 years. From this viewpoint, implemented pit will be long lasted more than 30 years.

Pit lining

The sides of holes in the ground may collapse if not supported. Soils close to the surface are particularly vulnerable because they are much looser than deeper soils. In fact, one of the main causes of pit latrine failure is the collapse of the soil close to the surface causing the platform to fall into the pit. That's why partial pit line was established to reduce collapsing chance. A partially lined pit latrine is one where the upper part of the hole in the ground is lined. For lining RCC pit ring made by cement, brick's piece and soil were used as layered onto the soil. This lining will increase permanence and allow emptying of the pit without it collapsing easily. The bottom of the pit was remained unlined to allow for the infiltration of liquids out of the pit.

Cover slab

A slab is necessary to cover the pit and to provide a place for the user to excrete. For the user, this is probably the most important part of the pit latrine and therefore great care should be taken over its design and construction. The slab was placed directly on top of the pit lining about 15cm above the surrounding ground level. It was elevated above the surrounding ground to prevent surface water from entering the pit. The hole is provided with a sanitary pan for safety (to stop young children accidentally falling into the pit), to reduce odor and to help prevent flies from breeding in the pit.

Plinth

Masonry 2 ft. plinth was developed for sealing the space between the lining, the cover slab, and the ground. It will also prevent any rainwater from the roof or floodwater to enter the pit.

Toilet building

The toilet building or superstructure was primarily constructed to provide privacy for the users. It was made of CGI sheet roof and a window for proper ventilation. A schematic diagram of the toilet and full constructed sanitation system is shown in Figure 6.24.

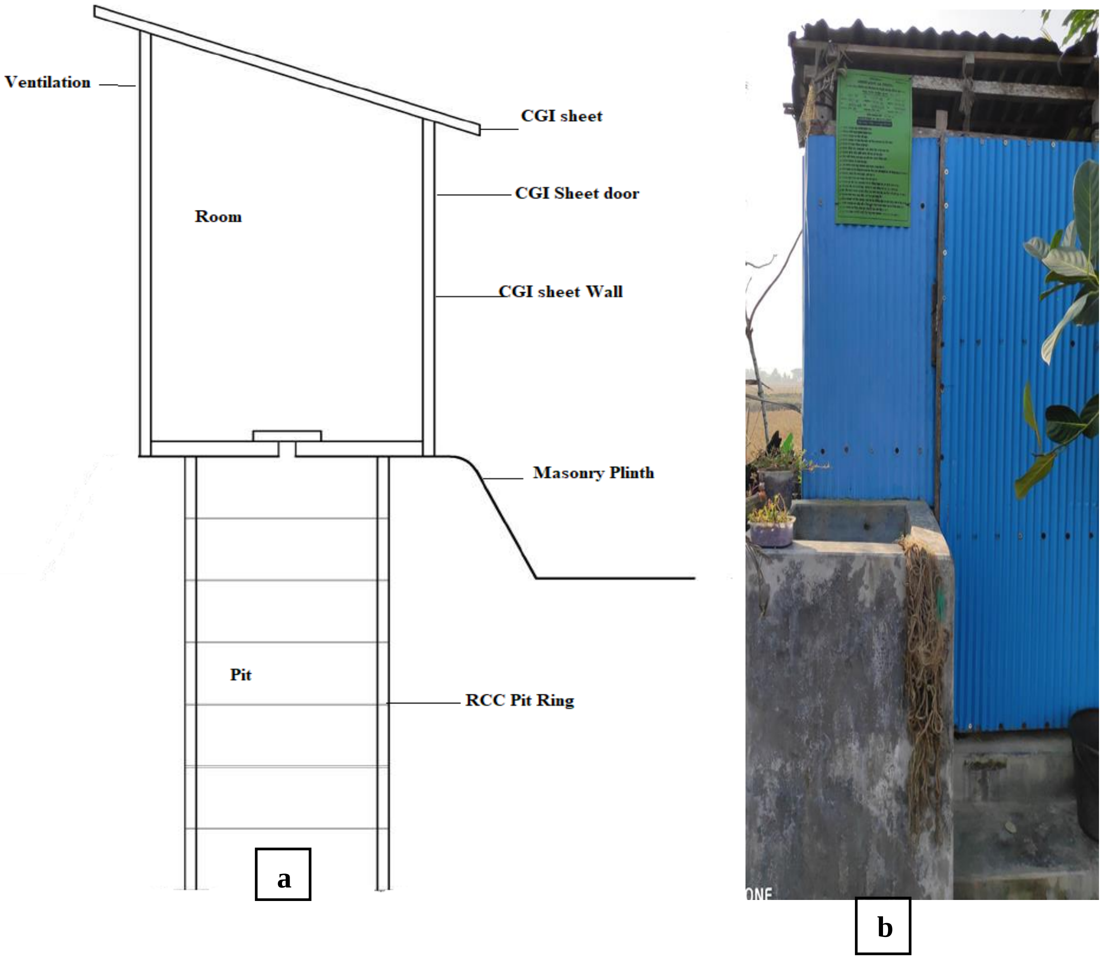


Figure 6.24: (a) Schematic diagram of sanitation (b) Completed sanitation

6.4 Resilient features of the houses for community based DRR

6.4.1 Design Process

The research has been focusing on generating resilient housing design and implementation for the community's present socio-economic and climatic contexts adopting the 'Participatory design' process to define and resolve the present challenges, generating climate, culture, economic, and gender-responsive housing system. The housing design has involved the community including women and children to exploit local wisdom and technocrats would contribute through incorporating appropriate technology to adapt and mitigate the prevailing challenges. This consensus design process has empowered them; they worked as co-designer and have designed their architecture and achieved resilience. So, the implemented housing systems have been the reflection of their aspiration and need; so, they would be able to change in any manner themselves in the near future if needed.

6.4.2 Low-cost housing design

According to Tran, et al. (2012), the socio-economic situation of households leads to differing levels of housing vulnerability. Low-income people buy the cheapest lands in the most vulnerable places away from city centers, in the suburban, peripheral zones, or disaster-prone areas. The implemented housing designs are made in a cost-effective way with optimum uses of values and materials. The gross cost of each house is affordable to the community people with very minimal formal support in development. The total cost for each house with a drinking and sanitation system was 1,78, 466 BDT (2088 USD) which is very cost-effective for making a disaster resilient house. The breakdown of total costing is given in Table 6.2.

Table 6.2: Costing for implementation of a disaster resilient house. (Sources: Author, 2017)

SL	Expenditure	Amount (BDT)
1	Bamboo (142 pc.)	42600
2	Bending materials (GI wire,Nut, Screw)	4775
3	14 CFT wood	5350
4	Labor bill for raising plinth	9000
5	Materials processing fee	3200
6	CGI sheet, Color, Motka	32175
7	Palm leaves	9000
8	Bamboo matt	10070
9	11 CFT wood	4550
10	Separate materials for building	2736
11	Bricks and ferro cement	5560
12	Pit, pan, and ring slab	4320
13	Mason and Carpenter bill	26500
14	1500 liter. Tank	10395
15	Transportation Cost	8235
	Total	1,78, 466

6.4.3 Resilient Building Materials

In general, the choice of building materials for housing depends on various factors such as type, budget, culture, climatic condition, and labor to name a few. Particularly in the context of low-cost housing building materials need to be cost-effective, environmentally friendly. However, in housing practice, the use of substandard materials, design, and shoddy construction, poor maintenance are key reasons for structural failure. It is important to select appropriate building materials with the designing process to reduce structural vulnerability. That’s why a bamboo-based foundation was selected which is indigenously approved. With this local wisdom, proper architectural and engineering knowledge was blended to make the structure more strengthen than typical bamboo housing. Besides, the LEED green building certification program promotes bamboo living structures for reducing environmental disturbance and construction waste. A brief description of resilient building materials was mentioned in section 6.2.3 & 6.3.8.

6.4.4 Guided Local Builders and Masons

The local masons or builders of the rural areas lack knowledge of building materials and construction methods. They construct the houses based on their limited skill and without any consultation or supervision with the in-field professionals such as architects and engineers. Professional expertise and skills are crucial to effectively assist at-risk communities (Tran and

Tran, 2013). Therefore, expert professionals, architect personal, and local engineers guided local masons and builders, enlightened them regarding building materials, construction methods, and integration of DRR into the design process. By recognizing the need to improve the skills, measures were taken at various levels in improving the skill sets of local builders and masons and trained them on climate risks and DRR for a hazard safe and resilient housing.

6.4.5 Integrating indigenous Knowledge with DRR

Rural areas are rich in indigenous and local knowledge. Even though vernacular houses lack technical adequacy there is a lot to learn from them. The design of houses was focused on local practice. There is a gap in understanding the local knowledge for having effective design and technology for the construction. This gap was linked by learning from the local people and then improving the housing design. It is important to consider that each of the communities in the rural areas has its materials and construction techniques for housing. Therefore, inputs from the local people and local artisans, a strong understanding of the local culture, and general context were taken into consideration for sustainability and to achieve a better impact on local housing resilience. It was more beneficial to adopt local technologies, materials, and methods with little scientific improvement in the housing construction than introducing alternative technologies. It was necessary to incorporate certain hazard mitigation mechanisms against future disasters in housing planning and construction.

Adopting local approaches to disaster response in housing preserves local knowledge, strengthens social capital, and makes the reconstruction more acceptable to the community in terms of culture, climate, technology, and economy. Schilderman (2004) mentioned that community-based planning for disaster mitigation has proven to be more successful than formal, institutional approaches imposed upon the community; since the new construction standards introduced by formal approaches usually tend to be alien and costly to local groups. Relatively small changes and improvements in traditional construction could make housing more disaster resistant.

Incorporating new materials and technology into a local building culture was carried out carefully and critically. Local technology wasn’t completely replaced by architectural and engineering opinions. A participatory approach was introduced to replace certain steps in the building process, material procurement, material processing, and stages of construction, rather than propose a total negation of the traditional method.

6.4.6 Strong structural system

The structures were being made of good quality bamboo available in the local context and have been reinforced using extra structural members like cross-bracing and buttresses. The roof materials have been properly tied with the roof structure with extra protection over it to avoid any pressure that could blow away the roof. Besides the plinth was raised more than 1.5m to avoid direct surge stress to the structure

6.4.7 Food and Water security

Safe and readily available water is important for public health, whether it is used for drinking, domestic use, food production, or recreational purposes. Sustainable Development Goal target

6.1 calls for universal and equitable access to safe and affordable drinking water. The target is tracked with the indicator of "safely managed drinking water services" drinking water from an improved water source that is located on-premises, available when needed, and free from fecal and priority chemical contamination. The housing design was considered the fact that the study area is under a crisis of safe drinking water due to salinity. Besides when water comes from improved and more accessible sources, people spend less time and effort physically collecting it, meaning they can be productive in other ways. This can also result in greater personal safety by reducing the need to make long or risky journeys to collect water. Better water sources also mean less expenditure on health, as people are less likely to fall ill and incur medical costs, and are better able to remain economically productive. A 1500-liter water tank was established for harvesting fresh rainwater during the monsoon. This water system will fill up the drinking water need of the family for a complete year. For emergency food support like after a cyclone, a granary was established where the family can store their food for emergencies.

6.4.8 Hygiene and Sanitation

Contaminated water and poor sanitation are linked to the transmission of diseases such as cholera, diarrhea, dysentery, hepatitis A, typhoid, and polio. Absent, inadequate, or inappropriately managed water and sanitation services expose individuals to preventable health risks. This is particularly the case in a family where one healthy member is placed at additional risk of infection and disease by an affected family member when water, sanitation, and hygiene services are lacking. For considering the fact, A half masonry pit toilet was established near the house to maintain hygiene with proper water and licking facilities. This covered sanitation system is gender-friendly and safe for female members of the family.

6.4.9 Repair and Reconstruction

Commonly, the implemented housing design will be affected by several hazards. Consequently, the design will be fully or partially damaged. The repair or reconstruction of the structures will be easy with significant cost and time effective. Because community people were directly involved with the development of the structures. They can repair significant damages by themselves. Construction materials are homegrown, easily accessible, and have low pricing. That's why the reconstruction of this design will take less time and ¼ price than a masonry building's reconstruction.

6.5 Limitations of the housing design

The implemented housing design has been made of natural materials, which are prone to decay and easy to be hampered. Though all the possible measures have been taken to increase the longevity of the materials. Still the recipients should be aware of this fact and act accordingly.

CHAPTER SEVEN

DESIGN PERFORMANCE AND EVALUATION

7.1 Introduction

A Cyclone Classifier Model was developed during the SATREPS project of BUET that quantifies cyclone wind speed, surge depth, the status of coastal embankments, and the status of housing during the passage of a real-time cyclone (Haque et al. 2019). All these messages give improved cyclone warning information as well as probable damage data for a real-time cyclone. Cyclone scenarios (pseudo-cyclone) of 170 cyclones were simulated by applying four models which are mentioned in section 4.5.1. These scenarios are generated by considering historical and synthetic cyclone paths along the coast during both high tide and low tide landfall times of cyclones. For each of the pseudo-cyclones, hazard maps are created by using cyclone wind speed, surge depth, and thrust force as the three hazard indicators (Haque et al. 2019). In this chapter cyclone classifier model is used to measure implemented design performance by considering four real-time major cyclones.

