A STUDY OF GEO-CLIMATIC VULNERABILITY AND ITS RESPONSE IN THE SETTLEMENT PATTERN IN COASTAL BANGLADESH

by

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ABSTRACT

Settlements in low elevation coastal zone (LECZ) of Bangladesh are exposed to the risk of geo-climate hazards at present and anticipated sea level rise (SLR) resulting from possible climate change. This will have serious impact on natural and built environment of coastal areas including loss of ecosystem and habitable land due to inundation. The present study is an analytical attempt to identify key vulnerabilities of coastal settlement in selected area to the current and anticipated geo-climatic risk with an aim to set criteria for local level mitigational intervention in settlement planning and design in response to hazards.

It is learned that, settlement's exposure to geo-climatic risk is not alike and the level of vulnerability within same risk exposure differs depending on the degree of settlement resilience i.e. the ability of settlement components or features to resist or recover. The study reveals that, in addition to the geo-climatic risk, the existing settlement features including dispersed settlement pattern, transient nature of house, poor access to service and shelter and inappropriate measure of protection makes the coastal community most vulnerable. To reduce vulnerability, adaptation is the most viable and manageable of the responses to climate change especially for the least developed country like Bangladesh. Measures like protection (mitigation), accommodation (modification) and retreat (migration) are the three structural forms of adaptation in settlement pattern in coastal area. Both planned and autonomous measures are observed to improve the capacity of settlement resilience at local level. To date, planned adaptation in human settlements in response to geo-climatic risk has been observed minimal and mostly limited to coastal afforestation, embankment construction and establishment of community and family shelters by the government and non government organization. Autonomous measures include structural and non structural coping practices by the local people and mostly confined within household level.

The study suggested that, creation of effective shelter belt with mangrove species and adoption of indigenous measure of tidal river management (TRM) to allow natural siltation inside the polder area should be the key protection measures. Vulnerability of settlement can be reduced by improving the community or group resilience through planned densification in settlement pattern in low risk area and Nucleated settlement elevated on stilts in high and moderate risk zone along with management of geomorphology and hydrological process of the context (allow natural siltation, improve water drainage, rainwater harvesting etc). Local coping measures to reduce vulnerability due to existing climate related hazards (erosion, water logging, flooding, surge, cyclone) can also serve as means and guide for adapting to climate change. It is likely to be easier if action is taken in rural areas where development is still sparse as opposed to the dense urban area.

The study concludes that, national policy of adaptation should be revised to include strategies for in-situ settlement adaptation. Care should be given to adoption of measures that are responsive, contextual and culturally accepted by the coastal community as a whole.

Keywords: Coastal settlement, vulnerability, adaptation, geo-climate, hazard, climate change.

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List of Abbreviation

ADB- Asian Development Bank
BBS- Bangladesh Bureau of Statistics
BUET- Bangladesh University of Engineering and Technology
BWDB- Bangladesh Water development Board
CEGIS- Center of Environmental Geographic Information LECZ – Low Elevation Coastal Zone
CERP-Coastal Embankment Rehabilitation Project
CBA- Community Based Adaptation
CCC- Climate Change Cell
CEP- Coastal Embankment Project
DRRO-District Relief and Rehabilitation Office
GHG- Green House Gas
HYV-Hybrid Yield Variety
ICZMP-Integrated Coastal Zone Management Programme
IPCC- Intergovernmental Panel on Climate Change
IWM – Institute of Water Modeling
KJDRP-Khulna-Jessore Drainage Rehabilitation Project
LGED- Local Government Engineering Department
MCE-Multiple Criteria Evaluation
MCSP-Multi-purpose Cyclone Shelter Programme
MoFDM- Ministry of Food and disaster Management
MoWR-Ministry of Water Resources
NAPA- National Adaptation Programme of Action
NGO-Non Government Organization
OED-Operation Evaluation Department
PDO-ICZMP-Programme Development Office- Integrated Coastal Zone Management Programme
SLR – Sea Level Rise
SMRC- SAARC Meteorology Research Center
SRDI-Soil Resource Development Institute
TRM – Tidal River Management
UKCIP-United Kingdom Climate Impacts Programme

Chapter 1

Introduction

1.1 Background of the problem

Human settlement of Bangladesh is eked out of the geo-climate of the region and their physical manifestation in the landscape is the outcome of the interaction of man and environment. Change in any part of the natural environment (terrestrial, aquatic or atmospheric) has subsequent impact on other parts including the human settlement. It has now been widely recognized that climate is changing and anticipated change in global climate will have significant impact on the natural environment and therefore on human settlement. Among the manifold impacts of climate change, rise of sea level may cause serious damage to marine and terrestrial environment of coastal area. Though there is still considerable uncertainty about the course and magnitude of the changes, there is a little doubt that sea level rise (SLR) is an unavoidable phenomenon and if unnoticed human settlements in low elevation coastal zone (LECZ) will be adversely affected by the anticipated geo-climatic change in near future.

Historically Bangladesh is subject to a variety of natural hazards, which has potential to threat both its population and environment. As one of the biggest deltas of the world the country has some melancholy experiences regarding the floods of 1987, 1988, 1998, 2004 and 2007, and the cyclones of 1970, 1985, 1991, 1997 and 2007 where massive damages and casualties had been occurred (GOB-MoFDM, 2008; Khan, 2008).This multi-hazardous situation does not create an immense human disruption only; obstruct the sustainable socioeconomic and environmental development also (Khan, 2008). The geographical shapes and characteristics of the coastal areas of Bangladesh make this situation multifaceted. Due to these numerous attack of natural disasters especially cyclone and flood the vulnerability of the affected communities has been increasing alarmingly. It is forecasted that these vulnerabilities would be acute due to the combined effects of climate changes, sea level rise, subsidence, and change of upstream river drainage.

Coasts are, in fact, already experiencing the adverse consequences of hazards related to climate and sea level rise (IPCC, 2007a). Through the 20th century, global rise of sea level contributed to increased coastal inundation, erosion and ecosystem losses along with growing frequency and magnitude of sea borne hazards like storm surges and cyclones etc (IPCC, 2007a & Oliver-Smith, 2009). Considering present trends and future projection of SLR, of the 40 deltas globally, Ganges Brahmaputra delta of Bangladesh is identified as an ‗extreme vulnerable coastal delta' where more than 16% land is at risk of permanent inundation. Even sea level rise at current trends, there is a risk of displacement of one million populations by the year 2050 (Ericson et al., 2006).In case of 1m rise in local sea-level, the scenario will be much worse as indicated by UN Intergovernmental Panel on Climate Change (IPCC) where they predicted 15 million of climate refugees (IPCC, 2007b). The resettlement of these displaces people (climate refugees) to inland will pose a serious problem for densely populated country like Bangladesh (Mowla & Choudhury, 2011).

The coastal zone of Bangladesh is a unique ecosystem of incalculable value in a social, cultural, economic and environmental terms characterized by its diverse and dynamic geo-hydrologic features and dense human settlement. Historically settlements in coastal area are exposed to different natural hazard like cyclone, tidal inundation, water-logging, salinity and erosion etc. The people of coastal region have been living with adverse climate for long and adapting over generations responding to the natural hazards and geo-hydrology of the context with their indigenous knowhow and practices. As geo-climate of entire coastal zone is not alike, response to local environment differs so as the pattern of human settlements. In other words a diverse pattern of coastal settlement has emerged to respond to its context. Climate and Geo-physical environment such as physiography, natural drainage, soil productivity and vegetation etc. all plays an important role in shaping the settlement pattern. Sea level rise (SLR), as anticipated, will severely affect the geo-climate of the coastal area. Failure to respond to frequent or severe changes in the geo-climate may lead to unfavorable environment for living thus cause vulnerability.

Assuming the SLR projection and forecasts to be true it calls for preemptive response to limit the effects of SLR, to reduce their vulnerability and to help the coastal population adapt to the changes. The question is whether the traditional settlement pattern has the potential to adapt with the changing climate and if not then what are the potential options for in-situ adaptation in settlement pattern? The study would investigate the present scenario and possible impact of relative SLR on human settlement of selected area of low elevation coastal zone (LECZ) with an aim to identify the key vulnerabilities and possible adaptation response to them in the settlement pattern.

1.2 Specific problem: Sea Level Rise (SLR) and risk of inundation

Vulnerability of coastal settlement in the present and anticipated future context varies widely within the regions depending on the geophysical and ecological parameters of the coastal area, socio-economic system and management capability (Hoque et al, 1999). Since the entire coastal region of Bangladesh is delineated into two physiographic divisions; one is ‗exterior coast' which have areas exposed to the sea and/or lower estuaries and other one is ‗interior coast' which have no area directly exposed to the sea (PDO-ICZMP, 2003a) (Appendix- A), so it can be assume that nature and degree of vulnerability will not be same in those regions.

Then again vulnerability of a system primarily depends on its exposure to risk. Coastal region of Bangladesh is at great risk of inundation from projected sea-level rise (SLR) that refers both to the conversion of dryland to wetland and the conversion of wetlands to open water. Since most of the coastal plains are within 3 to 5 meters from the mean sea level, it was previously thought that a significant part of the coastal areas (as high as 18 percent of the country) would be completely inundated by rising sea waters. Such a speculation was made based on two major approximations: (a) the coastal plains are not protected and (b) the seawater front will follow the contour line. In reality, however, it is found that most of the coastal plains are protected by embankment. Considering all the physical facts a comprehensive study has been conducted on the impact of relative sea level rise on coastal area of Bangladesh jointly by IWM and CEGIS. In the study the physical impact of relative sea level rise[1] for the year 2020, 2050 and 2080 assessed using the mathematical modeling tools MIKE 11 and MIKE 21. The result shows that:

1. Interior coast of southwest region may experience severe drainage congestion / waterlogging due to 62cm sealevel rise . About 32% more area will be deeply inundated due to overtopping of embankment.

2. Exposed coast will experience increased intensity of cyclone and seasonal inundation due to increased rainfall in addition to 62 cm sea level rise. Besides this area will be severely exposed to storm surge inundation . About 16% more area in Patukahali and 18% of Chittagong district will be inundated seasonlly due to sea level rise and high tide.

3. In both areas (exposed and interior coast) salinity problem will increase. (IWM and CEGIS, 2007)

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[1] To calculate relative sea level rise it is necessary to calculate Global rise in sea level. In the following study conducted by IWM and CEGIS, Global sea level rise for the projected year 2020 , 2050 and 2080 has been selected from third assessment report (TAR) of IPCC 2001 for high (A2)and low (B1) green house gas emission scenario. (IWM + CEGIS , 2007,P.11)

Considering the impact on society, coastal area both interior and exterior coast is the residing place for 28% of total population of the country comprising total 35 million population with an average density is 743 person per sq km (PDO-ICZMP, 2003b) and is at great risk of massive disaster from humanitarian ground. There is an impending threat of mass displacement of population or climate refugee in the event of sea level rise. The resettlement of this displaced people to new and existing settlements will put additional pressure on infrastructure and other services (IPCC, 2007a).

Thus there are two folds impact of climate change and resultant sea level rise (SLR) on human settlement: firstly loss of habitable land and ecosystem due to permanent inundation in directly affected area; secondly the rehabilitation of the displaced or migrant population will exert additional pressure to the settlement in relatively safe area (Mowla and Choudhury, 2011). In such reality, it is may not be possible for the coastal dweller to live and continue their battle against such severe catastrophic event with their indigenous knowhow by themselves alone. Thus it calls for immediate action in settlement planning and design addressing geo-climatic vulnerability of coastal Bangladesh.

1.3 Research question and objectives with specific aims

On the basis of above discussed problem three governing research questions are developed. These are:

1. What causes vulnerability to coastal settlements?
2. How this vulnerability can be reduced? / What are the potential responses to reduce vulnerability?

The first question tries to unveil the aspects and extent of vulnerability of coastal settlement due to present and anticipated geo-climatic context. The third enquiry intends to investigate the state of local coping measures in settlement at present and its scope to reduce future vulnerability.

Aim and Objectives

The research is outlined with an aim to formulate a strategic plan for coastal settlement of Bangladesh in response to the current and anticipated geo-climatic threats. The specific objectives are:

1. To assess the relative vulnerability of existing settlement to environmental risk in selected coastal area at present and future context in order to identify the key aspects of vulnerability coastal settlement.

2. To formulate an inventory of local responses in hazard prone area to develop adaptation strategies for settlement planning and design in coastal context of Bangladesh.

1.4 Keyword definition: Delineation of Vulnerability and Adaptation

Vulnerability

Vulnerability is the degree to which a system acts adversely to the occurrence of hazardous events (Timmerman, 1981).Vulnerability to climate change is the degree to which a system is susceptible to and unable to cope with adverse impacts of climate change. Vulnerability is a function of the character, magnitude and rate of climate change and variation to which a system is exposed, its sensitivity and its adaptive capacity. (IPCC, 2001a, p995)

The vulnerability of settlement is measured on the scale of nature and severity of the event or issue as well as the physical and socio-economic factors that determine the degree of settlement resilience; how they are affected and the capacity of settlement component or community to recover (Pelling, M. ,2003), ie. Coping or adaptation mechanism of settlements and people determines the vulnerability level.

Vulnerability is a function of two attributes: 1. Exposure (the risk of experiencing a hazardous event) 2. Coping ability, subdivided into resistance (the ability to absorb impact and continue functioning) and resilience (the ability to recover from losses after an impact) (Clark et al, 1998)

Adaptation:

Adaptation can be defined as method of adjustment or coping mechanism with its surroundings that helps improve the quality of living environment under strenuous circumstances (Mowla & Zareen, 2005).

Adaptation is the process or outcome of a process that leads to a reduction in harm or risk of harm, or realization of benefits associated with climate variability and climate change. (UKCIP, 2003)

Adaptation is adjustment in natural and human systems in response to actual or expected climatic stimuli and their effects or impacts. This term refers to changes in processes, practices, or structures to moderate or offset potential damages or to take advantage of opportunities associated with changes in climate. It involves adjustments to reduce the vulnerability of communities, regions, or activities to climatic change and variability. (IPCC, 2001a)

Thus in climate change research adaptation and coping are often used synonymously as both concepts imply the ability of a system (whether natural or human) to adjust to climate change.

1.5 Context and characteristics of coastal area

Coastal area of Bangladesh is characterized as land of hazards and resources. Coastal plain is a shallow basin that receives the discharge of numerous rivers and is characterized by its funnel shape. Most importantly, coastal area is an active part of Ganges-Brahmaputra Delta, one of the largest Deltas of the world. This deltaic plain is very young if compared to other deltas in the world where accretion process is still active. Several past studies have demonstrated evidence that the coastal Delta has growing horizontally (seaward) and vertically (upward) since its creation. In 1993, SPARRSO undertook a comparative study of accretion and erosion for the entire coast and reveals that coastline of the central part has been changed considerably, mainly accreted, over the years. Besides accretion it also has faces severe erosions, specifically at the confluence of the estuary.

Geographically the entire coastal zone of Bangladesh is divided into three regions: the eastern region, the central region and the western region. Except the eastern region, all parts of the coastal zone are flat plain with a very low gradient and hence delineated as Low Elevation Coastal Zone (LECZ). Average land elevation of the coastal zone lies within the contour of 3m (Hoque et al., 1999). These vast low-lying areas are exposed to the risk of sea born natural hazard like cyclone, tidal surge, soil and water salinity and shoreline erosion along with terrestrial hazard like water logging. These hazards when turn into disasters make the coastal dwellers very vulnerable (Islam, 2004) and make the whole coastal and marine environment threatened.

Coastal areas of Bangladesh contain some of the world‘s most diverse natural and socio-economic resources (Rasheed, 2008, p.55) such as agricultural land, marine fisheries, forestry, waterways, salt production, sea trade and tourism. Human settlement has long been drawn to the coastal areas captivated by the resources and trading opportunities. About 35 million people, representing 28% of total population live in the coastal area of Bangladesh (PDO-ICZMP, 2003b, p. 05). Like other region of Bangladesh human settlement in coastal area predominantly reflects a rural character (59% rural and 11% Urban and other commercial area) (Appendix B) and extensive urbanization in terms of infrastructures and services has not yet taken place (PDO-ICZMP, 2003c, p. 01). Population density of the interior coast is much higher (1,012 persons per sq km) than that of the exterior coast (482 persons per sq km) and the country‘s average (839 persons per sq km).

Thus the generalized definition of coastal system as outlined in IPCC third assessment report (2001) can be adopted to delineate the coastal area of Bangladesh. According to the definition coastal system are considered as the interacting low lying areas and shallow coastal waters including their human components. In addition to local drivers and interactions, coasts are subjected to external events that pose a hazard to human and may comprise the natural functioning of coastal systems. Terrestrial sourced hazards include river floods and inputs of sediments and pollutants; marine source hazards include storm surges, cyclones and tsunamis. (IPCC, 2007a, p 318)

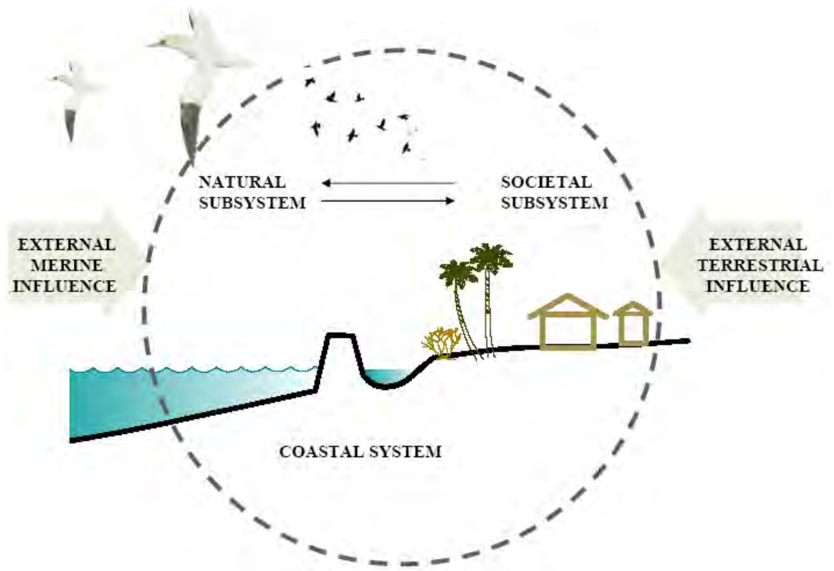


Fig 1.1: Coastal system (source: IPCC ,2007a)

1.6 Selection of study area

From the above discussion it is understood that the geographic and demographic composition of interior coast and exterior coast is not alike and so the nature of severity of the problem. Therefore, to study on coastal region it is necessary to encompass this regional variation while formulating strategic framework on vulnerability and adaptation in coastal settlement in general. Considering above, two representative upazila; one is from interior coast and another is from exterior coast has been selected to understand the variability of geo-climatic risk and their corresponding settlement pattern.

Table 1.1 Geo-physical profile of the study Upazila

Coastal zone	Selected Upazila	Geo-climatic risk
Interior	Keshabpur (district Jessore)	Water logging
Exterior	Kalapara (district Patuakhali)	Cyclone and related storm surge

For vulnerability analysis, choice of the study area (a UNION) within the above mentioned upazila has been guided by the following selection criteria:

1. Severity of the problem (considering both present and anticipated future context)
2. Settlement character representative of predominant type.

Finally, a ‗Locality' or ‗Village' has been selected from each union of two different vulnerable context for micro level study of local adaptation practice in settlement pattern with an aim to outline an overall scenario of the coastal region.

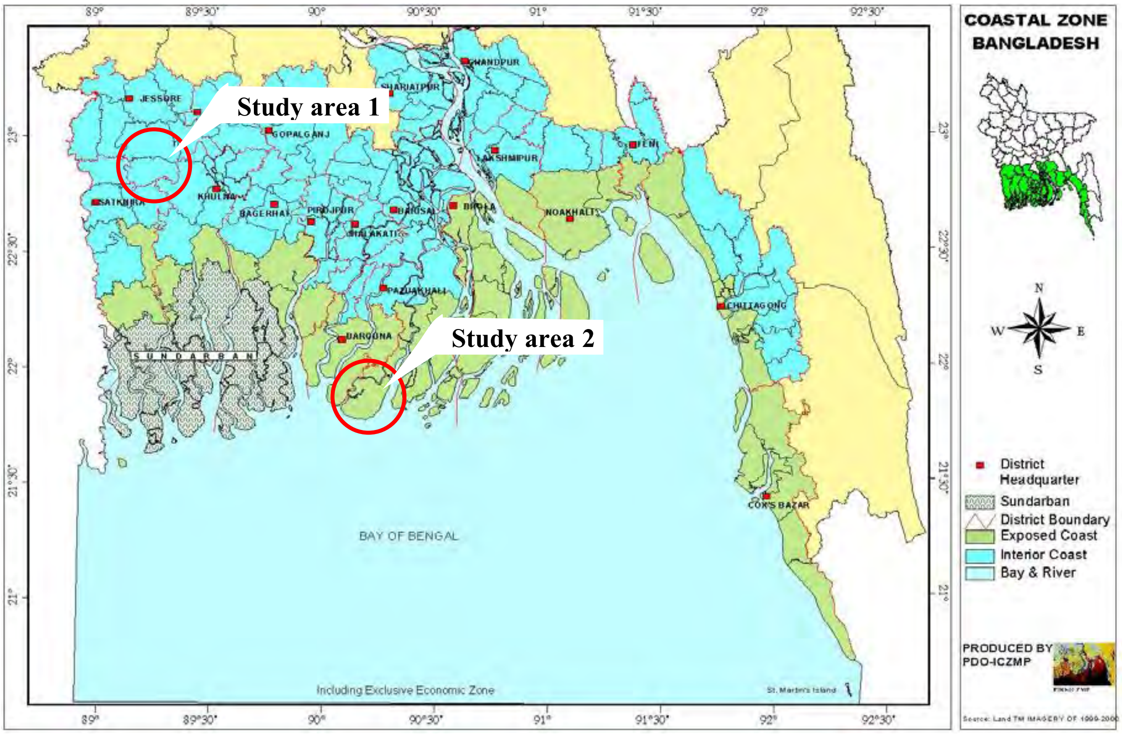


Fig 1.2 Map of the coastal zone of Bangladesh (Source: PDO-ICZMP,2003a)

Fig 1.3 Study area 1: Keshabpur Upazila

Fig 1.4 Study area 2: Kalapara Upazila

1.7 Research rational

Climate change and its impact on Bengal delta is an emerging issue and especially it is the coastal people who are going to be homeless/ landless. Moreover, considering the high population density, future population projections and shortage of land, it is not feasible to retreat the entire affected population. Since there have been attempts to assess the impact of global warming by individuals, national and international research community but no effort has been taken yet to evolve a physical planning for sustainable settlement in coastal area of Bangladesh.

Of the two fundamental responses to climate change: mitigation and adaptation, adaptation is often considered as the most viable and manageable responses to contend with, especially for the least developing country like Bangladesh. Coastal people must, therefore, adapt themselves to the changing circumstances. The National Adaptation Program of Action (NAPA), launched by the Govt. of Bangladesh, in 2005, provides a response to the immediate needs of adaptation and identifies priority programs. Adaptation measure in agriculture is already in progress which infact widens the opportunity for in-situ settlement adaptation in coastal area. At present, measures taken to cope with existing hazard are mostly reactive and short term without any coordination to each other. The present study is an attempt to fill up the gap with an aim to offer proactive measures for long term adaptation in coastal settlement system.

Settlement being a ‗physical locale where the members of a community live' is an ideal issue for research where architect and planner can contribute. The research investigates the possibilities and potentialities for adaption in settlement pattern in order to enhance livability in risk area and will contribute significantly to in-situ adaption and thus reduce out migration.

1.8 Scope and limitation

Study on human settlement focusing on climate change issue is almost non-existent. In the present study emphasis is given in attaining a methodical framework for assessment of vulnerability and responsiveness of local adaptive measures for better understanding of the impact and potential response in coastal settlement. The scope of the vulnerability assessment is limited to exploration of in-built weakness or inequity in distribution of the existing settlement feature that are susceptible to future climate related stress of the context primarily based on secondary information. Since there have been very limited updated statistical data available on housing characteristics at community level, the assessment is based on available data on housing and household in community series of population census last updated in 2001. However some updated data regarding infrastructural facility including common services and shelter are comparatively available and collected from Local government engineering department and other related sources. Then again findings related to coping measures are case specific and may not reflect entire coastal community in general. So the conclusion derived from the study may be true for areas with similar circumstances, but may not be generalized for other areas of coastal region. Thus limited research work in relevant field, updated statistical data and time constraints are the main limitation of the study.

1.9 Outline of study:

To attain the objectives, the study follows an analytical approach to understand the case specific vulnerability and responses to draw an inference for coastal settlement in general. The study is proposed to be divided into following steps:

Step 1: Literature review: Prior to case studies, relevant literatures are reviewed to comprehend the geo-climatic context and settlement characteristics of coastal area, present problem and future threat induced by geo-climate and measures taken in the country and t abroad in response to the problem.

Step 2: Case studies: The study then proceeds to identify representative study sites in coastal area based on nature of the problem. Each case study is conceptualized to be carried out in two phases:

First phase: **vulnerability assessment**: The vulnerability of settlement will be determined following the vulnerability index method (discussed in Chapter 3). Prior to assessment indicators are identified on the basis of sensitivity of settlement features to hazard or how settlement is affected by the nature and extent of the problem in the past and present context. Based on the indicators, the study will then analyze vulnerability of settlement at micro level due to geo-climatic risk. The result is expected to delineate the vulnerable locality under three strata: high, moderate and low.

Second phase: **local response to vulnerability:** Once the problem is identified possible response is explored. Of the most vulnerable locality, a sample community/ area will be selected to collect first hand information on local coping measures. Based on selected criteria, the responsiveness of the existing measures is analyzed (discussed in Chapter 3).

Step 3: Synthesis of findings for strategic decision: Case specific findings are synthesized to identify key aspects of vulnerability in coastal settlement in general followed by development of an inventory of potential adaptation strategies for settlement planning and design in response to future change in geo-climate of coastal area. Responsive settlement pattern for the context will come as final recommendation.

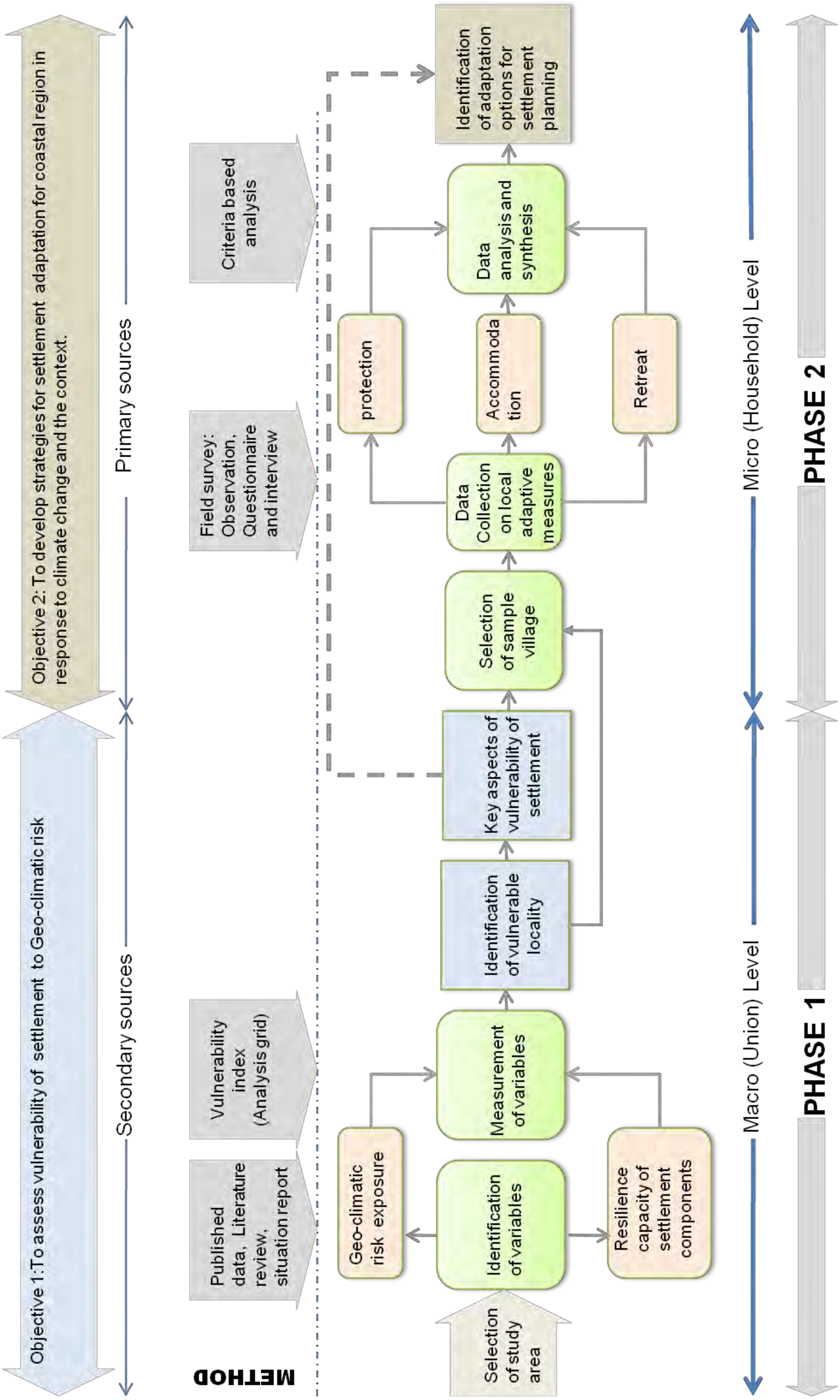


Fig 1.5 Methodological framework of the study

1.10 Structure of the thesis

The entire research is organized within seven chapters.

The introductory chapter defines the problem and set out the argument to examine how the human settlement in coastal area in Bangladesh may be affected by the global change in geo-climate and what will be the possible response to cope with the change. This chapter also delineates the key concept of vulnerability and adaptation in settlement focusing on sea level rise resulted from climate change.

The second chapter reviews the theoretical notions of human settlement and its components. Review also includes literatures regarding geo-climatic context and settlement characteristics of coastal area of Bangladesh with an aim to develop understanding about the problem site in general. In addition a range of overseas and local examples of adaptations are also reviewed with special emphasis on inundation.

The third chapter describes the selected methodologies for directing the present research towards the specific objectives as outlined in the first chapter. The chapter highlights ***method for spatial analysis of settlement pattern***, ***Index method of vulnerability analysis*** and its representation techniques using analysis grid and ***Multi-criteria analysis of adaptation measures*** to evaluate the responsiveness of local measures. The chapter also includes details of data collection method and sources used in the study.

The fourth and fifth chapter deals with the case studies. Selected study areas are discussed to understand the setting and vulnerability context at Upazila (sub district) level. After delineation of indicators the chapter includes analysis of settlement vulnerability at village (settlement unit) level following the index method as outlined in chapter three. The subsequent sections in the chapter include description of local measures followed by analysis of responsiveness of the measures.

The sixth and seven chapters incorporate synthesized information regarding key aspects of settlement vulnerability in coastal areas at present and anticipated future context and includes inventory of potential local responses to be adopted in settlement pattern for in-situ adaptation. Finally the chapter seven tries to draw conclusion by recommending possible strategies for settlement adaption in coastal area of Bangladesh in response to anticipated sea level rise.

Chapter 2

Theoretical Framework

Study on human settlement is an omni discussed issue and generally has been the subject matter of planning, environment and social sciences such as anthropology, geography, sociology, ecology etc. Predicted climate change scenario adds new dimensions in the settlement research and is becoming a research interest in the field of disaster management, development studies, built environment planning and design and even in architecture to examine the scope and possibilities of development to adapt with the changes. There are, however, substantial published and ongoing research works focusing on vulnerability and adaptation on agro-ecological and geo-hydrological sectors but very limited studies have been conducted on form and feature of climate resilience human settlement. The few works that give some light in the issue are primarily confined to analysis of spatial vulnerability at macro level (regional) or documentation of traditional coping practice at household level under present context. Moreover, existing study often failed to infer the future of human settlement in the area exposed to the risk of inundation due to sea level rise and other climate change related impact. Understanding the deficiency of resources, this chapter basically brings together the scattered information about the form and pattern of coastal settlement and their vulnerability in respect to local geography and present biophysical risk. The review also incorporates information about the future risk of changing climate and proactive measures taken in the country or elsewhere in the world to adapt with. In this chapter the complied information is presented in three broad sections. First section includes discussion about the theoretical notions and principals of human settlement with special focus on coastal settlement pattern of Bangladesh. The second part describes vulnerability of coastal settlement to anticipated sea level rise (SLR). And the last section comprises of information about past, present and future of adaptation measures in the settlement patterns in response to possible climate change induced inundation and flooding.

2.1 Overview of human settlement with special focus on coastal Bangladesh

2.1.1 Theoretical notion of human settlement

The voluminous work by Doxiadis (1968), titled ‗Ekistics: the science of human settlements concentrates on the theory and morphological aspects of human settlements. By definition, human settlements are the places for human habitation. Their physical manifestation on the landscape is the outcome of the interaction of man and environment. Thus human settlement consists of:

a) **content** or man alone and in societies

b) **container** or the physical settlement which consists of both natural and manmade elements

These elements are evident on the landscape as the ensemble of houses with their linkages through networks through which there are grouping of population into occupance units of different orders, ranging in size and functions from the simple isolated one family farmsteads to the ecumenopolis, the largest possible units of settlement. Thus it is conspicuous that **settlements are not only the built up part made by man, but all the space – natural or manmade, used by man** (Doxiadis, 1968).

Any settlement consists of:

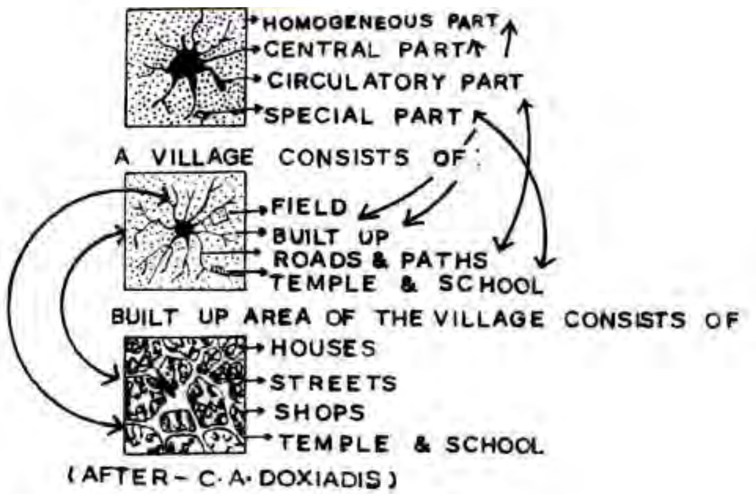


Fig 2.1: Structural model of Doxiadis. (Source: Mondol, RB, 1989, p.68)

Doxiadis has developed four stage model which can be applied to the composite individual settlement of all size in a territory as well as in its constituent parts. Hypothetically any settlement consists of four parts: a) homogenous part, b) central part, c) circulatory part, d) special part. These parts are subject to change but they are always presents in a living settlement or ekistics unit.

In 1976 the United Nations held its first conference in Vancouver where the concept of human settlements was established as consisting of several elements that had been previously considered separately from one another - housing, building, planning and the relationship of these and such other activities as environmental change and national and international development. Vancouver Declaration defined human settlements as follows:

"Human settlements means the totality of the human community - whether city, town or village - with all the social, material, organizational, spiritual and cultural elements that sustain it. The fabric of human settlements consists of physical elements and services to which these elements provide the material support." The physical components comprise,

i. **Shelter/ Dwellings** , i.e. the structures of different shapes, sizes, types and materials erected by mankind for security, privacy and protection from the elements and for his singularity within a community;

ii. **Infrastructure**, i.e. the complex networks designed to deliver to or remove from the shelter people, goods, energy or information;

iii. **Services** cover those which are required by a community for the fulfillment of its functions as a social body, such as education, health, culture, welfare, recreation and nutrition. (Sarkar, 2010, pp1-2, 5-6)

In short, **settlement designates an organized colony of human beings together with their residence and other supporting facilities and the paths and streets over which they travel**. All these are the facilities man constructs in the process of living (Trewartha et al. 1967). Thus, the process of settlement inherently involves grouping of people and apportioning of territory as their resource base. One settlement is distinguishable from that of the other in the architectural style of the age or time, culture and region from which they spring (Sultana, S., 1990, p.14).

The pattern of rural settlement has two separate but related components: the way in which the land is divided among its owners and the way in which the owners arrange buildings on their land. Thus, types of the settlement are determined by the extent of the built-up area and the inter-house space. Naturally, the pattern of agricultural fields is an important component of rural settlement landscapes and is an essential landscape feature that often contributes greatly to the character of a place.

There are various factors and conditions responsible for different patterns of rural settlements. These are:
a) Physical factors – nature of terrain, altitude, climate and availability of water; **b) Cultural and ethnic factors** – social structure, caste and religion and **c) Safety and security factors** – defense against wild animal, natural hazard (storm, flood) and manmade offense (thefts and robberies). These factors, both physical and cultural, lead to a compact

(agglomeration) and dispersed settlements according to the relative influence of centripetal and centrifugal forces as given in fig 2.2. (Mondol, 2001, p.187)

Hence the understanding of a settlement pattern involves the understanding of settlement growth, its function and related factors.

There is an overall hierarchical pattern within rural settlements in Bangladesh. It begins with a *gram* (village), composed of a number of *Paras* (neighborhoods). This segmentation of a large village is often motivated by social and ethnic factors. Each *Para* again consists of a number of *Baris* (homesteads) usually established on raised land, which in turn are comprised of several *Ghars* (dwelling units of individual households within an extended family) and ancillary buildings typically arrange around a rectangular courtyard. (Banglapedia). Ponds are an ubiquitous feature of these settlement-providing water for domestic uses (Baqee 1998). Until recently, ponds were the main source of drinking water in rural Bangladesh before the beginning of large scale sinking of tubewells. (Rasheed, 2008, p.204)

The pattern of settlements in any area refers to the spatial relations between one dwelling to another , i.e. whether they are located close to each other or they are further apart and if the spacing of dwellings exhibits any geometric form (Hudson,1981 quoted in Rasheed,2008,p.203). As Bangladesh is a geographically diverse country, patterns of settlements found in its different parts are also varied. Rahman (1974) and Rashid (1991) identified three distinct patterns of rural settlement in Bangladesh: Linear, Scattered or dispersed hamlet and Nucleated. On the other hand Rasheed (2008) categorized rural settlements into two broad groups: i) clustered and ii) dispersed where linear pattern is a subtype of clustered settlement. However, the pattern of coastal settlements in Bangladesh as refer to different literatures and documents in general are discussed in the following section.

2.1.2 Settlement pattern of coastal Bangladesh

There are few literatures that describe the pattern and form of coastal settlement in Bangladesh and how the local factors influence it. A research report (MCSP,1993) referred by World Bank is an important source that describes the coastal settlement pattern in general. According to the report, a predominant linear type settlement pattern has been observed in the western and central districts of coastal region (the area is indicated as high cyclone risk area), where an extensive network of rivers and canals exist, and water is the principal mode of transportation. Linear settlements have also been found along the coastal embankments, especially on the islands, and along the roadsides and riverbanks in the eastern districts. Other patterns of human settlements in the coastal areas include nucleated, scattered/ dispersed, and mixed type settlements. Nucleated/clustered human settlements have been formed on the plains and foothills in the East zone. In the hilly areas different tribes also lives separately form each other forming mostly nucleated settlement. In the Central zone where density of population is high human settlement is mostly of scattered type. Mixed pattern of linear and scattered settlement generally found in the central and lower part of Chittagong hill tracts in the eastern coast. In the newly formed charlands the settlement is thin and of scattered type (MCSP, 1993) (Appendix G). From the above discussion, settlement pattern of coastal area can be categorized into four types as follows:

(a) Clustered or agglomerated pattern: The clustered settlement is a compact or closely built up area of houses, in which the general living area is distinct and separated from the surrounding farms, barns and pastures. Such settlements are generally found in the fertile alluvial plains. Sometimes, people live in compact village for security or defense reasons. Clusters are groups of houses that also occur near a restricted resource such as a mine or logging site (Sarkar, 2010, pp.6- 7). In settlement geography, the term nucleated and clustered often used synonymously (Sultana, 1990; Rahman, 1974) to describe the agglomerated character of settlement. Rasheed argued that it may not be correct to call the clustered settlement in Bangladesh as nucleated settlement. The term ‗nucleation' connotes the evolution of settlement around a nucleus like a plaza or church as in Latin America or inside the perimeter of defense wall like in West Africa or around a water hole or natural spring like in the Saharan parts of Algeria (Rasheed, 2008, p.204) or around a temple / mosque or house of landlord or even a banyan tree in case of Indian village. (Mondol, RB,2001,p.198) Clustered settlements are observed in the thanas of Patiya, Cox's Bazar and Maheskhali.

(b) Linear pattern: A subtype of agglomerated settlement is linear settlement where dwellings are located in a linear fashion along the rivers or roads (Rasheed, 2008, p.204). This pattern is the most dominant type in the immature delta, the lower parts of the mature and active delta, Linear pattern is noticed in the thanas of Banskhali, Sitakunda, Kutubdia, Chakaria, Ramu, Teknaf and Ukhiya forming along the sides of the roads, highways and foothills, and along the banks of rivers and canals in the eastern region. A predominant linear settlement pattern is observed along the natural levee of water channel or following the transportation route specially in tidal flood plain or Beel area of western region. In the thanas of Dacope, Koyra, Soronkhola, Monglaport, Shyamnagar, Barguna, Patharghata and Kalapara along the banks of innumerable rivers and canals and along the sides of roads human settlement pattern is mostly of linear type.

(c) Dispersed/ scattered pattern: Dispersed settlements consist of scattered dwellings or small collection or dwelling (Hamlet) built on artificially raised higher grounds in the midst of the flood plain. A variant of the dispersed pattern of settlement is the scattered type in which individual homesteads are spread out across the landscape. The physical linkage among these dispersed dwellings is obtained through rudimentary pathways through the farmlands, unpaved rural roads and by boats in the wet season. Dispersion pattern reflects the poor population–resource relationship; covered mostly with soils with lesser fertility and far away from the well-connected and developed regions. Scattered pattern is specially pronounced in the settled and newly formed charlands in the districts of Bauphal, Dashmina, Charfasson, Lalmohan, Sonagazi, Ramgati, Raipur, Hatiya and Comapniganj of central region, low lying areas of Mirsarai and Anawara thanas of eastern region. In Sunderban region few homestead are scattered or dispersed (Shahriar, 2008) where the habitation follow the raised bank of streams. Some scattered settlements are also noticed in some settled char lands and by the sides of swamps in the Thanas of Dacope, Morrelganj, Shymnnagar, Mathbaria, Bamna and Betagi in western region. (MCSP, 1993)

(d) Mixed type or semi-dispersal pattern results from combination of linear or cluster pattern of older settlement with the scattered pattern. In this case, one or more sections of the village society choose or forced to live away from the main community. In such cases, generally, the land-owning and dominant community occupies the central part of the main village; whereas people of lower strata of society or people migrated from other area settle on the outer flanks of the village as satellite settlements. (Sarkar, 2010, p.7) Mixed types patterns are noticed in thanas like Bhola and Burhanuddin, Daulatkhana, Tazumuddin and Sandwip of central region; (MCSP, 1993)

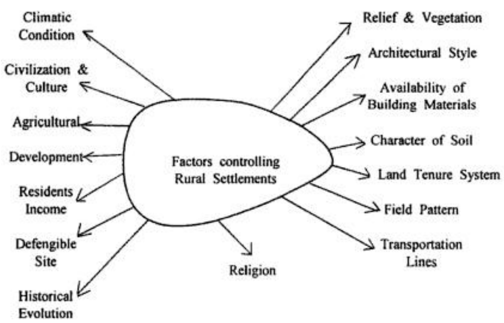


Fig 2.2: Factors affecting settlement types (source: Mondol, RB, 2001, p.187)

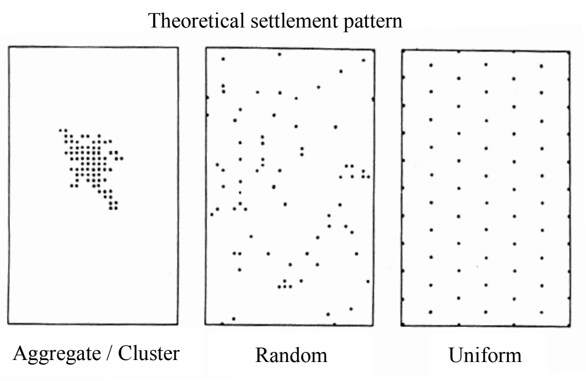


Fig 2.3: Settlement patterns based on spacing or distribution (source: Mondol, RB, 2001, p.82)

2.1.3 Spatial analysis of settlement pattern: Nearest neighborhood analysis

Nearest neighbor analysis is a statistical method to describe the settlement pattern. It is very difficult to describe the pattern of a settlement accurately just by looking at the distribution of the points representing settlement units on the map. The description might be arbitrary and will be certainly subjective. In order to overcome the problem of describing the pattern of given settlement, a quantitative technique has been introduced which has been used by the geographer widely. This is a method to measure the distance between every point and its nearest neighbor, and hence has been termed as nearest neighbor analysis. Two ecologists, Clark and Evans (1954), gave a lead in the measurement of such analysis. The method has been refined several times by different scholars and lately adopted by Sultana (1990) to delineate the settlement pattern of rural Bangladesh.

The method is used to identify a tendency towards nucleation (clustering) and dispersion of settlement which appear as point in the map. The formula used in nearest neighbor analysis produce a figure (expressed as Rn) which measures the extent to which a particular pattern is clustered (nucleated), random or regular. Thus according to this theory,

Clustering occurs when all the points (settlement units) are very close to each other. When all the points are clustered together in a single location, theoretically the Rn would be 0.

Random distribution occurs when there is no pattern at all or points are distributed randomly. In that case Rn would be 1.0

Regular pattern are perfectly uniform. If ever found in reality they would have an Rn value of 2.15 which would mean that each point (settlement unit) is equidistant from all its neighbors.

While analyzing rural settlement pattern of Bangladesh, Sultana (1990) has introduced a fourth type of linear pattern in between absolute cluster (0) and completely random (1.0) pattern of settlement with an Rn value of 0.23. Owing to have similar characteristics random pattern can be used to describe the scattered or disperse nature of settlement. Detail of the analysis techniques are described in methodology chapter.

2.2 Vulnerability of Coastal settlement

2.2.1 Vulnerability to environmental hazard: Theoretical perspectives

Vulnerability is an essential concept in human environment research. The term vulnerability is frequently used in the risk, hazard and disaster literature but is becoming more prominent in the domain of climate change and environment and development studies. Cutter (1996), Wu et al(2002) and Dolan et al (2003) have provided excellent reviews of major literature on the development of the concept. Broadly speaking, vulnerability is the potential for loss (Cutter

1996), but the definition varies with topic (e.g. hazards, disasters, or risk assessment) and with discipline (e.g. geography, sociology, or political science). The IPCC-CZMS (1992) defines vulnerability of coastal zones by their degree of incapability to cope with the impacts of climate change and accelerated sea-level rise.

Despite this diversity, there are 3 dominant perspectives in conceptualizing vulnerability. The first characterizes vulnerability in terms of exposure to hazardous events (e.g., droughts, floods) and how this affects people and structures. As such, a physical event places people at risk and the focus is to identify vulnerable places. However, methods aimed at reducing physical risk do not necessarily reduce exposure and damages and may increase the vulnerability of populations to such events (Hewitt, 1997 quoted in Dolan et al, 2003). For example, structural adaptations (e.g., flood protection) do not necessarily discourage people from living in high-risk areas (e.g., floodplains), but may encourage development and consequently, increase vulnerability.

A second perspective views vulnerability as a human relationship not a physical one (i.e., vulnerability is socially constructed rather than determined by the occurrence of a physical event) and hence delineated as social vulnerability. As such, vulnerability is socially constructed and rooted in historical, cultural, social and economic processes that impinge on the individual‘s or society‘s ability to cope with disaster and adequately response to them people at risk to a diverse range of climate-related, political, or economic stresses (Cutter,1996).Here, exposure is determined by the inequitable distribution of damage and risk among groups of people (WU et al., 2002) and vulnerability is a result of social processes and structures that constrain access to resources that enable people to cope with impacts (Blaikie et al., 1994). Thus, protection from the social forces imposed on people that create inequitable exposure to risk is just as, or more important than protection from natural hazards (Hewitt, 1997). Social vulnerability and how it is produced, becomes the focus, regardless of the nature of the exposure (Dolan et al, 2003).

A third perspective integrates both the physical event and the underlying causal characteristics of populations that lead to risk exposure and limited capacity of communities to respond (Liverman,1990; Burton et al., 1993; Cutter et al., 1996). Vulnerability is therefore a physical risk and a social response within a defined geographic context. Several studies have integrated in some way both physical and social vulnerability perspectives (e.g., Blaikie and Brookfield, 1987; WU et al., 2002).

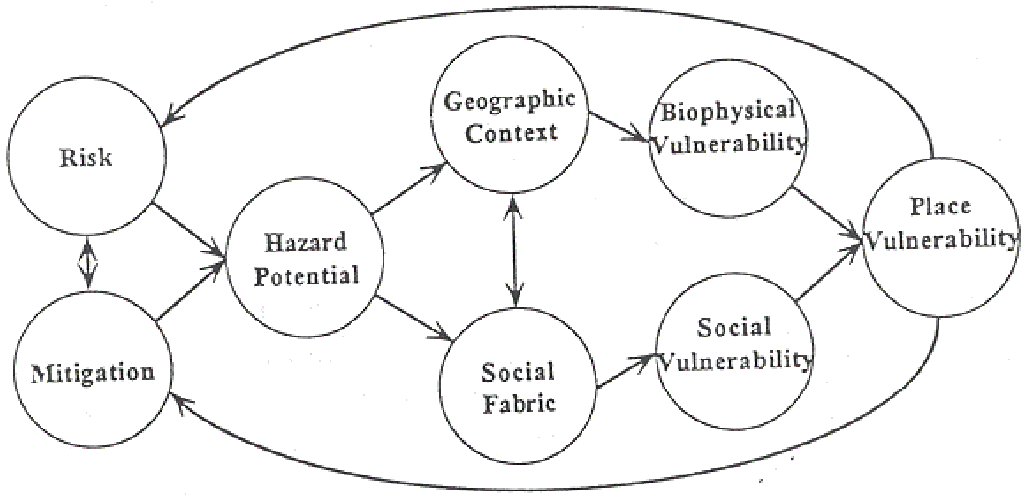


Fig 2.4: The ‗Hazard of Place' model of vulnerability (Source: Cutter, 1996, p.536)

Fig 2.4 represents a more integrated perspective of vulnerability. The model was first presented by Cutter (1996). Social vulnerability often referred as Human vulnerability (Pelling, 2001) and commonly determined by coping ability or capacity of the exposed society/ system which is again subdivided into resistance and resilience (Clark et al, 1998). Thus vulnerability is broken down into three components: exposure, resistance and resilience.

Exposure is usually indicated by geographical and temporal proximity to a hazard with susceptibility referring to the propensity for an exposed unit to suffer harm (Pelling, 2011). It is largely a product of physical location and the character of the surrounding built and natural environment. The exposure component can be reduced by improving resistance and resilience capacity and thus increasing coping capacity of a system.

Resistance represents the capacity of a system, an individual or a group of people to withstand the impact of a hazard. If resistance is low then even a small hazard stress can lead to systems failure. The most successful efforts to enhance resistance will not directly target disaster vulnerability but focus on the wider goals of economic social and political inclusion.

Resilience to natural hazard is the ability of a system or an actor to cope with or adapt to hazard stress. It is a product of the degree of planned preparation undertaken in the light of potential hazard and of spontaneous or premeditated adjustments made in response to felt hazard, including relief and rescue.

Exposure, resistance and resilience are all shaped by an actor‘s access to rights, resources and assets (Burton et al, 1993; Blaikie et, 1994). Access profiles are in turn rooted in local and global political and socio-economic structures. Though the relationship between these components of vulnerability may not always be reinforcing, this is often the case, so that opportunities for resilience tend to be less common when resistance is already low and exposure is high and vulnerability increase with each successive disaster event. (Pelling, 2003)

2.2.2 Characterizing vulnerability of coastal community in the context of SLR

It has been now widely accepted that settlements in the low elevation coastal zone (LECZ: 0-10m) will be largely affected by the anticipated sea level change. 600 million people (around 10% of the current global population) residing in communities in the low elevation coastal zone (McGranahan et al 2007) is extremely under threat. Coasts are, in fact, already experiencing the adverse consequences of hazards related to climate and sea level (very high confidence) (IPCC, 2007a). Through the 20th century, global rise of sea level contributed to increased coastal inundation, erosion and ecosystem losses along with growing frequency and magnitude of sea borne hazards like storm surges and cyclones etc (IPCC, 2007a ; Oliver-Smith, 2009).

Coastal region of Bangladesh is at great risk from the projected climate change and consequent sea level rising. Potential bio-physical impacts (WB, 2000; Agarwala et al., 2003; IWM, 2005) would include:

(i) Changes in water levels and induced inundations and water logging,

(ii) Increased incidence of natural hazards like cyclone,

(iii) Increased coastal morphological dynamics (erosion and accretion), and

(iv) Increased salinity in ground and surface water, and corresponding impacts on soil salinity.

Among the potential biophysical impacts of sea-level changes on coastal systems summarized above, this study focuses on the impact of inundation.

A comprehensive study has been conducted on the impact of relative sea level rise on coastal area of Bangladesh jointly by IWM and CEGIS. In the study the physical impact of relative sea level rise[2] for the year 2020, 2050 and 2080 assessed using the mathematical modeling tools MIKE 11 and MIKE 21. The result shows that about 13% more area (469,000 ha) will be inundated in the monsoon due to 62 cm sea level rise by the year 2080 . Though in dry season the affected area will be reduced to 10% (364, 00 ha) but salinity will intrude more landward in this period. The most vulnerable areas are the areas without polders like Patuakhali, Pirojpur, Barisal, Jhalokathi, Bagerhat, Narail. But problem will be more severe in the area protected by polder. About 32% area will be deeply inundated due to overtopping of

[2] To calculate relative sea level rise it is necessary to calculate Global rise in sea level. In the following study conducted by IWM and CEGIS, Global sea level rise for the projected year 2020 , 2050 and 2080 has been selected from third assessment report (TAR) of IPCC 2001 for high (A2)and low (B1) green house gas emission scenario. (IWM + CEGIS , 2007,P.11)

embankment. Of them 25 polders in southwest region may experience severe drainage congestion and 13 polders embankment will be overtopped due to increased water level in the peripheral river (IWM and CEGIS, 2007). The eastern coast is, however, will comparatively less affected due to drainage congestion or rise in water level. But the area will expose to the risk of storm surge inundation due to increased intensity of cyclone in future. Cox‘s bazaar, Chittagong district and Hatiya are the most vulnerable to such risk as sea level rise.

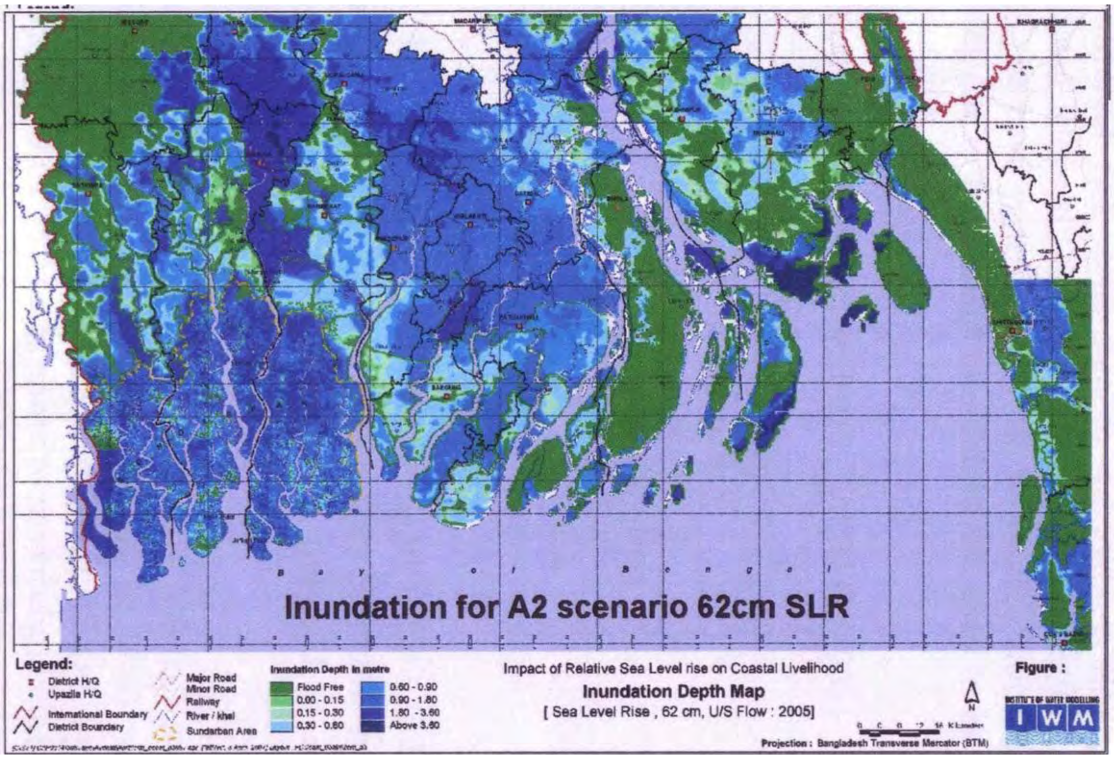


Fig 2.5: Inundated area for 62 cm (A2) sea level by the year 2080 (Source: IWM and CEGIS, 2007).

2.2.3 Impact of SLR on human settlement

There are very limited resources that describe how coastal settlement and people will be affected by the sea level rise (SLR). However, the extent or degree of impact largely depends on regional and local geo-morphology and socio-economic context. Being a densely populated low elevation coastal delta, Bangladesh stands to be the worst affected one. Of the 40 deltas globally, the Ganges-Brahmaputra delta in Bangladesh is identified as an *‗extreme vulnerable'* coastal delta where more than one million population is estimated to be displaced by current sea level trends to 2050 (Ericson et al.,2006)**.** Pioneer research work by Mcgranahan et al (2007) is the most relevant literature that particularly highlights how human settlements in low elevation coastal zones are at risk from sea-level rise. Another work by Oliver-Smith (2009) focuses on economic, social and cultural impacts on coastal communities by displacement due to climate change induced sea level rise is also reviewed. The summary of the review are given bellow:

There are many aspects of sea level rise that will affect the sustainability of coastal peoples and communities (Oliver-Smith, 2009). Coastal storm surges, subsidence and erosion, salinization of ground water and rising water tables, and impeded drainage all may seriously impact both residence and agricultural production in vulnerable communities. Wetlands, estuaries and mangroves, constituting both the ecological and economic base, of many coastal communities may be seriously damaged by sea level rise. Vulnerability science, however, has made clear that **exposure to hazards alone, does not determine where the serious effects of any hazard, including sea level rise will most likely be experienced.** The challenge lies in determining not just absolute exposed land and absolute exposed population but specific lands and populations in different socially configured conditions of resilience or vulnerability. Coastal regions of low-income countries have fewer resources for protection and adaptation. Poor communities of these countries have less economic capacity to recover/ resilience. Moreover the poorest residents of coastal area of low-income countries are often forced (implicitly or explicitly) to settle in flood plains or other hazard-prone locations, as they cannot afford more suitable alternatives. From this perspective low-income settlements and poor groups within all settlements, tend to be the most vulnerable.

These conditions of vulnerability are accentuating rapidly due to increasing human induced pressures on coastal systems. Study shows that coastal populations around the world have increased enormously in the 20th century and are expected to continue to grow in the 21st century from 1.2 billion (in 1990) to between 1.8 and 5.2 billion by 2080 (Nicholls et al, 2007,p. 317). Bangladesh is ranked as 3rd based on total country‘s population lived in coastal area and the population in the LECZ of Bangladesh grew at almost twice the national population growth rate between 1990 and 2000 (McGranahan et al 2007, p.26). Thus the lesser developed countries have a significantly higher proportion of their total populations in the low elevation coastal zone suggesting that the impacts of climate change will probably be greater on coastal regions of developing countries with fewer resources for mitigation and adaptation (Nicholls et al, 2007, p. 331).

From environmental perspective, there is a double disadvantage to excessive (and potentially rapid) coastal settlement. First, uncontrolled coastal development is likely to damage sensitive and important ecosystems and other resources. Second, coastal settlement, particularly in the lowlands, is likely to expose residents to seaward hazards such as sea-level rise and tropical storms, both of which are likely to become more serious with climate change. Unfortunately, such environmental considerations do not have the influence on settlement patterns that they deserve.

From social perspective, sea level rise is predicted to have major effects on terrestrial and marine life and is considered to portend significant population displacements over the next century, particularly in the developing world (McGranahan et al, 2007). This environmentally displaced people will face a complex series of events most often involving: dislocation, homelessness, unemployment, the dismantling of families and communities, adaptive stresses, food insecurity, loss of privacy, marginalization, loss of access to common property, a decrease in mental and physical health status, social disarticulation and the daunting challenge of reconstituting one's livelihood, family, and community (Cernea, 1996).

People uprooted by sea level rise will face the daunting task of rebuilding not only personal lives, but also those relationships, networks, and structures that support people as individuals that we understand as communities. Resettlement, if not sensibly done, may destroy local cultures, sense of community or enhance isolation. Moreover problems generated from climate refugee induced ethnic tension, distrust and other conditions may destabilize host areas (Choudhury and Mowla, 2011). Often conflict in some cases may erupt due to resource scarcity and competition and this conflict can lead to greater migration (Salehyan, 2005).

2.2.4 Spatial analysis of Vulnerability: A grid based method

The selection of appropriate approach and methodologies is important for spatial analysis of vulnerability. As there are various approaches to assess spatial vulnerability, the review draws attention to ‗vulnerability of places' model as formalized by Cutter et al. (2000). The approach integrates both biophysical risk and social response within a specific geographic domain to analyze vulnerability. Many researchers have used, implicitly or explicitly, this integrative approach in a wide array of spatial contexts, ranging from national to local level. For example, Wu et al. (2002) applied this approach to assess physical vulnerability of a coastal region to flood hazards under varying storm intensities and projected sea level rise. In Bangladesh context, Roy et al (2011) applied this approach for assessment of spatial vulnerability of coastal community to floods. The methodology incorporates different physical, social, economic and environmental indicators for spatial vulnerability assessment to hazard. Together, this identifies the broader vulnerability of the area and its distribution within a community to geo-climatic hazard.

There are two methods to assess spatial vulnerability following this approach. The conventional method incorporates administrative units as the operational unit for vulnerability and risk assessment. But this method has limited scope of application at community level as there is no administrative boundary that defines a community. To overcome this limitation Roy et al applied grid based method where the geographic area is converted into spatial grids. Each grid is then assigned with numeric data relevant to indictors. Overlaying the grid data with pre-assigned weight and statistical equations gives the resultant spatial data of vulnerability.

The method has some limitation as well. The smaller the grid size is, finer the spatial resolution and more precise the result. In develop countries census population data are usually available on aggregated grid cells (1 km resolution). But presently no grid-based data at higher resolution exist especially in the developing countries like Bangladesh. Roy et al used the community level census population and settlement data to transform it into grid data of 100m x 100m resolution using the Hawths Tool in ArcGIS environment. The present study also adopts this method with a change in grid size (250m x 250m) and analysis tools (AutoCAD Map Tools). The details of the method are discussed in methodology chapter.

2.3 Adaptation as a response to coastal vulnerability

2.3.1 Concept and objectives of adaptation

In terms of climate change, there are two fundamental response strategies: mitigation and adaptation. Mitigation involves stopping or limiting climate change by preventing the cause of the change that means reduction of GHG (Green House Gas) emission. But the measure for mitigation is much slower process (Meehl et al. 2007) and requires collective effort of the developed and developing countries responsible for GHS emission. Even with reductions in greenhouse gas (GHG) emissions, global temperatures are expected to increase, other changes in climate are likely including sea level rise (IPCC, 2001b). Hence, development of planned adaptation strategies to deal with these risks is regarded as a necessary complement to mitigation actions. It is now commonly agreed that adaptation will provide immediate and longer-term reductions in risk in the specific area that is adapting.

Successful adaptation to climate change and sea-level rise depends greatly on coping capacity or adaptive capacity, that is, the ability of an affected (human or natural) system, region, or community to cope with or adapt to the impacts and risks of climate change induced sea-level rise (Peltonen, 2005). Although ‗Adaptation' and ‗Coping' is essentially same thing Peltonen (2005) and Oliver-Smith (2009) makes a subtle distinction between them. According Peltonen ―While the concept of coping capacity is more directly related to an extreme event (e.g. a flood or a winter storm), the concept of adaptive capacity refers to a longer time frame and implies that some learning either before or after an extreme event is happening".

According to Smith (2009), adaptation is culturally constructed and developed over many years of time frame where as a coping strategy is an immediate response to a challenge, may or may not be culturally practiced by the subject groups. From this sense, relief house engineered to resist cyclonic wind is a coping response to cyclone but may not be an adaption if the technology is not culturally practiced by the community as a whole.

Klein and Tol (1997) identify **five generic objectives of adaptation**:

i) Increasing robustness of infrastructural designs —for example, by extending the range of climatic stresses a system can withstand without failure or changing the tolerance of failure.

ii) Increasing the flexibility of vulnerable managed systems— for example, by allowing mid-term adjustments including change of activities or location.

iii) Enhancing the adaptability of vulnerable natural systems— for example, by reducing other (non climatic) stresses and removing barriers to migration.

iv) Reversing trends that increase vulnerability (also termed —maladaptation")—for example, by introducing setbacks for development in vulnerable areas such as floodplains and coastal zones.

v) Improving societal awareness and preparedness—for example, by informing the public of the risks and possible consequences of climate change and setting up early-warning systems.

2.3.2 Types and forms of Adaptation

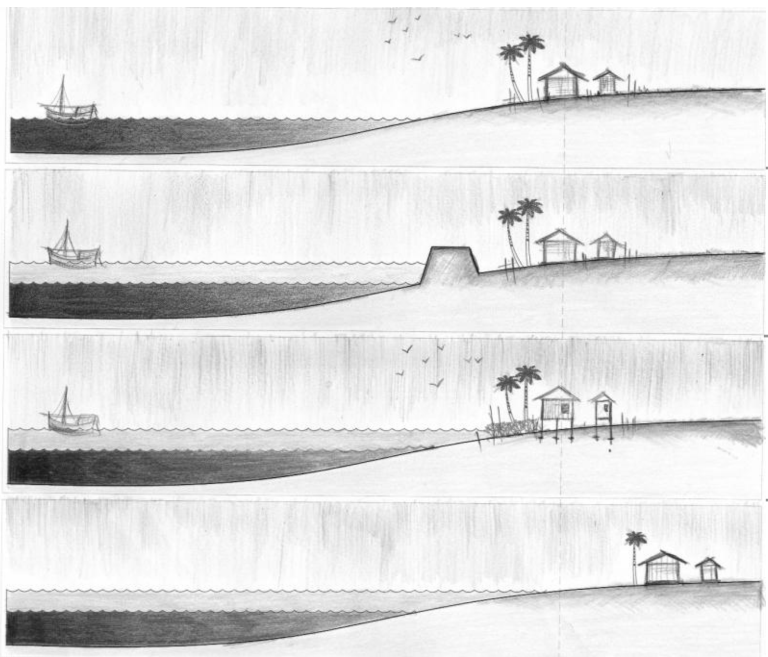
There are many forms and characteristics to define adaptation in terms of a suite of attributes. Adaptation types are commonly distinguished by purposefulness (autonomous or planned) and timing (Reactive, concurrent or anticipatory). Beside there may be temporal range (short- versus long-term) or spatial magnitude (localized or widespread) of adaptation (Bradshaw, et al., 2004). Autonomous or spontaneous adaptations are considered to be those that take place in reactive response to climate stimuli, i.e. after initial impact manifest, without the direct intervention of public agency (Smit and Pilifosova 2001). Planned adaptations can be either reactive or anticipatory (undertaken before impacts are apparent), and are often interpreted as a result of policy decision based on an awareness that conditions are about to change or have changed. Autonomous adaptations are widely interpreted as initiatives by the private sector like individuals or communities rather than by governments.

Focusing on adaptation to the impact of global warming and sea-level changes on coastal systems, there are three structural forms of adaptations (Nicholls 2003; Mclean 2001).

1. Protection, which aims to protect the land from the sea so that existing land can continue, by constructing hard (or semi-hard) structures (e.g., seawalls, sandbags) as well as using soft measures (e.g., beach nourishment)

2. Accommodation, which implies that people continue to occupy the land but make some adjustments to avoid the impacts, for example, by elevating buildings on piles, growing flood-tolerant or salt-tolerant crops.

3. Retreat, which implies that all natural system effects are allowed to occur and human impacts are minimized by pulling back from the coast. This approach involves no attempt to protect the land from the sea.



PRESENT DAY

PROTECTION
Protect the land from submergence, population cluster and natural resources by constructing sea walls, embankments etc

ACCOMODATION
Continuation of the present occupance with some adjustments through non structural and structural measures

RETREAT
Abandon structure, relocation of population, new set back distances from the shore line for future development.

Fig 2.6: Three structural forms of adaptation to sea-level rise, comprising: Protection; Accommodation; and Retreat. Source: Biljsma *et al.* (1996) adopted by IPCC (2001a).