7.2 Model Simulation

n Cyclone Classifier Model, the Structural Finite Element model (ETABS) was applied to study the impact of storm surge thrust on coastal housing. According to Haque et al. (2019), 100 survey data of household types were gathered along the coastal zone to establish model simulation. Among the data 39% was Jhupri house, 44% was Katcha house. 6% was Semi-paka house and 11% was Paka house. For this research purpose, only model simulation results on katcha houses are shown from the study of Haque et al. 2019.

The model results show that a significant amount of deflection is found in all structural components under different loads. This is due to the lack of stiffness in the lateral load resisting system. Purlins of the roof structure were more stressed than the other components resulting in the failure of the roof structure followed by blowing of the roof. In summary, Coastal houses can withstand a much stronger wind when there is no storm surge. Only a 1 feet surge height can cause damage to a house during a cyclone (Haque et al. 2019.) The model simulation and its consisted results are shown in Figures 7.1 and 7.2.

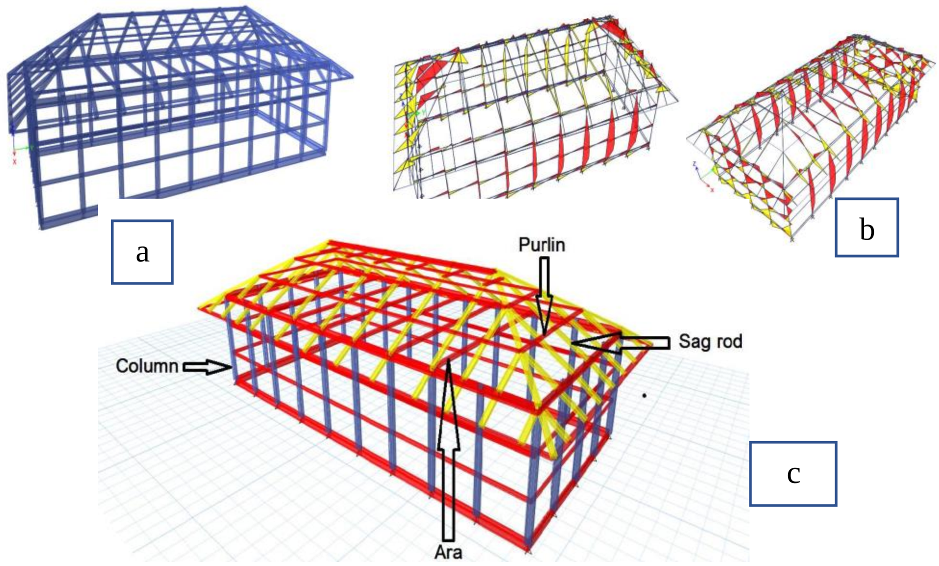


Figure 7.1: (a) Kutcha house (model) (b) Model simulation under different wind load (c) Model simulation under different wind & surge load (Source: Haque et al. 2019)

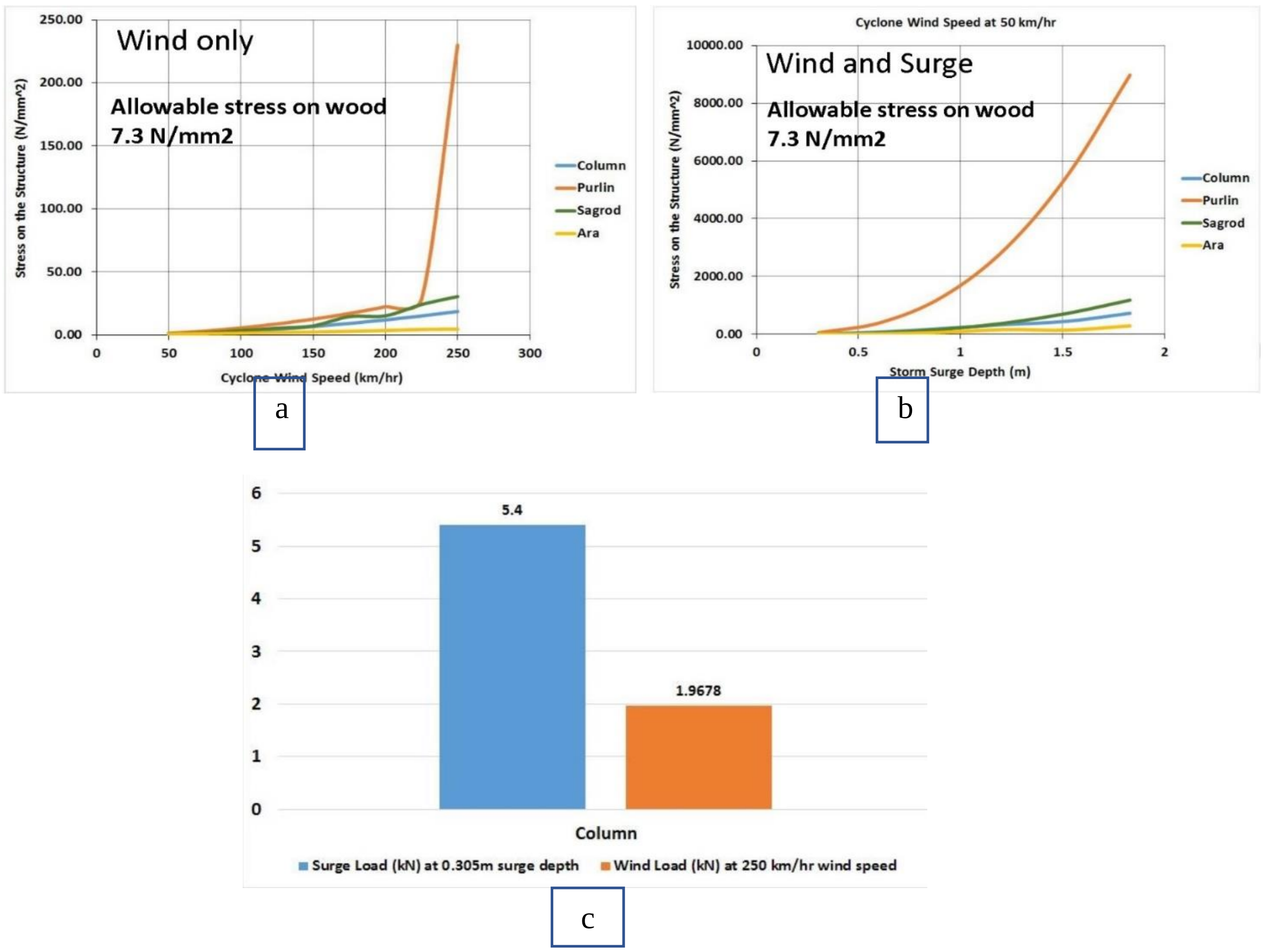


Figure 7.2: (a) Simulated wind stress on housing structure (b) Simulated wind and surge stress on housing structure. (c) Load comparison of least surge with maximum wind in column. (Source: Haque et al. 2019)

7.3 Design performance against Real time cyclone

For testing design performance four real-time cyclones such as Cyclone Mora (2017), Cyclone Fani (2019), Cyclone Bulbul (2019), and Cyclone Amphan (2020) were considered. All these cyclonic events have occurred after design implementation. Possible landfall data, landfall time, estimated surge height, and both high tide and low tide landfall situations of cyclones were considered in the model to measure the design performance. General information on these cyclones is shown in Table 7.1

Table 7.1: Cyclone's information

Cyclone	Landfall Date and time	Landfall location	Wind speed	Surge height	Category	Source
Mora	May 30, 2017, 6.00 AM BST.	Cox's Bazar-Chittagong Coast near Kutubdia	110-130 km/h	1.2-1.5 m	Category 1	BMD, 2017
Fani	May 3, 2019, 8.00 AM. BST	Puri, Odisha	185-230 km/h	1.5-2 m	Category 5	IMD, 2019
Bulbul	November 9, 2019, 12.30 AM. BST	Sagar Island West Bengal	70-80 km/h	1-2 m	Category 1	IMD, 2019
Amphan	May 20, 2020, 4.00 PM BS%	West Bengal	155-240 km/h	3-5 m	Category 5	IMD, 2019

7.3.1 Testing performance against Cyclone Mora (2017)

A low-pressure area developed over Southeast Bay and adjoining Central Bay in the afternoon of 26 May 2017. It intensified in to a Well-Marked Low (WML) over the same area at 0900 UTC of 27 May 2017. The system concentrated into a Depression (Lat 15.2°N, long 90.6°E) over the same area at 0300 UTC of 28 May 2017. It then moved northward and intensified into Deep Depression (DD) over Southeast Bay and adjoining Central Bay (Lat 15.4°N, long 90.6°E) at 0900UTC of 28 May 2017. It then moved further north-northeastward and intensified into a Cyclonic Storm (CS) 'MORA' over East-Central Bay and adjoining area (Lat 16.2°N, long 91.2°E). In continuation to this, cyclone 'MORA' moved north-northeastwards and intensified into Severe Cyclonic Storm (SCS) 'MORA' over North Bay and adjoining East-Central Bay (Lat 18.8°N, long 91.3°E). Then it moved north-northeastward and crossed Cox's Bazar-Chittagong Coast during 06 AM to 12 Noon of 30.05.2017. After making landfall, SCS 'MORA' moved north-northeastward weakened into a Land DD over Rangamati Region at 0600 UTC of 30.05.2017. It then weakened further and became unimportant. The observed track of the SCS 'MORA' is shown in Figure: 7.3.

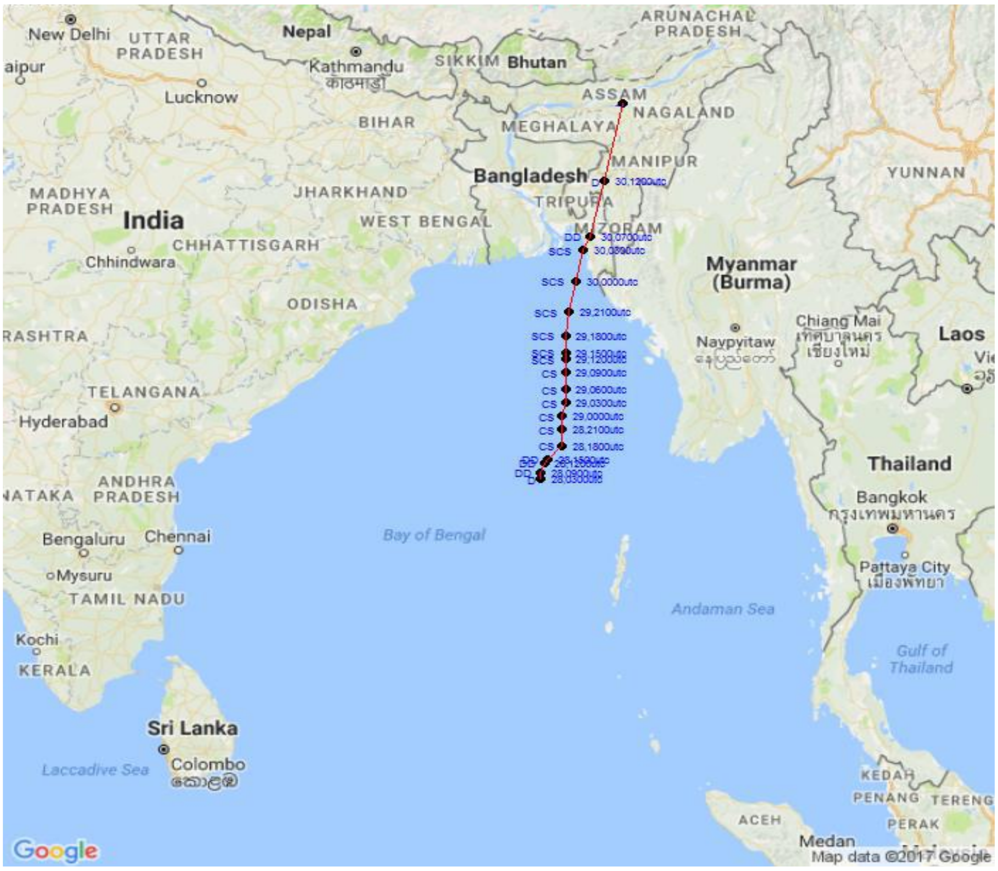


Figure 7.3: Observed Cyclone track of Mora (Source: BMD, 2017)

7.3.1.1 Model Results

Total six observed tracking locations (from 29.05.2017. 06 PM to 30.05.2017. 12 PM) with a proper wind speed of Cyclone Mora (See Table 1) from BMD were considered in CCM to measure the possible damage information in Dacope Khulna. At first, the model results show probabilistic scenarios of cyclone mora track while it passing the coastal area of Bangladesh considering both high and low tidal conditions (See Figure 7.4). Then the model provides information on possible wind speed, surge height, polder, and housing status for the coastal area. For testing housing performance in the study area,

information on Dacope Upazilla is only considered against these scenarios which are presented in Table 7.2.