2.3.3 Overview of adaptation strategies to coastal inundation

Choice of adaptation measures depends on particular impacts and geographical factors in each country (Jarungrattanapong & Manasboonphempool, *2009).*Adaptation options are also constrained by economic, social, technological, and political conditions. For instance, protection strategy is most often used as adaptation in coastal area of developed countries where economic activities are highly concentrated. In the case of Japan where most of the major cities and infrastructures supporting industrial production, power generation, transportation, fisheries, etc. are located in the coastal zones, the protection approach is the most important adaptation initiative (Kojima 2000). Apart from this high tech engineering measure there are also examples to live in water with very low tech indigenous measures. Examples of adaptation initiatives and measures undertaken in countries affected by coastal inundation or flooding are presented in the following clauses:

2.3.3.1 Adaptation Examples: Overseas context

2.3.3.1.1 Stilt village of Ganvie, Benin, Ghana, Africa

Ganvie in Benin popularly known as "Venice of Africa" is a unique village built on stilts on Lake Nokoué located north of the Benin's administrative capital Cotonou. Ganvie is an indigenous settlement of ethnic tribe *Tofinu* who settled here 400 years ago. In fact the reason of living on the water was social defense: to keep their settlement safe from invaders. Currently it has a population of 20,000, all living on the water in stilt houses built entirely of wood and plant materials capable of withstanding exposure to water and weather conditions for decades (fig 2.8). Fishing activity is the main source of income here. Local people has practiced an indigenous system of fish rearing known as *acadja* enclosure or "fish ambush trap," that enabling villagers to engage in self-sufficient fish farming. Boat is the only means of transport in the village. A small patch of land that is the only dry area in the whole village is used as the site of village school and cemetery. Recently the village is added to the UNESCO World Heritage List. (http://whc.unesco.org/fr/listesindicatives/869)

2.3.3.1.2 High tech engineering measures of Netherlands

The Dutch have always fought against the harshness of the sea and have attempted to preserve existing and to reclaim more land areas. Presently, about one quarter of the Netherlands' total territory lies below sea level and are protected by dykes. Without dykes, this part of the country would be permanently flooded and more than 60% of this area with its 10 million inhabitants would be threatened by storm surges. At Oosterschelde, a high-tech bridge was completed in 1986 that can quickly be turned into a dyke (fig 2.10). If a heavy storm is approaching, shields come from the bridge down into the water in order to prevent flooding due to storm surge. It is one of the largest coastal engineering projects ever completed in the world and a major engineering achievement. (Germanwatch, 2004)

a

b

Fig 2.7a: Aerial view of the storm surge barrier at Oosterschelde in Netherlands
Fig 2.7b: The movable gates of the storm surge barrier (Sourec: Germanwatch, 2004)

Apart from these high cost engineering measures of protection, a new way of living afloat is emerging in the Netherlands. Planners, hydrologists, architects and others introduced living on water as a proactive response to predicted sea level rise (SLR). The designers of Netherlands are putting their efforts to develop a sustainable model for floating neighborhood where houses are built over a hollow concrete basement with expanded polystyrene which can float upto certain flood limit (fig 2.9). The main objective of this new concept floating home in Netherlands is to prevent any damage or loss from flooding due to the increasing of water level in Netherlands year after year (Yang, 2007).

PAST, PRESENT AND FUTURE OF FLOATING / STILTED SETTLEMENT

Fig 2.8: Stilt village of Ganvie, Benin, Ghana, Africa **(**Source- http://en.wikipedia.org/wiki/Ganvie)

Fig 2.9: Floating neighborhood at IJburg, Amsterdam, Netherlands (source: http://www.rohmer.nl/)

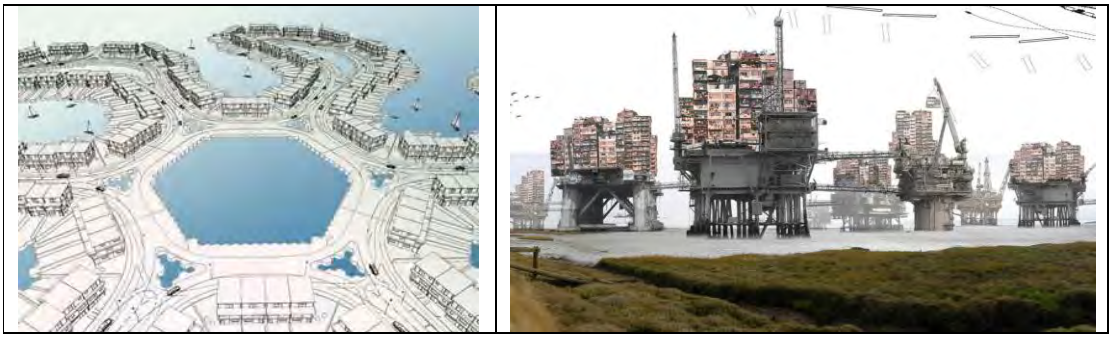


Fig 2.10: Glimpse of many futuristic concepts of floating and stilt settlement in the context of SLR
a. Floating City 2030: Thames Estuary Aquatic Urbanism by Anthony Lau (source: http://bldgblog.blogspot.com/2010/06/flooded-london-2030.html) b.

2.3.2.2 Adaptation Examples: Bangladesh context

Unlike the Netherlands, however, there hardly exist any hard measures of protection such as modern dykes in Bangladesh. **Due to its fragile geophysical context construction of big, modern dykes is not feasible as well**. Moreover, if sea levels rise up to 1 meter, "normal" flood waves can be expected to increase from presently 7.4 meters to 9.1 metres (World Bank, 2000). This shows clearly that coastal dykes must be very high to really protect the inhabitants. Being a least developed country Bangladesh lacks both the financial and technical support for such mega construction. Even if a complete dyke construction could be financed, it would destroy valuable agricultural areas (Germanwatch, 2004). Since 1989, this issue has aroused local protests against a World Bank project that foresees to construct 8,000 kilometers of embankments in coastal area.

But with the help of international co-operation Bangladesh also achieved successes: Over the last three decades, the government has invested over 10 billion dollar to make the country more climate resilient and less vulnerable to natural disasters. Comparing the damage and loss data of recent cyclone with the past of similar intensity and track it is observed that the death toll in last 3 decades has been significantly reduced. ‗Coastal Greenbelt Project' and ‗Multipurpose Cyclone Shelter' are two significant contribution made by the GoB to cope with coastal hazard.

‗Coastal Greenbelt Projects' (1995-2002) implemented by Forest Department of Bangladesh involves mangrove plantation along nearly 9000 km of the shoreline (MoEF, 2009). Experiment and experiences shows that planting mangrove along the coastal belt would help stabilize the land, create more accretion leading to more land and also raise the level of land so that inundation by sea-level rise is reduced. Mangroves also reduce the wave height due to their ability to dissipate wave energy. It has been estimated that a 100 - 200 m wide mangrove belt reduces wave heights by 20 to 25% (MoWR, 2000). Besides under Coastal Embankment Rehabilitation Project (CERP) 1300 km of embankment plantation, 7500 of strip plantation, 665 ha of foreshore plantations were carried out.

The multipurpose cyclone shelter is a concrete example of institutional adaptation to extreme climatic events in Bangladesh (MoEF, 2009).In many directly affected coastal areas shelters on concrete pillars of 5m high were built. These shelters are designed to use as school and thus have duel functions: to protect the inhabitants during disaster and to provide education in normal time. To protect the livestock these shelters are built with Killa or raised platform. There are a total of 2,583 cyclone shelters located in the coastal districts (MoFDM, 2009a)

Fig 2.11 Multipurpose cyclone shelter design by Architect Bashirul Haq, coastal afforestation (photograph by Basak palash in 2008) and embankment are the key adaptive measures taken by the GoB.

Of the non structural measures, GoB has developed early warning systems for floods, cyclones and storm surges and is expanding community based disaster preparedness (MoEF, 2001). Moreover Bangladesh is the pioneer one to initiate the CBA in practicing from different projects to build local capacity in the regional level. Now there are nine other countries around the world are implementing CBA following the footsteps of Bangladesh. These are Bolivia, Guatemala, Jamaica, Kazakhstan, Morocco, Niger, Namibia, Samoa and Vietnam (Huq et.al 2009). In agriculture sector CBA includes floating gardens for cropping and vegetables, cage culture, community based rich-fish farm in the low lands; cultivation of saline resistant varieties of rice and other crops to improve productivity and nutritional security (Rahman et al 2009). At policy level, the GoB launched its National Adaptation Programme of Action (NAPA) in 2005, which highlights the main adverse effects of climate change and identifies adaptation needs.

2.3.2.2.1 Autonomous adaptation in coastal settlement of Bangladesh

The people of Bangladesh have adopted over generation to the risk of floods, droughts and cyclones. In areas where inundation is a risk, they raise their houses on mounds above the normal flood level and adjust their cropping patterns to take advantage of the flood waters. Rural roads, paths, tracks and other infrastructure such as schools are also raised above flood levels where possible.

In coastal zone of Bangladesh, people are taking different adaptation options to cope with existing natural disasters. Both structural and non structural measures are taken to cope with the context. While describing the indigenous house pattern of Chittagong coast, Haq (2000) mention that cyclonic storm and high wind seems the most obvious factor in the development of the form and shape of these houses. The house plan, roof shape and orientation have developed in response to harsh climate, topography and available building materials of the area. Alam and Collins (2003) stated that the coastal and island people in the central coast enhanced their protection by raising the plinth of houses in order to save his seed store and valuable property from abnormal tidal surge from the Bay of Bengal. The author reported that construction of pacca and semi-pacca houses has increased in this area rapidly because of its robustness to cyclonic wind. Bhiti (plinth) made of brick, another technique was adopted by island occupants to protect erosion from tidal surge (Alam and Collins, 2003, pp.13-14).

In a study on village settlement of Sundarbans region by Nahiduzzaman (2008) and Shahriar (2008) observed a predominant clustered pattern. Authors argued that ―this area is prone to nor-western storm and cyclone and therefore settlement pattern is highly influenced by such hostile weather.” Houses in this area are oriented to south and east directions (opposite to the direction of nor-western wind) and most of the orchards/gardens are located in the rear side of housing units which offer a primary protection from any intensity of storm. This traditional practice of plantation surrounding the homestead, act as impediment to wave and surge, provide anchorage for people and stabilized the ground (Shahriar, 2008, p 64). To protect the floor from washed away by storm surge, most of the housing units are built with clayish soil that gives a dry, mildly hard surface. Another empirical study on settlement in same region by Gaffer (2008) documented that house shape are more compact with annex building attached to main unit. This compact layout of homestead is often vulnerable to fire, but local people specially the poor are adapting this layout as to compensate with the damage after every cyclone.

Fig 2.12: Various structural and non structural measures taken by the coastal people to cope with inundation. (source: Ahmed, 2005)

2.3.2.2.2 Planned adaptation in coastal settlement of Bangladesh: Urir Char project 1985

After the devastating cyclone of May 24, 1984, a national committee was formed by the government for designing, planning and rehabilitating the settlers and settlement of the Urir char, an offshore island located in the Meghna estuary. The project was developed by the coordinated efforts of Dept of Architecture, Public Works Dept. and Housing and Building Research Institute of the Ministry of Works, Bangladesh and was financed by Saudi Arabian government.

The proposed scheme was a nucleated dyke settlements elevated on stilts as opposed to the vulnerable scattered pattern of the settlement in Urir char. The master plan was conceived as an inclusive development of neighborhood including all the physical components of settlement i.e. shelter, service and infrastructure. The settlement layout was kept open ended to allow growth as and when needed subject to a maximum of about 15 to 20 clusters (baries) per village. Natural process of land formation was allowed to work and afforestation was proposed on the seaward side of the island. The community facilities were located near the main road, as observed in the traditional linear pattern, at right angel to the proposed spine. A central community zone wasdeveloped along the main road where community services like primary school or mosque were provided. The Mosque and school were designed to serve as a community shelters for the neighborhood during emergency. The spines were intended to be developed as road communication network, making possible easy hooking of services to the individual clusters

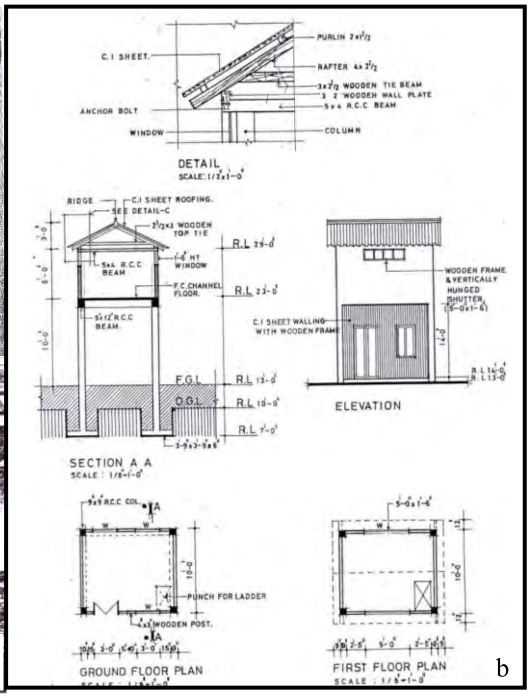


Fig 2.13a: Nucleus settlement of Urir Char after the cyclonic surge of 1991. (Source: Zahiruddin et al, 1991)
Fig 2.13b: Stilt house details of nucleus settlement constructed in 1985. (Source: Mowla , 1998)

The core of the settlement was homestead conceived as a nucleus shelter on RCC stilts. A number of 20 homesteads were clustered around a community pond with a protective dyke around to form a para. Each homestead was given a land holding of one bigha and each para was provided with agricultural land 5 bigha per household around it. To cope with the natural hazard and dynamic process of the coast, the settlement layout was conceived in such a way as to allow natural process of siltation and land formation rather than other engineering means of protection by dykes or embankment. Mowla (1998) reported that the Urir char settlement has remarkably passed its first field test by withstanding furry of 1991 cyclone storm with no loss of life and property. The author observed that after 6 years of completion of the project the houses the homesteads, the clusters, the village and even the central community zone has grown exactly the way it was conceived by the designer. He also claimed that the natural process of siltation has taken place by 1991, proving it successful and sustainable development filled up borrow pits, dug during the construction in 1985. The concept and technique of nucleus house was later adopted by the Grameen bank as a part of a sustainable development of the poor people. (Mowla, 1998)

2.3.4 Assessment of adaptation measure: Multi-criteria Evaluation

Not every adaptive measures whether planned or autonomous may not be equally performed well under strenuous climate change scenario. Particularly in autonomous adaptation decisions on adaptation are rarely made in response to climate stimuli alone (IPCC, 2007b). So it is necessary to assess the performance of the adaptive measures prior to any strategic decision in response to anticipated change in climate. In climate change research various methodologies are used to assess suitability of adaptation options. *Klein* and *Tol* (1997) and UNEP (1998) describe methodologies for evaluation, including ‗Cost-Benefit Evaluation' (CBE), ‗Cost-Effectiveness Evaluation' (CEE) and ‗Multi-Criteria Evaluation' (MCA) methods. Both CBA and CEA focus on economic criteria and determine the relative merit of an adaptation based on economic efficiency primarily whereas ‗Multiple Criteria Evaluation' (MCE) is designed to assess alternatives using more than one criterion (IPCC, 2007b). This method has been demonstrated for coastal zones (El-Raey *et al*., 1999) and other sectors because of its flexibility to evaluate adaptation options relative to a range of different considerations or goals. These methods, sometimes collectively referred to as decision analysis.

Selection of criteria is a first and foremost step of MCE method. According to Smith and Lenhart (1996), at a very basic level, the success of potential adaptations depends on the **flexibility** or **effectiveness** of the measures, such as their ability to meet stated objectives given a range of future climate scenarios (through either robustness or resilience), and their potential to produce benefits over costs (physical, social or financial). IPCC framework for adaptation research offers supplementary criteria for the identification of adaptations:

• The measure **generates benefits** to the society and environment under current conditions (i.e., independent of climate change).
• The measure addresses high-priority adaptation issues such as irreversible or catastrophic impacts of climate change (e.g., species extinction), **long-term planning** for adaptation (e.g., infrastructure), and unfavorable trends (e.g., deforestation, which may inhibit future adaptive flexibility).
• The measure targets **current areas of opportunity** (e.g., land purchases, revision of national environmental action or development plans, research and development).
• The measure is **feasible**—that is, its adoption is not significantly constrained by institutional, social/cultural, financial, or technological barriers.
• The measure is **consistent with**, or even **complementary to**, adaptation or mitigation efforts in **other sectors**. (IPCC, 2007b)

Clearly, these are difficult criteria to assess, given the complexity of adaptation measures, the variable sensitivities and capacities of regions, and uncertainties associated with climate change and variability. However, in MCE method, results can then be presented in either aggregated or disaggregated form. In aggregated form of presentation, the results can also be transformed into a single index value by converting criteria values to comparative performance scores and thus allow statistical analysis of the adaption options. The disaggregated from of presentation reflecting a descriptive exercise. Often this method is sufficient and informative, allowing a researcher to apply a judgment regarding the relative importance of the various criteria (Dolan et al, 2001). The present study adopts the Multi-criteria Evaluation (MCE) method following a descriptive approach to assess the suitability/ appropriateness of adaptive measure because of its relevance to study objectives.

2.4 Summary

Settlement is designated as an organized colony of human being comprises both natural and manmade part. The manmade part again encompasses both material (physical) and non material (social and cultural) elements. Housing units, common services and infrastructural facilities in a settlement whether rural or urban in together make up the physical fabric of that settlement.

Settlement patterns in coastal area of Bangladesh are not alike and largely influenced by the local context i.e. climate and geography. A predominant linear settlement pattern is observed along the natural levees of the water channel or transportation network in the interior part of the coast whereas in exterior coast, in foreshore and offshore areas, settlements are predominantly scattered with considerable linear pattern following the embankment.

The coast of Bangladesh is known as a zone of opportunities as well as multiple hazards. The entire coastal belt including its interior part is subject to periodic and occasional calamities, such as tidal floods and cyclones at present and is exposed to the risk of sea level rise resulted from climate change in future. Scientific research shows that the nature and exposure of geo-climatic risk due to sea level rise will not be same in all parts of coastal region. Settlement in the interior coast will experience severe water logging while in exterior coast problem due to cyclone and storm surge inundation will be severe.

Degree of exposure to hazard is not the sole determinant of vulnerability of settlement. The resistance and resilience capacity of existing physical and non physical component of the settlement also determines its vulnerability level. Being a least developed country where the inhabitants are predominantly poor have less economic capacity to recover/ resilience and fewer resources for protection and thus is estimated to be the most vulnerable among all. It is predicted that sea level rise will have long term impact in the coastal region of low income countries like Bangladesh. Along with serious environmental crisis in the directly affected area, sea level rise may threaten the social order in relatively safe area due to resettlement of the displaced people.

Adaptation is often considered as the most manageable response to contend with. Coastal development can adapt by taking measures in the form of protection, accommodation and retreat. Proper emphasis should be given to the fact that: protection measures against inundation by embankments interrupt the natural processes of land sedimentation and delta formation. This implies that subsidence and sea level rise will not be compensated by sedimentation and the risks of inundation and drainage congestion will be even greater in the future. Thus it calls for a different approach to face the problems especially in the seaward parts of Bangladesh. Retreat should come as the last option when the risk crosses its threshold limit. Therefore proper emphasis should be given on accommodation measure that means modifying the settlement components to improve its resistance and resilience capacity to future context.

Embedding accommodative measures within the urban infrastructure is again either very costly or very slow. It is likely to be easier if action is taken in rural areas where development is still sparse as opposed to the dense urban area. To date, adaptation measures in Coastal Bangladesh motivated by geo-climate have been minimal and mostly limited to afforestation and construction of cyclone shelter. In early 90‘s attempt had been taken for the development of cyclonic surge resistant settlement at *Urir Char* but the concept was not widely implemented. Urir Char experience proved its resilience and responsiveness to the context. However, autonomous measures to reduce exposure to existing climate related hazards can also serve as means of adapting to climate change and resultant sea level rise.

Chapter 3

Methodology

The study follows a bottom up approach to understand the research problem and possible responses through spatial analysis of vulnerability and settlement pattern followed by empirical study on local adaptive measures in selected coastal areas. Both primary and secondary data are collected and structured in a sequence of macro (Upazila) to micro (village) level following the methodological framework of the study as stated in chapter one. Finally a combined method of quantitative and qualitative analysis of the research data is applied in order to produce credible end results. The details of the applied methods are explained in the following clauses:

3.1 Data collection

Different datasets such as risk map, settlement data, household census data and a number of satellite images are collected for spatial vulnerability assessment. Geophysical risk data of selected areas for present and anticipated climate change scenario are collected from various research publications primarily from the study of IWM, CEGIS and BUET. To prepare the base map for analysis topographic map of 1:50000 scale containing data about settlement features including spatial distribution of houses and infrastructural facilities is updated form high resolution satellite image and LGED map and used. Household census and other socio-economic data are collected from the Bangladesh Bureau of Statistics (BBS). The community series of population census 2001 was the latest source of household census data at community level during the field survey in 2010.

Data related to local response to present risk is primarily on site information collected form transect walk/ direct observation and door to door physical survey. General information about the context and characteristics of settlement are collected from transect walk through study area and surroundings. Particular information about sample area collected from physical survey of settlement features followed by questionnaire survey (Household and key informants) on socio-economic profile and copping measures (Appendix H).

3.2 Data analysis and representation

3.2.1 Nearest neighborhood analysis of settlement pattern

For determining the pattern of coastal settlement, nearest neighborhood analysis has been applied to measure the degree of randomness or conversely tendency towards nucleation. The equation used in the present study is formulated by Tideswell and Baker (1971) and adopted by Sultana (1990). According to the equation, degree of randomness of settlement is the ratio of measured mean nearest distance between settlements to the expected mean in a random distribution. The mathematical expression of the equation can be represented as follows:

$$\mathbf{Rn = d_{obs} / d_{ran}}$$

Here, Rn = degree of randomness of settlement

d_{obs}= observed and measured mean distance between settlements

d_{ran}= expected mean in a random distribution

d_{ran} is calculated from the following equation :

$d_{ran} = 1/2\sqrt{P}$, here P = density of settlement

As mentioned earlier Rn value ranging from 0 to 2.15 is used to determine the settlement pattern where 0 indicates complete nucleation and 1.00 indicates scattered or random pattern. While describing settlement pattern of Bangladesh Sultana (1990) introduced an intermediated range in between 0 (complete cluster) and 1.00 (complete random) to state the linear pattern. For describing settlement pattern of coastal area the present study adopts the Rn scale as developed by Sultana (1990).

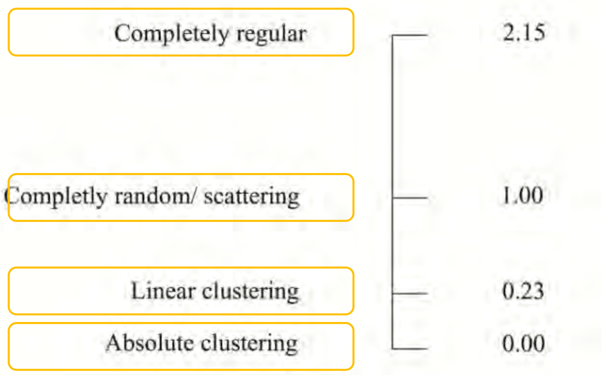


Fig 3.1 Rn value indicating the pattern of settlement (Adopted from Sultana, 1990, p. 94)

3.2.2 Grid based analysis of vulnerability

Geo-climatic vulnerability as defined is a composite index of settlements exposure to geophysical risk and capacity of settlement‘s physical components i.e. housing and infrastructure to cope with. In this study spatial vulnerability of study area is analyzed at community level based on selective variables following analysis grid (250mx250m) method (Appendix C). Geo-climatic vulnerability of settlement pattern of the study area is thus measured by analyzing their relative exposure to inundation situation primarily and sensitivity of physical features of settlement i.e. features that are susceptible to inundation. Simple statistical tools and formula are used to analyze the data followed by a visual representation of the empirical results for the study area. Steps followed to measure Geo-climatic vulnerability of settlement are:

Step 01 Preparation of base map

Step 02 Measuring Geo-physical risks

Step 03 Measuring resilience capacity of Settlement feature: Housing index and Infrastructure / service index

Step 04 Analyzing Geo-climatic vulnerability by comparing geo-physical risk exposure to settlement resilience capacity

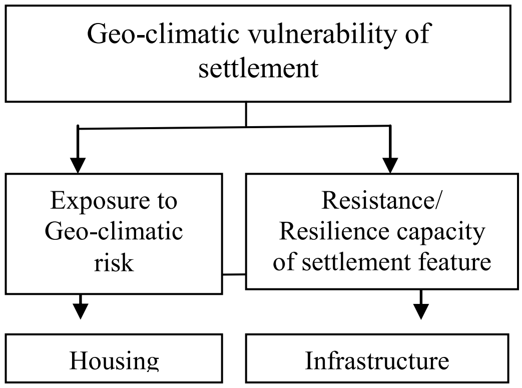


Fig 3.2 Steps to measure Geo-climatic vulnerability

Variables for physical vulnerability are determined on the basis of indicators. For better understanding and ease of calculation the indicators are categorized into two groups following the generic components of human settlement: Housing index and Infrastructural index. Each of these indices is again breakdown into number of variables and weighted accordingly.

Housing Capacity Index (HC_i)

Step 01: Calculation of no katcha house for each grid cell:

Spatial location of main house block is obtained from the topographic map of the study union. Then number of houses in each cell of analysis grid is calculated. This data will give the household density data for each cell area.

To get the number of katcha house in each grid cell first ratio of katcha house is calculated for each village or locality from BBS, Community series 2001 and then multiply this ratio with the number of household in each cell (household density).

NO OF KATCHA HOUSE IN EACH CELL = KATCHA HOUSE RATIO FOR EACH VILLAGE X NO OF HOUSE HOLD IN EACH CELL

Step 02 : Calculation of ratio index R_i **:**

To obtain a relative/ comparable data set, ratio index of katcha house is computed by dividing the no of katcha house in each cell with the total no of katcha house in the study union.

Ri_katcha house = NO OF KATCHA HOUSE IN EACH CELL / TOTAL NO OF KATCHA HOUSE IN THE UNION

Step 03: Calculation of housing Capacity Index HC_i **:**

Housing capacity index is then computed for each grid cell by using the maximum ratio value Ri max observed in the union. This will give a data set ranging from 0.00 to 1.00.

HV_i **= Ri** _katcha house **/ Ri max** _katcha house

Infrastructural Capacity Index (CIC_i):

Infrastructural capcity is assessed on the basis of deprivation of services or facilities in the study union. It is a measurement of accessibility which is essentially based on distance to the nearest facilities or services from the locality. Spatial distance of these facilities is measured from the upazila infrastructural map prepared by Local Govt. Engineering Dept. Weights in the scale of 1.00 were assigned to each variables based on the desirability/ need of the facility during disaster period from focus group discussion and expert opinion.

Step 01: Calculation of spatial distance of nearest facility

For each variable spatial distance of nearest facility is measured from the center of each grid cell. In case of access to pacca road, shortest distance from the nearest pacca road is considered.

Step 02: Calculation of ratio index R_i **:**

Ratio index for each variable is computed in order to obtain a dataset in relation with the average value.

Ri = DISTANCE TO THE NEAREST FACILITY FROM THE CENTER OF THE CELL / AVERAGE DISTANCE OF THE FACILITY IN THE UNION

Step 03: Calculation of Access to Service index AS_i **:**

Access to service index for variable I using the maximum ratio value Rmax observed in the union was computed.

$AS_i = R_i / R_{max}$

Step 04: Calculation of Composite Infrastructural Capacity Index CIC_i **:** To combine multiple variables in the assessment of Infrastructural vulnerability , weighted mean of the access to service indices is calculated by dividing the sum of the weighted index value of all variables by the number of variables n considered.

CICi = ∑ Wi * ASi / n

The value range from 0 to 1 and are not influenced by the number of variables included in the computation. Higher score for this index indicates greater vulnerability for the unions.

3.3 Multi-Criteria analysis of adaptive response

To enumerate the local response, descriptive approach is applied followed by statistical analysis of frequency of coping measure or trends of development or growth etc. All the collected information is then aggregated under three functional strategies of adaptation as identified by Biljsma *et al.* (1996), these are: Adaptation by protection, Adaptation by

Accommodation and Adaptation by Retreat. Responsiveness of local measures is then discussed on the basis of scientific inference of respective measures.

To analyze the performance of adaptation measures in the coastal zone, there have been developed principles and set of criteria with a scale to rank them.

Selected Criteria for adaptation assessment adopted form UKCIP, IPCC (2001b), EEA (2009), ETC/ACC (2010) and Karim, R (2010) are discussed below:

1. Effectiveness for potential mitigation: The measure provides robustness / adaptation to specific objective in terms of reducing impacts, reducing exposure, enhancing resilience or enhancing opportunities.

2. Suitability to future context/ risk: The measure is robust under different climate and socioeconomic scenarios

3. Feasibility/ Implement ability: The measures do not have any social, technical, institutional or time scale barrier to implementation.

4. Flexibility: Adjustments can be made later if conditions change again

5. Environmental friendliness: The measure does not cause or exacerbate other environmental pressures.

6. Ecosystem connectivity: The measure helps to sustain/ stimulate the natural processes which lend connectivity to ecosystem and promote biodiversity.

7. Equity: The measure has equal benefit to different social groups the measure does not affect other sectors or agents in terms of their adaptive capacity (not helping some at the expense of others)

8. Economic viability: The measure has low monetary cost during implementation, operation, maintenance period.

9. Local people Participation: The measure involves or creates opportunities for local people participation

10. Cultural acceptability: The measure is culturally acceptable by the community

11. Synergies /Multi-purposefulness: The measure is consistent with, or even complementary to, adaptation or mitigation efforts in other sectors.

The criteria‘s of adaptation are then rated using the scale of High (H), Moderate (M) and Low (L). For rating results from multiple simulation tools, findings from experimental research and expert‘s opinions including author‘s onsite experience are used.

Chapter 4

Vulnerability and Adaptation Practices in Waterlogged Area: A case of Southwest Coastal Region in Bangladesh: Keshabpur Upazila, Jessore

Keshabpur, an upazila (sub district) of Jessore district, is located in the southwest region of the interior coastal zone as delineated in ICZMP. The upazila is bounded by two rivers; Kobodak on the west, Upper Bhadra on the east. And a third river Harihar bifurcating the upazila into two distinct zones: The western zone (Trimohoni, Sagardari, Bidyananakati, Majidpur and part of Keshabpur and Mangalkot union) and the eastern zone (Safulakati , Panjia , Gaurighona and rest of the part of Keshabpur and Mangalkot union).

4.1 Demography, geography & settlement profile of Keshabpur Upazila:

According to population census 2001, upazila has a total population of 2, 26,367. Considering the growth rate between the year 1991 to 2001 the projected population for 2011 is 2, 55,907. However the avg. density as enumerated in the census is 875 per sqkm which is higher than the national avg. of 834 per sqkm. Total households in the upazila is 49,900 with family size is 4.53 persons (BBS, 2001a).

The western zone of the upazila is high Ganges flood plain with pockets of low flood plain or Beels. The soils of the high Ganges flood plain constitute a good agricultural potential and are intensively cultivated (Haskoning, 1992). These have positive influence on settlement growth. Average population density in the western part of Harihar River is 970.59 per sqkm and among the households majority are farmers (tabulated from BBS, 2001a).

Eastern part of the area is largely covered by peat basins mixed with Ganges floodplain. These areas are mostly low lying with many Beels and are crisscrossed by many tidal streams and creeks. Such physiographic condition restricts agricultural practices as well as settlement growth. Settlement in this area is predominantly linear in pattern with an average population density of 758.69 per sqkm comparatively lower than the western region (tabulated from BBS, 2001). Apart from agriculture, fishing is a major livelihood activity here. The upazila consists of 142 villages (142 mauzas) distributed under 9 Unions (smallest administrative unit). The modal village size is 751 – 1500 persons.

Table 4.1 Distribution of villages by size, class of population

Size class	**Population**	**No of villages**		**difference**
		2001	1991	
V1	UPTO- 250	4	6	(-) 2
V2	251-750	27	33	(-) 6
V3	**751-1500**	**50**	**55**	**(-) 5**
V4	1501-2500	30	29	(-) 1
V5	2501 & ABOVE	31	20	(-) 11

Source: Population census, 2001 (community series: Jessore district)

Average spacing of settlement is 1.49 km which is considered as high (Appendix D), a common characteristic of settlement of coastal region. As the upazila is saline prone, that declines the productivity of land and is exposed to tidal flooding; settlements are found to be clustered and concentrated on the high land and separated by a wide distance. In western region the villages are relatively closely spaced with avg spacing of 1.46 km as the area is characterized as upland with soils of moderate productivity. In contrast, the avg. spacing between settlements of eastern zone is comparatively high i.e. 1.53km as substantial part of the area is occupied by wetlands / shallow basin (Beels) causing homestead to be concentrated on the highlands or along the transportation line with villages wide apart.

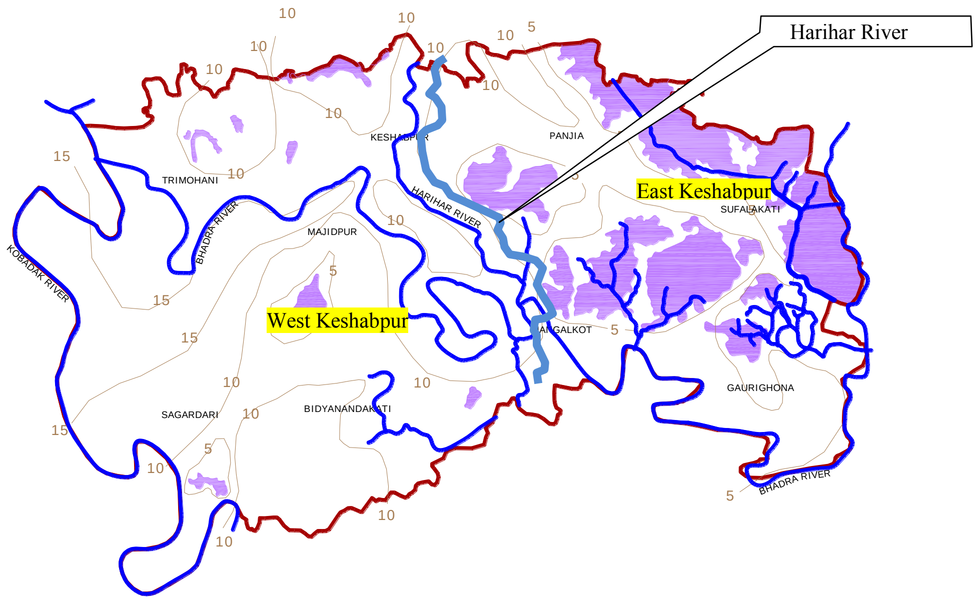


Fig 4.1 Topographic map of Keshabpur upazila (adopted from Haskoning, 1992)

Fig 4.2 Settlement pattern of Keshabpur Upazila (Shaded area shows the area of settlements) (adopted from LGED, Bd)

4.2 Nature and severity of the problem

Water logging is the most pressing problem in both western and eastern part of Keshabpur. The problem has been much deteriorated for last 7 to 8 years (Adri and Islam, 2010, p-33). A vast areas of Trimohoni, Sagardri, Bidyananakati union of west Keshabpur and Safulakati and Panjia union of east Keshabpur are water logged. Waterlogged population in these 5 unions was 10100, 7100, 6060, 4200 and 1800 respectively (Keshabpur Thana Information Booklet, 2008).

But the cause and exposure of vulnerability of western and eastern Kesahbpur is different. The reason for water logging in the western part of Keshabpur is gradual siltation of Kabodak riverbed, the coastal embankment project, Farakka barrage etc. accelerated the process of sedimentation of River Kabodak (Adri and Islam, 2010, p.33). Hence, the water inundated the riverside and adjacent Beel areas. These areas remain inundated during the months of June to November (FFWC, 2007).

Reason for water logging in east Keashabpur is both natural and manmade. Two unions of east Keshabpur are affected due to Bhabadah River namely Safulakati and Panjia (Adri, 2009). Origin of the problem begins in early ‗80s, when severe water logging had resulted in many parts of the southwest region. The region is a tidal wetland and prior to construction of permanent embankment the area used to be flooded by high tide twice in a day in harmony with lunar cycle. But after construction of embankment the area compartmentalized into polders[3] and sedimentation took place in river channels, causing very rapid deposition on the river beds. This process ultimately raised the riverbeds in comparison to adjacent Beels or wetlands subsided and gradually over 106,000 thousands hectors of land became permanently waterlogged (Islam and Kibria, 2006). In this area nearly 8 months in a year most of the parts remain inundated (Adri, and Islam, 2010).

Again sea level rise will exacerbate water logging problem in the area (IWM, 2005). A rise of 14 cm in sea level will inundate 20 % more area. In the worst condition (for SLR 88 cm) almost 45% land will be inundated / waterlogged. (fig 4.3) This will occur in two ways: 1. Overtopping of polder, as the existing flood control infrastructure was designed for historical water levels and tidal fluctuation; 2. Sediment deposition on tidal meeting point will impede upstream drainage and change drainage characteristics of the of the region (Choudhury et al, 2005). This will lead to more saline water intrusion in the area detrimental to aquatic and terrestrial environment.

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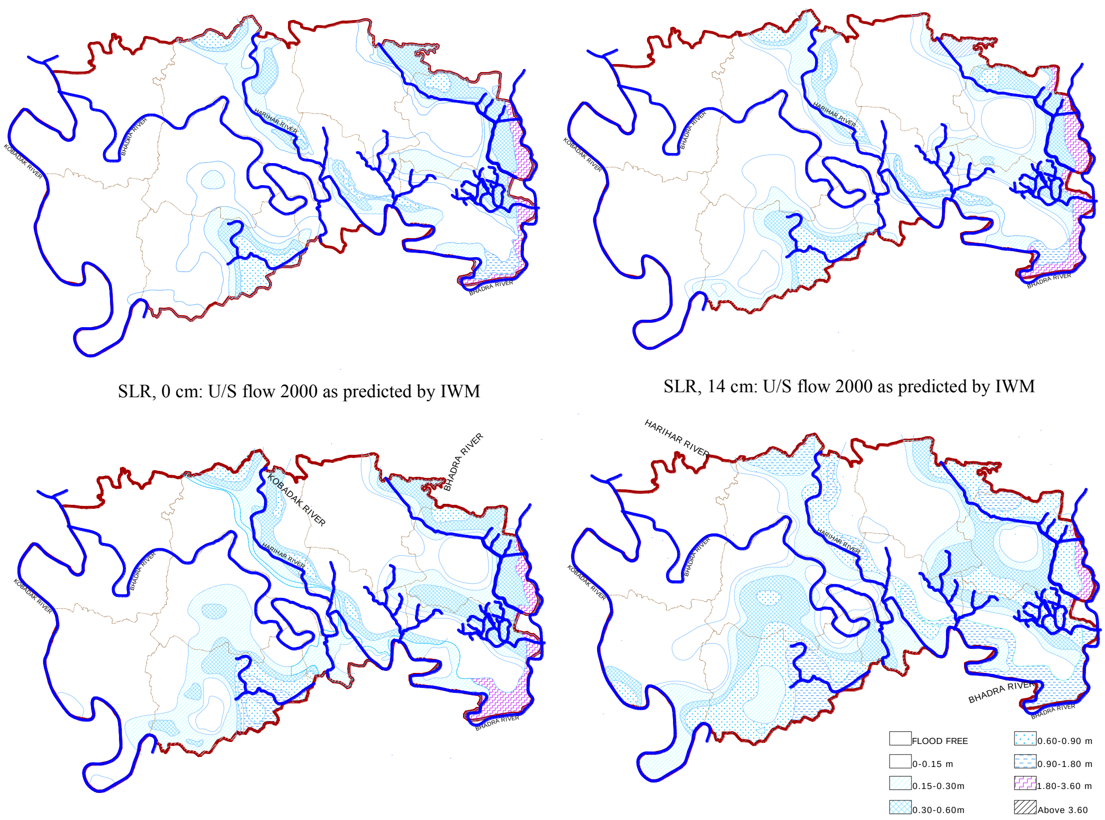
[3] A polder is a tract of land, surrounded by embankments in which the discharge and supply of surface water are controlled mechanically by regulators.



SLR, 0 cm: U/S flow 2000 as predicted by IWM

SLR, 14 cm: U/S flow 2000 as predicted by IWM

SLR, 32 cm: U/S flow 2000 as predicted by IWM

SLR, 88 cm: U/S flow 2000 as predicted by IWM

Fig 4.3: Impact of sea level rise in Keshabpur upazila (adopted from: IWM, 2005)

4.3. Impacts of water logging on human settlement

The water logging has brought extreme suffering to the local communities in the region. During water logging period normal life of the inhabitants greatly interrupted as the homesteads with their farmland, roads and infrastructure immerse under stagnant water. Many people moved onto embankments and roadside. Educational institutions have been severely damaged and children have been forced to discontinue education. On the other hand, biodiversity and livestock have been greatly decreased. Salinity has increased due to capillary action and vast areas of agricultural land lost soil fertility. Firewood and pure drinking water have become scarce. Moreover, unemployment has forced many people to migrate to urban areas in search of livelihood (EGIS, 1998; Islam, and Kibria, 2006).

Water logging not only disrupts normal life of the inhabitants but also keep long term imprint on the settlement. It is the poor and marginal people who are the most affected as their houses being poorly built rot during prolonged water logging. Often these people find it difficult economically to reconstruct their houses fully knowing that their efforts will again be destroyed in the next water logging period. Affected households are often facing severe sanitation problem. Most of the latrines are reported to be destroyed by standing water. The poor are forced to defecate in open water that surrounds them (CCC, 2009). As a result waterborne diseases like diarrhea and scabies have become endemic. Besides, inundated roads and other physical infrastructures are severely damaged in water logged conditions. Household in severely affected area are forced to shift and take shelter in the nearest refugee shelter or on high lands/road free from inundation. During the prolonged water logging of 2008, 3500 people from Trimohani, 2900 from Sagardari, 1300 from Bidyanandakati and 450 from Safulakati union shifted to the refugee shelter (Thana information booklet, 2008).

It is reported that for the heavy pour of September and November in 2005, around 10,825 hectares of cultivable land of 184 villages of Manirampur, Keshabpur, and Abhaynagar Thanas under Jessore District went under water. 2, 87200 people of 57445 families became waterlogged. 80% houses of the affected areas, roads and village paths, educational institutes, clinic and hospitals, religious institutes are under water.

Table 4.2 Description of loses, Keshabpur

Affected area	2004	2005
Village	98	74
House damage	6792	4565
Family / house hold	21,430	27,240
People		136100
Cultivable land	26573 hectares	3430 hectares
Village path (unpaved)	-	55 km
Metal road	-	6 km
Educational inst	-	24

Source: (CDP, 2006 and PPS, 2006; Uttran, 2004)

4.4 Vulnerability of Settlement to water logging: Identification of key variables

4.4.1 Settlement Density

Density of settlements indicates how many households are exposed to the risk within a confined geographic area. The more dense the settlement is the more people is at risk. The average settlement density of Keshabpur upazila (190.70 HH/sqkm) is higher than the national average (171.8 HH/ sqkm). To be specific, density is higher in west Keshabpur (214.69 HH/sqkm) and lower in east part (166.71) than country‘s average. Historical data of population growth rate shows that a significant increase of population during 1951 -74 period has caused a change in the settlement density. At that period, a series of embankments and polders were constructed as a part of the CEP (Coastal Embankment Project) and HYV (Hybrid Yield Variety) rice and wheat cultivation were introduced which initially cause green revolution in the area (CCC, 2009. p.15). Many people from have moved from the more densely populated areas of the mid-eastern districts to this area during this period (Sultana, 1990, p.67).

Table 4.3 Household/settlement density of West and East Keshabpur

	Union	HH density (per sqkm)	Avg. HH density (per sqkm)
West Keshabpur	Trimohoni	196.17	**214.69**
	Sagardari	218.88	
	Bidyananakati	202.60	
	Majidpur	208.08	
	Keshabpur	247.73	
East Keshabpur	Safulkati	135.81	**166.71**
	Gaurighona	151.10	
	Panjia	173.83	
	Mangalkot	206.11	

Source: calculated by author *

4.4.2 Housing characteristics

During the prolonged water logging, homestead in affected area are inundated under 5 to 1 ft stagnant water. Jhupri and Katcha houses are more vulnerable in water logging condition. It is reported that, Most of the mud-built houses are destroyed in water logged condition (CCC, 2009, p.36). Specially the earthen plinth and Biomass based walls erode and rot in submerged condition and weakened the foundation of the structure. Compare to Jhupri and Katcha houses, semi-pacca and pacca houses are structurally less vulnerable (Hafiz, 2000, p.157), though they often require maintenance after prolong inundation period. However roofing system doesn‘t have any co-relation with the structural vulnerability of dwelling unit due to water logging.

Like other rural area of Bangladesh housing condition of Keshabpur upazila is dominated by Katcha houses (73.57%).Besides, semi-pacca houses built with brick walls and CI sheet/ tile roofing is also observed. Except some institutional building and houses of local landlords very few houses in the rural area of Keshabpur are pacca or made of brick and concrete.

Table 4.4 Distribution of the main houses of the dwelling households by type of structures

Locality	Total	Jhupri	Katcha	Semi Pacca	Pacca
upazila	100	1.80	73.57	13.33	11.31
Rural	100	1.69	74.73	13.30	10.28
urban	100	2.70	63.52	13.66	20.11

Source: BBS 2001a

4.4.3 Access to service and shelter

It is observed that distribution of services is not uniform in Keshabpur upazila. Access to these services is influenced by nature of communication network and travel distance from the locality and greatly disrupted by water logging phenomena. To assess the relative vulnerability it is essential to analyze overall distribution pattern of services and their accessibility.

4.4.3.1 Access to education facility

The needs for general education in the upazila is met by 67 primary schools, 22 high schools and by a college located at upazila headquarter. On an avg. the primary schools are located at every 2.2 km distance and for every 456 primary school attendance (5-9 years) there is a primary school.

Access to education is greatly disrupted in waterlogged areas of Keshabpur. Most of the affected education facilities in inundated areas were remains closed for even upto six months in a year (Khan, 2008). In 2005 IFIW watch reported 500 schools and colleges were closed only in Jessore upazila for 1years. Perhaps not only the education system in waterlogged areas is disrupted but schools in adjacent areas those are free from water logging are used for the purpose of community relief shelter. Besides, another reason for decreasing number of school attendants is lack of accessibility as communication system is disrupted due to water logging and students are often facing difficulty to find their path from residence to school and vice versa (Khan, 2008).

4.4.3.2 Access to village market

To meet the households material need there are in total 45 hats and bazaars in the upazila (LGED official website). On an average for every 5000 (4990) people there is a hat/ bazaar in the upazila with an average spacing of 2.66 km .In terms of travel distance and catchment population, east Keshabpur has poor access to bazaar facility than the western part (for every 4000 people there are a hat or bazaar in west Keshabpur where as in east Keshabpur the figure is 5,532). Water logging causes additional declination of the accessibility to bazaar facility as communications are greatly disrupted due to inundation.

4.4.3.3 Access to community clinic

In waterlogged area people often suffer from water-borne diseases like diarrhea, dysentery and skin diseases. The nearest community clinic is the only place where the rural people get their health care services. Of the 15 healthcare facilities in Keshabpur upazila there are an Upazila health complex at Keshabpur, a subcenter at Panjia and 13 community clinics. It is observed that there is an unequal distribution of healthcare services in Keshabpur. On an average there is a health care facility for every 15,000 people and east Keshabpur has better access to health facility than the west. People of Gaurighona, Safulakati, Bidyananakati have poor access to this services. In this union the spatial distance of the nearest community clinic from the union center is more than 4 km.

4.4.3.4 Access to pacca road/ high land

Although major portion of the union and upazila roads are pacca or paved but the village roads comprising 75% of total road network are predominantly earthen or katcha. These unpaved or earthen roads are subjected to erosion due to prolonged water logging. Often these roads immerse under water particularly in peak monsoon and cause immense sufferings to the households. Boat is the only means of communication then. On the other hand the pacca roads not only ensure uninterrupted inland communication and access to other services but also provide shelter for the refugee.

Table 4.5 State of road communication in Keshabpur upazila

	Total (km)	Paved road (km)	Unpaved road (km)
Road length	823.92	219.38	604.53
%	100	26.62	73.38

Source: Road data base on LGED official website

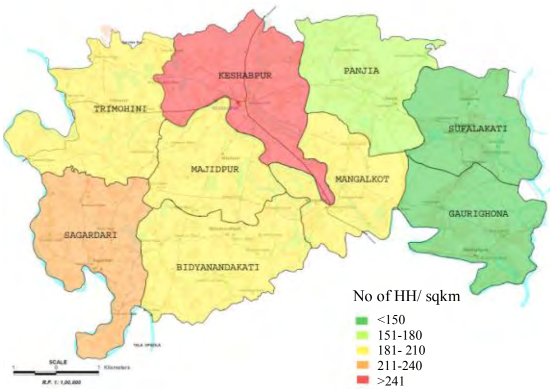


Fig 4.4. a. Density of settlement, Keshabpur

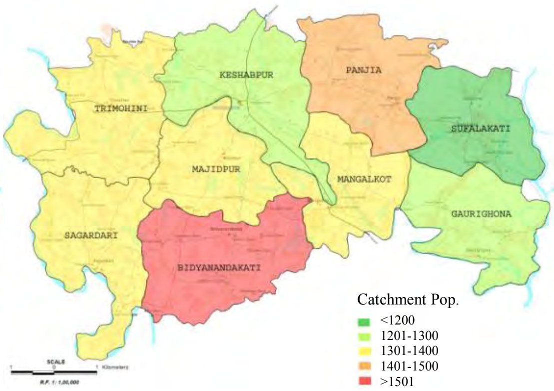


Fig 4.4. b. Access to educational facility, Keshabpur

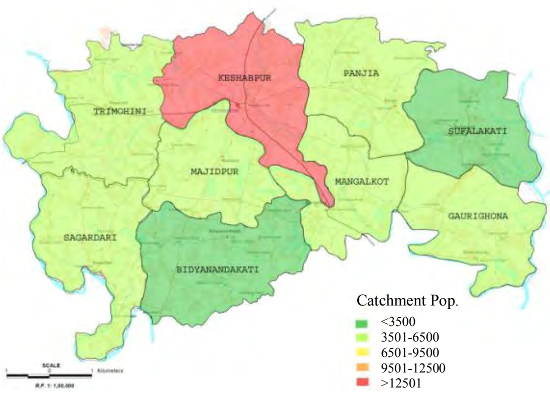


Fig 4.4. c. Access to Hat bazar, Keshabpur

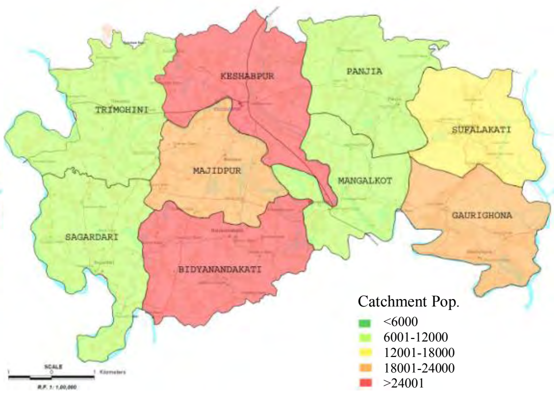


Fig 4.4. d. Access to health facility, Keshabpur

Therefore, high settlement density, weak structure of the house, unavailability of community services within close proximity that provides the material need or assistance to the households and poor inland transportation network that connect this services to the settlement are the key aspects of settlement‘s physical vulnerability in water logged area.

4.5 Spatial analysis of geo-climatic vulnerability of settlement in Safulakati union - Keshabpur:

In this study Safulakati union located in eastern part of the upazila is selected for micro-level analysis of geo-climatic vulnerability following analysis grid method. This area is selected because of high geo-physical risk exposure. Settlements in this area are subjected to seasonal water logging at present and at risk of permanent water logging in future in much greater extent. In Safulkati Union there are 16 localities or villages. Kalagachi is the growth center. Beel Khuksia comprising a major part of the eastern union is a tidal basin. Total population in the union is 15938 with an average density of 626.30 people per sqkm (BBS Community series, 2001a).

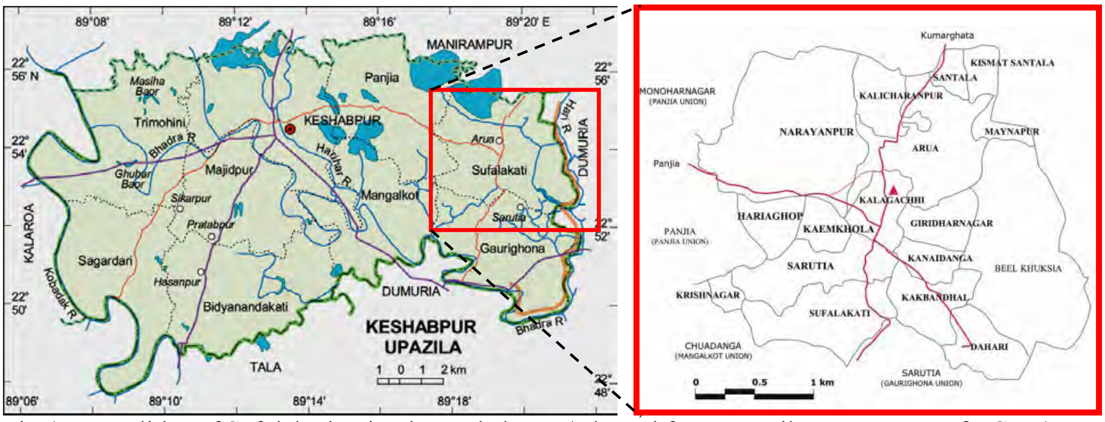


Fig 4.5 Localities of Safulakati union in Keshabpur. (adopted from Upazila Mauza map of LGED)

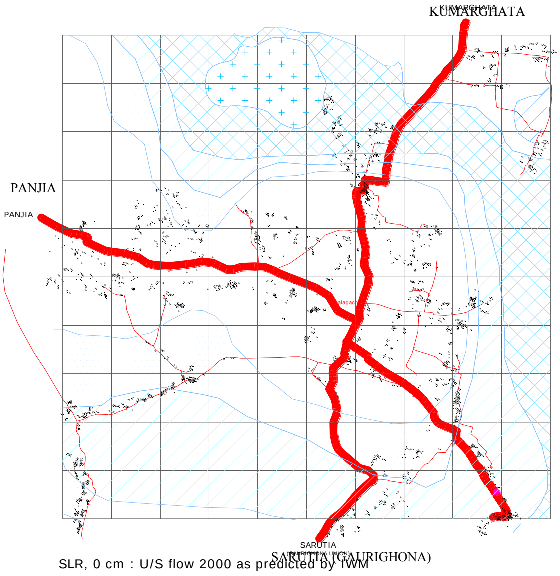
Table 4.6 Variable matrix used to determine Geo-climatic vulnerability of settlement in Safulakati

Domain	Indicators	Proxy Variables	Measurable component
Exposure to Geophysical risk	Geophysical risk index	Inundation due to water logging	Depth of inundation in each cell
Resistance and Resilience capacity of settlement	Housing vulnerability index (60)	Number of katcha house	Katcha house ratio X no of household in each cell (density of settlement)
		Household density	
	Infrastructural vulnerability index (40)	Access to pucca road	Spatial distance of the grid cell from nearest pucca road
		Access to healthcare facility	Spatial distance of the grid cell from nearest health care facility
		Access to hat / bazaar	Spatial distance of the grid cell from nearest village market
		Access to educational facility (primary school and high school)	Spatial distance of the grid cell from nearest educational facility.

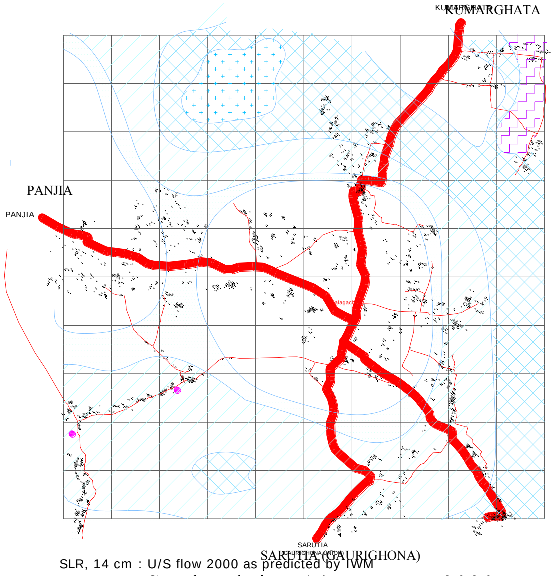
4.5.1 Measuring geophysical risk

Geophysical risk of the study union (Safulakati) is measured on the basis of inundation map adopted from IWM for four different sea level rise scenario for next 100 years. Regional sea level rise scenarios are adopted from NAPA recommendation. NAPA adopted the ranges for the projected years 2030, 2050 and 2100 which are based on Third Assessment Report (TAR) of the IPCC and SMRC studies for Bangladesh. Base condition is measured on the basis of inundation depth data on monsoon period for the year 2000.

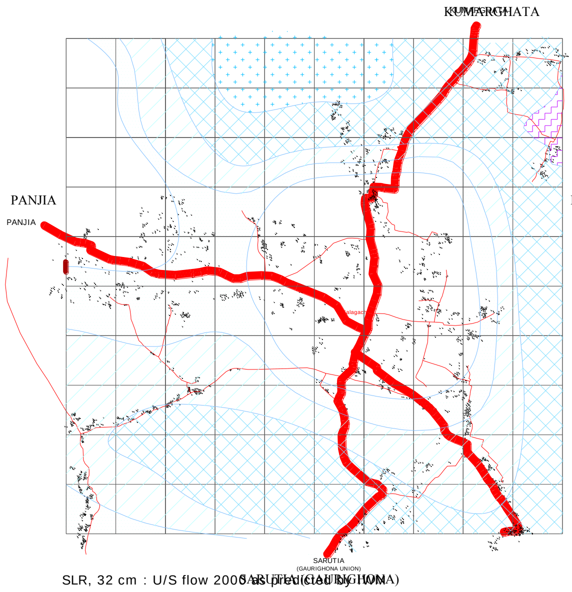
The regenerated inundation map for Safulakati union is then prepared for spatial grid analysis. Each cell of analysis grid is assigned with the respected inundation depth data for four different sea level rise scenario. Cell containing more than one data is reduced to one considering the maximum spatial coverage of individual data. It is observed that, for the study union inundation depth data varies from 0 m to 1.80 m. Based on spatial variation of inundation depth risk area has been identified for individual case. Inundation depth map for base condition and projected years has been presented in the following:



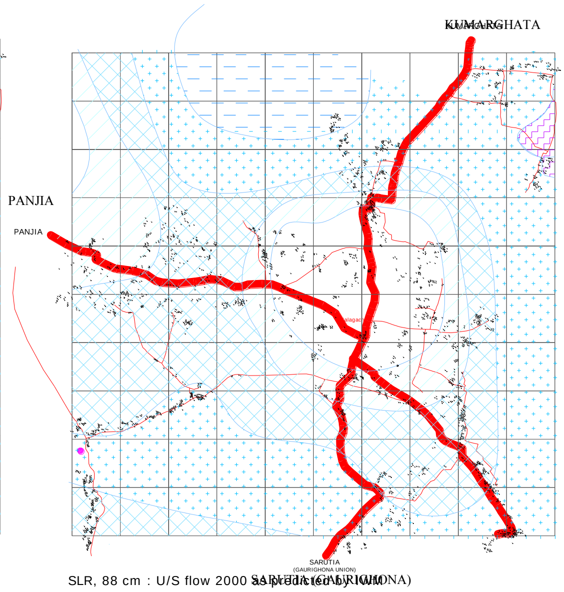
Sea level rise, 0 cm Year -2000



Sea level rise, 14 cm Year -2030



Sea level rise, 32 cm Year -2050



Sea level rise, 88 cm Year -2100

Fig 4.6 Inundation depth map of Safulakati union: regenerated from IWM study, 2005

To compute composite risk index, four individual data sets are overlapped and maximum and minimum value of each grid cell for next 100 years is calculated. The data series then again categorized into five risk groups following the minimum and maximum range of the data. The final map (fig 4.6) shows a composite geophysical risk scenario of the study union at neighborhood or micro level (1 grid = 1/4 sqkm).

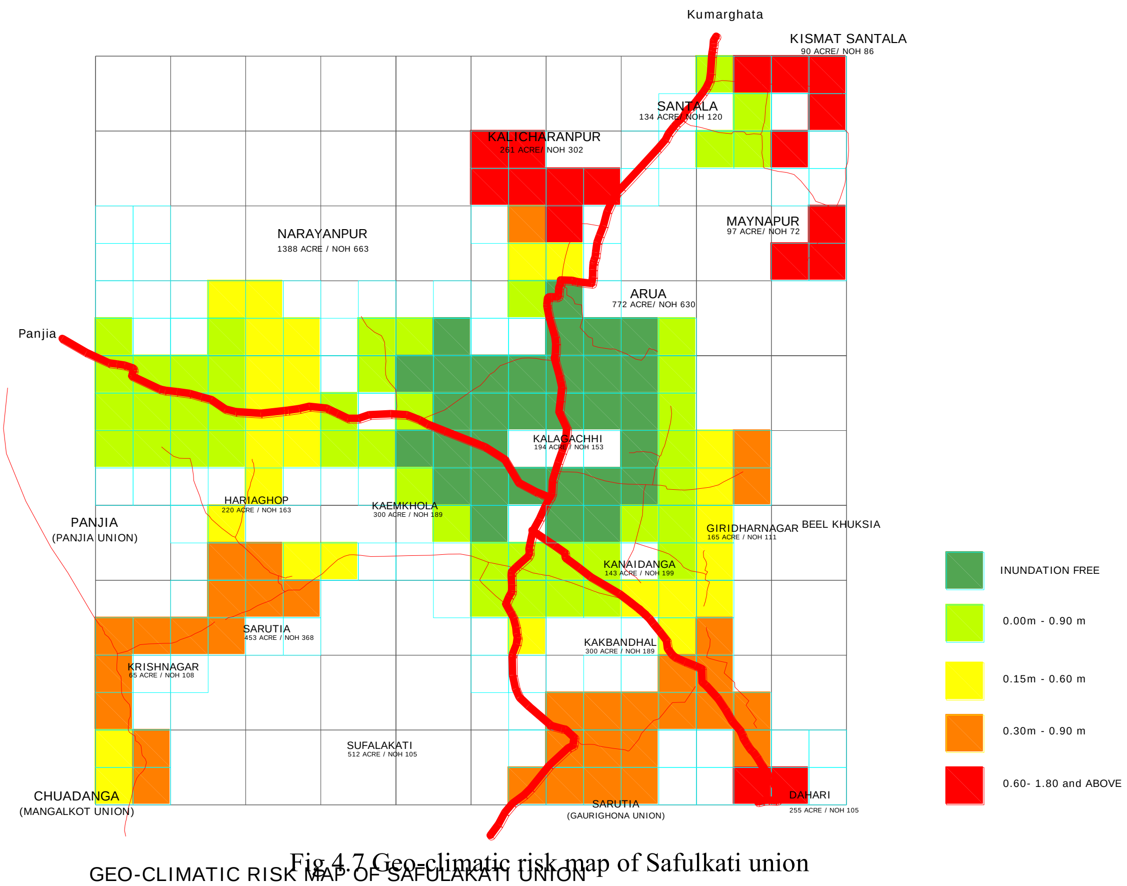


Fig 4.7 Geo-climatic risk map of Safulkati union

From the map (fig 4.7) it is evident that central part of the union will remain inundation free even under worst condition of sea level rise. Inundation risk is highest among localities of north earten part of the union in Maynapur , Kismat Santala and part of Kalicharanpur. These localities are at risk of permanent water logging with maximum depth of 1.8 m and above. Besides localities adjacent to Beel areas and localities of the south are also at risk of 0.3 to 0.9 m depth inundation.

4.5.2 Measuring resilience capacity of settlement

Settlement‘s resilience capacity is analyzed in terms of two physical components; i) Housing and ii) Infrastructure. It is assumed that katcha and jupri houses are more susceptible to damage by stagnant water and thus more sensitive thus have less resistance capacity. Again in case of infrastructure, it is assumed that settlements that lack services within their close proximity is more sensitive and thus have less resilience capacity. It is measured on the basis of spatial distance of a settlement grid from the nearest available facility consider.

4.5.2.1 Measuring capacity of housing structure

Resistance capacity of housing structure to water logging is measured on the basis of density of katcha houses i.e. no of katcha houses in each grid cell. There are total 3456 dwelling units in the union with predominant katcha structures which comprises 40% of total holdings. In Krishnagar and Maynapur percentage of katcha house is highest and so as the density of katcha house. Considering housing structure settlement in this area is more sensitive to geophysical risk and thus resilience capacity is lowest. On the contrary settlements in central part of the union are less sensitive or more resilient to the risk of cyclone as the relative density of *katcha* house is lower. Spatial distribution of housing structure and their relative sensitivity is given in fig 4.8 and fig 4.9.

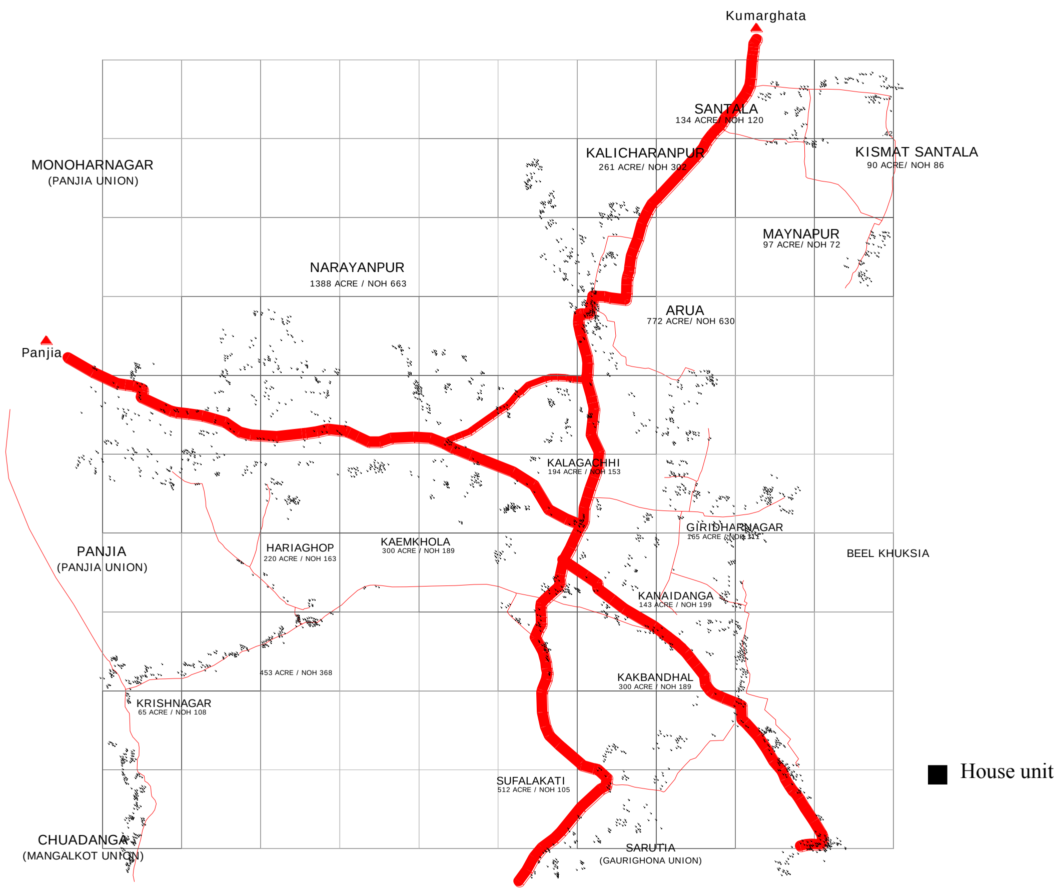


Fig 4.8 Spatial distribution of houses in Safulakati union (adopted from Topographic map, Survey of Bangladesh and updated from satellite image)

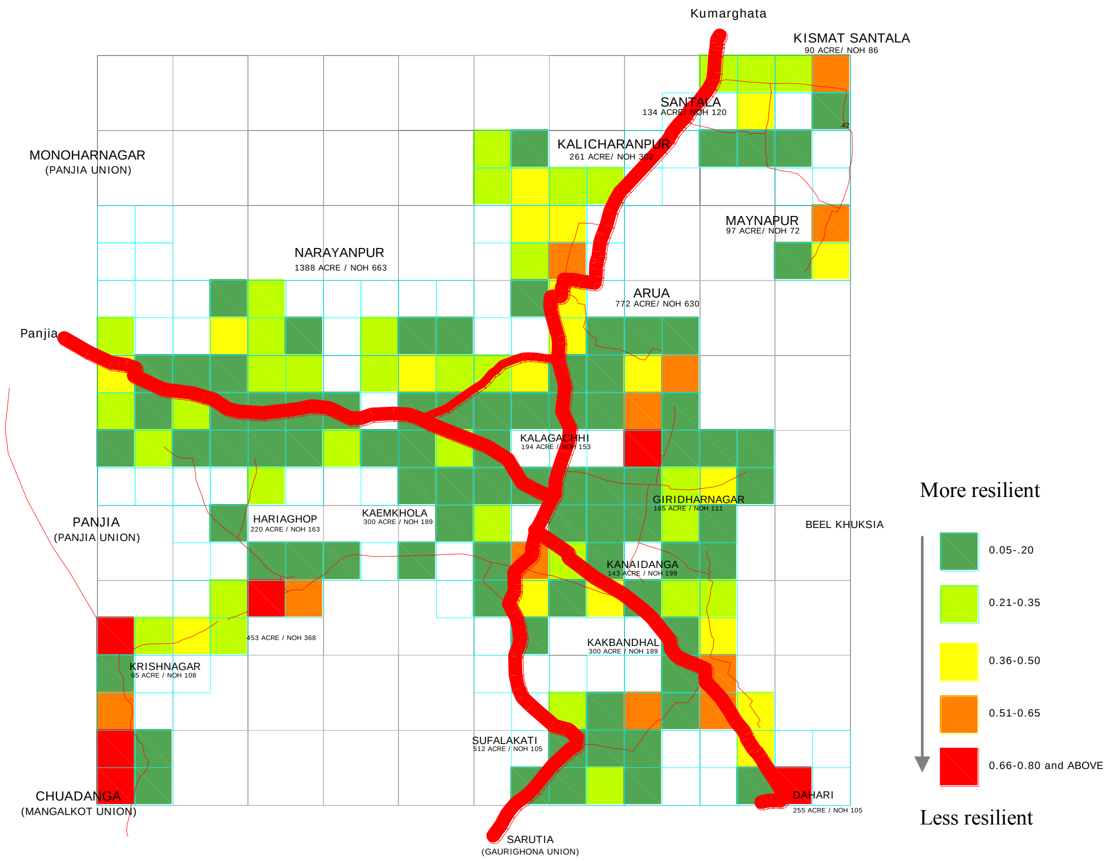


Fig 4.9 Resilience Capacity of Housing structure in Safulakati Union

4.5.2.2 Measuring Infrastructural capacity

Capacity of existing infrastructure and services commonly termed as infrastructural resilience capacity is measured in terms of proximity or spatial distance of the settlement grid from the service / facility considered. To serve the inhabitants there are 11 schools including 5 high schools (table 4.6), 1 community clinic at Kalagachi and 5 bazars or village markets. The union road is criss-crossing the whole area and relatively high land from rest of the part. This road comprising 12.34 km of length is pacca and forms the central artery for the settlements. All the major common facilities are concentrated along the sides of this road. However, access roads to the village are predominantly katcha.