Table 7.2: Position and Status of Cyclone 'MORA' *(Source: BMD, 2017)*

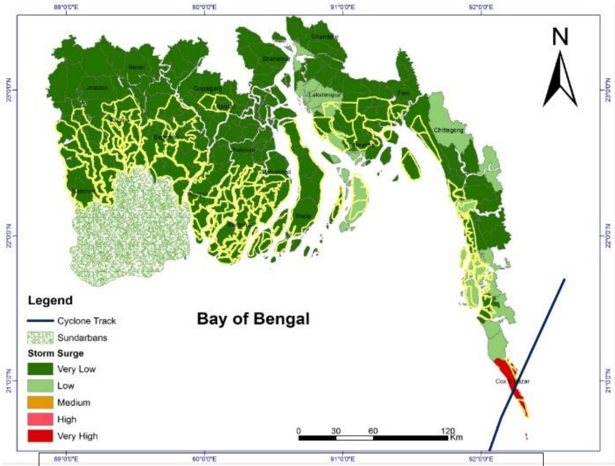
Scenarios	Date	Time	Status	Area of the system	Latitude/ Longitude	Wind Speed	Distance (km)
1	29.05.2017	06 PM (12 UTC)	SCS	North Bay and adj EC Bay	18.8° N /91.3°E	93 km/hr.	Ctg: 385. Cxb: 305. Mgl: 450. Payra:370
2	29.05.2017	09 PM (15 UTC)	SCS	North Bay and adj EC Bay	19.0° N /91.3°E	84 km/hr.	Ctg: 360. Cxb: 280. Mgl: 430. Payra:35

3	30.05.2017	12 AM (18 UTC)	SCS	North Bay and adj EC Bay	19.5° N /91.3°E	74 Km/hr.	Ctg: 305. Cxb: 230. Mgl: 380. Payra:300
4	30.05.2017	03 AM (21 UTC)	SCS	North Bay and adj EC Bay	20.2° N /91.4°E	112 km/hr.	Ctg: 230. Cxb: 150. Mgl: 320. Payra:235
5	30.05.2017	06 AM (00 UTC)	SCS	North Bay Chittagong Coast	21.9 N/ 91.8 E	101 km/hr.	Landfall
6	30.05.2017	12 PM (06 UTC)	DD	Rangamati and adjoining area	22.8 N/ 91.9 E	84 km/hr.	----

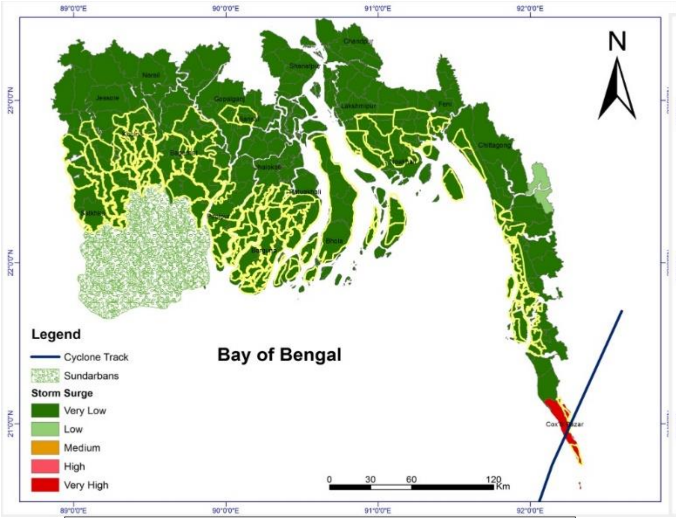
Figure 7.4 shows probabilistic surge-affected scenarios along the coastal area due to Cyclone Mora. In scenarios 1 to 4, the cyclone was tracked in North Bay and adjoined EC Bay with 74-112 km/hr. wind speed. Using the track records, the map of CCM indicates the possible landfall of Mora will be near Cox’s Bazar of Chittagong district with a high chance of storm surge. After landfall near Chittagong, scenario 5 and 6 indicates more area has the probability to be affected by storm surge.

Mora made landfall near Kutubdia of Cox's Bazar. It had wind gusts up to 128km/hr. But southwest regions of Bangladesh experienced almost no effect of the cyclone, apart from some light rain and breeze. The model shows similar results for Cyclone Mora. From scenario 1 to scenario 6, the maximum wind speed in Dacope Upazilla was 28 km/hr. for high tide conditions and minimum wind speed was 10 km/hr. for low tide conditions with no surge (See Table 7.3). Possibility of substantial damage is found for embankments as structural conditions of southwest region polders are relatively poor than other regions. There is no damage is found for any type of housing structure as they are likely to remain safe in all scenarios of Cyclone Mora (See Table 7.3). According to the damage information of the model, the performance of the implemented housing design should play an effective role against the impact of Cyclone Mora.

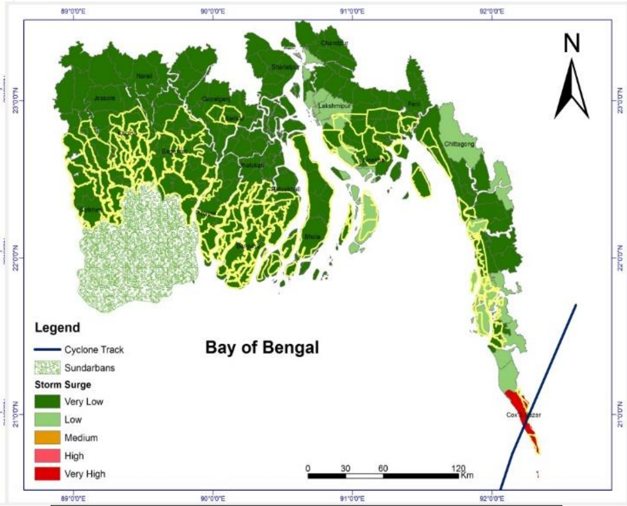
Scenario 1 (High tide)



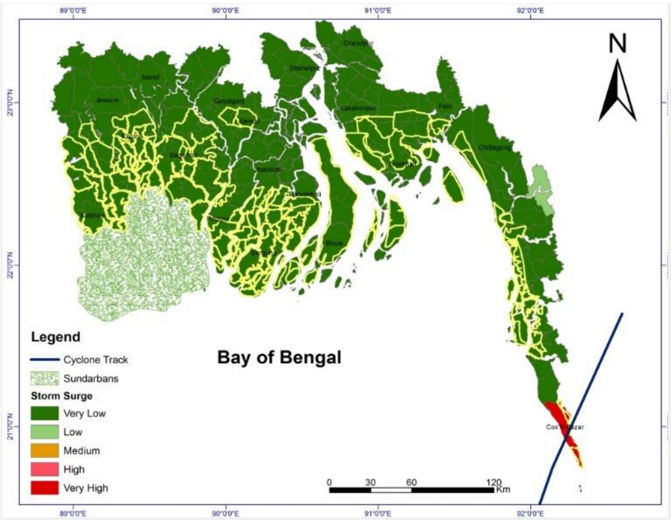
Scenario 1 (Low tide)



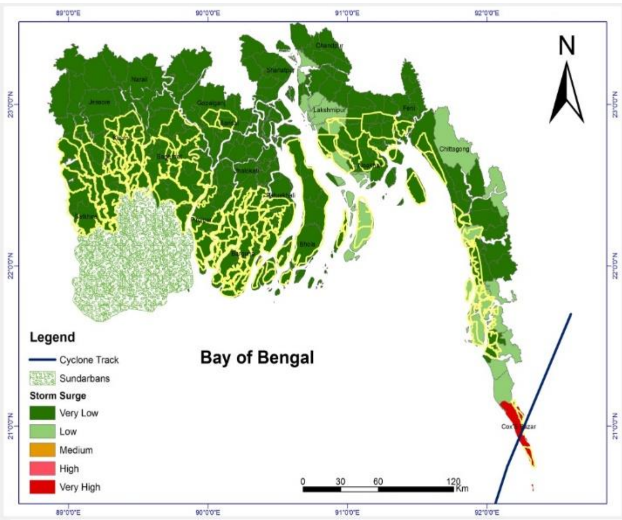
Scenario 2 (High tide)



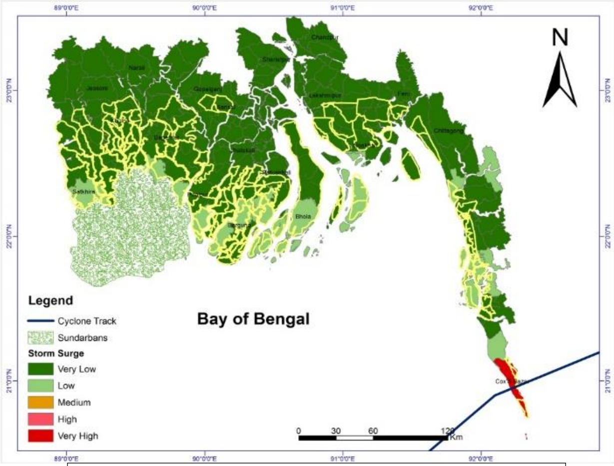
Scenario 2 (Low tide)



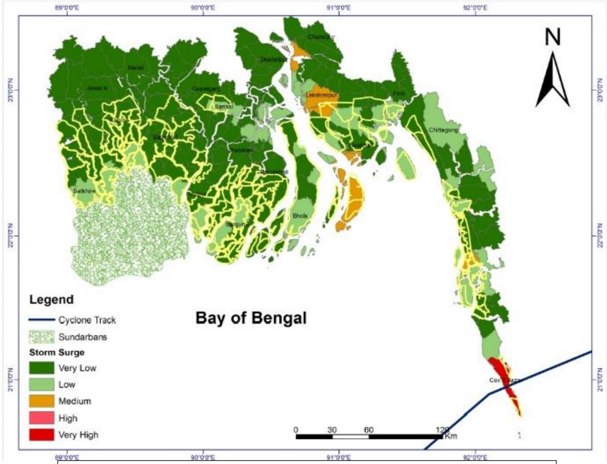
Scenario 3 (High tide)



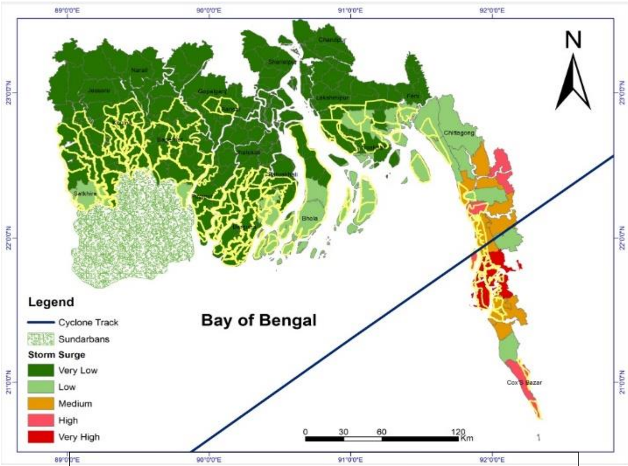
Scenario 3 (Low tide)



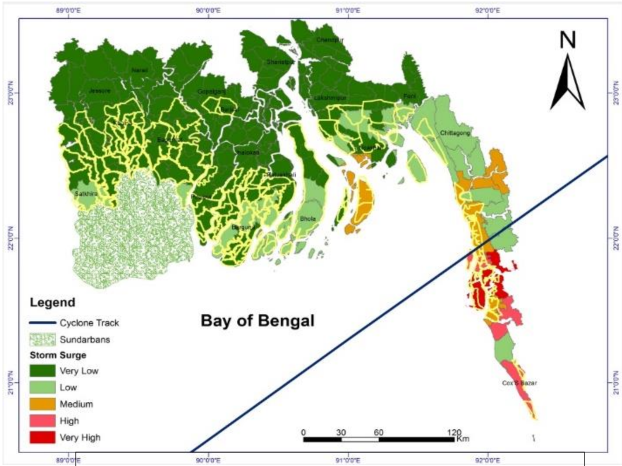
Scenario 4 (High tide)



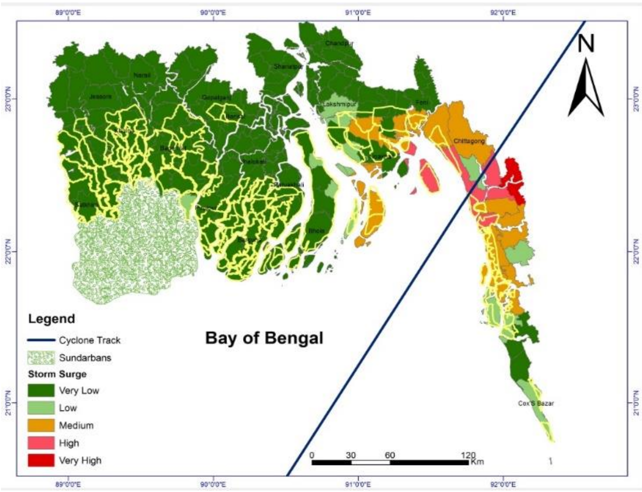
Scenario 4 (Low tide)



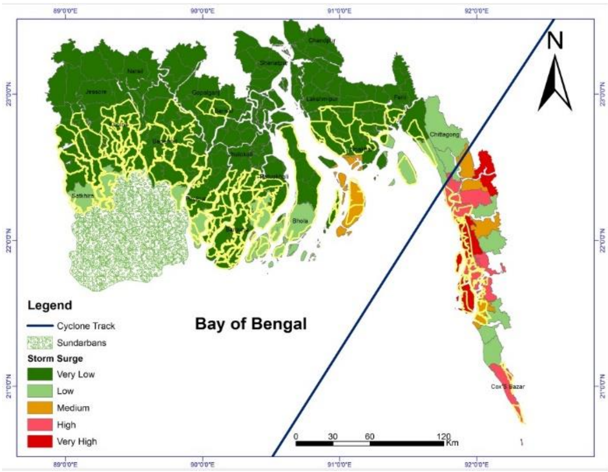
Scenario 5 (High tide)



Scenario 5 (Low tide)



Scenario 6 (High tide)



Scenario 6 (Low tide)

Figure 7.4: Probabilistic scenarios of cyclone mora track while passing coastal area of Bangladesh (Scenario 1-6).