Table 4.7 Profile of High school in Safulakati Union

Shelter name	Catchment group	Total student
Arua High School	Co education (Boys and Girls)	295
Palli Unnayan Girls High School	Girls	355
Katakhali High School	Co education	221
Kanaidanga High School	Co education	389
Narayenpur High School	Co education	320
Total attendants		1580

Source: BANBEIS, General and Madrasa education Database

After analyzing relative sensitivity or resilience capacity of settlement grid for each of the variables separately the data set are overlapped to calculate composite index. To combine the data, weight is assigned to individual variable on the basis of need / desirability, multi-purpose uses of the facility and period of contribution. It is obvious that good communication is the most desired facility in order to continue normal life of the waterlogged population and thus weighted accordingly. Moreover unhindered access to education is equally important during prolonged period of water logging considering knowledge development for future generation.

Table 4.8 Selected variables with weighting value

Variables	weight	comments	Contributing period
Proximity to nearest high land / pacca road	0.30	Provide communication to other material support and act as temporary shelter for refugee and livestock	During and post disaster rehabilitation and recovery
Proximity to nearest Educational facility	0.30	Meet the basic rights of education of the inhabitants. Also serve as rehabilitation and relief center.	Pre disaster preparedness and during disaster recovery.
Proximity to nearest Health facility	0.20	source of emergency medicare	During and Post disaster health safety
Proximity to nearest Hat / Bazar	0.20	Source of material for domestic need and economic opportunities.	During and post disaster material support.
Total	1.00		

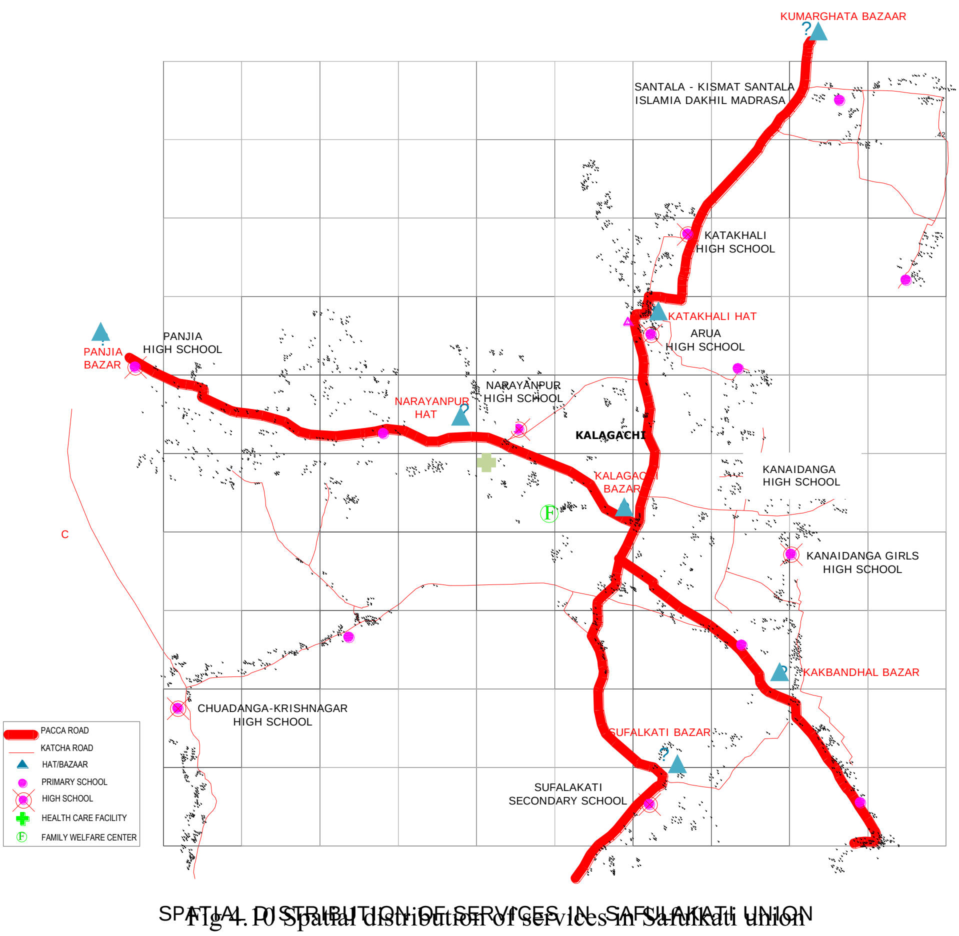


Fig 4.10 Spatial distribution of services in Safulkati union

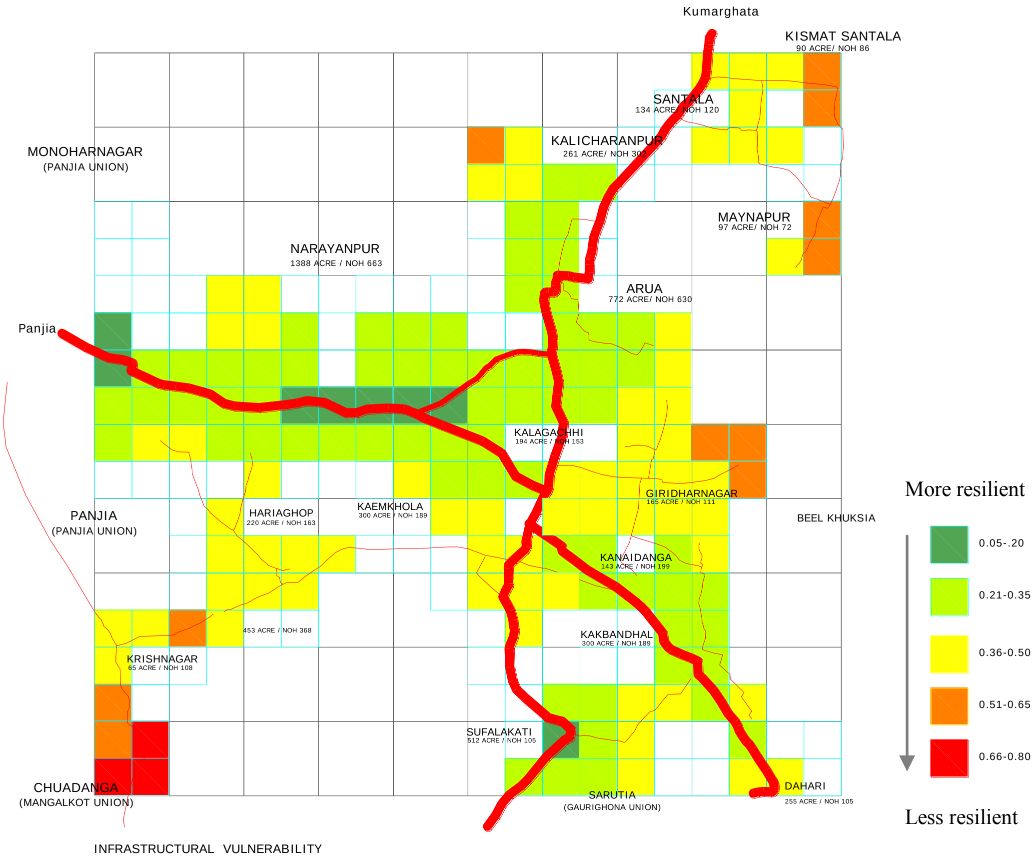


Fig 4.11 Composite infrastructural capacity of Safulakati union

It is found that, being a growth center settlement in the central part of the union has better infrastructural facility than other parts. Households in this area have better access to common services as these are located within close proximity to settlement area. Settlements away from the union center have less infrastructural development and devoid of many essential services. To be particular, remote settlements of Maynapur, Krisnagar and part of Giridharnagar have poor access to community services and thus have less capacity to recover.

4.5.2.3 Measuring Composite Settlement Capacity Index (Housing + Infrastructure):

As mentioned in methodology chapter overall settlement‘s resilience capacity is a composite result of housing and infrastructural capacity to resistance and recovers. The composite index of settlement is thus prepared by overlapping the weighted mean of housing and infrastructural capacity indices. While adding these two index values a weight of 0.6 is applied on housing and 0.4 on infrastructural part as it is assumed that capacity of housing structure to sustain in water logging situation is the key determinant of settlement‘s reliance capacity. The following equation is used to calculate the composite index of settlement in Safulakati.

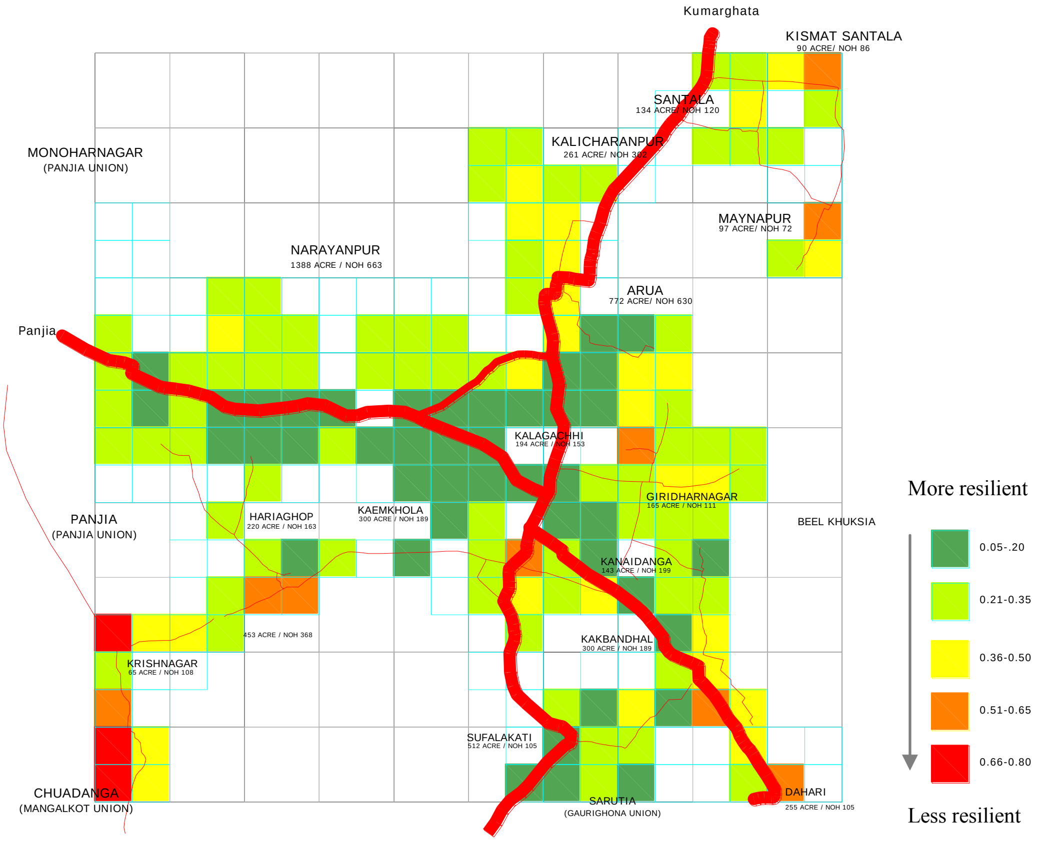


Fig 4.12: Composite Settlement Capacity of Safulakati Union

COMPOSITE INDEX OF SETTLEMENT CAPACITY (CSC_i) = HOUSING INDEX (HC_i)x 0.6 + INFRASTRUCTURE INDEX (CIC_i) x 0.4

The result shows that, settlements in close proximity to transportation spine and growth center have better housing capacity with better access to communal facility and thus less susceptible to water logging. In fact there is no single locality where entire locality is equally sensitive to the problem. However considering average situation, localities of Maynapur and Krisnagar have less capacity and thus are more sensitive to water logging.

4.5.3 Comparison of result: Analyzing Geo-Climatic Vulnerability of Settlement

Finally both the results from Geo-physical risk index and composite settlements capacity index are compared to analyze overall geo-climatic vulnerability of settlement. Settlements/ parts of settlement that are exposed to highest risk of inundation but have lowest resilience capacity is thus considered to be the most vulnerable and vice-versa. Maynapur Kismat santala, and part of Kalicharanpur and Dahari are exposed to the highest risk of inundation where inundation depth may vary from 0.6 m to 1.80 m . Settlement sensitivity in terms of housing and access to infrastructural services for this locality is analyzed and observed that

Maynapur village has poor housing condition with poor access to services and thus most vulnerable to geo-climatic risk.

As central part of the union is relatively high land, this part will remain inundation free for next 100 years. It is also observed that settlement sensitivity is relatively low here that means locality of these area (Kalagachi , Naryanpur , Arua , Kaemkhola and Kanidanga) are relatively less vulnerable to waterlogging situation.

Table 4.9 Degree of Geo-climatic vulnerability and pattern of settlement in Safulakati Union.

Village/ locality	Settlements Exposure to Geophysical risk (-)	Settlements resilience capacity (+)	Settlement vulnerability	Settlement pattern	
					Rn
Maynapur	Highest	Low	High	Linear cluster	0.22
Kismat santala	Highest	Moderate	High	Linear cluster	0.35
Dhahari	Highest	Moderate	High	Linear cluster	0.29
Krishnagar	High	Lowest	High	Linear cluster	0.15
Kalicharanpur	Highest	Moderate	High	Linear cluster	0.18
Arua	Low	High	Low	Semi linear	0.49
Narayanpur	Low	High	Low	Semi-dispersed	0.51
Kanidanga	Low	High	Low	Semi dispersed	0.50
Kaemkhola	Lowest	Highest	Lowest	Semi-dispersed	0.50
Kalagachi	Lowest	Highest	Lowest	Semi-dispersed	0.50

0.00- 0.09 absolute cluster/nucleated 0.10-0.22 semi nucleated 0.23-0.39 linear 0.40-0.49 semi linear 0.50-0.99 semi dispersed 1.00-1.50 dispersed / scattered

Settlement pattern of Safulakati is predominantly linear cluster (Rn value ranging from 0.51-.0.15). The avg. Rn value is 0.33. It is interesting to observe that, there is a strong correlation between the settlement pattern and its relative exposure to the risk. Localities/ villages that lie within the high and highest risk zone, settlements are relatively compact and linear in pattern (Rn value ranging from 0.18-0.29). On the contrary, settlements in the risk free area or low risk zone (central part of the union) are loose cluster in pattern.The profile of most vulnerable localities of Dhulasar union in terms of geophysical risk and existing housing and infrastructural conditions are given bellow:

Table 4.10 Statistics of highest vulnerable locality of Safulkati union

Most vulnerable Locality	Inundation depth		% of household having katcha house	Nearest pacca road	Nearest health care facility	Nearest Hat/ bazaar	Nearest educational facility	
	min	Max					Primary school	High school
Maynapur	0.6m	1.80m	58%	1.23 km	6.26 km	1.56 km	0.18 km	1.45 km
Kismat santala	0.6m	1.80m	42%	0.69 km	6.30 km	0.81 km	0.48 km	1.61 km
Kalicharanpur	0.6m	1.80m	38%	0.51 km	4.43 km	0.84 km	0.51 km	0.51 km
Dhahari	0.6m	1.80m	51%	0.11 km	5.93 km	1.10 km	0.20 km	1.43 km

4.6 Local response to vulnerability due to water logging

To understand how the local people are adapting with the situation a village named Maynapur is selected from the most vulnerable zone for micro level analysis. Primary data about the settlement features and adaptation measures are collected from field survey and focus group discussion conducted between the years 2010-11. Maynapur village is situated in the eastern boundary of Safulkati union of Keshabpur upazila along the border region of Jessore and Khulna Zila. The contextual setting has made the study area unique compare to other vulnerable village in the union. The village is located within the wetland basin of *Beel Khuksia*. Before the implementation of TRM (discussed in sec 4.6.3.1) the area was used to characterize as fallow land which was flooded by high tide in harmony with the lunar cycle. To cope with the situation local people used to construct temporary earthen embankments (*ostomashi bandh*) and wooden sluice gates around the areas to protect the arable land from saline water intrusion. In the rainy season farming community exchanged saline water of their fields with river water when it becomes almost sweet. Sweet water normally minimizes the salinity of the land .Thus they got good harvest and variety of fish. Due to sedimentation of Bhabadaha river bed the drainage of the tidal water was disrupted and gradually the area became water logged.

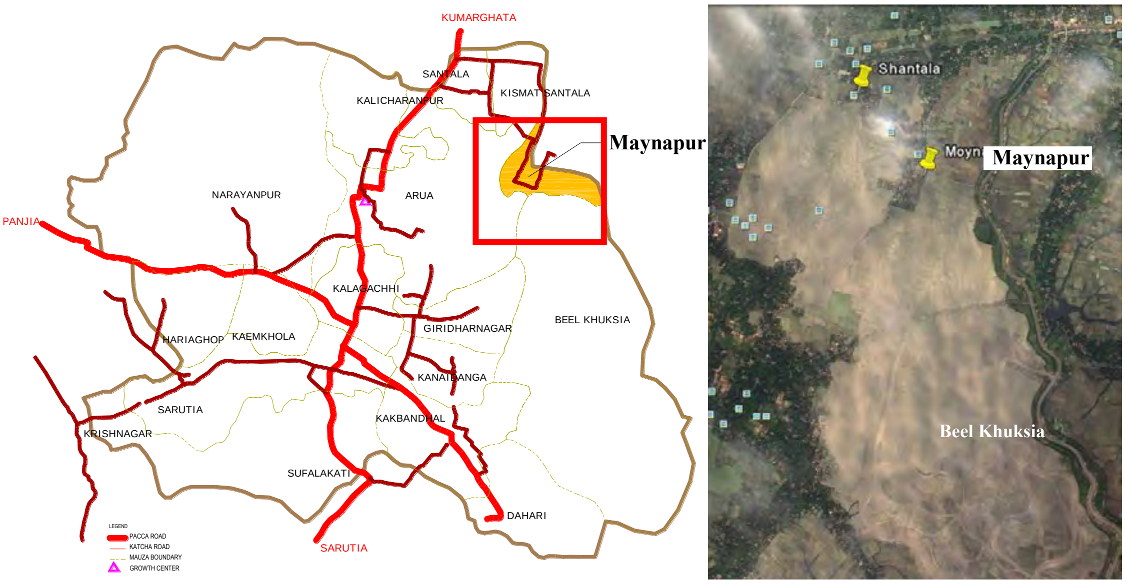


Fig 4.13: Maynapur village and adjacent Beel Khuksia (source: LGED and Google earth, 2010)

To identify the physical change in settlement pattern, historical satellite image of the village is analyzed. As vulnerability analysis is based on the data for the period of 2000-2001, the study will provide a holistic idea about the measures they have taken in last ten years to cope with the situation both at community and individual level. The study is limited to exploration of socio-spatial adaptation in terms of spatial aspects of settlement pattern, homestead layout, housing characteristics, vegetation practices and social aspects of the household: family size, occupation and behavioral response.

4.6.1 Settlement pattern and Vulnerabilty profile of Maynapur village

The study area Maynapur is a small village with current population of 495 (Union Parishad Office, 2011) covering an area of 97 acre. According to the population census of 1981 the village had 50 households with population of 253. A negative growth in population is observed in next 10 years and the number was reduced to 40 in household and 181 in total population (BBS,1991). Peoples were forced to migrate due to adverse environmental impact of the polder causing drainage congestion and severe water logging from the beginning of early 90‘s. However, situation was relatively improved in next decades by the government and local initiatives. Khulna-Jessore drainage rehabilitation project was initiated and implemented during this period. According to the last population census population of Maynapur was raised to 271 (72 households) by the year 2001 (BBS, 2001a).

Historically the village Maynapur was linear in pattern and ‗amorphous‘ in shape where the dwelling units were compacted along the primary circulation spine or the village path. The spatial composition of the settlement pattern was evolved historically to cope better with the physical and hydro-morphological characteristics of the landscape. Geographically the village is located in tidal basin area where the low land was flooded twice in a day with lunar cycle during pre-polder period. Homestead, in response, was constructed on relatively high ground to protect it from flooding. This of course limited the growth of the settlement and concentrated it along the transportation network (fig 7.a). After construction of polder, the huge chunk of fallow land in tidal basin area became free of tidal flooding and used for agricultural purpose. This in return brought green revolution to agricultural production and thus socio-economic condition of the villagers. Besides the new landscape allow the settlement to grow beyond its topographic boundary (fig 7.b). A tendency of linear growth in the settlement along the north south direction is observed in this period and was prevalent till the construction of TRM. Morphologically the village had no define edge or physical boundary then but the extent of homestead area was limited to Dakhsin para in the south and Uttar para in the north and Beel bari in the west. The village was then only exposed to seasonal flood due to heavy pour in the monsoon or overtopping of the Hari River embankment during depression in the sea. The problem became more severe as the river bed was silted up with course of time by sediment deposition. This created drainage congestion in the area and eventually the village became waterlogged for almost eight months in a year.

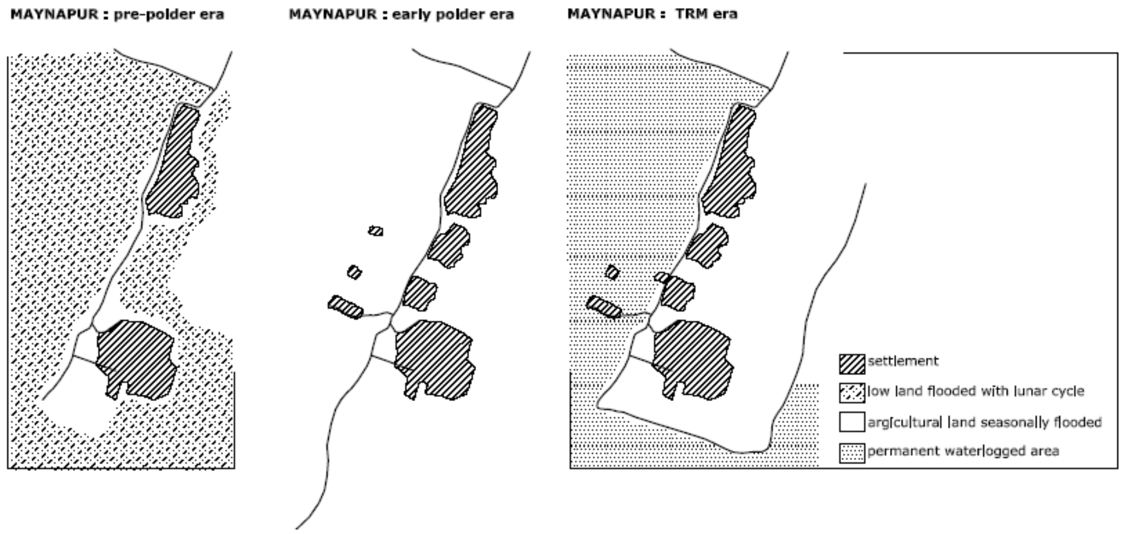


Fig 4.14: Settlement growth pattern of Maynapur village (prepared by author from historical satellite imagery of Google earth)

The village is reached by an earthen road after walking 1.75 km from the nearest *pacca* road. Land communication is often disrupted as this road is subjected to erosion due to prolong water logging. Boat is the only means of communication then. Nearest neighborhood villages are *Santala* and *Kismat santla*, 1.22 km and 1.01 km away respectively (measured from the geometric center of the village). A primary school is located at the far end of the Maynapur village. This is the only institution for primary education of the children within these localities. The school building is one storied *pacca* structure which remains submerge under 2 to 3 feet water during the whole period of monsoon. The open space infront of the school, the only play area or community gathering place in the village, is also inundated during this period.

Homesteads in Maynapur are clustered along the village path or communication spine. This path way cum embankment runs along the periphery of the village defining the edge between the Beel area and homestead area. Most of the homesteads in the villages are concentrated inside the embankment and grouped into three *paras* or neighborhoods namely *Dakhsin para*, *Madha para* and *Uttar para*. The remaining few are scattered or dispersed outside the embankment within the *Beel* area locally known as ‗*Beel bari*'. Each *para* is sharing a deep tubewell and spatially separated by wetlands or waterlogged area and.

The house of the landlord is located in the *Dakhsin para* and other homesteads are organized around it. This area is the oldest part of settlement containing 18 homesteads at present. Morphologically this *para* displays a distinct characteristic of its own. The *para* is elliptical in shape surrounded by orchard garden. A village lane perpendicular to the primary road leads into the *para* towards the house of the landlord; the only two storied structure in the village.

The other *paras* inside the embankment do not show a definite pattern in organization and are clustered close to the primary road cum embankment on relatively high land. In almost every rainy season *Dakhsin para* is inundated under 3 feet water. Inundation depth of *Madha para* and *Uttar para* is vary from 2 to 1 feet. Homesteads in *Beel baria,* indeed, are most exposed to the risk of inundation and are clustered on raised mound (*bhiti*) like an island. Even in dry season communication to *Beel baria* is cumbersome as the households have to cross a bamboo bridge to reach their homesteads.

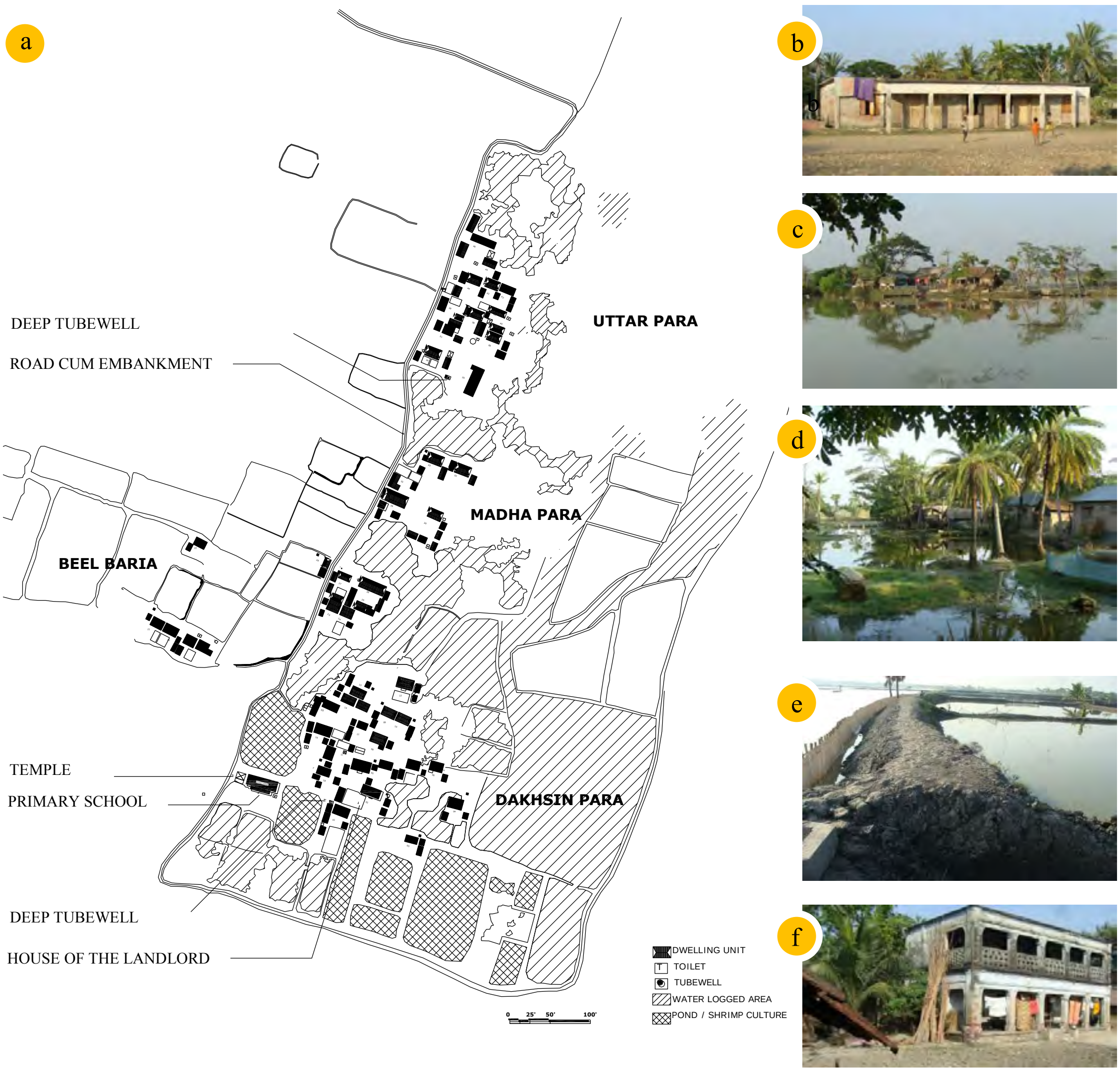
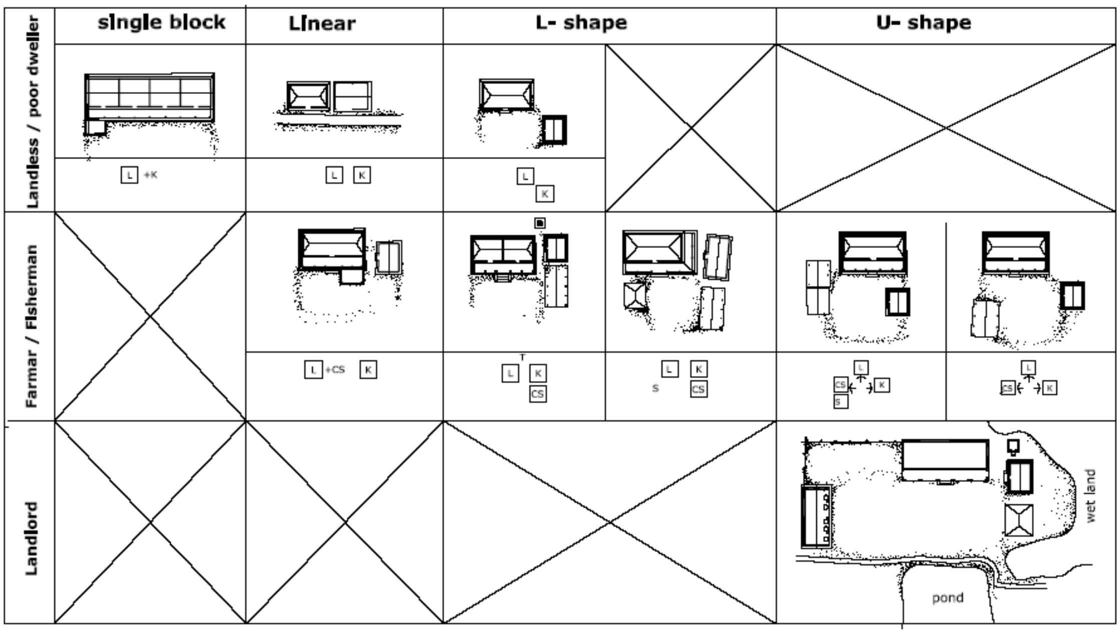


Fig 4.15: Settlement feature of Maynapur village: a. spatial layout of the village, b. Primary school, c. Beel baria, d. Waterlogged area inside the embankment e. Pathway to village in dilapidated condition f. House of the landlord.

In a homestead individual houses are organized around a courtyard or *uthan* independently or in common. Completely enclosed courtyard is not evident in the village. However, the size and number of building unit in a homestead varies in accordance with the economic condition of the household. The main dwelling, which is the sleeping unit, is of primary importance in a homestead and modeled to resist the adverse impact the environment. Most of the main blocks are raised on a high plinth to avoid inundation and tend to be more permanent. The ancillary structures such as kitchen, cowsheds (*Goalghar*), storage of fire wood etc. tend to be semi-permanent and are constructed of perishable materials. Granary or crop storage is also observed in several homesteads at *Dakhsin para* and few at Uttar para. These are constructed on stilts or raised platform above the flood level. Affluent households have sanitary latrine located behind or at the corner of the homestead away from main block. Poor villagers have temporary arrangement or unhygienic state of toilet facility.

The structure and layout of the homesteads are not uniform, although certain systems of organization can be observed. The dwellings of five socio-economic groups were studied; however, according to systems of organization, the dwellings can be categorized in three main groups - homesteads of the landless, the farmers and the landlords (table 4.11)

Table 4.11 Homestead layout of Maynapur village



L = Living block; **K**= Kitchen; **CS**= Cowshed; **S**= Storage

Traditionally the courtyard is the heart of the rural homestead where most of the domestic activities like drying of cloth or firewood, drying and repairing of fishing net, fetching water from the tubewell, outdoor cooking , gossiping etc are taken place in dry season (fig 4.16). The life of the household is greatly disrupted by the water logging phenomenon as the courtyard is inundated. This restricts household mobility and daily activity pattern (fig 4.17). The sufferings become more intense as in typical layout the cooking area and latrine are located distance away from the dwelling unit. The household need to cross the waterlogged courtyard as necessity and often suffer from waterborne diseases like diarrhea, dysentery and skin diseases.

Fig 4.16: Activity in courtyard in the dry period

Fig 4.17: Water logging hampers day to day activity of the villagers in the monsoon period

In plan, the main house within the homestead is generally rectangular in shape and mostly single-storied, except the house of the village chief. In most cases the main block consists of a single room with or without veranda in front. In newly built house, often more than one room is observed. Except few, most of the main houses/ sleeping units are oriented facing north-south to take advantage of the prevailing wind direction to relieve humidity and the ancillary structures added subsequently to form a courtyard. Factors like scarcity of dry land, location of immediate homestead, privacy and social relationship with the adjacent neighbor play vital role in the orientation of few others. Based on building material, housing structure of Maynapur can be categorized into following groups:

Table 4.12 House type on the basis of building material in Maynapur village

Category		Construction material		
		Roof	**Wall**	**Plinth**
Type A	pacca / Permanent house	Reinforced concrete	Brick	Brick with cement finish
Type B1	semi pacca / Semi permanent house	CI sheet	Brick	Brick with cement finish
Type B2		CI sheet	Brick	Compacted earth floor with brick lining
Type C1	katcha / bio-mass house	CI sheet	Mud	Mud
Type C2		Clay tile	Mud	Mud
Type C3		Clay tile	Mud with bamboo mat / date leaf	Mud
Type C4		Clay tile	Bamboo mat	Mud
Type C5		CI sheet	Bamboo mat	Mud
Type D1	Jhupri house / temporary	Thatch	Bamboo mat	Mud
Type D2		Thatch	Thatch	Mud

4.6.2 Social (non structural) response to water logging

Water logging phenomenon restricts the natural growth of the population in Maynapur. Compare to other upland village in the union the population growth in the waterlogged village is low. For instance, in an upland village Kalagachi no of household has increased twice in last 20 years (from 1881-2001) where as the population has grown approx. 1.5 times in Maynapur village for same time period. The data‘s of average family size also supports the similar trend as shown in the following table:

Table 4.13 Comparison of population growth between upland and water logged village

	Village name	**No of HH (1981)**	**No of HH (2001)**	**Total pop. (2001)**	**Avg family size (2001)**
Water logged village	Maynapur	50	72	271	3.76
Upland village/	Kalagachi	85	153	798	5.21

Source: BBS 2001a

There has been a significant change in the occupational pattern in the study area. The area was once well known as a ―store house of paddy". A crop storage or Gola in the homestead is still evident in old part of the settlement. The survey identify that 94 % of households had agriculture as their principle occupation (BBS, 1981) before water logging became acute. But now, it is found only 10 % of the household heads in the study area identify agriculture as the principle occupation. Most of the households adopt fishing as secondary occupation in the study village. The villagers reported that, adjacent Beel Khuksia was an abundant natural source of fishes and the villagers were benefited initially after implementation of TRM. But as long term impact, TRM cause permanent inundation of seasonal agriculture land which made the household dependent on a single source for their income. This eventually has created extra pressure on the source results scarcity of fish and led the poor villagers to adopt a new occupation for survival. In last few years, as it is observed, the percentage of agriculture/day laborer increases at considerable rate in the study area.

4.6.3 Spatial (structural) response to water logging

Both public agencies and local communities have exerted effort to alleviate impact of water logging. It is observed more than one strategies have applied or practiced since each strategy has its own function. The course of actions taken by the villagers and public agencies following these strategies often leads to a change to the indigenous pattern of the settlement. The structural measures taken by the local community and public agencies to adapt with water logging are discussed under following three strategies as mention by Mclean (2001) and Nicholl (2003).

4.6.3.1 Adaptation by protection

To protect the human settlement from inundation, as a measure of planned adaptation, TRM or Tidal River Management project was implemented by the year 2006 (initiated in 2002) in 4000 hector of *Beel khuksia* and adjoining low land by the Water Development Board under the master plan of KJDRP and is planned for three other tidal basins in *Beel buruli*, *Pathra* and *Panjia* (ADB, 2007). The idea of TRM is simple: to allow tidal flow into wetland basin, locally known as *Jowar bhata khelano* and releasing tidal flow back to the river. As a result of this process, sediments carried by tidal flow deposits on the wetland basin instead of riverbed. It required construction of embankment around the project area. In the process the existing road of the Maynapur village is converted to road cum embankment creating an enclosure. The modification has significant impact on the settlement pattern of the Maynapur village. The original amorphous shape (compactness value 3.86) of the village now transformed into a more compact recto- linear shape (compactness value 1.84) bounded by the embankment (fig 4.18). Spatially the village now divided into two discrete segments: settlement inside the embankment and settlement outside the embankment (fig 4.19).

Length of long axis= 2300‘
(*Distance between two farthest point (homestead) along longitudinal axis*)
Length of short axis= 595‘
(*Distance between two farthest point (homestead) along transverse axis*)
Length/width ratio= 2300/595=**3.86**

Length of long axis= 1200‘
(*Distance between two farthest point (homestead) along longitudinal axis*)
Length of short axis= 650‘
(*Distance between two farthest point (homestead) along transverse axis*)
Length/width ratio= 1200/650=**1.84**

Fig 4.18: Analysis of settlement shape compactness[4] for Maynapur village for pre and post period of institutional adaption by protection.

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4 [The compactness of the shape of the village is measured through the ratio of length and breath (L/B), which is: LB= length of long axis of cell / length of short axis of cell ; (Hammond, R. and McCullagh, 1974).]

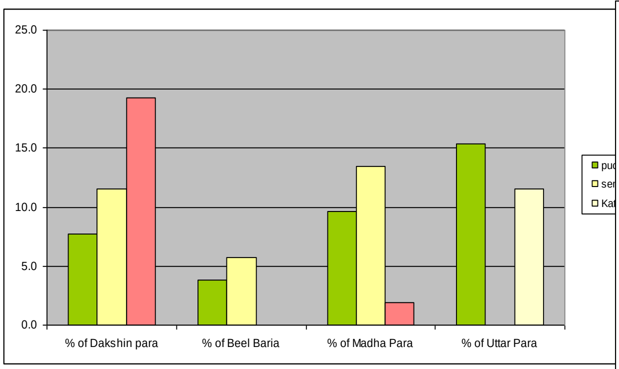
Fig 4.19: Earthen embankment to protect the settlement from inundation.

4.6.3.2 **Adaptation by accommodation**

4.6.3.2.1 Structural modification of the house

4.6.3.2.1.1 Adoption of permanent building material: To cope with water logging situation an increasing trend of constructing the house with more permanent building material is observed. This change, however, doesn't solely indicate that this is happening in the process of adaptation to water logging as the housing pattern may change due to socio-economic up gradation of a society.

In this process of structural adaptation from temporary to permanent kitchen is the second priority for the villagers after main housing unit. It is also observed affected households equally prioritize to save their livestock and build the plinth and wall of the cowshed with more permanent material. Toilet comes next in the sequence. Of the 54 households in the village it is observed that 63.46% of main dwelling unit is *pacca* or *semipacca* in nature. Kitchen and cowshed appears next 24.32% and 22.22% respectively. With the recent initiatives of GO and NGOs under rural health and sanitation program, almost 75% households in the village have access to fixed place latrine of any type. Of them 18% households have *pacca* and sanitary latrine. Rest of the households have ring slab latrine of *katcha* and open type (temporary arrangement where the enclosure is low height and made of polythene or thatch).



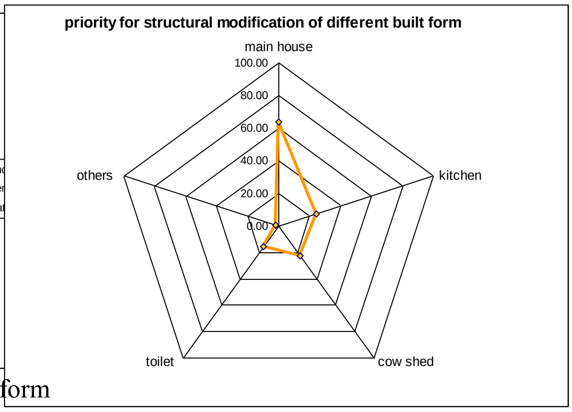


Fig 4.20: Structural adaptation priority for different built form

It is common practice among the villagers to adopt permanent material for vulnerable components of the houses first. As water logging may cause substantial damage to the mud plinth the priority is given to strengthen and maintenance of the plinth than the wall or roof of the structure. Almost 69% households in the village remodel the plinth with permanent material. Of them 100% households in Beel baria (most vulnerable part of the settlement) and 99% in Madha para have adopted permanent material to construct their plinth despite of the fact that the average socio economic condition of the households of this part is relatively lower than the rest.

It is observed that, to reduce the erosion of the plinth, the villagers used to lining the mud plinth with brick either exposed or with cement finishes and thus protect the compact earth inside from direct contact with the water (fig 4.20). This method of plinth construction is more economic which widely used in the flood prone region of Bangladesh and proves effective against the inundation. Apart from the 36% houses with *pacca* plinth almost 31% of total household adopted this semi permanent measure to strengthen the plinth.

Fig 4.21: Contruction of plinth with compct earth with brick lining is a popular practice in Maynapur.

4.6.3.2.1.2 Raising the plinth level: Besides using more permanent material for plinth construction, adjustment of the plinth height is another local response to adapt with water logging situation. Traditionally, people in this region used to build their house on raised mud plinth. House on stilts is not customary in the region. The affected households have raised the plinth level of the main house above the local flood level. The houses that are constructed or reconstructed lately have plinth height of nearly 3 feet. However the old structures, specially the pacca houses, have limited option to alter the plinth height. Household of this type raise their furniture on bricks and store their valuable documents and foods on a ceiling mounted wooden plank locally known as *Darma*; a temporary measure to keep it dry and protect it from damage by water. Household having mud plinth house reported that they had changed their plinth height after the devastating flood of 2006 to adjust with the maximum inundation level. Apart from these measures, a structure with elevated platform made by bamboo/

wooden section locally known as *Machan* is used to store the fire wood or other source of domestic fuel (fig 4.23).

Table 4.14 Comparative statistics of plinth height in relation to inundation level in Maynapur

Para	Max plinth height	Min plinth height	Avg plinth height	Avg. inundation level	Topography of Homestead site
Dakhsin para	3 feet	1.5 feet	2.5 feet	1.5‘- 2.5‘	Relatively low land
Beel baria	2.5 feet	1 feet	2 feet	1‘-1.5‘	Raised mound
Madha para	3 feet	1.5 feet	2 feet	1‘-2‘	Moderately low land
Uttar para	2.5	1 feet	1.5 feet	0-1‘	relatively high land

Only the plinth of main house is considered

Table 4.15 Comparative statistics of plinth height of different structure in Maynapur

Type of structure	% of structure with respect to plinth height					
	3 feet	2.5 feet	2feet	1.5 feet	1 feet	> 1feet
Main house	15.38%	21.15%	26.92%	15.38%	15.38%	5.77%
Kitchen	2.22%	2.22%	26.67%	28.89%	28.89%	11.11%
Cowshed	-	-	5.26%	23.68%	55.26%	15.79%
Toilet	5.88%	-	8.82%	11.76%	32.35%	41.18%
Others	-	-	50%	25%	25%	-

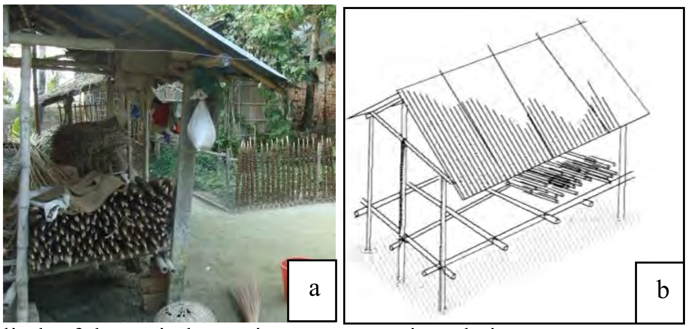


Fig 4.22: Household raised the *bhiti* or plinth of the main house in response to inundation.
Fig 4.23a and 4.23b: *Machan* or elevated platform to store the raw material of domestic fuel.

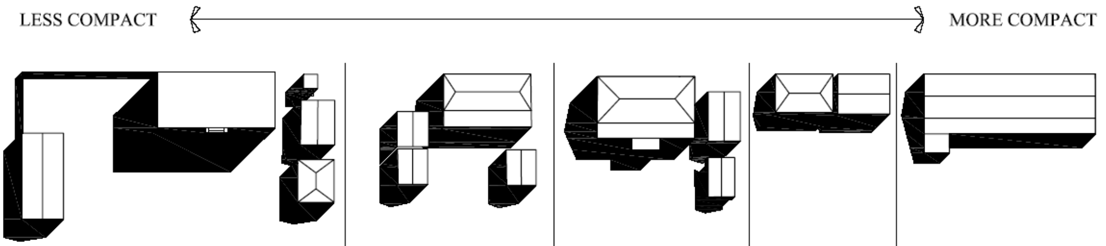
In addition to that few measures were taken by the public agencies at community level to ensure sanitation and fresh water supply during inundation period. As a part of ‗Rural Health and Sanitation Program‘, PWD of Bangladesh government set up two *pacca* sanitary latrines and a deep tube well on raised plinth or elevated platform (fig 4.24 & 4.25). The average plinth height of this establishment is 3 feet. People reported that, these latrines were shared by the communities especially by the women during acute water logging period. Fresh water supply is ensured by two deep tubewells located at strategic location of the community and raised on a platform above the maximum inundation level.

Fig 4.24.a & b: Community sanitation at Maynapur village, provided by PWD of Bd Government.
Fig 4.25: Deep tubewell on a raised platform located at the center of the village.

4.6.3.2.2 Compact arrangement of homestead structures

By origin homestead pattern of Maynapur can be characterized as loosely built structure organized around a courtyard where communication from one structure to other is done through courtyard. Water logging creates disruption to this indigenous pattern of living. As an autonomous response of the household a compact layout of the homestead is observed in the village. Table 4.16 shows that, a significant ratio (54.4%) of the household adopted L- shape layout with additional 18.3% of more compact layout of linear and single block type. Affected households often rebuild their ancillary structure close to the main house or even attached rather placing them at a distance from each other which is a significant alteration in the indigenous practice of organizing their homestead. In most cases this annex building is a cowshed or sometimes kitchen and constructed with more perishable material. The traditional U-shape or loose U-shape layout of the homestead comprises only 27.3% of the total homestead in the village.

Table 4.16 Compactness[5] value of homestead structures in Maynapur village



Type	**loose U- shape**	**U - shape**	**L - shape**	**Linear**	**Single block**
comapctness value	0.10	0.23 - 0.26	0.31 - 0.40	0.50 - 0.57	0.54
% of household	2.3%	25%	54.4%	16 %	2.3%

Calculated by author

[5] [Measurement of compactness of shape can be obtained by, $\mathbf{Sc = 4\pi A / P^2}$; here Sc = shape compactness, A = area of the shape and P = perimeter of the shape. Most compact shape according to this index is a Circle (index of 1.00), then the Square (index of 0.78). (Adopted from Ebdon, 1985 and modified by author)]

4.6.3.2.3 Practicing horticulture at homestead yard

The indigenous practice of growing vegetables in the homestead garden is greatly disrupted by water logging phenomenon. Traditionally the garden was prepared a few meters away from the homestead, either at the front or at the back (Deka and Bhagabati, 2011). As the area becomes waterlogged, land is scarce and to fulfill the domestic need of nutrition the households cultivate vegetable in the courtyard. This autonomous practice of homestead horticulture by the household brings a morphological change in the homestead pattern as the once open courtyard is now tilling and often fenced with bamboo or fishing net in order to protect them from cattle and other domesticated animals. In general homestead garden is the only cultivated plot in the village and becomes a dry season activity in the lowlying part in particular.

Table 4.17 No of household practicing horticulture at homestead yard

Dakhsin para	Beel baria	Madha para	Uttar para
5 / 18	4/ 6	4 / 14	3/16

Ring gardening, floating vegetation etc are some new technologies which are introduced by the local NGO *Samadhan* and recently being practiced by the waterlogged villagers of Trimohani and Sagardari (Adri, 2009 p.77). Local people found ring gardening very useful where lands are mostly waterlogged as vegetation is accepted to grow at a higher level than the ground. In Maynapur village, however, none of these adaptive measures is practiced.

Fig 4.26: Households practice horticulture in their courtyard due to scarcity of dry land

4.6.3.2.4 Use of alternative fuel source

Water logging has severely affected indigenous sources of fuel in Maynapur village. Due to prolong water logging and salinity problem in the village, plants and trees are dying out. Few that are able to survive are in very poor health with low dense foliage. Villagers depend on outsourcing for their fire wood. It is observed that, most of the villagers use cowdung as fuel . But the supply of cowdung is affected as the number of cows and bullocks has declined. It is reported that, dried peat soil is used as fuel in peat basin area like Beel Dakatia during waterlogged period (Rahman, A, 1995).

4.6.3.2 **Adaptation by retreat**

In case of Maynapur, adaptation by retreat is a reactive response of the household and practiced to cope with the extreme situation. No of villagers have moved their ponds for fish culture (locally known as *gher*) inside the embankment. In case of the homestead outside the embankment, the meaning of adaptation is actually nothing but their act of survival. The most unfortunate households who have failed to survive in the extreme situation are forced to relocate and rebuild their homestead close to the embankment.

Besides these structural measures, in severe water logging period villagers often forced to migrate and take shelter to the nearest school or even *pacca* road. Villagers reported that no measure has been taken so far by the public agencies for planned retreat. Except few schools that serve as temporary shelter, there is no permanent shelter for the refugees in the union.

Fig 4.27: Three autonomous measures of adaptation by retreat: a) Reconstruction of homestead on high land b) Migration to temporary shelter c) Relocation of aquaculture land inside the embankment.

4.6.4 Evaluation of adaptive measures

In this section, each of the local adaptive measures has been evaluated on the basis of selected criteria as outlined in chapter 3 to understand the responsiveness of the measurers both at present and future context.

To remove water logging construction of tidal basin in rotational basis (TRM) seems effective and this measure has potential to mitigate the future risk. The measure allows natural processes of sedimentation which lend connectivity to ecosystem and promote biodiversity. Moreover the measure is flexible, environmental friendly, locally accepted and create scope for participation of local people while implementation. The only limitation of the measure is that it doesn‘t ensure equity. Although the measure ensure greater benefit but it may bring sufferings for the inhabitants in and adjacent to project site as they often need to let their own land for implementing the project.

As autonomous measure, compact homestead layout is highly effective in terms of functionality as it allows more people to live on a small piece of dry land. Besides the compact layout reduce health hazard of the occupants by minimizing the household‘s movement through stagnant water during water logging period. The measure is also suitable to future context of high population density. Moreover the measure is economically viable and equally accepted by the local people specially in affected area.

In case of housing structure, permanent material is flood proof to some extent and can withstand flood water for a long period but it is not economically viable or feasible to implement in mass level. Permanent structure is moreover less flexible and less responsive to environment. Besides measures like raising the plinth level, hardening the plinth with brick lining, building *machan* for storage and practicing horticulture at courtyard is responsive in terms of their functional effectiveness, environmental soundness, flexibility, economic feasibility, cultural acceptability etc. However, measures like temporary shifting or relocation of homestead is not equally responsive as these may create social and environmental degradation in host area and does not offer any long term solution.

Table 4.18 Responsiveness matrix of local adaptive measures to water logging

	Effectiveness	Suitability to future context/ risk	Implement ability/ feasibility	Flexibility	Environmental friendliness	Ecosystem connectivity	Equity	Economic viability	Local people Participation	Cultural acceptability	Multi-purposefulness
Tidal River Management (TRM)	H	H	M	H	H	H	L	M	H	H	M
Semi hard Embankment	M	L	M	L	L	L	L	L	H	M	H
Compact layout of the homestead structures	H	H	H	L	M	L	H	H	H	H	L
Adoption of permanent material for housing	H	H	L	L	M	L	L	L	L	M	H
House built on raised plinth with brick lining	H	H	H	M	M	L	H	H	H	H	M
Building Machan for storage	H	H	H	H	H	H	H	H	H	H	H
Practicing horticulture at courtyard	M	H	H	M	H	H	H	H	H	L	H
Community deep tubelwell on raised platform	M	M	M	L	M	L	H	L	M	M	L
Community sanitary toilet on raised plinth	M	H	H	L	H	L	H	M	H	M	L
Relocation of homestead near embankment	M	L	L	L	L	L	L	L	L	M	L
Temporary shifting to nearest school or pacca road	M	L	M	H	L	L	L	L	L	M	L

H= High, **M**= Moderate and L = Low

4.7. Summary

Settlement in southwestern coastal region is exposed to the risk of water logging. Water logging in east Keshabpur is a disaster rather than hazard. Coping is, therefore, the other meaning of survival for the waterlogged villagers in Keshabpur. As water logging has manifold impacts on human settlement, measures taken by the community or household to adapt is also dynamic in response. Structural measure of adaptation is one of these dynamic responses by the households apart from the other socio-economic or agricultural measures. Due to this particular measure a significant change in the indigenous pattern of settlement and land use is observed. Both public agencies and local household are involved in the process. Not necessarily all their efforts were proved effective. For instance, the way TRM project was implemented is reported as ‗unsuccessful' by Operation Evaluation Department of ADB due to drying up of active River and heavy silt disposition, faulty design of drainage regulator, poor operation and maintenance (poorly located and/or maintained sluice gates), constrained the achievement of anticipated outcome [ADB ,2007]. The OED estimation shows that a relatively smaller area was free from water logging in March 2007 and water logging problem is more intensify in the villages adjacent to the project area as the agricultural lands inside the project area of these villages are now permanently inundated. However, people adapt until they cross their threshold limit. In the process of adaptation, measures taken by the villagers often led to a change in the spatial structure of the indigenous settlement pattern. Study shows that except few most of the adaptation strategies of the households are autonomous and are not practiced by the every household uniformly. Choice of adaptation strategies for any structural modification is influenced by the relative risk exposure and financial ability ie adaptive capacity of the household. Households have individually adapted to their problems. No significant collective effort is seen for community based adaptation.

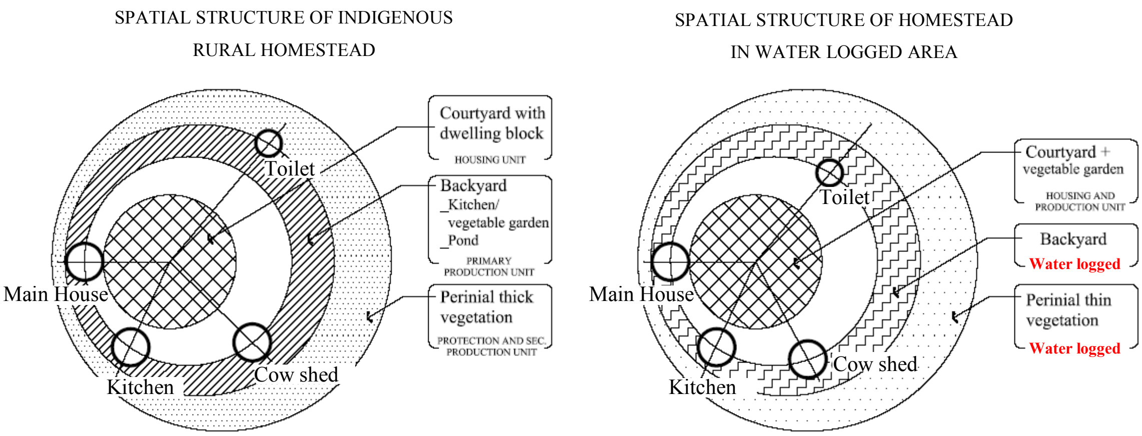


Fig 4.28 Transformation of spatial structure of indigenous homestead pattern in waterlogged area

Most importantly, the survey shows that these individual efforts of the households and the applied protection measures of the public agencies all together have contributed to transform the spatial pattern of the indigenous settlement. Settlements now become more compact with shifted spatial focus as priority is given to minimize the adverse impact rather than preservation of their cultural trait. Spatial segregation of homestead structures in traditional scheme, socio-cultural value of the courtyard or indigenous practice of forestry surrounding the homestead are often forfeited by the affected household due to constrain of dry land and household basic needs of nutrition/ food. Besides, the manmade embankment and institutional measures of water resource management significantly restrict the natural growth of the settlement and traditional practice of agriculture or even aquaculture in the study village. This, in turn, changes the land use pattern of the traditional rural settlement.

In conclusion, both protection and accommodation should be the strategies to adapt with water logging problem. As a protective measure construction of tidal basin in rotational basis (TRM) is probably the best option for removing water logging in the polder area. But implementation of TRM is very much difficult because of social reason as inhabitants need to let their own land and homestead area for implementing the project. However, priority should be given to derive more practical solution considering greater benefits rather than few beneficial. As the accommodation measures of adaptation are mostly practiced by the household individually and greatly influenced by their financial ability, incentives may be provided for the truly affected household after micro-level vulnerability assessment. Moreover, community based adaptation must be encouraged where NGO might play a vital role. Institutional initiative should be taken parallely for the development of the infrastructure and better access to the services and shelter (health facility, bazaar, school etc) at community level and access to amenities (fresh water supply, sanitation) at *para* or neighborhood level.

Chapter 5

Vulnerability and Adaptation Practices in Cyclone prone Area: A case of South-central Coastal Region in Bangladesh**:** Kalapara Upazila, Patuakhali

The present study has been conducted in Kalapara Upazilla (sub-district) of Patuakhali district that is one of the biggest coastal zones, situated in the southern region of Bangladesh. Kalapara Upazila with an area of 483.27 sq km is bounded by Amtali upazila on the north, the Bay of Bengal on the south, Rabnabad channel and Galachipa upazila on the east and Amtali upazila on the west. Main rivers are Andharmanik, Nilganj and Dhankhali. In fact, Kalapara has a historical profile related to hydro-meteorological hazards like cyclones, storm surge, salinity and tidal flooding. This multi-hazard proneness as well as the limited capacity of communities and local authorities to respond to the existing hazards, weak preparedness and insufficient mitigation strategies, lack of community based organizations; lack of coordination among the local organizations makes the people more vulnerable.

5.1 Demography, geography and settlement profile of Kalapara Upazila

According to population census 2001, the total population of the upazila was 2, 02,078. Considering the growth rate between the year 1991 to 2001 the projected population for 2011 is 2, 33,400. However the avg. density as enumerated in the census is 418 per sqkm which is far below compare to the national avg. of 834 per sqkm. Total households in the upazila is 40,734 with family size is 5.0 persons (BBS, 2001b). Primary occupation of the households is agriculture (45.63 percent). Besides a considerable portion of households are involved in fishing, agricultural labour and other commerce oriented activities. Most of the people are living below the poverty line because of their backward inefficiency in business, agriculture, fishing and other professions.

Fig 5.1: Settlement pattern along the river and natural creeks in the inland part of the Kalapara upazila (adopted from Google earth satellite image, 2010)

The Upazila is flanked by Bay of Bengal and 0 to 100 cm (1 m contour) above mean sea level. The whole area is crisscrossed by hundreds of natural canals and creeks which are immediately connected with three river system and Bay of Bengal (Saroar & Routray, 2010). The physiography of Kalapara upazila is predominantly flat and is classified as ‗interdistributary tidal floodplain' where the area is periodically inundated by the spring tide. Constant changing flow of the tidal river does not allow developing natural levee along the sides of the channels in this area (IWM & BISR, 2009). Settlements are mostly concentrated along the internal canals and creeks or inside the embankment avoiding the flood plain of tidal river (fig 5.1).

Fig 5.2: Settlement pattern of Kalapara upazila , Patuakhali district (Source: LGED, Bangladesh)

The crescent shape coast running from west to east is bordering the upzila at south. The length of coastline is 25 km and 22.82 sqkm area (9.3% of total land area) of coastal belt is protected by mangrove forest (Nahar, 2001). The width of the beach area varies as the coastline is subjected to erosion and accretion. The western part (Kuakata beach) is subjected to erosion and eastern part is experiencing accretion of new lands near Chargangamati (Khan, 2004). Presently width of the beach area varies from 70 to 200m as measured from satellite image. Scattered and linear settlement parallel to coastline is observed within 250m to 500 m distance from shoreline. Settler in this area are migrant people mostly came from Barisal, Barguna and other parts of the district.

Kalapara upazila consists of 9 Unions and 217 villages. Latachapli and Dhulasar are two foreshore unions. Settlement in the upazila is predominantly rural in character where above 88% of total inhabitants are indicated as rural population in the census (BBS, 2001b). Village being the unit of this settlement is largely smaller in size with avg. population of 251 to 750 (table 5.1). These villages are widely spaced to each other with an avg. spacing of 1.67 which is considered as high (Appendix E). As the area belongs to tidal zone, salinity problem restricts agricultural practices as well as settlement growth. Then again the tidal channel and creeks crisscrossed over the entire land area causing homestead to be concentrated on the narrow and constricted natural levees with villages wide apart.

Table 5.1 Settlement unit size of Kalapara Upazila

Size class	Population	No of villages		Difference
		2001	1991	
V1	UPTO- 250	15	25	(-) 10
V2	**251-750**	**120**	**146**	(-) 26
V3	751-1500	61	56	(+) 5
V4	1501-2500	13	13	0
V5	2501 & ABOVE	8	7	(+) 1

Source: Population census, 2001 (community series: Patuakhali district)

5.2 Nature and severity of risk

5.2.1 Cyclone and storm surge inundation

Historically, Kalapara upazila was prone to frequent cyclones associated with storm surges and delineated as High Risk Area (HRA) in MCSP (1993). After the severe cyclone of 1970, the upazila has experienced vicious cyclonic wind coupled with inundation to a wider extent in recent past during super cyclone Sidr. Besides cyclone Sidr , Aila and Bizli also have wider impact on the inhabitants (Islam., 2009) (fig 5.3) . Cyclone is an occasional event and from the past record it is observed that it occurs most frequently in between the month of April and May or October and November.

Table 5.2 State of Kalapara to historical Cyclones that hits the coastline in past 40 years

	1970	1974	1988	1991	1997	2007
Wind speed (km/hr)	222	161	161	224	200	240
Max surge height at elsewhere	5-7m	2-4m	2-3m	4-5m	2-4m	4-5m
Max Surge height at Kalapara	3-4 m	1-2m	1-2m	_	_	3-4m
Affected area in upazila	Most of the part are severely affected	North-eastern union & area along South East coast	Central and northern part and area along South East coast	Inundatio n free	Inundatio n free	Most of the part are severely affected

Source: IWM and BISR, 2009

It is observed that in comparison to other part of the Upazila, settlements along the south eastern coast and Rabnabad channel are exposed to the severe risk of inundation. Inundation depth in these areas varies from 3 to 4 meter. Though the settlement in the central part was occasionally inundated under 1 to 3 m water but often experienced prolonged water logging due to poor drainage. From past 18 cyclones between the periods of 1960-2007, IWM has generated an inundation risk map for storm surge. The following table represents the extracted inundation depth data for Kalapara upazila. It shows that almost 75% area of the upazila is exposed to the risk of inundation over 1m depth.

Table 5.3 Area under storm surge inundation risk in Kalapara upazila

Total area	**Inundation depth (d) in meter**							
	d≤ 1m		1m> d ≤ 3m		3m> d ≤ 6m		d> 6m	
	Area	%	Area	%	Area	%	Area	%
42672	10292	24	16316	38	15928	37	136	0

Source: IWM, 2009

Fig 5.3.a. Vast areas of Kalapara remain inundated for several days after the submersion caused by cyclone Aila. (source: New Age online edition, May 29, 2009)
Fig 5.3.b. Aman seedbeds at Nilganj village, Kalapara get flooded due to heavy downpour & tidal surge. (source: The Daily Star , online edition, March 27, 2012)

Fig 5.4. a. Damage of built-up structure, Kalapara . (The photograph was taken on 20 Jan, 2007 ; 1 months after cyclone Sidr , (source: GoB-MoFDM, 2008, p 155)
Fig 5.4. b. Partially rebuilt house after complete destruction, Kalapara . (The photograph was taken on 20 Jan, 2007; 1 months after cyclone Sidr, (source: GoB-MoFDM, 2008, p 157)

5.2.2 Salinity

Being a seafront upazila the soil and water of Kalapara is strongly saline. According to PDO-ICZMP the upazila is categorized as highly saline upazila. A study of Soil Resource Development Institute (SRDI) shows that soil salinity has intruded far inland in the upazila during last three decades and it is highest along the southern coast. Compare to western part of the upazila eastern part is more saline next to southern coast (SDRI, 2000). Another study shows that, river water salinity in the upazila has increased about 12-24% from 2001 to 2009. Predicted sea level rise no doubt will exacerbate the situation further. Agriculture, forestry and fisheries sectors along with fresh water reservoir are severely affected by increased water and soil salinity.

Apart from cyclone, storm surge and salinity intrusion, the settlement in the upazila is prone tidal flood and river bank erosion. At least two thousand families in the upazila have lost their houses and croplands to the Ramnabad River in twenty years (The Independent, June 3, 2011)

5.3 Impacts of Cyclonic wind and storm surge on human settlement

Cyclone causes damage to human settlement in three ways— i) strong cyclonic winds blow away the weakly jointed roofs and walls of houses and other structures of katcha and semi-pacca nature; ii) thrust from surge water flush away the houses and other standing structures of weak foundation, uproot the trees and washout the crops and iii) sudden flooding caused by breaching of embankment cause inundation to homestead and agricultural land, disrupt inland communication and contaminate (salinize) freshwater reservoir. Pucca structure were much more resistant to wind, often serving very well as local ad hoc shelters, but still sustaining destruction by flooding and surge. Storm surge was by far the most powerful agent of destruction to housing and non-engineered structures. Wind caused some direct destruction which was generally quickly repairable, as well as a substantial number of tree blow downs—a major cause of wind-related housing destruction. (GoB-MoFDM, 2008)

Kalapara is in Patuakhali district, one of the areas hardest hit by Tropical Cyclone Sidr occurred in the month of November in 2007 and reported as worst affected upazila (GoB-MoFDM, 2008). Mostly affected union is Mithagange, Lalua, Dhulashar, Khaprabhanga, Nilganj (District Relief and Rehabilitation Office, DRRO). Initial reports suggest that the cyclone caused extensive damage to houses, crops, school buildings, roads, trees, and has disrupted electricity and telecommunication systems.

The upazila is embanked with sea dykes and polders to provide primary defense from storm surge tidal influx. Most of the embankments are soft (earthen construction) or hemi hard type. In areas where the structures had not been properly maintained or where they had eroded (especially in areas where the forest cover in front of the structures was negligible), the impact of the storm surge had devastating consequences. A vast area of south- east and eastern part of the upazila was flooded due to breaching of embankment (fig 5.5) which had severe consequences for the agriculture and housing sectors.

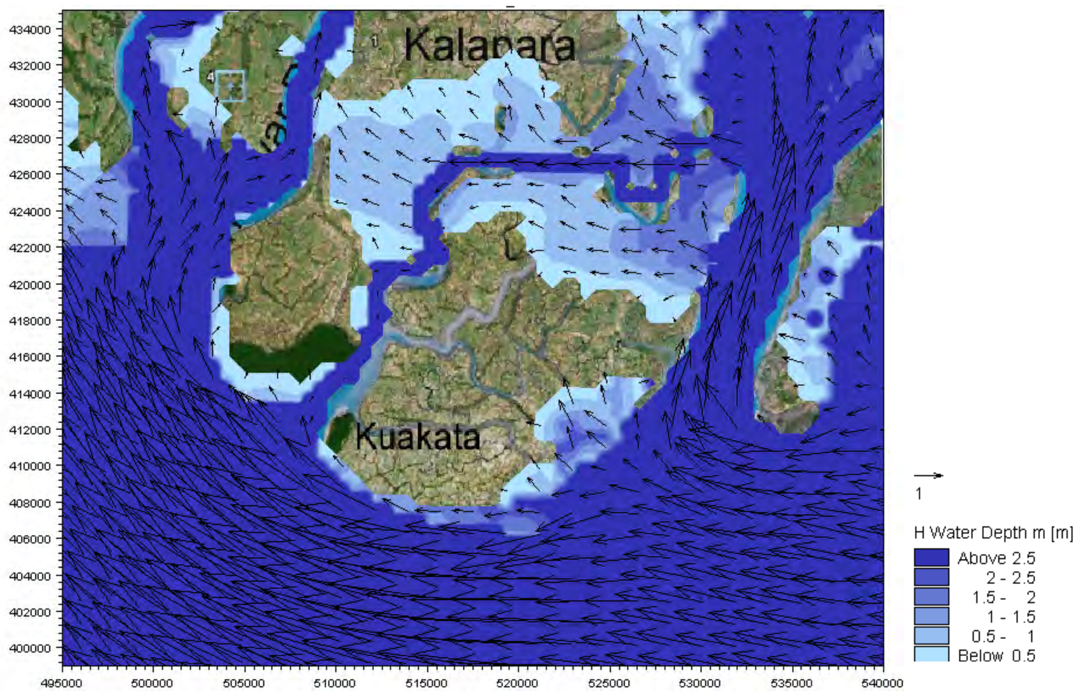


Fig 5.5: Surge water intrusion due to breaching of embankment during cyclone Sidr. (Source: IWM quoted in Choudhury, 2008)

The most affected sectors as reported were housing followed by agriculture, transport, fresh water resources and education in sequential order (GoB, 2008). Over 25% of houses of the upazila were completely shattered and washed away and 30% houses were partially damaged. Majority of the damaged houses were katcha and semi-pacca nature and located outside or near the embankment (LCG Bd, 2008)

Damage to fresh water supply and sanitation facilities was also significant in all the worst affected unions particularly in the rural areas of the upazila. Drinking water sources (tube wells and ponds) in many communities were contaminated by saline water and debris. Physical damage to household latrines with major percentage of slab latrines was fairly common. The affected population often suffers to various water borne diseases like diarrhea, cholera etc.

Communication was greatly disrupted as roads were severely damaged to Cyclone Sidr. Roads were mainly affected in the area located along the coastline or on the banks of estuarine rivers. Most of the affected roads are embankment-cum-roads and were destroyed by the high tidal surge during the cyclone.

Apart from this a number of community facilities and educational institutions of semi- pacca nature were damaged that disrupt household‘s needs of basic services and education for long after the cyclonic event. Strong winds of the cyclone caused major destruction to local power supply system. Damage was incurred by several transmission lines--due to high sustained winds and fallen trees.