Table 7.3: Probabilistic damage information on housing due to Cyclone Mora in Dacope Upazilla Khulna.

Scenario	Tidal condition	District	Upazilla	Surge height (m)	Wind speed (km/hr.)	Embankment damage conditions	Housing damage conditions
1	High tide	Khulna	Dacope	0.0	28	Possibility of substantial damage	All types of houses are likely to remain safe.
1	Low tide	Khulna	Dacope	0.0	12	Possibility of substantial damage	All types of houses are likely to remain safe.
2	High tide	Khulna	Dacope	0.0	27	Possibility of substantial damage	All types of houses are likely to remain safe.
2	Low tide	Khulna	Dacope	0.0	11	Possibility of substantial damage	All types of houses are likely to remain safe.
3	High tide	Khulna	Dacope	0.0	26	Possibility of substantial damage	All types of houses are likely to remain safe.
3	Low tide	Khulna	Dacope	0.0	10	Possibility of substantial damage	All types of houses are likely to remain safe.
4	High tide	Khulna	Dacope	0.0	14	Possibility of substantial damage	All types of houses are likely to remain safe.
4	Low tide	Khulna	Dacope	0.0	14	Possibility of substantial damage	All types of houses are likely to remain safe.
5	High tide	Khulna	Dacope	0.0	12	Possibility of substantial damage	All types of houses are likely to remain safe.
5	Low tide	Khulna	Dacope	0.0	12	Possibility of substantial damage	All types of houses are likely to remain safe.
6	High tide	Khulna	Dacope	0.0	16	Possibility of substantial damage	All types of houses are likely to remain safe.
6	Low tide	Khulna	Dacope	0.0	16	Possibility of substantial damage	All types of houses are likely to remain safe.

7.3.2 Testing performance against Cyclone Fani (2019)

Cyclone Fani made landfall on India's eastern coast on May 3, 2019, as a grade 5 storm, lashing beaches with rain and wind gusting up to 205 kilometers (127 miles) per hour. According to, India Meteorological Department (2019), the "extremely severe" cyclone in the Bay of Bengal hit the coastal state of Odisha around 8 a.m. and was forecast to weaken to a "very severe" storm as it moved north-northeast toward the Indian state of West Bengal. Special weather bulletin-35 of Bangladesh Meteorological Department informs that the very severe cyclonic storm "Fani" moved north-northeastwards, weakened slightly and lies over coastal Odisha and adjoining northwest bay (near lat. 20.5°n, long. 86.1°e) as a very severe cyclonic storm at 03 pm today (03 may 2019) and was about 445 km southwest of Mongla port, 495 km southwest of Payra port, 660 km west of Cox's Bazar port and 660 km west of Chattogram Port. It is likely to move in a North Northeasterly direction further over Odisha-West Bengal coastal area, reach Khulna and adjoining southwestern part of Bangladesh by midnight of 03 May 2019. Under the influence of the very severe cyclonic storm "Fani" and the new moon phase, the low-lying areas of the coastal districts of Chattogram, Noakhali, Laxmipur, Feni, Chandpur, Borguna, Bhola, Patuakhali, Barishal, Pirozpur, Jhalokathi, Bagherhat, Khulna, Satkhira and their offshore islands and chars were likely to be inundated by storm surge of 4-5 feet height above normal astronomical tide. The observed track of the SCS ‘FANI’ is shown in Figure 7.5

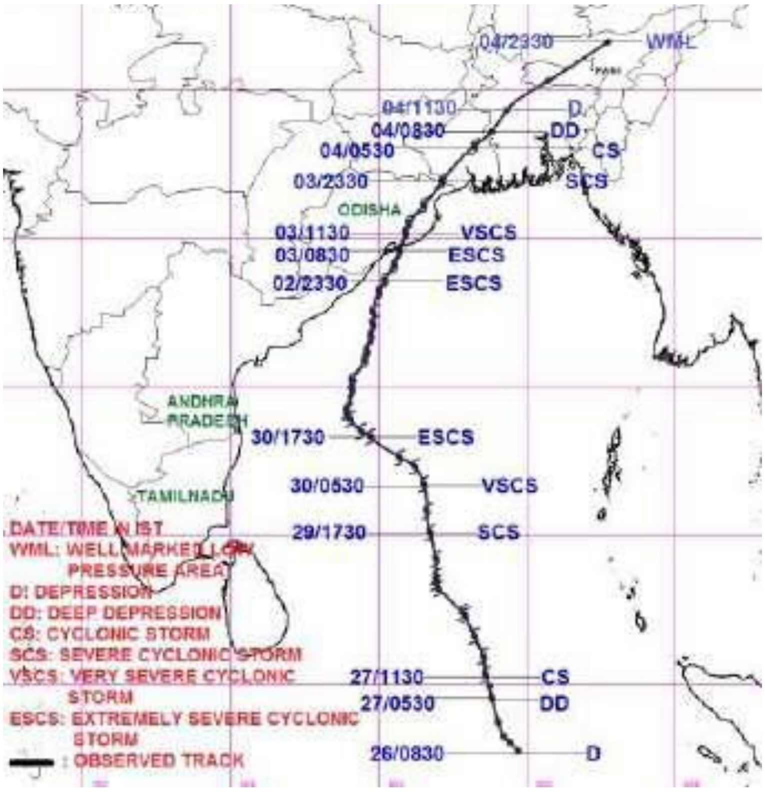


Figure 7.5: Observed Cyclone track of Fani (Source: IMD, 2019)

7.3.2.1 Model Results

After making landfall on Odisha, Khulna and the adjoining southwestern coastal region of Bangladesh have been experiencing the peripheral effect of the very severe cyclonic storm “Fani” from the morning of 03 May 2019. Maximum sustained wind speed within 74 km/hr. of the storm, center is about 140 kph rising to 160 kph in gusts/ squalls. After Landfall, two observed locations inside Bangladesh (from 04.05.2019. 12 AM to 04.05.2019 3 AM) and the proper wind speed of Cyclone Fani from IMD (See Table 7.4) were considered in CCM to measure the possible damage information in Dacope Khulna.

Table 7.4: Position and Status of Cyclone ‘FANI’ *(Source: IMD, 2019)*

Scenarios	Date	Time	Status	Area of the system	Latitude/ Longitude	Wind Speed
1	04.05.2019	12 AM	CS	Khulna and adj southwestern zone	23.1° N /88.2°E	74 km/hr.
2	04.05.2019	3 AM	DD	Khulna and adj southwestern zone	23.6° N /88.8°E	55 km/hr.

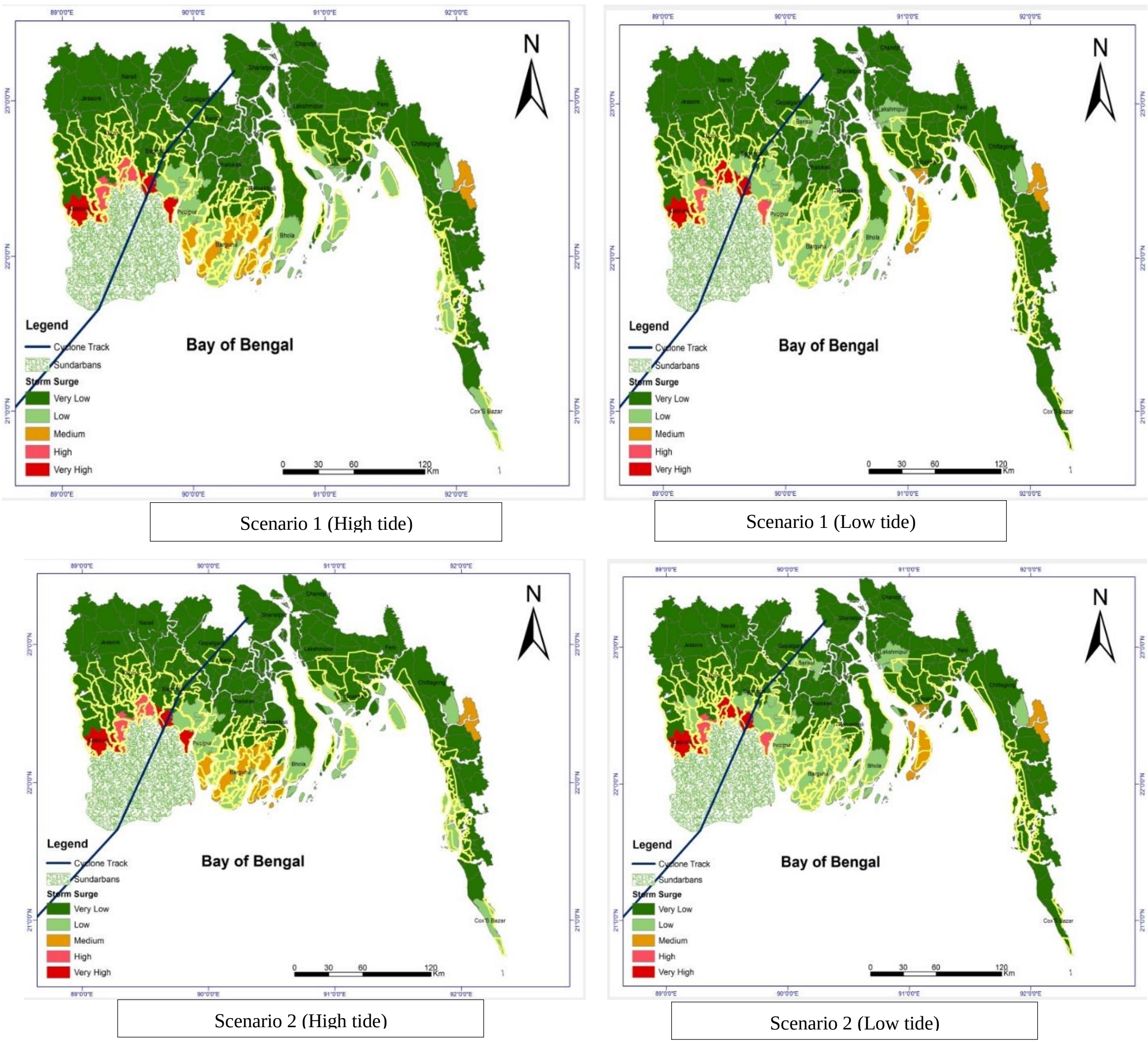


Figure 7.6: Probabilistic scenarios of Cyclone Fani track while passing southwestern area of Bangladesh (Scenario 1-2).

Fani weakened to a deep depression and moved into Bangladesh on 4 May. Figure 7.6 shows southwestern zone was highly vulnerable to surge impact for this deep depression. Especially Khulna and its adjoining districts were highly suspectable to storm surge water during high tide conditions. In both scenarios, the probable maximum wind speed in Dacope Upazilla was 83 km/hr. for high tide conditions and minimum wind speed was 62 km/hr. for low tide conditions. The probable surge height was found at 0.1m during high tide conditions in both scenarios. Possibility of substantial damage is found for embankments as structural conditions of southwest region polders are relatively poor than other regions. For both scenarios, Katcha houses were likely to be partially damaged, semi-paka and paka houses were likely to remain safe during high tide conditions. For low tide, all types of houses were likely to remain safe (See Table 7.5). According to the damage information of the model, the performance of the implemented housing design was moderate to high against Fani. There was a possibility have been found from the model results that the design may be collapsed or partially damaged due to Cyclone Fani.

Table 7.5: Probabilistic damage information on housing due to Cyclone Mora in Dacope Upazilla Khulna.

Scenario	Tidal condition	District	Upazilla	Surge height (m)	Wind speed (km/hr.)	Embankment damage conditions	Housing damage conditions
1	High tide	Khulna	Dacope	0.1	83	Possibility of substantial damage	Kacha houses are likely to be partially damaged. Semi-paka and paka houses are likely to remain safe.
1	Low tide	Khulna	Dacope	0.0	81	Possibility of substantial damage	All types of houses are likely to remain safe.
2	High tide	Khulna	Dacope	0.1	67	Possibility of substantial damage	Kacha houses are likely to be partially damaged. Semi-paka and paka houses are likely to remain safe.
2	Low tide	Khulna	Dacope	0.0	62	Possibility of substantial damage	All types of houses are likely to remain safe.