Though the impact of cyclone Sidr on built environment is yet devastating but death toll has been significantly reduced in last 4 decades. A comparative analysis of damage profile between cyclones 2007 and 1970 (both of the cyclones have similar wind speed and surge height following the similar track) shows that death casualties of the inhabitants was far less in the recent cyclone Sidr than that of the past. Improved disaster prevention measures, including early warning system, coastal afforestation projects, cyclone shelters are credited with lower casualty rates than what would have been expected, given the severity of the storm (GoB-MoFDM, 2008).

Table 5.4 Description of loses, Kalapara during Cyclone 1970 and 2007

Affected area	Bhola cyclone 1970	Cyclone Sidr 2007
Pre –cyclone population	87,906	2,05,008
Total death	8175	91
Cyclone mortality	9.3%	0.04 %
Severely damaged house	12,462	
%	84.4%	25%

Source: Somer, A. & Mosley, 1971 and GoB-MoFDM, 2008

5.4 Vulnerability of Settlement to Cyclone and storm surge inundation: Identification of key variables

5.4.1 Settlement density

People‘s exposure to risk is correlated with the density of settlement. The greater settlement density and more difficult it is to respond to hazardous events in terms of evacuation planning and disaster recovery. It is observed that, apart from Kalapara municipality avg. density of households in western part of the upazila is higher than that of eastern part (table 5.5). Of the unions in the west Kalapara settlement (household) density is highest in southern most localities at Latachapli and Khaprabhanga union (fig 5.6c/ table 5.3). Historically these areas were less prone to cyclonic surge (fig 5.5/ table 5.2) and grown as a center for marine-based commerce. Besides *Kuakata* sea beach, one of the major tourist spot in the country is located in Latachapli union and acting as pull factor for the development of settlement here. Then again eastern part of the upazila is exposed to the risk of multi hazards like cyclonic surge, tidal flooding, river erosion etc and settlement is less dense here. As the area is adjacent to sea estuary the landmass of respective vicinity is still in formative stage. Much of the agricultural land suffers from salinity problems and agricultural production is relatively lower than elsewhere in the upazila. Villages in this area are small cluster of houses widely spaced to each other and spotted the landscape ubiquitously (fig 5.2).

Table 5.5: Household density of West and East Kalapara

	Union	HH density (per sqkm)	Avg. HH density (per sqkm)
West Kalapara	Lata chapli	90.7	90.0
	Khaprabhanga	98.5	
	Nilganj	82.6	
	Chakamaiya	88.3	
East Kalapara	Dhulasar	71.8	72.8
	Mithaganj	65.8	
	Lalua	75.4	
	Tiakhali	72.3	
	Dhankhali	78.8	

Source: calculated by author *

5.4.2 Housing characteristics

It is reported that Pacca houses are more resistant to cyclone (GoB-MoFDM, 2008). In spite of high risk to cyclone the housing condition in the upazila can be characterized as ‗temporary' type with predominant *jupri* and *katcha* structures comprising over 97% of total houses. Unlike other upazilas in the district a significant portion (42.43%) of *Jupri* structure is observed in Kalapara. Houses of this type are mostly constructed with perishable material like thatch and bamboo. *Katcha* structures are mostly constructed with CI sheet over timber framework. The ratio of *semi-pacca* or *pacca* house is very insignificant. Even in urban area in upazila the percentage of *semi pacca* and *pacca* house is limited to 9.7 % only.

Table 5.6 Distribution of the main houses of the dwelling households by type of structures

Locality	Total	Jhupri	Katcha	Semi Pucca	Pucca
upazila	100	42.43	55.46	1.68	0.43
Rural	100	45.31	53.56	0.96	0.17
urban	100	20.16	70.13	7.29	2.42

BBS, 2001b

5.4.3 Access to service and shelter

Apart from housing structures the resilience capacity of a settlement depends on its available infrastructural facility providing shelter and necessary services required at disaster period. In this study availability of cyclone shelter, pacca road/ high land, primary education facility and health care services are taken as indicator to assess settlement‘s infrastructural capacity.

5.4.3.1 Access to cyclone shelter

To save the life of the inhabitants there are 113 cyclone shelters in the upazila. Of them 82 shelters are in good and moderately usable condition with total capacity of 75325 persons which represents only 38% of total inhabitants. On an avg. for every 2500 population there is a usable shelter in the upazila. Because of its high risk exposure a major number of cyclone shelter is located in south and south eastern part of the upazila comprising 60% of total shelter. Inhabitants of Chakamaiya and Mithaganj union have poor access to shelter where the existing shelters have the capacity to serve less that 30 % of total inhabitants of those unions. Most of the cyclone shelter is used as educational center in normal time. Apart from this a considerable no of shelter is also used as office, health center, community center etc.

5.4.3.2 Access to high land pacca road

Good road communication can save life in two ways – i) proving safe route from community to shelter earlier to hazard event ; ii) ensuring post disaster outside assistance and transportation of relief goods. In the upazila the inland communication is greatly disrupted by the rivers and their tributaries criss-crossing the land masses. As most of this water bodies are running from east to west, roads running from south to north is minimum with maximum interruption by number of ferry crossing. Then again major portion of this road network is unpaved or earthen type which is subjected to erosion and often severely damaged by cyclonic surge. The overall percentage of unpaved road in the Upazila is 88%. In case of village road the figure is over 93%.

Table 5.7 State of road communication in Kalapara upazila

	Total (km)	Paved road (km)	Unpaved road (km)
Road length	1514.19	182.96	1331.23
%	100	12.1	87.9

Source: LGED, Road data base

5.4.3.3 Access to primary education

There is a general consensus that illiteracy constrains the ability of a person to understand early warning and access to recovery information. Access to primary education is therefore an indicator of household‘s resilience capacity to disaster. There are 158 govt. and non govt. institutes in the upazila providing primary education to the inhabitants (Kalapara Upazila Parishad, 2009). On an avg. for every 1500 people there is a primary school in the upazila. The ratio of educational facility is relatively lower in southern unions and it is lowest in Dhulasar union (fig 5.6.b) where the ratio is 2500: 1 i.e for every 2500 population there is one primary school in the union.

5.4.3.4 Access to health facility

Health facilities are emergency medicare provider and important post-event source of relief. The lack of proximate medical services will lengthen immediate relief and long term recovery from disaster. To provide health service for the inhabitants there are 50 bed upazila health complex with 20 bed heath facility at *kuakata* and number of community clinics in other unions. On an avg. for every 8000 people there is a health facility in the upazila. From the map it is observed the inhabitants of south and southwestern unions have poor access to health care services (fig 5.6.d).

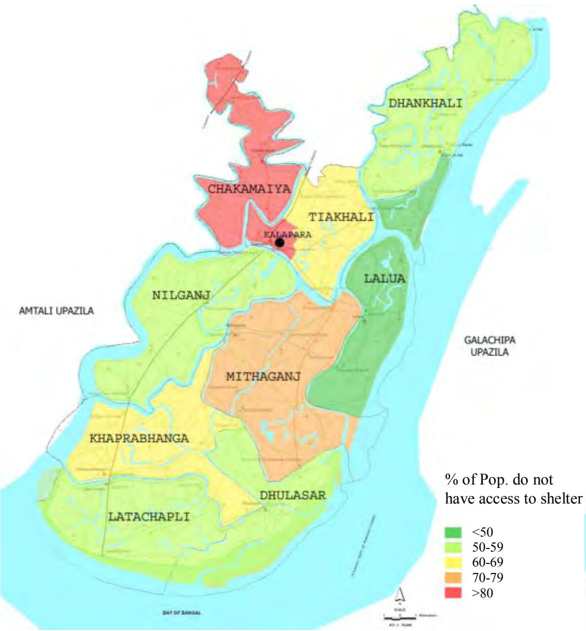


Fig 5.6. a Access to cyclone shelter, Kalapara

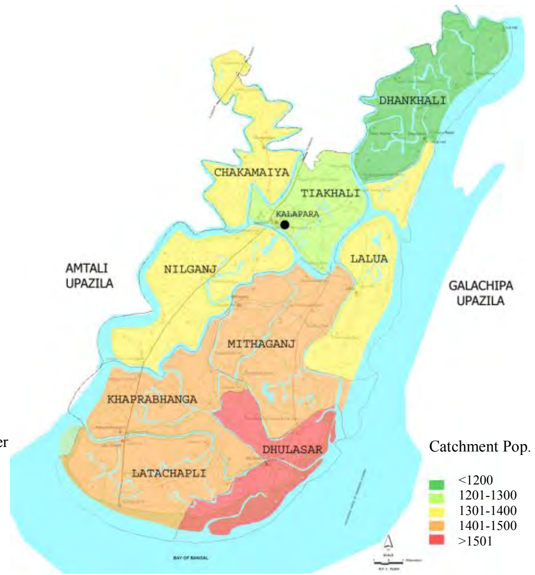


Fig 5.6. b. Access to educational facility, Kalapara

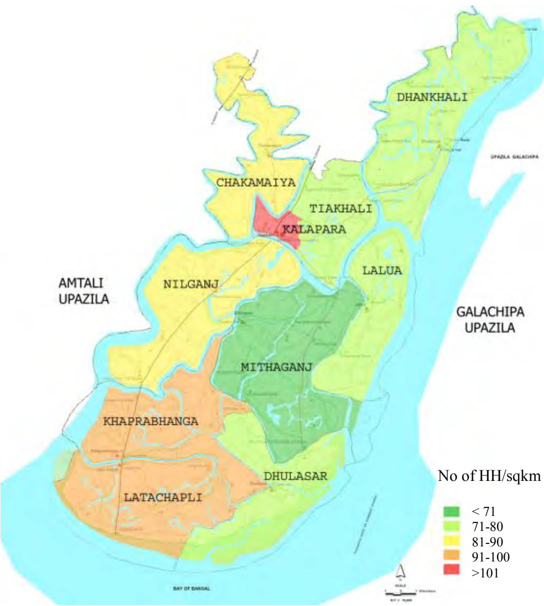


Fig 5.6.c Density of settlement, Kalapara

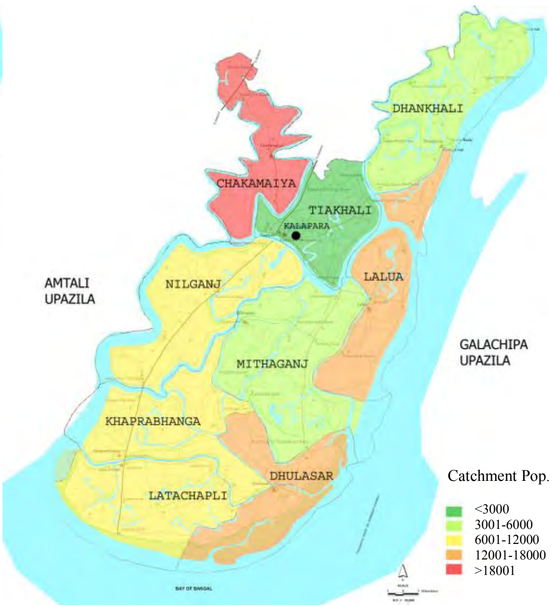


Fig 5.6.d Access to health facility, Kalapara

To sum up, poor housing condition along with poor infrastructural facilities including poor access to cyclone shelter, high land / pacca road, primary education and emergency health care facility are the key aspects of settlement‘s vulnerability in exposed coast where the risk are primarily from cyclone and storm surge hazards both in present and future context. It is observed that settlements in southernmost unions of study upazila being exposed to highest risk of cyclone and devoid of emergency services and shelter with predominant katcha structure for housing are most vulnerable among all.

5.5 Spatial analysis of geo-climatic vulnerability of settlement in Dhulasar union-Kalapara

Geo-climatic vulnerability as defined is a composite index of settlements exposure to geophysical risk and capacity of settlement‘s physical components i.e. housing and infrastructure to cope with. In this study Dhulasar union is selected for micro-level analysis of geo-climatic vulnerability following analysis grid method. The union is a foreshore area and exposed to marine hazard. Settlements in this area are subjected to periodic cyclone and storm surge inundation at present and at risk of permanent inundation due to sea level rise in future. In Safulkati Union there are 15 villages within 4 mauzas. Char chapli is the growth center. Total population in the union is 15119 with an average density of 341.12 people per sqkm which is nearly half than Safulakati union of interior coast (BBS, 2001b).

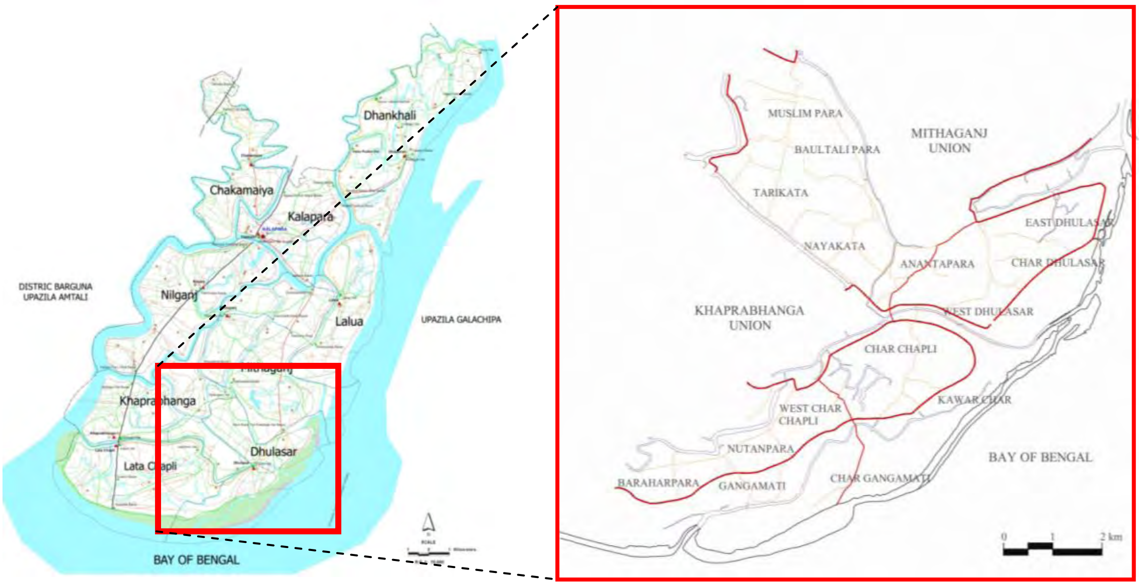


Fig 5.7 Localities of Dhulasar union in Keshabpur (adopted from Upazila Mauza map of LGED)

Table 5.8 Variable matrix used to determine Geo-climatic vulnerability of settlement in Dhulasar

Domain	**Indicators**	**Proxy variables**	**Measurable component**
Exposure to Geophysical risk	Geophysical risk index	Cyclonic wind	Wind speed in each cell
		Storm surge inundation inundation	Depth of inundation in each cell
Resistance and Resilience capacity of settlement pattern	Housing vulnerability index (60)	Density of katcha house	Katcha house ratio X no of household in each cell (density of settlement)
		Household density	
	Infrastructural vulnerability index (40)	Access to cyclone shelter	Spatial distance of the grid cell from nearest shelter
		Access to pacca road / high land	Spatial distance of the grid cell from nearest pucca road
		Access to health care facility	Spatial distance of the grid cell from nearest health care facility
		Access to nearest primary school	Spatial distance of the grid cell from nearest educational facility.

5.5.1. Measuring Geo-physical risk

In this study, geophysical risk of cyclone is analyzed on the basis of two indicators: i) storm surge inundation depth and ii) wind speed. Inundation risk is measured on the basis of storm surge inundation depth map prepared by IWM generated from maximum inundation maps of 18 cyclones from 1960 to 2007 (fig) . Exposure to wind risk is measured on the basis of cyclone risk zone as identified in the study of Multipurpose Cyclone Shelter Program (MCSP) 1993. According to MCSP study the Dhulasar union of Kalapara upazila falls in High Risk Area (HRA) and thus the exposure to wind risk is considered as same in all parts of the union.

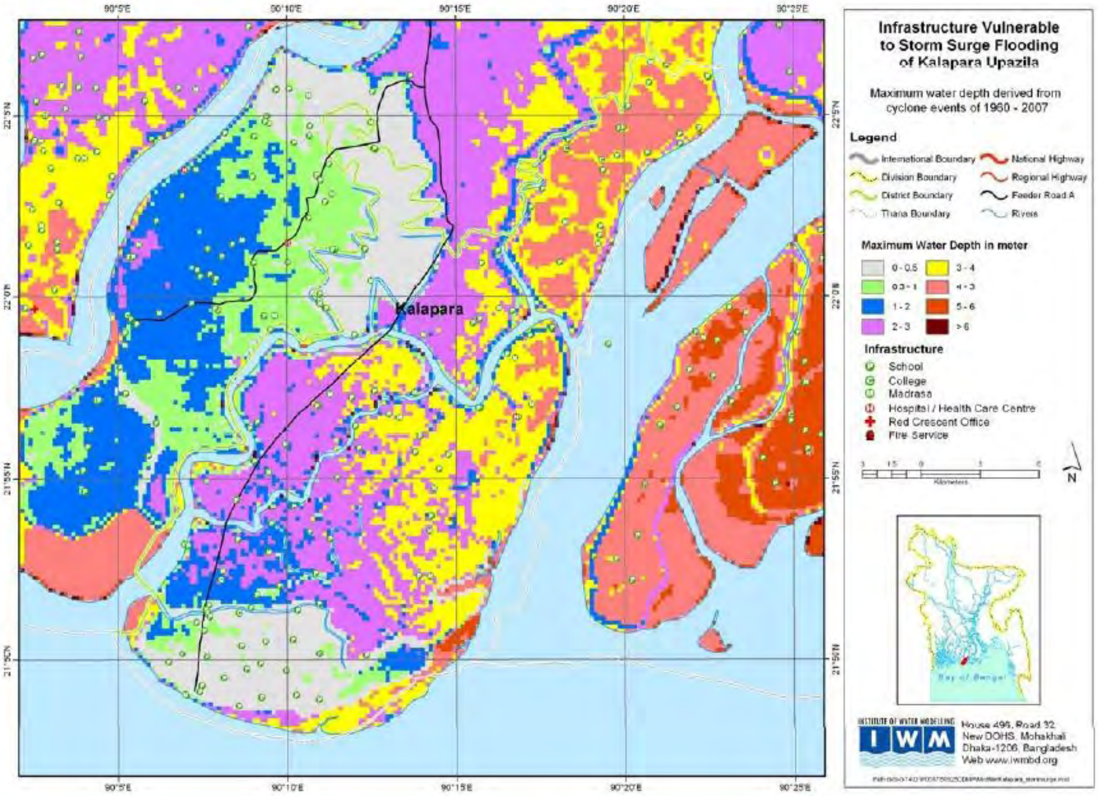


Fig 5.8: Storm surge inundation risk map of Kalapara Upazila. (IWM, 2009)

Considering the slight variation in local topography and existing polder it is found that the risk of inundation is not same in all parts of the union. Inundation risk is high in foreshore areas like char Gangamati, Char Dhulasar, Kawar char etc. Settlements in these areas are at risk of 2 to 6m storm surge inundation. As oppose to that the risk of inundation is lowest in Baraharpara , Gangamati and Char Chapli. Settlements in these areas are however protected by green belt and embankment which act as primary means of defense against the wind and cyclonic surge.

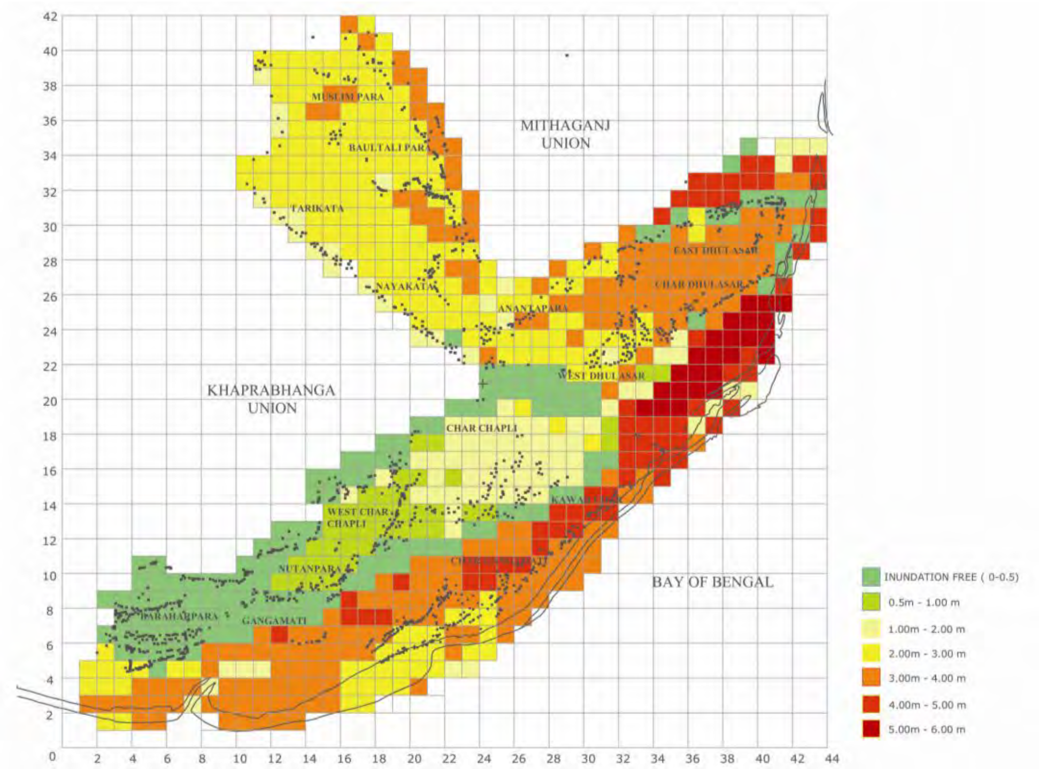


Fig 5.9: Storm surge inundation risk map of Dhulasar Union adopted from IWM, 2009

5.5.2 Measuring resilience capacity of settlement

Settlement‘s resilience capacity is analyzed in terms of two physical components; i) Housing and ii) Infrastructure. It is assumed that katcha houses are more susceptible to damage by cyclonic force and thus more sensitive. The more sensitive the housing structure is the less capacity it has to put any resistance against the strong wind and surge generated during cyclone. Again in case of infrastructure, it is assumed that settlements that lacks pre and post event shelter and services within their close proximity is more sensitive and thus have less capacity to recover or reduce the losses.

5.5.2.1 Measuring capacity of housing structure:

Capacity of housing structure to cope with the risk is measured on the basis of density of *katcha* houses i.e. no of *katcha* houses in each cell. There are total 3198 dwelling units in the union with predominant katcha structures which comprises 78% of total holdings. It is found that, localities in foreshore areas like char Gangamati, Char Dhulasar and east Dhulasar density of *katcha* households is higher than rest of the part of Union. Considering housing structure settlement in this area is more sensitive to geophysical risk and thus resilience capacity is lowest. On the contrary settlements in northern part of the union are less sensitive or more resilient to the risk of cyclone as the relative density of *katcha* house is lower.

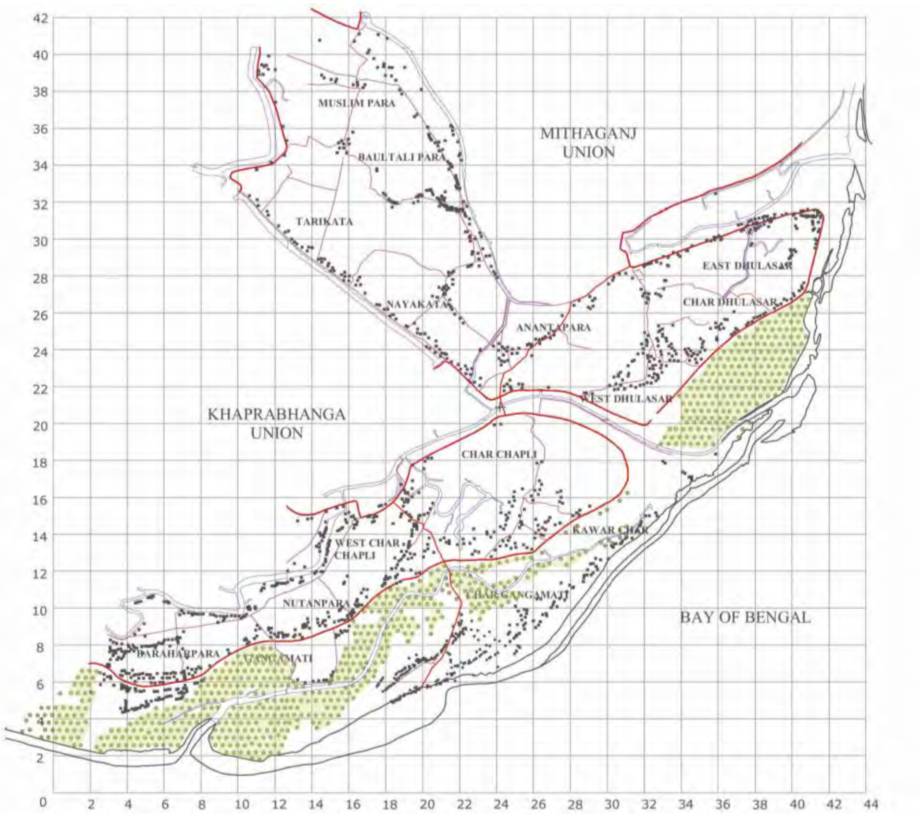


Fig 5.10: Distribution of houses in Dhulasar Union (adopted from Topographic map, Survey of Bangladesh and updated from satellite image)

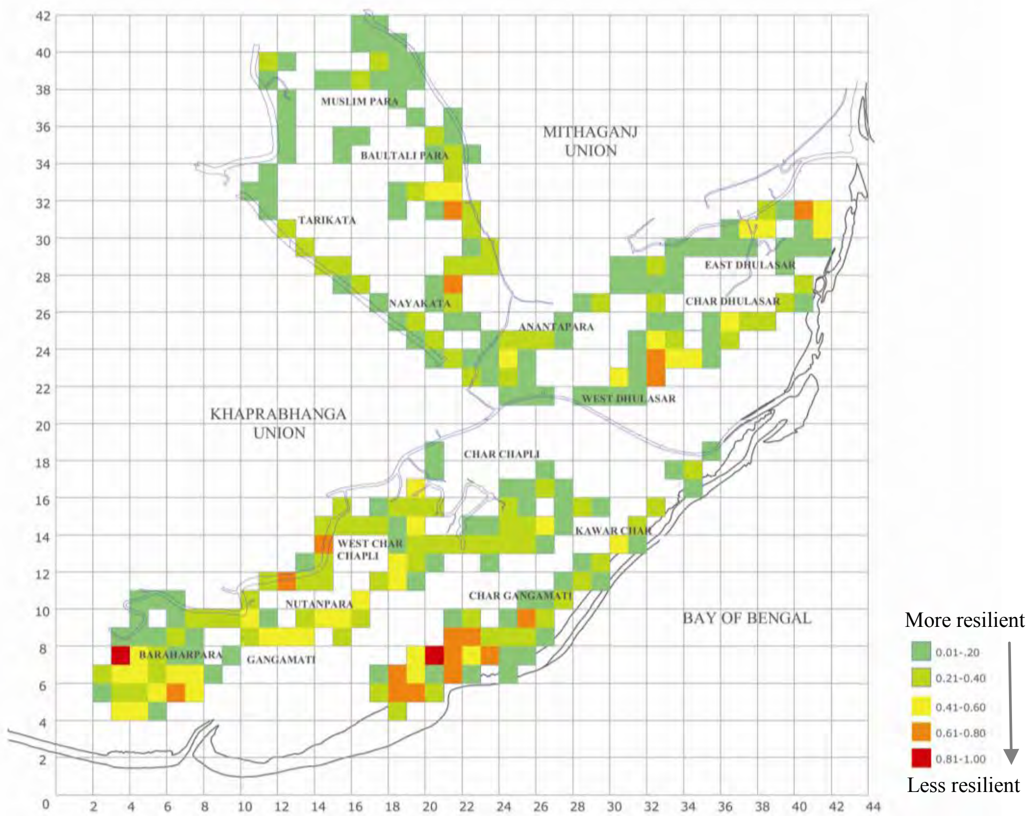


Fig 5.11: Resilience Capacity of Housing structure in Dhulasar Union

It is to be mentioned that, although the percentage of *katcha* house is highest in Kawar char (95%) but overall sensitivity is relatively lower as the settlements are more sparse or less dense. Conversely in Baraharpara where percentage of katcha house is lower (59%), the overall housing sensitivity is higher because of high density of settlement.

5.5.2.2 Measuring infrastructural capacity:

Infrastructural capacity of existing settlement to adapt with climate change induce risk is assessed in terms of proximity to nearest shelter and services required for during disaster safety and post disaster recovery. There are 8 shelters in the union with a capacity of 7500 person (table 5.9) are proving shelter for 49% of total inhabitants. In addition there are 6.25 km of Pacca road or road cum embankment in the union which serve the population as a means of safe route for evacuation and temporary shelter in disaster period. In addition availability of health care center and primary education facility within the vicinity of community is considered as indicators of settlement‘s resilience capacity to cyclone.

Table 5.9 Profile of usable cyclone shelter in Dhulasar Union

Shelter name	Normal time uses	Capacity
57 no. Dhulasar GPS	Educational Center (EC)	600
57 No. Dhulasar GPS	EC	600
Anantopara GPS	EC	825
Char Dhulasar Regi. Primary school	EC	850
Char Gangamati cyclone shelter	EC	850
Dhulasar High school	EC	1050
Dhulasar Union Parishad	OFFICE	700
Dhulasar Union Parishad (new)	OFFICE	2025
Total capacity		7500

Source: MoFDM, Cyclone shelter Database

Table 5.10 Selected variables with weighting value

Variables	weight	comments	Contributing period
Proximity to nearest Cyclone shelter	0.40	Most desired destination. Shelter can act as safe house for the affected.	During disaster safety
Proximity to nearest high land / pacca road	0.30	Provide safe evacuation route and temporary shelter for refugee.	During and post disaster safety and rehabilitation
Proximity to nearest Health facility	0.20	Source of emergency medi-care and relief.	Post disaster recovery
Proximity to nearest primary school	0.10	Raise awareness and provide information for early recovery	Pre disaster preparedness
Total	1.00		

It is found that, being a growth center settlement in the central part of the union has better infrastructural facility than other parts. Households in this area have better access to emergency shelter and services as these are located within close proximity to settlement area. Settlements away from the union center have poor infrastructural development and devoid of many essential services. In general it can be said that due to its high risk exposure the seaward part of the union is facilitated time to time with several infrastructural developments including establishment of cyclone shelters and construction of embankments etc.

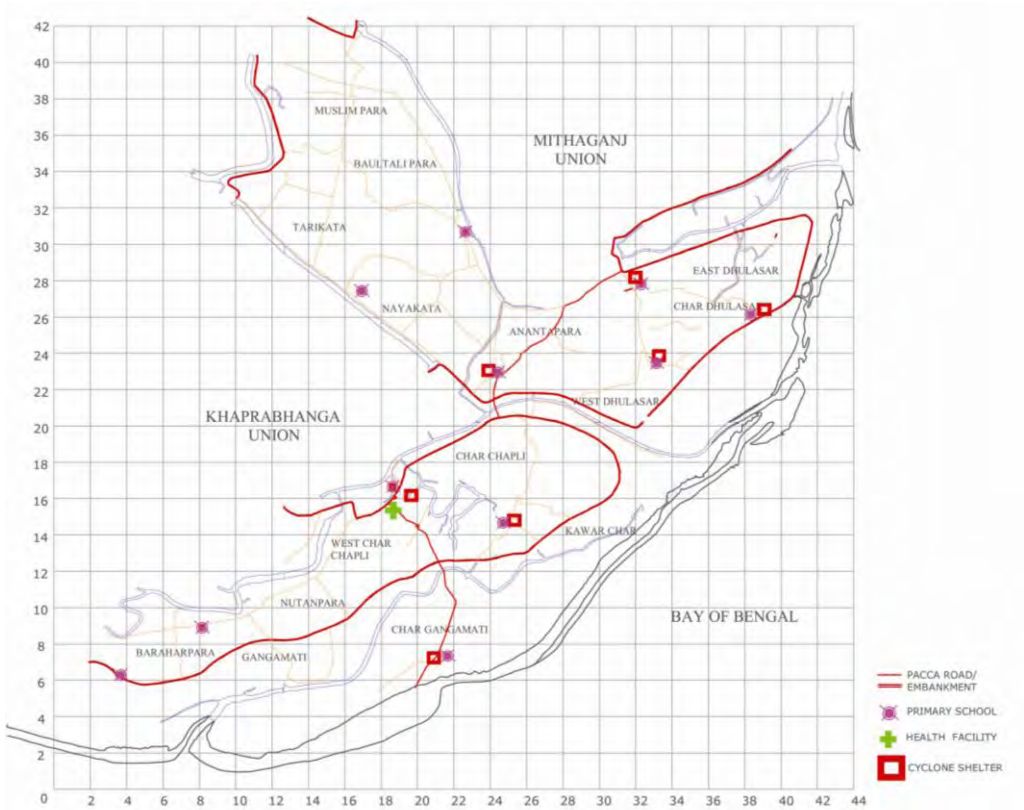


Fig 5.12: Infrastructure facilities in Dhulasar Union (adopted from MoFDM, Cyclone shelter Database)

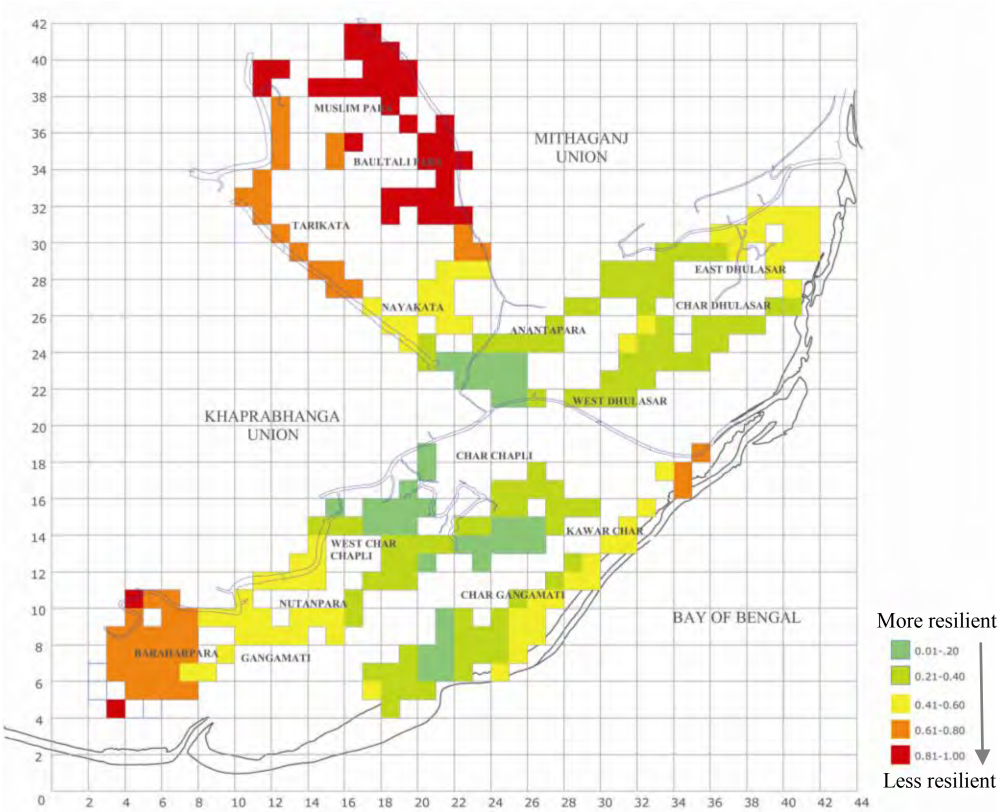


Fig 5.13: Composite Infrastructural Capacity of Dhulasar Union

5.5.2.3 Measuring Composite Capacity Index of settlement (housing + infrastructure):

Overall settlement capacity is a composite result of housing and infrastructural capacity to put structural resistance during disaster or to recover from post disaster period. The composite index of settlement is thus prepared by overlapping the results of housing and infrastructural sensitivity index as calculated beforehand. While adding these two indices, a weight of 0.6 is applied on housing and 0.4 on infrastructural part as it is assumed that capacity of housing structure to cope with disaster is the key determinant of settlement‘s reliance capacity. The following equation is used to calculate the composite index of settlement in Dhulasar.