7.3.3 Testing performance against Cyclone Bulbul (2019)

Description of the disaster the special weather bulletin issued by the Bangladesh Meteorological Department (BMD) informed about a cyclone developing over the northwest Bay of Bengal (BoB) on 7 November 2019. Cyclone "Bulbul" reincarnating from Cyclone "Mamto" categorized as "very severe", made landfall over India on 9 November 2019 before entering Bangladesh on 10 November 2019 (local time at 12:00am-1:00am). The observed track of the SCS 'Bulbul' is shown in Figure 7.7

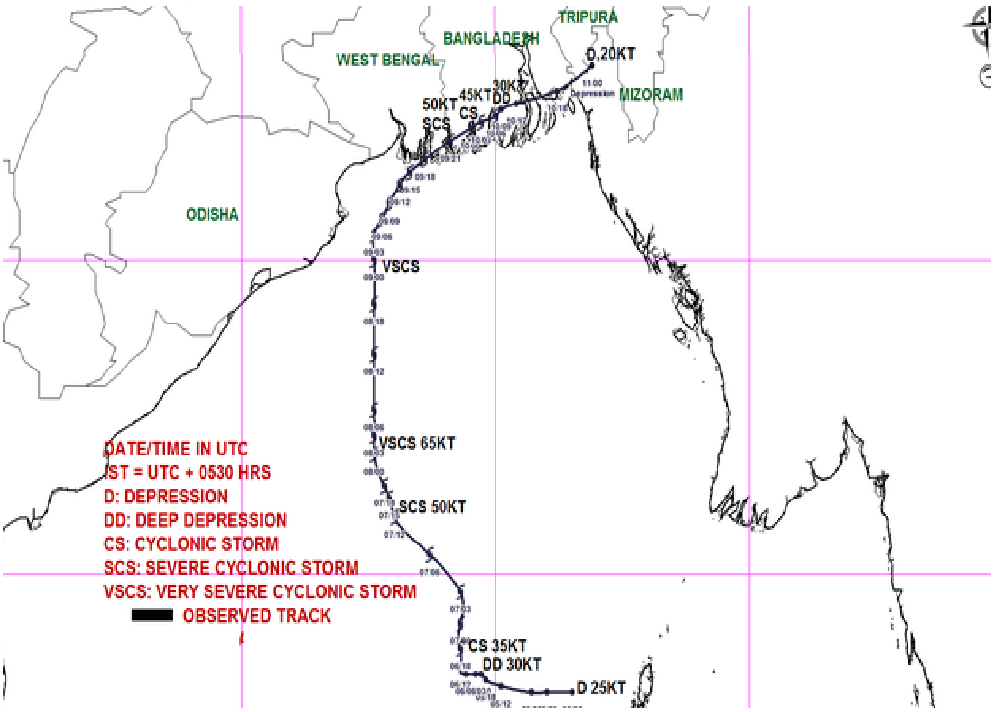


Figure 7.7: Observed Cyclone track of Fani (Source: IMD, 2019)

7.3.3.1 Model Results

After making landfall over India, the cyclone hit the Sundarbans with a wind speed of 120-130 km/h. The world's largest natural mangrove forest- the Sundarbans took a massive blow of Cyclone Bulbul which significantly slowed down the speed before it entered the locality. The cyclone impacted thirteen southern districts of Bangladesh while packing up winds of up to 120km/h and gusts of up to 130km/h. The cyclone stayed in Bangladesh for around 36 hours - one of the longest enduring cyclones that Bangladesh has ever faced in the last 52 years. For model results, three observed locations inside Bangladesh (from 09.11.2019. 12 AM to 10.11.2019 6 PM) and proper wind speed of Cyclone Bulbul from IMD (See Table 7.6) were considered in CCM to measure the possible damage information in Dacope Khulna.

Table 7.6: Position and Status of Cyclone 'Bulbul' (Source: IMD, 2019)

Scenarios	Date	Time	Status	Area of the system	Latitude/ Longitude	Wind Speed
1	09.11.2019	12 AM	SCS	Sundarbans coast	21.9° N /89.2°E	120 km/hr.
2	10.11.2019	6 AM	CS	Pirojpur and its adj districts	22.5° N /90.1°E	80 km/hr.
3	10.11.2019	6 PM	DD	Barisal division	22.8° N /90.3°E	45 km/hr.

Figure 7.8 shows coastal zone was highly vulnerable to surge impact for this severe cyclonic storm surge. Especially Khulna, Satkhira, Bagerhat, Barguna, Pirojpur, Barisal, and Jhalokathi districts were highly suspectable to storm surge water during high tide conditions. In 1 and 2 scenarios probable maximum wind speed in Dacope Upazilla was 101 km/hr. for high tide conditions and minimum wind speed was 57 km/hr. for low tide conditions. The probable surge height was found 0.4 -0.5 m during high tide conditions in both scenarios. Possibility of substantial damage is found for embankments as structural conditions of southwest region polders are relatively poor than other regions. In scenario 3 Cyclone Bublbul move towards the Barisal division as a deep depression. For this scenario, probable maximum wind speed in Dacope Upazilla was found at 32 km/hr. for high tide conditions and minimum wind speed was 26 km/hr. for low tide conditions with no surge impacts. In 1 and 2 scenarios of Bulbul, Katcha houses were likely to be fully damaged, semi-paka houses were likely to be fully damaged, and paka houses were likely to be partially damaged during both tidal conditions. In Scenario 3, all types of houses were likely to remain safe (See Table 7.7). According to the damage information of the model, the performance of the implemented housing design was low to moderate against Bulbul. There was a high possibility have been found from the results that the design may be fully damaged due to Cyclone Bulbul.

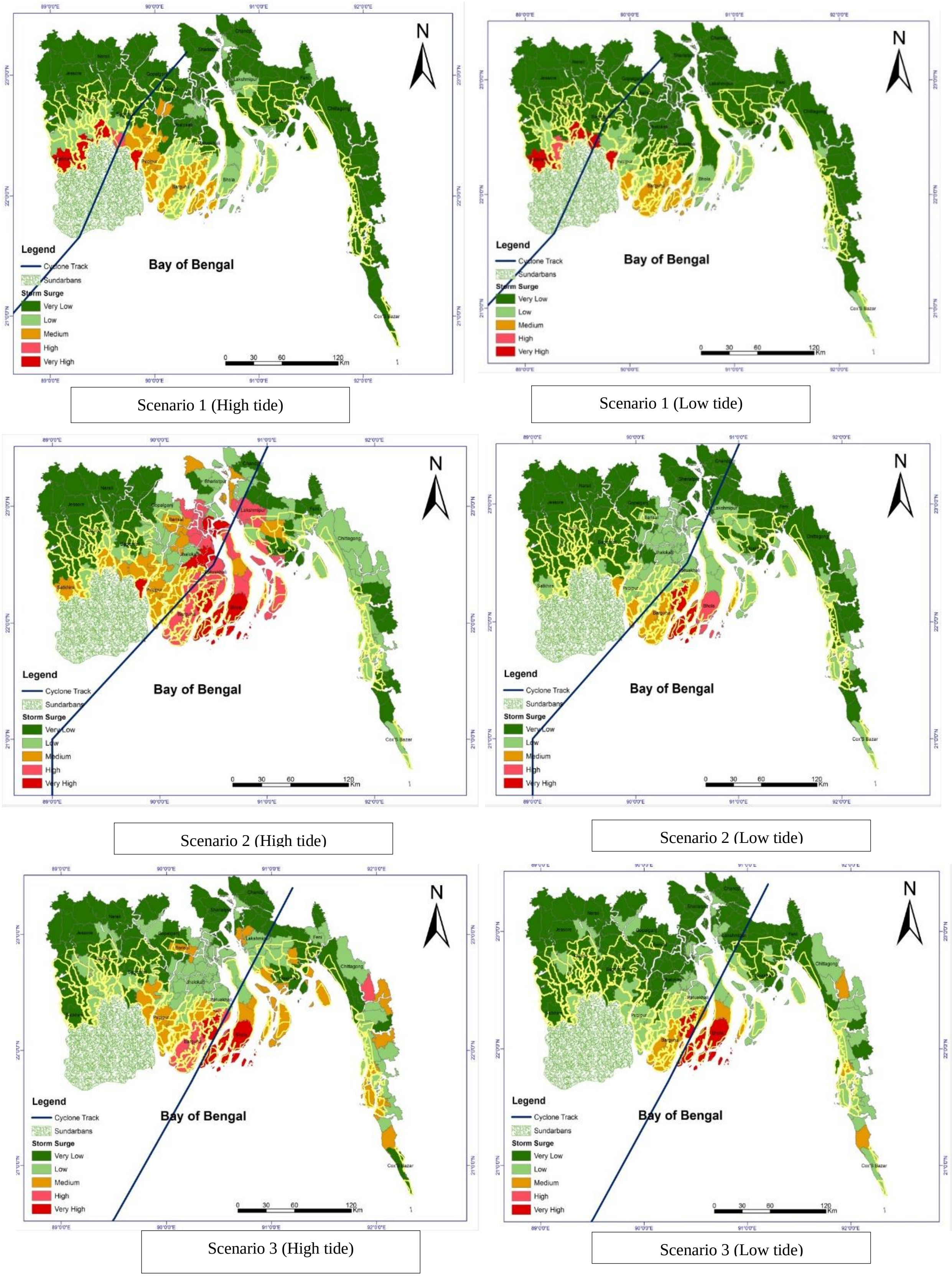


Figure 7.8: Probabilistic scenarios of Cyclone Bulbul track while passing coastal area of Bangladesh (Scenario 1-3).

Table 7.7: Probabilistic damage information on housing due to Cyclone Bulbul in Dacope Upazilla Khulna.

Scenario	Tidal condition	District	Upazilla	Surge height (m)	Wind speed (km/hr.)	Embankment damage conditions	Housing damage conditions
1	High tide	Khulna	Dacope	0.5	101	Possibility of substantial damage	Kacha houses are likely to be fully damaged. Semi-paka houses are likely to be fully damaged. Paka houses are likely to be partially damaged.
1	Low tide	Khulna	Dacope	0.4	98	Possibility of substantial damage	Kacha houses are likely to be fully damaged. Semi-paka houses are likely to be fully damaged. Paka houses are likely to be partially damaged.
2	High tide	Khulna	Dacope	0.4	57	Possibility of substantial damage	Kacha houses are likely to be fully damaged. Semi-paka houses are likely to be fully damaged. Paka houses are likely to be partially damaged.
2	Low tide	Khulna	Dacope	0.2	57	Possibility of substantial damage	Kacha houses are likely to be partially damaged. Semi-paka and paka houses are likely to remain safe
3	High tide	Khulna	Dacope	0.0	32	Possibility of substantial damage	All types of houses are likely to remain safe.
3	Low tide	Khulna	Dacope	0.0	26	Possibility of substantial damage	All types of houses are likely to remain safe.

7.3.4 Testing performance against Cyclone Amphan (2020)

Cyclone Amphan formed on 16 May 2020 over the Indian Ocean and started moving north over the Bay of Bengal, towards north-east India coastal areas and south of Bangladesh. According to Bangladesh Meteorological Department (BMD)'s special weather bulletin dated 19 May, the 'super cyclone' Amphan was lying over west central Bay and adjoining area and moved north to northeast wards and over same area and was centered at 06:00 of 19 May about 890km southwest of Chattagram port, 840km southwest of Cox's Bazar port, 785km south-southwest of Mongla port. It was forecasted likely to move in a north-easterly direction and may cross Bangladesh coast between Khulna Chattogram during late night of 19 May to afternoon/evening of 20 May. it weakened slightly and crossed West Bengal – Bangladesh coasts as a VSCS, across Sundarbans, near latitude 21.65°N and longitude 88.3°E on 20th May, with maximum sustained wind speed of 155 – 165 kmph gusting to 185 kmph. It lay over West Bengal as a VSCS, gradually moving north-northeastwards during late evening to night on 20th May. It moved very close to Kolkata during this period. Moving further north-northeastwards, it weakened into an SCS over Bangladesh & adjoining West Bengal around mid-night of 20th May, weakened further into a CS over Bangladesh in the early hours of 21st May, into DD over Bangladesh around noon of 21st May and into a D over north Bangladesh in the evening of the same day. It further weakened and lay as a well-marked low-pressure area over north

Bangladesh and neighborhood around mid-night of 21st May. The observed track of the ESCS 'Amphan' is shown in Figure 7.9

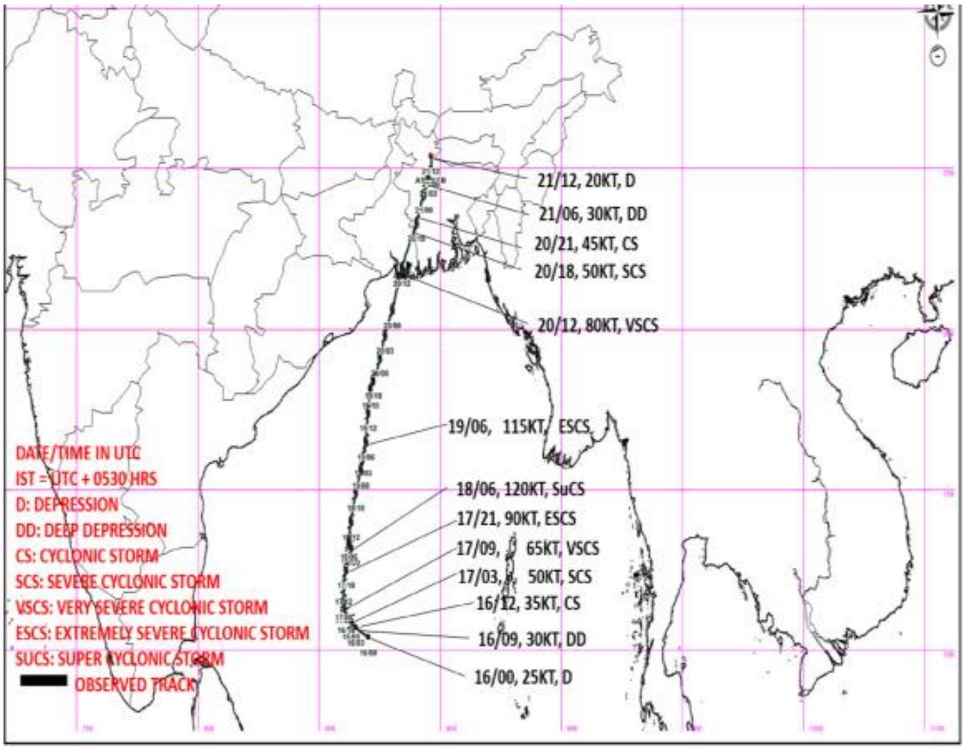


Figure 7.9: Observed Cyclone track of Amphan (Source: IMD, 2020)

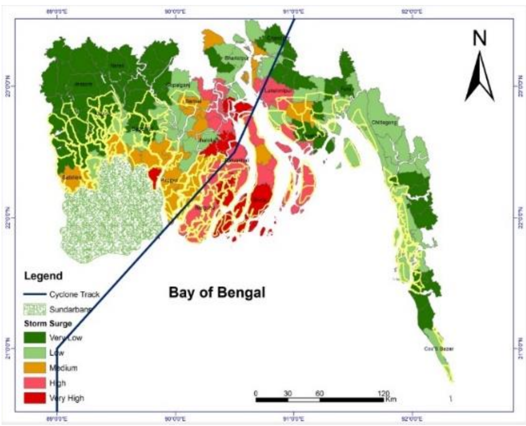
7.3.4.1 Model Results

The 'super cyclone' Amphan made landfall on 20 May 2020 on Jammu Island in West Bengal, India, and crossed Bangladesh on 20-21 May. In Bangladesh, the worst impact was experienced in Satkhira and Khulna where the storm speed was recorded between 60- 90 km/hr. with high tidal inundation. Barguna and Patuakhali also experienced high tidal inundation where the storm speed was recorded 60 km/hr. As the storm kept moving north, Jhenaidah, Chuadanga, Meherpur, Kushtia, Natore, Rajshahi, Naogaon, Joypurhat were also impacted by high winds and storms. It is notable that, due to the presence of Sundarbans, the wind speed reduced to minimal as well as the tidal surges were not that high as anticipated. For model results Five observed locations inside Bangladesh (from 20.05.2020. 12 AM to 21.05.2020. 12 PM) and proper wind speed of Cyclone Amphan from IMD (See Table 7.8) were considered in CCM to measure the possible damage information in Dacope Khulna.

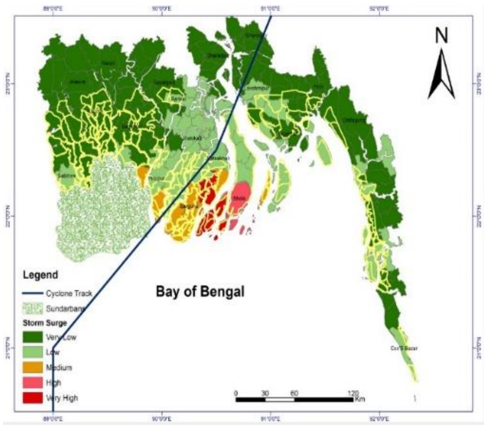
Table 7.8: Position and Status of Cyclone 'Amphan' (Source: IMD, 2020)

Scenarios	Date	Time	Status	Area of the system	Latitude/ Longitude	Wind Speed
1	20.05.2020	12 AM	SCS	Khulna region	23.3° N /89.0°E	92 km/hr.
2	20.05.2020	3 AM	CS	Khulna region	24.2° N /89.0°E	83 km/hr.
3	20.05.2020	6 AM	CS	Natore, Pabna	24.3° N /89.3°E	74 km/hr.
4	20.05.2020	9 AM	CS	Rajshahi	24.7° N /89.4°E	61 km/hr.
5	21.05.2020	12 PM	DS	Near Sirajganj	25.0 ° N /89.4°E	55 km/hr.

Figure 7.10 shows southwestern zone was highly vulnerable to surge impact for this severe cyclonic storm surge. Especially Khulna, Satkhira, Bagerhat districts were highly suspectable to storm surge water during high tide conditions. In 1-5 scenarios probable maximum wind speed in Dacope Upazilla was 57 km/hr. for high tide conditions and minimum wind speed was 45 km/hr. for low tide conditions. The probable surge height was found 0.2-0.4 m during high tide conditions in all scenarios. Possibility of substantial damage is found for embankments as structural conditions of southwest region polders are relatively poor than other regions. In all scenarios of Cyclone Amphan, katcha houses were likely to be fully or partially damaged during both tidal conditions (See Table 7.9). According to the damage information of the model, the performance of the implemented housing design was low to moderate against Amphan. There was high possibility have been found from the results that the design may be fully or partially damaged due to Cyclone Amphan.



Scenario 1 (High tide)



Scenario 1 (Low tide)

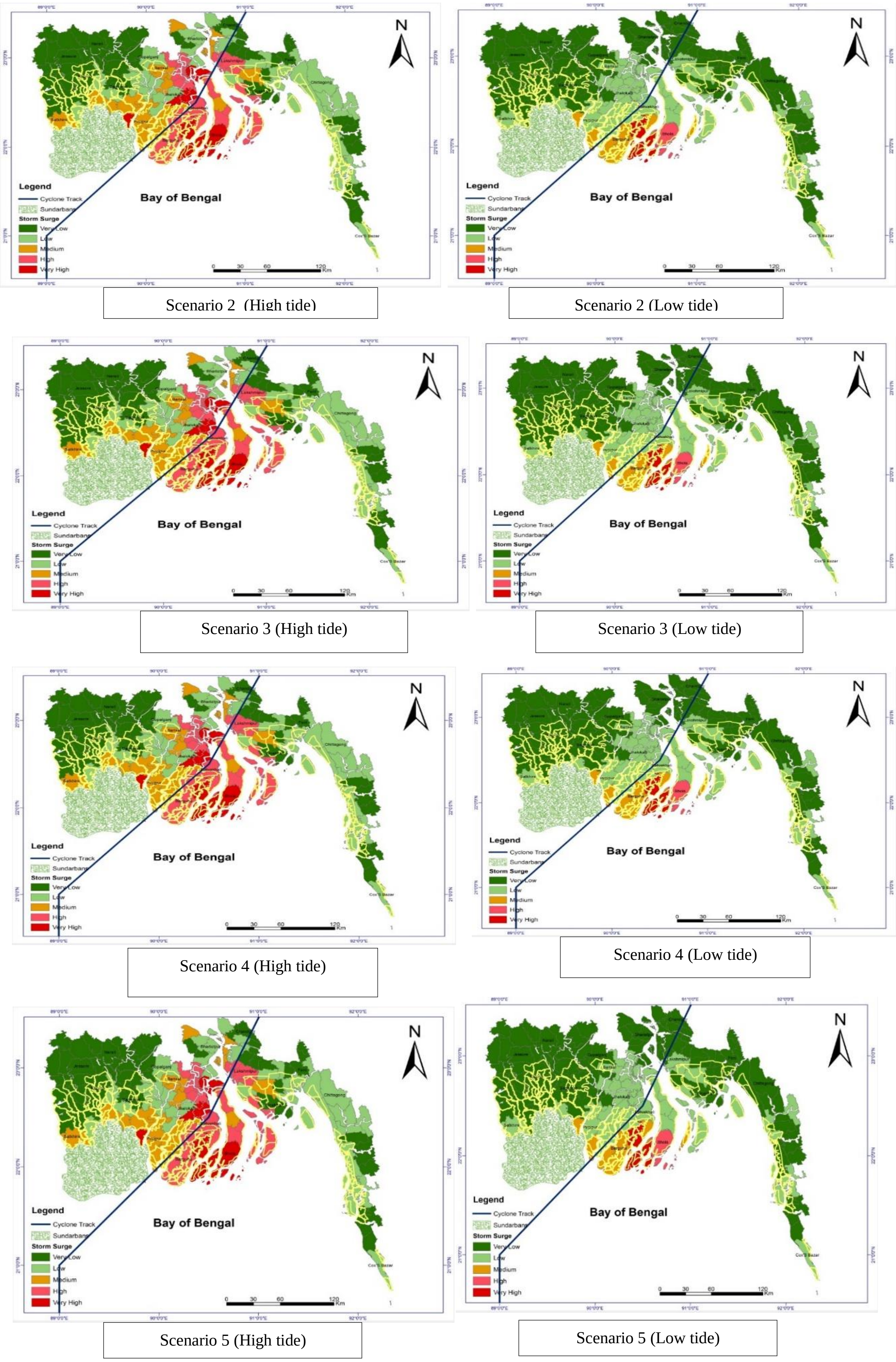


Figure 7.10: Probabilistic scenarios (1-5) of Cyclone Amphan track while passing Southwestern area of Bangladesh

Table 7.9: Probabilistic damage information on housing due to Cyclone Amphan in Dacope Upazilla Khulna.

Scenario	Tidal condition	District	Upazilla	Surge height(m)	Wind speed (km/h)	Embankment damage	Housing damage conditions
1	High tide	Khulna	Dacope	0.4	57	Possibility of substantial damage	Katcha houses are likely to be fully damaged. Semi-paka houses are likely to be fully damaged. Paka houses are likely to be partially damaged.
1	Low tide	Khulna	Dacope	0.2	57	Possibility of substantial damage	Katcha houses are likely to be partially damaged. Semi-paka and paka houses are likely to remain safe
2	High tide	Khulna	Dacope	0.4	51	Possibility of substantial damage	Katcha houses are likely to be fully damaged. Semi-paka houses are likely to be fully damaged. Paka houses are likely to be partially damaged.
2	Low tide	Khulna	Dacope	0.2	49	Possibility of substantial damage	Katcha houses are likely to be partially damaged. Semi-paka and paka houses are likely to remain safe
3	High tide	Khulna	Dacope	0.4	47	Possibility of substantial damage	Katcha houses are likely to be fully damaged. Semi-paka houses are likely to be fully damaged. Paka houses are likely to be partially damaged.
3	Low tide	Khulna	Dacope	0.2	47	Possibility of substantial damage	Katcha houses are likely to be fully damaged. Semi-paka and paka houses are likely to remain safe.
4	High tide	Khulna	Dacope	0.2	45	Possibility of substantial damage	Katcha houses are likely to be partially damaged. Semi-paka and paka houses are likely to remain safe
4	Low tide	Khulna	Dacope	0.1	45	Possibility of substantial damage	Katcha houses are likely to be partially damaged. Semi-paka and paka houses are likely to remain safe
5	High tide	Khulna	Dacope	0.2	45	Possibility of substantial damage	Katcha houses are likely to be partially damaged. Semi-paka and paka houses are likely to remain safe
5	Low tide	Khulna	Dacope	0.1	45	Possibility of substantial damage	Katcha houses are likely to be partially damaged. Semi-paka and paka houses are likely to remain safe

7.3.5 Validation from field observations.

CCM provides damage information of Katcha housing considering with or without any proper building approach. As mentioned earlier, 96% of people (in section 5.4.1) in the study area are living in Katcha or Jhupri houses which were made without any scientific collaboration. Before the implementation of the design, housing with a participatory approach in the study area was completely a new approach to the community.

Figure 7.11: (a) Impact of Cyclone Fani on housing in the study area (Captured: 06.05.2019). (b) Impact of Cyclone Bulbul on housing in the study area (Captured: 09.11.2019). (c) Impact of Cyclone Amphan on housing in the study area (Captured: 20.05.2020)

That's why damage information of these katcha houses in the field was quite similar to the model results. Especially, Cyclone Bulbul and Amphan made a significant negative impact on Katcha and Jhupri houses (See Figure 7.11). But for the participatory housing designs, damage information was different from the model results. lts that the design may be fully or partially damaged due to Cyclone Amphan.

Figure 7.12: Main structure of the designs sustained against impact of four cyclonic events after its implementation. (Captured date: 21.01.2021)

The main structure of the housing was sustained against all scenarios of the above-mentioned cyclones (see Figure 7.12). Few partial damages were found but not significant. In the last four years, beneficiaries of the implemented houses didn't evacuate to the cyclone shelter and stayed in their own houses without any major problems. For validation of the model results, 16 GDs were conducted among the community people immediately after every cyclone. A brief description between model results and field observation results is shown in Table 7.10

Table 7.10: Description between model results and field observation results

Cyclone Name	Model results	Field Results (households without any scientific approach)		Field Results (Participatory housing design approach)		
		Fully damaged (%)	Partially damaged (%)	Fully damaged	Partially damaged	Damage info.
Mora (2017)	All types of houses are likely to remain safe.	0%	0%	No	No	
Fani (2019)	Katcha houses were likely to be partially damaged	8%	32%	No	No	
Bulbul (2019)	Katcha houses were likely to be fully damaged	21%	36%	No	Yes	Several holes were found at wall.
Amphan (2020)	Katcha houses were likely to be fully damaged	34%	47%	No	Yes	Flood water washed few parts of plinth soil, several holes were found at wall.

As Cyclone Mora made landfall near the Chittagong coast, the southwestern region was unfamiliar with its impact. Both in model and field, no household damages were found. In Table 7.10, probabilistic model results for cyclone Fani are "Katcha houses were likely to be partially damaged". Immediate conducted GDs in the study areas after cyclone Fani was found that, 8% of participants completely lost their Katcha houses and 32% of participants had partially damaged. During Cyclone Bulbul and Amphan, both study areas Sreenagar and Jaliakhali inundated by 3-5 feet surge water claimed by the participants the GD. The model provides similar results for surge height with fully damaged information for the katcha houses. In the field after Cyclone Bulbul and Amphan the results were found that 21% of participants were against Bulbul and 34% of participants lost their katcha houses completely against Amphan respectively. And 36% of participants against Bulbul and 47% of respondents against Amphan had faced partial damage respectively.

Through the KII with architecture personal, local engineers, local builders, and local NGO representatives have identified a few points for sustaining the designed structure against these cyclones. From their observations the reasons are:

- The land use planning for the structure prevents direct hit from the wind and surge stress.
- Shape of the houses.
- Have wind tunnel to release extra pressure
- 2 m raising plinth
- Cross bracing on wall and roof structure

- Structural buttress
- Heavy roof installation mixing with palm leaves and CGI sheet.

7.4 Evaluation of the design impact

The evaluation of the design impact was done as outcome evaluation. Through the outcome evaluations it was assessed that how much effective of the design was for the beneficiaries against a cyclonic event as well as how much differences the design made in their normal life. Likert scale is used to rate the perceptions of the beneficiaries.

7.4.1 Effectiveness of main structure, storage, water system and sanitation

For the main structure, storage, water system and sanitation of the two houses, both beneficiaries rated the effectiveness scale against four real time cyclonic events that considered in model which is shown in Table 7.11

Table 7.11: Effectiveness of the implemented houses in the study area

Cyclone	Jaliakhali (Perceptions from Bikash Roy's family members)				Sreenaga (Perceptions from Bipul Mondal's family members)			
	Main Structure	Granary	Water System	Sanitation	Main Structure	Granary	Water System	Sanitation
Mora	Very High	Very High	Very High	Very High	Very High	Very High	Very High	Very High
Fani	Very High	High	Very High	Very High	High	High	High	High
Bulbul	High	High	Very High	Very High	High	Very High	High	High
Amphan	High	High	High	High	High	Low	High	High

7.4.2 Changes in beneficiaries' life

After implementation of participatory housing design approach for the beneficiaries, several changes have been identified in their normal livings. It's a complete package for them to become more resilient during and after disaster. The implemented houses not only gave them shelter against a hazard also helped them to make more empowered in livelihoods. The changes they have been identified before to after implementation of the houses are shown in Table 7.12.

Table 7.12: Changes in beneficiaries' life and livings after having ownership of a disaster resilient house

Sector	Before having the house	After having the house
Shelter during cyclones	Cyclone shelter with several constraints	In their own houses without having major problems during cyclone.
Social Status	Poor	Owner of a Disaster resilient house
Drinking Water	Had to collect from 1-1.5 km distanced PSF	Own safe drinking water source
Sanitation	Socially unsafe for female family members with no facilities	Safe for female family members with proper water and seal facilities
Livelihood	Had to loan amount of money for repairing house after a cyclone.	Minimal repairing cost which was accommodated from daily earnings.
Phycological conditions	Stressed after a cyclone	Stable and Calm

7.5 Cost Benefit Analysis

The present value of the benefits from resilient housing are likely to be highly sensitive to the expected timing of the cyclone events that would cause damage, yet these cyclones events are stochastic, or random to climate change. The results of cyclones modeling are, so far, mixed at best. Thus, it is not possible to add probabilities to different intensities of cyclones. Moreover, the damage caused is related to the wind speed and direction, and it is difficult to correlate wind speed, damages, and return periods for cyclones (see Khan et al., 2012). Table 7.13 shows the key driving factors of the cost-benefit analysis.

Table 7.13: Key driving factors of the cost-benefit analysis.

Factors	For DRH	Local Houses
Construction costs per house	18000 BDT	142000 BDT
Observed Year	4	4
Discount rate	10%	10%
Operation and maintenance (O&M	9% per year	22% per year
Annual asset growth	2.4%	2.2%

7.5.1. The CBA's results

The study utilized a scenarios approach to investigate the past economic impacts of cyclones in Dacope. Specifically, the research investigated two scenarios: (1) Without climate change where there are no damages are found, cause there no events were occurred in last four years and (2) With climate change where damages from the four real events were considered in particular years.

Without Climate change

In without climate change scenario, the NPV, IRR, and BCR are calculated using no cyclone events will be occur at different time periods over the lifetime of the house. Results of the base case (reported in Figure 7.13) show that NPV is >0 (i.e., market discount rate). This implies that the economic return on investment in cyclone resilient housing is desirable.

With Climate Change

As stated earlier, the ‘‘With Climate Change” scenario increases the amount of damage that occurs over the lifetime of the house. For the disaster resilient housing design, we considered four cyclone events that occurred after implementation of the houses. The return on investment in cyclone resilient housing is reported in Table 7.14.

Table 7.14: Calculation of the economic return of both designs

	For DRH Local Houses For DRH			Local Houses		
	Base case	**Best case**	**Worst case**	**Base case**	**Best case**	**Worst case**
NPV (BDT)	259484	310448	42420	75047	90560	-4272
NPV (US$)	$3126	$3740	$512	$905	$1092	$-51
IRR (%)	40.5	57.5	36.35	36.3	45.7	17.5
BCR	1.90	2.14	1.16	1.27	1.33	0.96

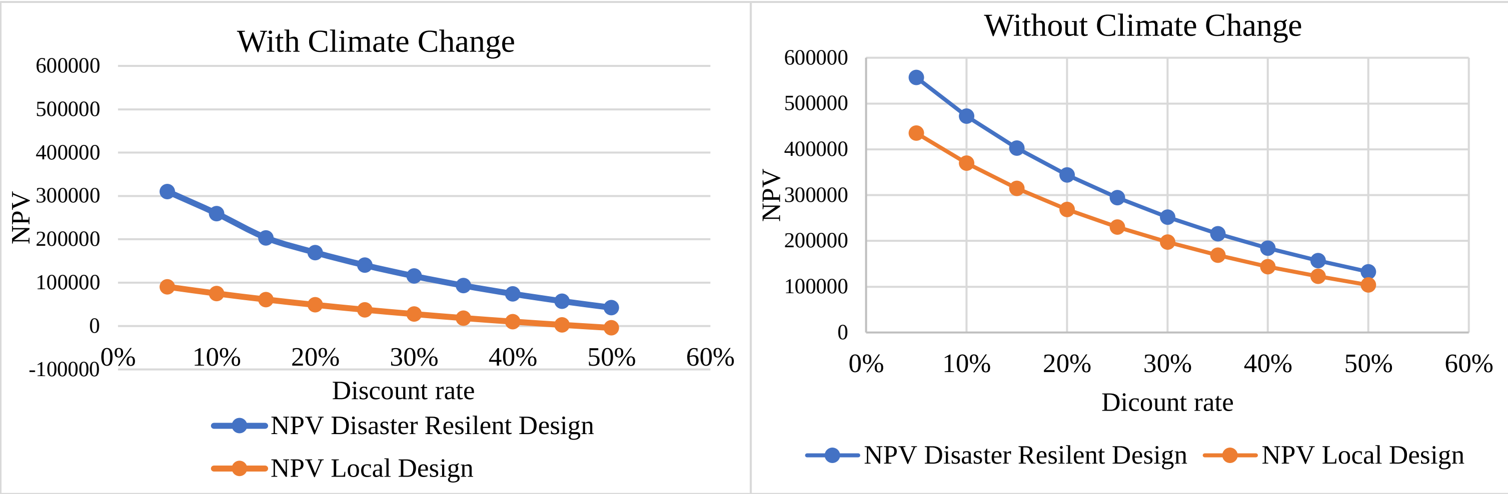


Figure 7.13: NPVs with different scenarios

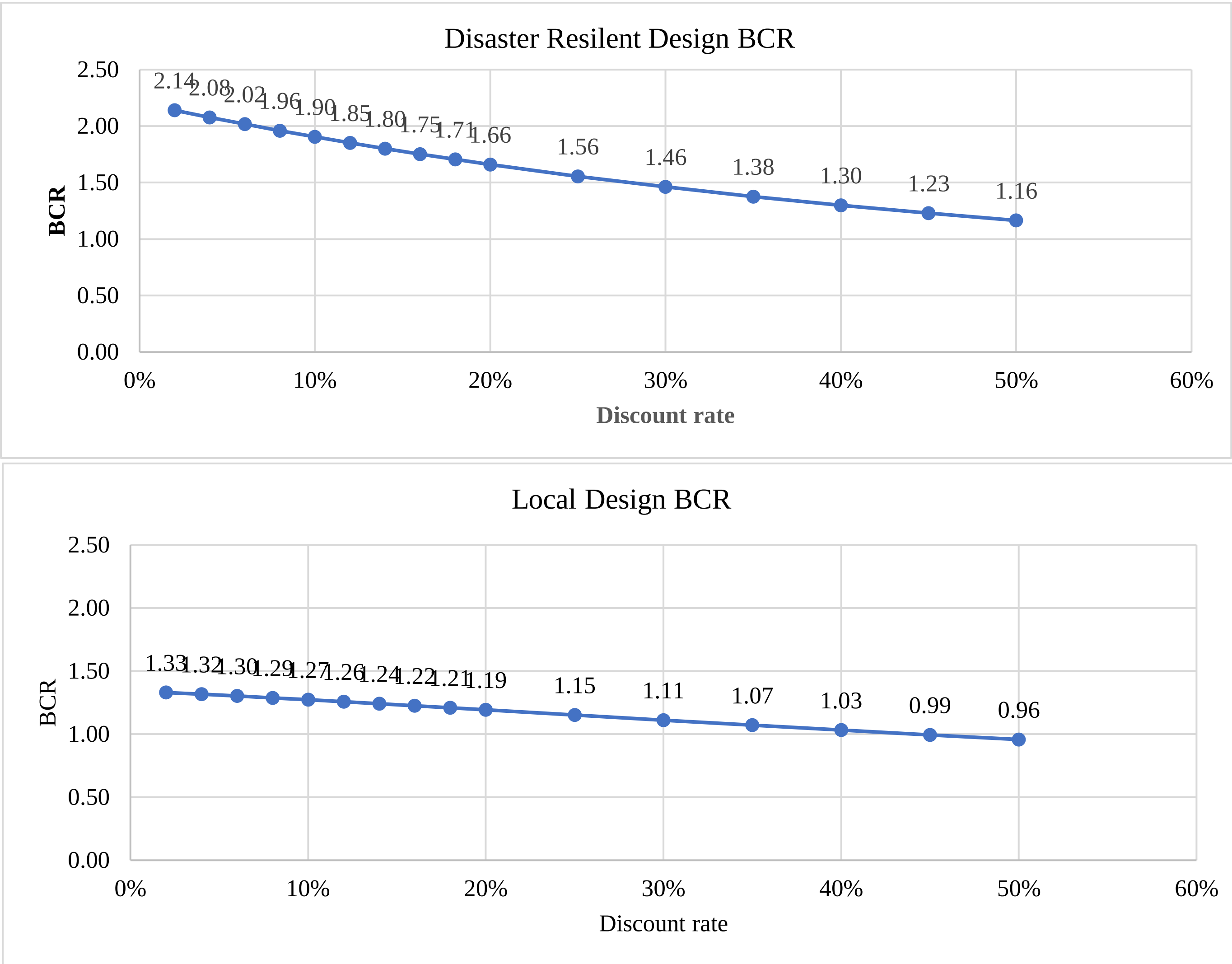


Figure 7.14: BCRs with different interest rates for housing design

Results of with climate change show that the BCRs for the sensitivity analysis range from 2.14 to 1.16 for disaster resilient housing design as seen in Fig. 7.14 compared to 1.33 to 0.96 for locally build design. In other words, the returns of disaster resilient housing design are higher than the returns of locally build design. This implies that considering the impact of climate change would result in higher returns on investment.

7.6 Limitations of the Study

1. The maximum capacity of the implemented design against wind load and surge velocity was unknown. Maximum wind load and surge velocity of the implemented design against cyclones, may create some unpredictable results on category 3-5 cyclones near future.

2. The model provides its output based on pseudo cyclone scenarios based on its database. The cyclones which were made landfall outside Bangladesh were difficult to precise accurate information. Though the provided information based on track location inside Bangladesh was validated with field data, actual information on housing damages still has some lacking.

3. The model provides information in large boundary unit such as Upazilla. Information on small boundary units like Mouza or village was completely missing. There may be a gap will create among the information of these units.

CHAPTER EIGHT

CONCLUSIONS AND RECOMMENDATIONS

8.1 Conclusion

This study was conducted to enhance community resilience through Disaster Resilient Housing design in two villages of Dacope Upazila of Khulna district. Most of the families in the study areas are poor, marginalized, and located in vulnerable areas that are prone to disasters. They live in vulnerable housing that is easily damaged by cyclone-induced storm surges.

To understand the underlying causes and vulnerabilities more briefly, problems associated with community resilience against cyclones were considered. It was found that the existing cyclone warning system of Bangladesh is not enough popular at the community level. The first problem associated with the warning system was the source. Several people still don't have any access to any types of warning signal sources. It was found that 28% of respondents in Jaliakhali and 17% of respondents in Sreenagar have no access to warning signals sources in the last four cyclone events. Financial barriers played a crucial role in impeding access to the sources. Then the problem associated with warning systems was warning message interpretation. Misinterpretation rates were high for information on "cyclone movement direction", "landfall time", and "surge height" compared to other information. 68% of respondents couldn't recognize the variations among the warning signals correctly. 82% of respondents claimed about several numbers of warning signals create confusion. 84% of respondents didn't understand the meaning of every signal and the differences among signal messages. And 67% of respondents had difficulties understanding forecasted formal language. Response to cyclone warning signals was relatively low in the study area as its effectiveness for supporting public and private properties were 'unknown' to the respondents in the study area. Another underlying cause that prevents community resilience against cyclones was the inadequate number of cyclone shelters and shortage of facilities in existing cyclone shelters for women and gender groups. Besides other influential reasons such as inadequate space, lacking food, water, and sanitation poor communication and transport system, distance to cyclone shelter, and lacking livestock place in cyclone shelter, etc. disheartened community people to evacuate in a shelter before a cyclone. The study results show that 74% of respondents in Jaliakhali and 81% of respondents in Sreenagar didn't evacuate during one cyclone out of the last four cyclones that occurred before the survey date. The effectiveness of the existing cyclone shelter is very high only for the 'life-saving structure for humans' indicator. Other's indicators were rated between 'unknown to low on the Likert scale by the respondents. Especially, for 'water, food, and sanitation facilities' 59% of respondents found it 'unknown'. The reasons behind the low effectiveness of the existing cyclone shelter were social, cultural, and political barriers. 51% of evacuee respondents had faced social barriers, about 41% had faced cultural barriers and 36% of respondents had faced political barriers by staying at a cyclone shelter during a cyclone. But still as a lifesaving structure, it plays very important role for the community people. 100% of respondents found it as highly effective to reduce human casualties.

The main findings in underlying causes that prevent community resilience against a cyclone were their housing conditions. About 96% of houses in the study area were Jhupri and Katcha and associated facilities such as drinking water systems and sanitation were unavailable. The reasons behind this condition were limited livelihood activities, lower-income levels, big family size, and inaccessibility to SSNP programs. The existed houses could play a resilient feature for the community people against a cyclone but the low quality of construction, lacking scientific knowledge and improper selection of materials made it difficult to achieve resilience through it. By understanding the findings, a participatory workshop was organized among the local masons, builders, architecture personals, engineers, NGO representatives, selected users, and so on to establish a housing design for further implementation. During the implementation phase, local wisdom and indigenous knowledge were used for materials selection, local builders and masons were instructed by architecture personal and engineers during construction and NGO representatives were involved in the monitoring of construction work.

After implementation, the performance of the structures against four observed cyclones were evaluated by regular basis monitoring proceedings. After a cyclone, beneficiaries' perception on the performance of the house was collected using a Likert scale. Through the field evaluations based on implemented housing performance found that there are no major damages occurred in the main structure during those cyclone events. Some insignificant damages to the wall and plinth were identified after cyclone Bulbul (2019) and Amphan (2020). The field evaluations also suggested that several changes have been identified in beneficiaries' normal lives and living. The disaster-resilient house was the key to reducing recovery time during the post-disaster phase and helped them to achieve resilience in pre-disaster conditions. In both disaster phases, it is a complete package for them to be one of the resilient families in the community.

To measure cyclone impacts on housing on large scale, Cyclone Classifier Model (CCM) is used to understand the community's scenarios. The model provides probabilistic damage information for the structure against a cyclone scenario. The model results show that the locally build Katcha structures were well performed against cyclone Mora. For cyclone Fani model provides structure damage information as "Katcha houses are likely to be partially damaged" and for cyclone Bulbul and Amphan "Katcha houses are likely to be fully damaged". The model results were validated with field data where it was observed that model gives accurate structure damage information of local Katcha households which were built without any scientific approach. In comparison between model and field evaluation results, the combination of scientific and local wisdom in participatory housing design was identified as the main reason for sustaining those cyclone impacts. The following conclusions on enhancing community resilience through disaster-resilient housing can be drawn from key findings.

- ✓ The formal supports which were government initiated for community resilience against cyclone-induced hazards were not properly operational, not oriented, and not easily accessible to community people. Several constraints are impeding these supports to community people for gaining its maximum effectiveness.
- ✓ After a cyclone, community people were more interested in long-term solutions after emergency response instead of relief-based solutions. In the recovery phase, from shelters to sanitation, disaster resilient housing was able to fill up every need of beneficiaries.

- ✓ The development of disaster-resilient housing was not possible without a combination of scientific knowledge and local wisdom in a participatory way. This concept reduced extra cost for the structures as well as enhanced effectivity of community people. The design ensured other facilities like food, water, sanitation, etc. which are related to resilient housing.
- ✓ Impeding indicators like cascading impact of the cyclone, losing land, or losing livelihoods, poverty etc. extended the recovery time of housing resilience in post disaster phase. To achieve resilience through housing formal supports like assisting for repair or reconstruction, managing livelihoods, food, and family education are the responders for making up the duration of recovery against a cyclone.
- ✓ Field results suggested that a disaster-resilient structure that was developed in a participatory way could be sustained against the category 3 cyclone

  By Considering the findings, if government will turn the existed local houses into Disaster Resilient House in the community using this participatory knowledge, it will be very easy to achieve the community resilience against category 3 cyclone. Especially it will enhance the capacity of Build Back Better policy in post-disaster phase. Besides cyclone shelter is the most important structure for saving human lives. It can withstand against category 5 cyclones. But often a bamboo made structure is unable to absorb category 5 stress. However, category 5 cyclones are intermittent, but category 3 cyclones are prominent. So, by integrating both cyclone shelters and Disaster Resilient House in the community level of Bangladesh, policymakers will find an easy lead to achieve resilience against any category cyclones.

8.2 Recommendations

Based on present studies following recommendations are made:

- ➢ Extensive research can be conducted in another cyclone-prone coastal area by implementing more disaster resilient housing prototypes or by converting existing locally build Katcha houses into disaster resilient houses using a participatory design approach. If the prototypes will perform properly against cyclone-induced storm surges, it will be a great way for providing information to policymakers to know the way of achieving community through Disaster Resilient Housing.
- ➢ The cyclone classifier model provides structure damage information based on locally built katcha houses. It will be very convenient to conduct another research on the possibility of adding resilient housing damage information to the cyclone classifier model.
- ➢ As the proposed design is still sustained. Extensive research can be done to measure its performance against cyclones by considering more real-time events.
- ➢ In this study, Cyclone Classifier Model was used in the Upazilla boundary unit. Further research at the village level can assist to validate the model results at the village boundary unit.
- ➢ In this study, there was a gap in the relationship between embankment damage with housing damage. Extensive research can be done to fill up this gap.

- The maximum capacity of the structure was unknown. Further research can be done by measuring direct wind load and surge stress on the proposed structure design.
- Evaluation of the design performance was done by considering only users' perceptions. More expert opinions can be assisted in this research to evaluate the performance.

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APPENDIX A

Damage data

Table A 1: Crops (n= 165), Granary (n= 78) and Livestock place (n=133)

Cyclones	Losing crops	Losing Livestock Place	Losing Granary
Cyclone Aila	94.9%	78.3%	89.2%
Cyclone Mahasen	25.2%	16.6%	6.7%
Cyclone Komen	23.5%	11.5%	3.2%
Cyclone Roanu	38.3%	19.2%	4.1%

APPENDIX B

APPENDIX B.1

COSTRUCTION COST OF A LOCAL HOUSE

SL	Expenditure	Amount (BDT)
1	Bamboo	40000
2	Bending materials	4000
3	Wood	4700
4	Labor bill	6000
6	CGI sheet	20000
8	Bamboo matt	7300
9	11 CFT wood	1700
11	Bricks and ferro cement	5000
12	Pit, pan, and ring slab	4320
13	Mason and Carpenter bill	30000
14	1500 liter. Tank	10000
15	Transportation Cost	9000
	Total	142020

APPENDIX B.2

NPV-DISATER RESILIENT DESIGN

Without Climate change				10%	With Climate change				
Year	Benefit	Cost	B-C	B-C/(1+r) ^t	Year	Benefit	Cost	B-C	B-C/(1+r) ^t
0	0	180000	-180000	-180000	0	0	180000	-180000	-180000
1	180000	0	180000	163636.3636	1	169000	11000	158000	143636.3636
2	180000	0	180000	148760.3306	2	152000	17000	135000	111570.2479
3	180000	0	180000	135236.6642	3	130000	22000	108000	81141.9985
4	180000	0	180000	122942.422	4	107000	23000	84000	57373.13025
S. Value	120000	0	120000	81961.61464	S. Value	67000	0	67000	45761.90151
				472537.395					259484

NPV-LOCAL RESILIENT DESIGN

Without Climate change				10%	With Climate change				
Year	Benefit	Cost	B-C	B-C/(1+r)^t	Year	Benefit	Cost	B-C	B-C/(1+r)^t
0	0	142000	-142000	-142000	0	0	142000	-142000	-142000
1	142000	0	142000	129090.9	1	135000	7000	128000	116363.6
2	142000	0	142000	117355.4	2	108000	27000	81000	66942.15
3	142000	0	142000	106686.7	3	96000	12000	84000	63110.44
4	142000	0	142000	96987.91	4	18000	78000	-60000	-40980.8
S. Value	90000	0	90000	61471.21	Scurp	17000	0	17000	11611.23
				369592.1					75047

APPENDIX B.3

IRR- DISATER RESILIENT DESIGN

		10%	Cash inflow				
Year		Cost	B-C	Discount factor 10%	PWCI	Discount factor 15%	PWCI
0	-180000	180000	-180000	1	-180000	1	-180000
1	169000	11000	158000	0.909090909	143636.3636	0.869565217	137391.3043
2	152000	17000	135000	0.826446281	111570.2479	0.756143667	102079.3951
3	130000	22000	108000	0.751314801	81141.9985	0.657516232	71011.7531
4	107000	23000	84000	0.683013455	57373.13025	0.571753246	48027.27263
					213721.7403		178509.7252
		IRR		40.35			

IRR-LOCAL RESILIENT DESIGN

		10%	Cash inflow				
Year	Benefit	Cost	B-C	Discount factor 10%	PWCI	Discount factor 15%	PWCI
0	0	142000	-142000	1	-142000	1	-142000
1	135000	7000	128000	0.909091	116363.6	0.869565	111304.3
2	108000	27000	81000	0.826446	66942.15	0.756144	61247.64
3	96000	12000	84000	0.751315	63110.44	0.657516	55231.36
4	18000	78000	-60000	0.683013	-40980.8	0.571753	-34305.2
					63435.42		51478.15
		IRR		36.52589			

APPENDIX B.4

BCR- DISATER RESILIENT DESIGN

		10%			
Year	Benefit	Cost	Discount factor	PWCI	PWCO
	0	180000	1	0	180000
1	169000	11000	0.909090909	153636.4	10000
2	152000	17000	0.826446281	125619.8	14049.59
3	130000	22000	0.751314801	97670.92	16528.93
4	107000	23000	0.683013455	73082.44	15709.31
				450009.6	236287.8
			BCR	1.904497	

APPENDIX B.4

BCR- LOCAL RESILIENT DESIGN

		10%			
Year	Benefit	Cost	Discount factor	PWCI	PWCO
	0	142000	1	0	142000
1	135000	7000	0.909091	122727.3	6363.636
2	108000	27000	0.826446	89256.2	22314.05
3	96000	12000	0.751315	72126.22	9015.778
4	18000	78000	0.683013	12294.24	53275.05
				296403.9	232968.5
			BCR	1.272292	

APPENDIX C

PHOTOGRAPHS

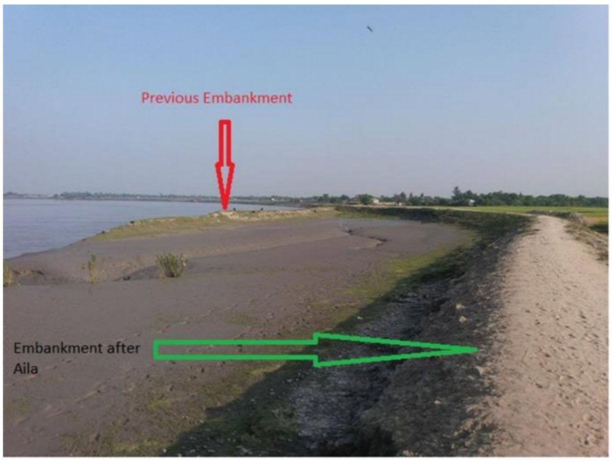

Photo B 1: Breached embankment due to Aila

Photo B 2: Communication system of Jaliakhali village

Photo B 3: Only shelter that available in study villages

Photo B 4: Non-operational PSF at Sreenagar

Photo B5: Housing conditions in Jaliakhali village

Photo B 6: Housing conditions in Sreenagar village

Photo B 7: Sanitation system in Jaliakhali village

Photo B 8: Sanitation system in Sreenagar village

Photo B 9: Social mapping with female group

Photo B 10: Notation of transect walk findings

Photo B 11: FGD with farmer group

Photo B 12: Group Discussion for model validation after Amphan

Photo B 13: KII with UP member of Jaliakhali village

Photo B 14: Outputs of participatory workshop at Sreenagar

Photo B 15: Local people, user, NGO members, builders etc. are participating at housing model development