COMPOSITE INDEX OF SETTLEMENT CAPACITY (CSC_i) = HOUSING INDEX (HC_i)x 0.6 + INFRASTRUCTURE INDEX (CIC_i)x 0.4

The result shows that, the existing housing and infrastructural facility in southwestern locality of Baraharpara , Gangamati, Char Gangamati, Nutan para and northern locality of Tiakhali , Baultali para, Betkata para and Muslim para have limited capacity to cope with cyclone. The settlements in and around union center is less sensitive and thus have better resilience capacity to cyclone.

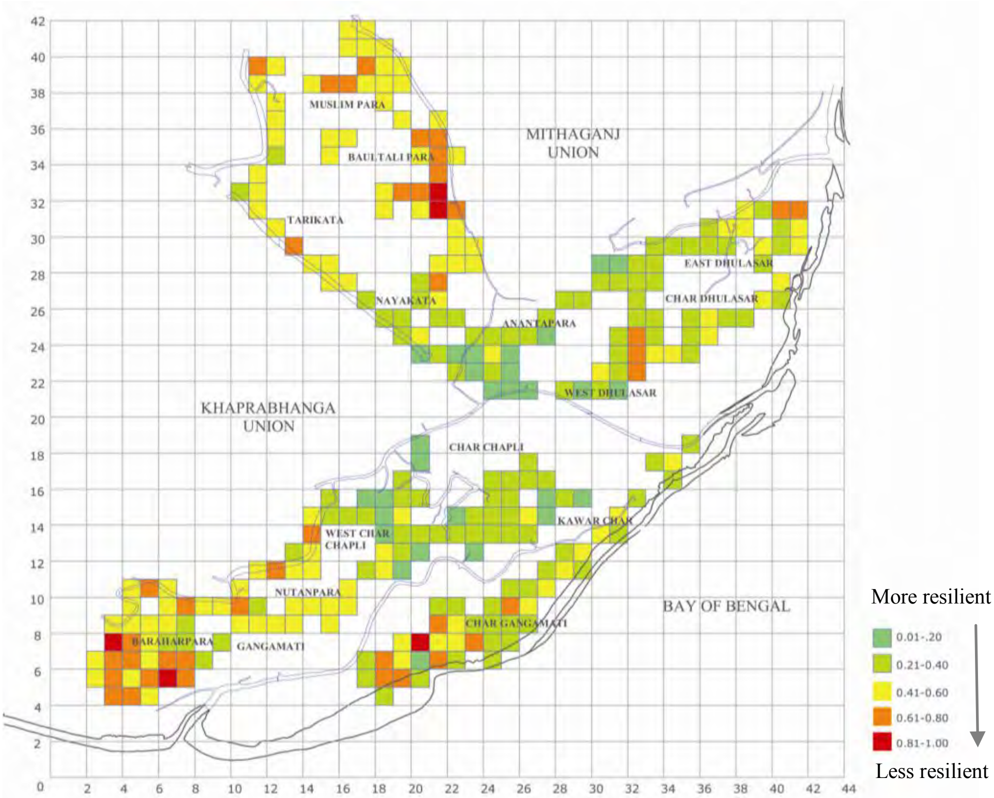


Fig 5.14: Composite Settlement Capacity of Dhulasar Union

5.5.3 Comparison of result: Analyzing Geo-climatic Vulnerability of Settlement

Finally settlement‘s geo-climatic vulnerability is analyzed by comparing the resilience capacity of existing settlement in relation to its exposure to geophysical risk. Settlements/ parts of settlement that are exposed to highest risk of inundation and wind but have lowest resilience capacity is thus considered to be the most vulnerable and vice-versa. For instance, settlement vulnerability in Char Chapli is lowest because of low risk exposure and highest resilience capacity. Conversely vulnerability of Char Gangamati is highest because of its high risk exposure and lowest resilience capacity. The combined results of settlement‘s exposure to risk and its resilience capacity for different localities in Dhulasar union are given below:

Table 5.11 Degree of Geo-climatic vulnerability and pattern of settlement in Dhulasar Union.

Village/ locality	Settlements exposure to Geophysical risk (-)	Settlements resilience capacity (+)	Settlement vulnerability	Settlement pattern	Rn
Char Dhulasar	Highest	Moderate	High	dispersed	1.04
Char Gangamti	Highest	Lowest	Highest	semi dispersed	0.56
Kawar Char	High	Moderate	High	dispersed	1.00
East Dhulasar	High	Low	High	semi dispersed	0.79
Baultali	Moderate	Lowest	High	semi linear	0.49
Muslim para	Moderate	Lowest	High	dispersed	1.49
West Dhulasar	Moderate	Moderate	Moderate	dispersed	1.00
Ananta para	Moderate	Highest	Low	dispersed	1.34
Nayakata	Moderate	Moderate	Moderate	semi dispersed	0.95
Tarikata	Moderate	Low	Moderate	semi dispersed	0.95
Char Chapli	Low	Highest	Lowest	dispersed	1.13
West Char Chapli	Low	High	Low	semi dispersed	0.97
Gangamti	Low	Moderate	Low	semi linear	0.42
Barahpara	Lowest	Lowest	Low	semi dispersed	0.67
Nutan para	Lowest	Low	Low	dispersed	1.13

0.00-0.09 – absolute cluster/ nucleated, 0.10-0.22 semi nucleated, 0.23-0.39linear, 0.40- .49 semi linear, 0.50 –.99 semi-dispersed, 1.00- 1.50 dispersed/ scattered

Settlement in Dhulasar is predominantly semi dispersed and dispersed pattern (Rn value ranging from 1.32-0.42 with an avg. of 0.93). The profile of most vulnerable localities of Dhulasar union in terms of geophysical risk and existing housing and infrastructural conditions are given bellow:

Table 5.12 Statistics of Highest and High vulnerable locality of Dhulasar union.

Most vulnerable Locality	Storm surge Inundation depth (m)		HH density (per sqkm)	% of katcha house	Nearest high land /pacca road(km)	Nearest cyclone shelter (km)	Nearest health facility (km)	Nearest Hat/ bazaar (km)	Nearest Primary school (km)
	Min	Max							
Char Dhulasar	2.00*	6.00	120	89%	0.26	0.81	4.84	1.68	0.48
Char Gangamati	2.00	5.00	65	81%	0.50	0.97	2.53	1.56	0.85
Kawar Char	1.00**	6.00	57	95%	0.39	0.95	2.19	1.70	0.71
East Dhulasar	2.00**	4.00	110	69%	0.16	1.76	5.44	1.41	0.79

* Area along the Embankment remains partly inundated (0-1.0 m)

** Area along the Embankment remains inundation free

5.6 Local response to cyclone and storm surge vulnerability

In this section, the follow-up of micro level study on vulnerability and corresponding response strategies primarily based on onsite information collected from the most vulnerable localities of Char Gangamati and Patilar char is presented. Both of the study areas are located within the Gangamati mauza along the southern coast of Dhulasar union (fig 5.15). The village of Char Gangamati is bounded by the coastline of Bay of Bengal on the south, Gangamati reserve forest on the north and east and Kawar char on the west. Next to it a remote settlement at Patilar char is selected which is 3 km away from Char Gangamati and located at the edge of Gangamati forest. The contextual settings has made the study areas vulnerable than other localities in the union. Both of the study areas are foreshore villages situated outside the embankment within half kilometer distance from the shoreline and thus exposed to the high risk of sea born hazards. During Sidr and Aila these villages were severely damaged and the signs of wound are still visible after four years of the event. During super cyclone Sidr, the villagers have experienced upto 3m high storm surge accompanied with severe cyclonic wind wiping out their crops and houses.

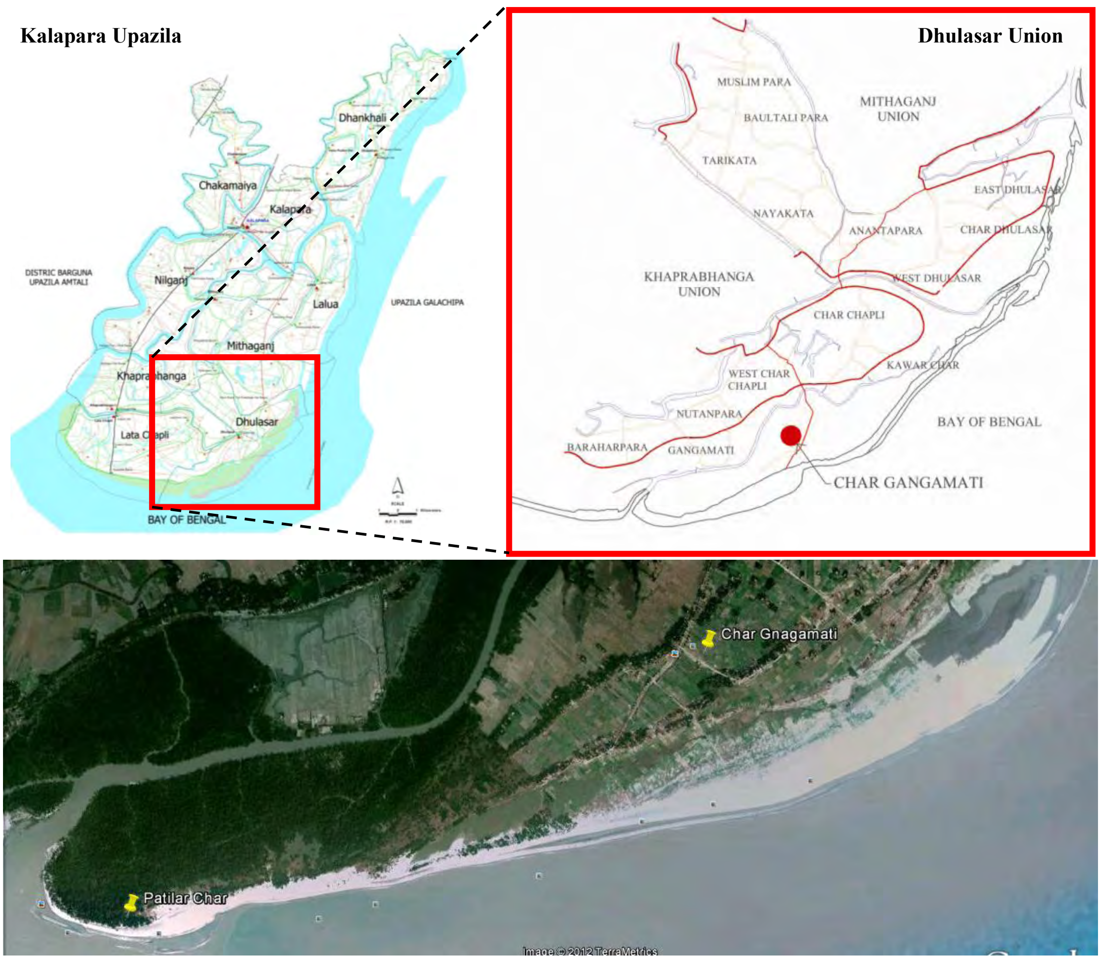


Fig 5.15: Foreshore locality of Char Gangamati and Patilar Char at Dhularsar Union, Kalapara.
(Source: LGED and Google earth, 2010)

5.6.1 Settlement pattern and vulnerability profile of study village

The settlements in Char Gangamati were founded very recently not more than 30 years ago with seven households at the beginning. Within thirty years it grows to 418 households at present. By origin all these households are landless people migrated from different parts of Barisal division. Compare to the village other part of the union the density of population is lower in Char Gangamati because of their high risk exposure. According to population census 2001 avg. population density of Dhulasar union is 675 persons per sq km where as in Char Gangamti it is 230 persons per sqkm. However in last ten years population has increased more than twice but density still remains far below the avg. A major portion of the inhabitants of the study village is illiterate. The avg. literacy rate of Char Gangamti is 34.5% which is bellow the avg. of the union (50.40) (BBS, 2001b). At present the primary occupation of the households is sea fishing. The household reported that, due to sedimentation the fishing opportunity near the coast has decreased a lot. And the fishermen need to travel more distance deep into the sea than earlier. This has increased the risk for the deep sea fishermen as they often failed to return early before the cyclone. In addition a major portion of household is also involved in agricultural practices. Due to high salinity, soil fertility has significantly reduced and thus the agricultural production of the households is severely interrupted. The households are able to cultivate single crop in a year. Rest of the year water melon is widely cultivated in the sandy soil of the locality. In every disaster event the households used to suffer a frequent loss of standing crops. For communal purpose there are six mosques, a madrasa and a cyclone shelter cum primary school in the village. The nearest health care facility and high school is two and half kilometer away at Char Chapli. Dholai market is the nearest local bazaar a kilometer away from the community.

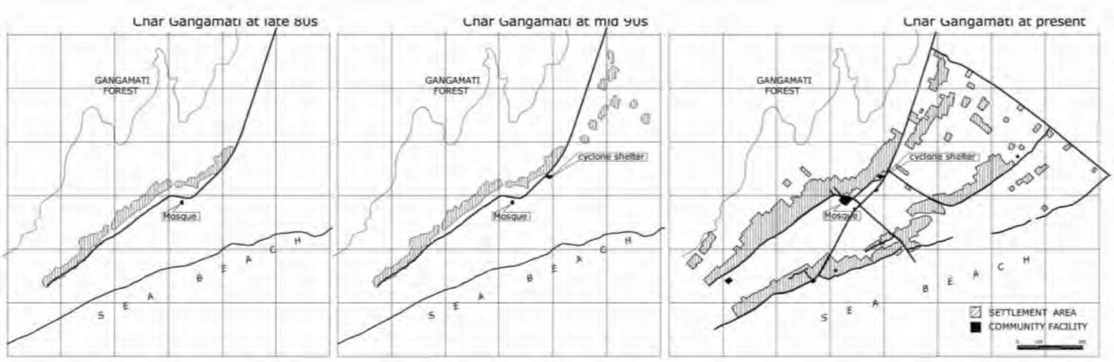


Fig 5.16: Settlement growth pattern of Char Gangamati since 1984 to 2012 (prepared by author from historical satellite imagery of Google earth)

The settlement pattern of the Char Gangamati is semi dispersed with combination of linear and scattered settlements (fig 5.17). The houses are primarily concentrated into two neighborhoods parallel to each other and separated by agricultural field. Neighborhood in northern part is the older one that forms the embryo of the settlement: from where settlement has originated. Settlement pattern is predominantly linear here where development of house patch is mostly confined in one side of the road and thereby creating segregation between the farm land and house patch. The distance of the shoreline is almost half kilometer from the settlement. Socio-economic condition of the households is comparatively better here than the other parts. Generally four households jointly own a single trawler. The households enjoy comparatively better access to community services and shelter. Among other community facilities the only cyclone shelter cum school and *madrasa* is located in this neighborhood. Density of households in northern part is also observed higher than other parts of the settlement. The house patches are predominantly single layered but in central and western part it has experienced a growth in secondary layer.

Neighborhood of south and south eastern part, settlements are still sparse and devoid of essential services and common facilities. Houses are sited in isolated manner within the farm land and widely spaced to each other. The neighborhood is located very close to sea only quarter kilometer away from shore line. Socio-economic condition of the household is relatively poor than the northern part. Due to its locational aspects, poor socio-economic condition of the household and poor access to shelter and services, the southern neighborhood stands to be the most vulnerable to cyclonic hazard. Settlements of that part receive the first impact of the cyclone and suffer great loss of life of properties. A pacca road is running from west to east connecting these neighborhoods and thus forming the central artery of the settlements. The cyclone shelter and other community services like grocery shops are situated along this road. Access to homestead is done by secondary *katcha* roads/ aisles branching out from the central artery.

On the other hand, the settlement of Patilar char is more transient in nature and founded only six years ago. Settlers are all marine fishermen and are not permanent residents here. They came from the interior part of the upazila for periodic fishing in deep sea. At present there are 12 households in the locality with few others who have already shifted or in the process of shifting. The household reported that, due to sedimentation the fishing opportunity near the coast has decreased a lot. And the fishermen need to travel more distance deep into the sea than earlier. This has increased the risk for the deep sea fishermen as they often failed to return early before the cyclone. Settlement pattern in Patilar char is linear where houses are grouped together along the shoreline. There is no road or pathway to access the village. There is an arrangement for congregational prayer at the center of the settlement which is the only community facility of the locality.

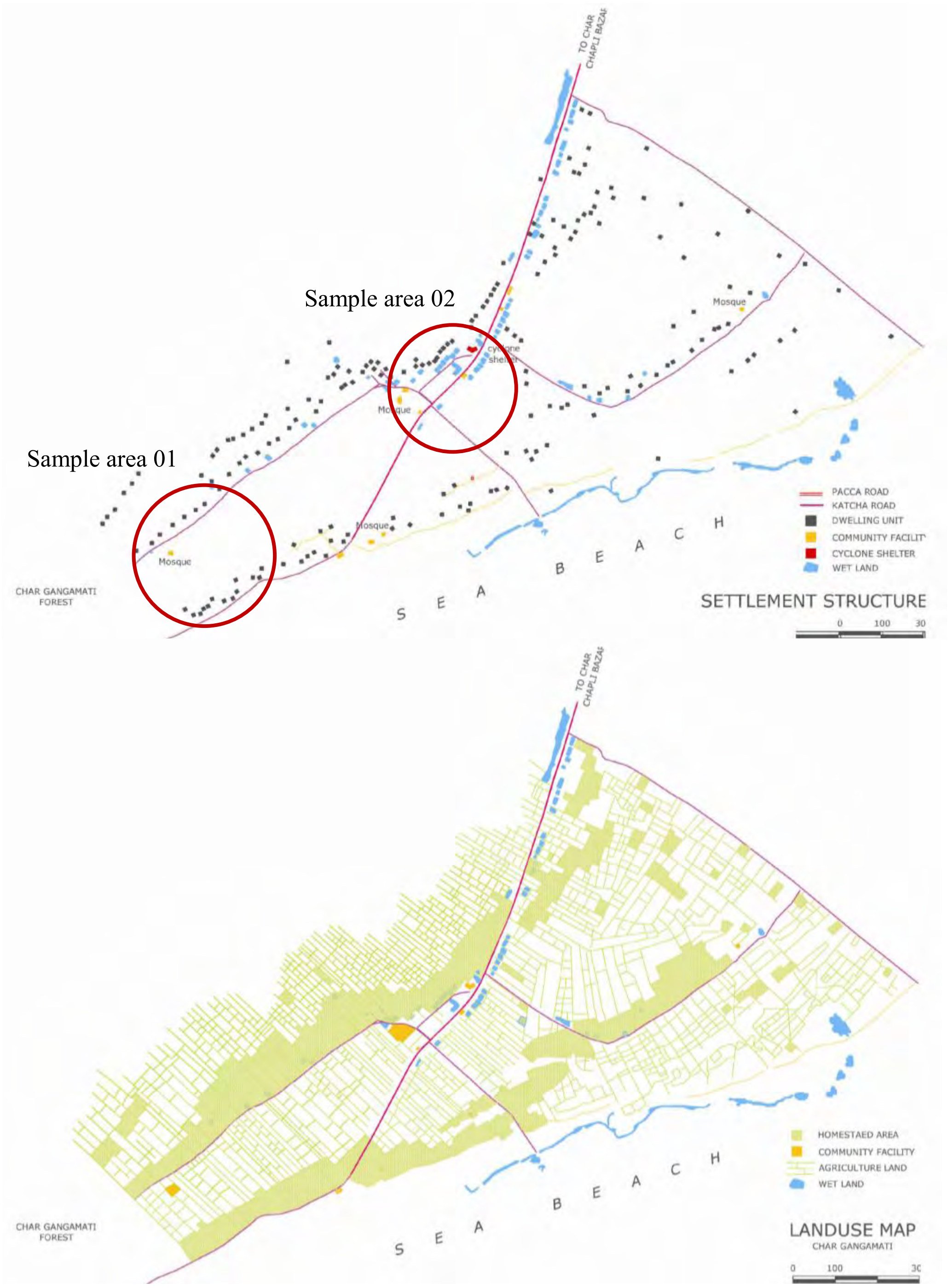


Fig 5.17: Settlement structure and land use pattern of study village 01: *Char Gangamati*

Fig 5.18: Foreshore village Char Gangamati , Dhulasar Union , Kalapara

Fig 5.19: Sample area 01 of study village

Fig 5.20: Sample area 02 of study village

Fig 5.21: Study village 02 : *Patilar Char*

Fig 5.22: A fisherman village at Patilar char , Dulasar union , Kalpara Upazila , Patuakhali

To study the morphological pattern of homestead, two sample house patches from northern part of the Char Gangamati village and entire locality of Patilar char have been selected (fig 5.19 & 5.20). Homesteads in this part are organized side by side facing the access road. Following schemes represent the fundamental layering in homestead layout in the study area:

Scheme 1 and Scheme 2 (fig 5.23 &5.24) is the representative type of homestead pattern in Char Gangamati and Scheme 3 (fig 5.25) is for newly formed settlement at Patilar char. In Char Gangamati where settlement is relatively older a discrete order in layering between activity space and production area is observed (scheme1). The number of subsequent layers diminishes as it progress towards the edge away from the centre of the settlement (scheme 2).

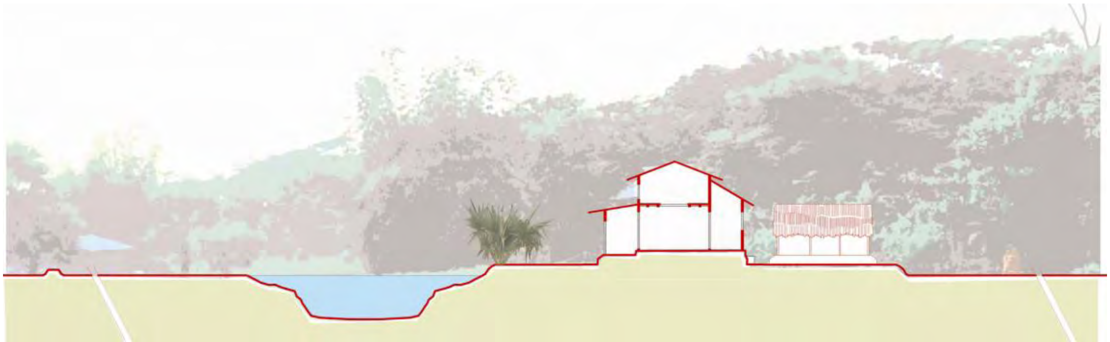


Fig5.23. Fundamental layering of **Scheme 1**: Village path → seed bed→ pond→ thin layer of vegetation→ cattle shed→ front yard→ main house → kitchen → backyard → thick layer of vegetation

Fig5.24. Fundamental layering of **Scheme 2:** Village path →thin layer of vegetation → front yard → main house → kitchen →backyard → thick layer of vegetation

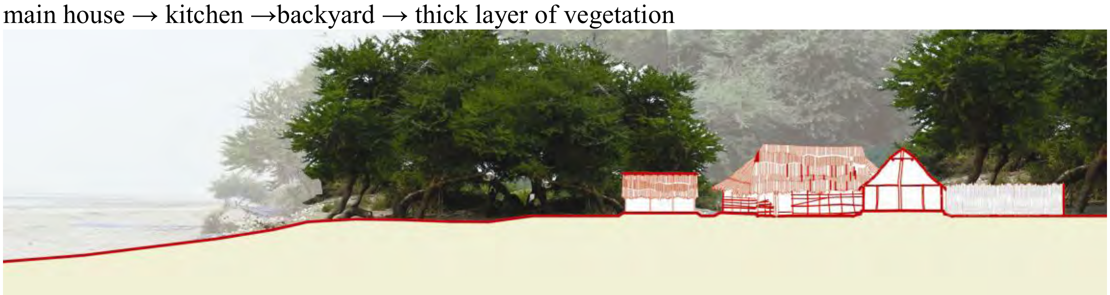


Fig5.25. Fundamental layering of **Scheme 3:** Seashore→ thin layer of vegetation→ shared space→ main house → private space/ outdoor kitchen → thick layer of vegetation / forest.

Two generic types of traditional house are found in the study village

Type A: Six pitch CI sheet house- Wall and roof of this house is commonly constructed with galvanized corrugated iron sheet over timber framework. House of this type has a core living unit with verandah in front and extension on the rear side. With verandah and extension part the house take the shape of rectangle with length and width ratio within 1: 1.125. The house has six pitched roof with hip roof over the core unit and single pitch over verandah and extension part. The height of the verandah is considerably lower than the core unit and of enclosed type having small openings with shutter.

Type B: Four pitch Thatch house – House of this type is primarily constructed with thatch over bamboo framework. In plan the house is rectangular in shape with extension on sides forming a ratio of length and width- 2.25: 1. One of the side extensions is typically used for indoor cooking area. The roof is the most dominant part in the house form of this type. It has four pitches: gable roof over main structure and single slope on sides, extending significantly almost to touch the ground. The house usually has no verandah or even window opening except the door way placed asymmetrically on sides.

Fig 5.26: Traditional House form at Char Gangamati (type A)

Fig 5.27: Traditional House form at Patilar Char (type B)

The field survey reveals that CI sheet is predominantly used for roof and wall of houses. Though the area is exposed to the risk of cyclonic surge, the avg. height of plinth of house is 0.6 m from the ground and made of mud. Based on building material, housing structure of Char Gangamati can be categorized into following groups:

Table 5.13 House type on the basis of building material in study village

Category		Construction material		
		Roof	Wall	Plinth
Type C6	Katcha house	CI sheet	CI Sheet with timber pole	Mud
Type C7		Cl sheet	CI sheet with concrete pillar	Mud
Type D1	Jhupri house / temporary	Thatch	Bamboo mat	Mud
Type D2		Thatch	Thatch	Mud

The study village is located outside the embankment and devoid of any protection measure from cyclone induced storm surge. Study shows that Char Ganagmati is presently at risk of 2-5 m storm surge inundation (IWM, 2009) and the risk will further increase due to anticipated sea level rise (SLR) resulted from climate change. A study conducted by Nahar (2001) in same area revealed that settlement outside the embankment suffers higher loss of lives and property compare to the settlement inside the embankment by the sudden impact of cyclone.

The existing settlement pattern is another aspect of vulnerability in study area. The linear pattern is governed due to land distribution policy of GoB under the enactment of the 1984

Land Reform Ordinance. Research shows that closely-spaced houses in linear regimental pattern is subjected to higher velocity as the obstructions severely restrict flow paths and may create funnel effect. The more closely-spaced the houses are, the higher the velocity as water trying to force its way between houses may accelerate and thus increasing local velocity and forces on the houses. (H-NFMSC, 2007)

Fig 5.28: Linear and scattered settlement of Char Gangamati

Orientation of the house is another aspect of structural vulnerability of house. To take advantage of prevailing wind in normal time major percentage of houses in Char Gangamati village is oriented towards seaward direction: south (32%) and south-east (42%). Such orientation often results serious damage to houses. Besides compact arrangement of houses allow easy access of the villagers to shelter by reducing the travel distance.

In addition, field survey reveals that predominant housing structure is *Katcha* and *Jupri* type constructed over mud plinth. In case of *katcha* house CI sheet is commonly used for roof and wall of houses. *Jupri* houses are majorly constructed with bamboo and thatch. Besides annex structures are all *jupri* type and constructed with more perishable material.

Table 5.14 State of Housing structure in sample area of Char Gangamati

	CI sheet with concrete pole , mud plinth	**CI sheet with timber pole , mud plinth**	**Jupri**	**Open**
Main House	19.35	45.16%	35.48%	-
Kitchen	-	-	96.77	3.33%
Cowshed	-	-	100%	-

Haq (2000) identified the main weakness of these house is the fact that, the foundation is not firmly anchored to the ground. This causes houses to be lifted up or blown away by cyclones. Then again, though the area is exposed to the risk of cyclonic surge of 3- 4 m high, the avg. height of plinth is less than 1 m from the ground and made of mud. In addition the fast deterioration of traditional building materials like bamboo, as these are not protected against decay , fungi , termites and high humidity when in contact with the ground. The main cause of wind damage on the houses, particularly houses built with bamboo section is insufficient weight of these houses when they are subjected to external pressure and suction on the walls during cyclone.

Tubewell is dominantly used for drinking and other domestic purpose. Community deep tubewells are 900 feet deep and mostly used for drinking purpose. Sanitation facility is still very poor in study village. Few sanitary toilets are constructed by USAID under post disaster rehabilitation program. Over 48 % percent of sample households are using sanitary toilet. A considerable no of households are still openly defecate.

Table 5.15 State of sanitation facility in sample area of Chargangamati

Type	Open(Katcha)	Open (ring slab)	Ring slab & CI sheet wall	USAID	None
No	8	5	6	4	8
%	25.81	16.13	19.35	12.90	25.81

5.6.2 Social (non structural) response to cyclone and induced surge

In the union where a decreasing/ downward trend in family size is prevalent, it is opposite in Char Gangamati. A growing tendency in family size is observed in Char Gangamati where no of member has increased from 4.85 to 5.26 per family in last 20 years. This is probably household‘s socio-adaptive response to recover their loss because of high death casualty after each cyclonic event. Besides low literacy rate (34.5%) and the need for assistance in fishing may motivate the inhabitants to expand their family.

Table 5.16 Avg. family size in Char Ganagamti in comparison to the respective Union

Year	Avg. family size in Char Gangamati	Avg. family size in the Union	source
1991	4.85	5.65	BBS, 1991
2001	4.99	4.75	BBS, 2001
2011	5.26	4.68	Union Parishad office

Prior to cyclone priority is given to save foods and valuable belongings. It is customary to store dry foods and drinking water along with few other essentials like match box / candle in a wooden box warped with polythene to be used for immediate recovery in post disaster period.

Due to high salinity, soil fertility has significantly reduced and thus the agricultural production of the households is severely interrupted. The households are able to cultivate single crop in a year. In other part of the year the water melon is widely cultivated in the sandy soil of the locality.

5.6.3 Spatial (structural) response to cyclone and induced surge

5.6.3.1 Adaptation by Protection

Coastal afforestation and construction of embankment are two planned measures adopted by the local government in primarily to protect the human settlement in the study area from sea born hazards. The efficiency of these adaptive measures is discussed below:

5.6.3.1.1. Coastal mangrove afforestation

As a measure of planned adaptation the forest department of Bangladesh govt. had implemented mangrove afforestation along the shoreline of Gangamati mauza locally known as Gangamati reserve forest. At present the forest belt of Gangamati is extended from west to east covering a major part of the western coast of the mauza and continues towards the east behind the settlement of Char Gangamati. The width of forest patch is uneven with minimum 0.5 km in the east along the edge of nutun para and maximum 1.25 km in the west along the settlement of Gangamati as measured from satellite image. A mixed patch of trees dominated by Keora (Sonneratia apetala) and Gewa (Excoecaria agallocha) is observed in the forest.

Experiment shows that the mangrove plantations along the coast are playing an important role in reducing the impact of cyclones and accompanying surges. It has been estimated that a 100 - 200 m wide mangrove belt reduces wave heights by 20 to 25% (Anon. 2000 quoted in Iftekhar and Islam, 2004). Mangrove plantation also helps in land maturation and makes the land suitable for human settlement. Moreover plantation on new accreted land enhances the process of siltation. Within 9 - 10 months of planting, silt deposition of up to 3 m has been recorded (Das & Siddiqi 1985). The existing tree species Koera and Gewa is also able to keep pace with low level sea rise (Rahman, 2010). Beside the forest is also contributing to fulfillment of households domestic need by providing timber, fodder and fuel wood.

5.6.3.1.2. Semi-hard embankment

In Dhulasar union 58% of total land area is protected by embankment constructed by BWDB. The primary objective of embankment construction was to support agriculture by preventing intrusion of saline water and provide protection to life and properties of the inhabitants during cyclones or tidal surges (BWDB). Both of study villages are located outside the embankment. Study shows that settlement outside the embankment suffers higher loss of lives and property compare to the settlement inside the embankment by the sudden impact of cyclone (Nahar, 2001). The embankment acts as first line of defense to dissipate the energy of cyclonic wave and prevent surge water to get inside. Apart from that, the road cum embankment is constructed above regular surge level and mostly remained inundation free in past years. This facilitates uninterrupted communication and provides shelter for the refugee during post disaster period.

As a measure of protection, however, the effectiveness of embankment is not unquestioned. Coastal embankment disrupts natural siltation and may cause long term impact on local ecology. It is found that due to structural failure and overtopping, surge water often crosses over the embankment and creates water logging inside the embankment (fig 5.5).

5.6.3.2 Adaptation by Accommodation

5.6.3.2.1. Cyclone shelter as multipurpose community center

To save the life of inhabitants in the vicinity of Char Gangamati a cyclone shelter was constructed by *CARITAS, Austria* in 1993. The frequency of cyclonic event is such that the shelter is likely to be used only once in four to five years. Unless the shelter is used round the year, it would be difficult to maintain them. Hence the shelter was conceptualized to be served as multipurpose community center. During field survey it is found that, in normal time the cyclone shelter is used as the center of primary education in the village. Establishment of cyclone shelter and its adoption as multipurpose community center in normal time is an example of in-situ community adaptation that ensures the safety and household‘s access to education at during and post disaster period. In addition, the measure also ensures the maintenance and long service life of the building.

Fig 5.29: Cyclone shelter in Char Gangamati is used as educational institution in normal time.

5.6.3.2.2. Densification near community shelter

Since its foundation the settlement of char Gangamati has experienced a rapid growth in population compare to rest of the part of the union. In spite of its high biophysical risk, the proximity to sea and chunk of unutilized *Khas* land raised from silt deposition act as a pull factor for the growth. Landless population migrated mostly from Barisal, Patharghata of Barguna district were settled here and continue to raise their family. It is observed that after the establishment of Cyclone shelter in 1993 population has increased at considerable rate (decadal growth between1991-2001 is 71.86%) (table 5.17).

Table 5.17 Decadal growth of population and household in Char Gangamati -2001-2010

	Total population	**No of household**	**Avg . family size**	**Household density**	**Growth rate %**	**Source**
1991	277	57	4.85	14 person/ sqkm	1991-2001 71.86	Population census 1991,community series*
2001	949	190	4.99 (5)	46 person / sq km	2001-2010	Population census 2001,community series
2010	2200	418	5.26	101 person / sqkm	56.86	Upazila Parisad office

* In BBS 1991, Char Gangamati has been mentioned as Nutan para.

To accommodate this increased population densification is taking place. It is observed that, settlement growth is largely motivated by the local topography and proximity to available community service and shelter. From spatial analysis it is found that, settlement density is highest near the shelter and it decreases as the distance from shelter increases (fig 5.23). This trend of settlement growth reveals the fact that, in hazard prone area, settlement growth is largely motivated/ influenced by the location of community shelter in addition to local topography and livelihood opportunity. In the village cyclone/ community shelter is transformed to be the spatial focus of the settlement.

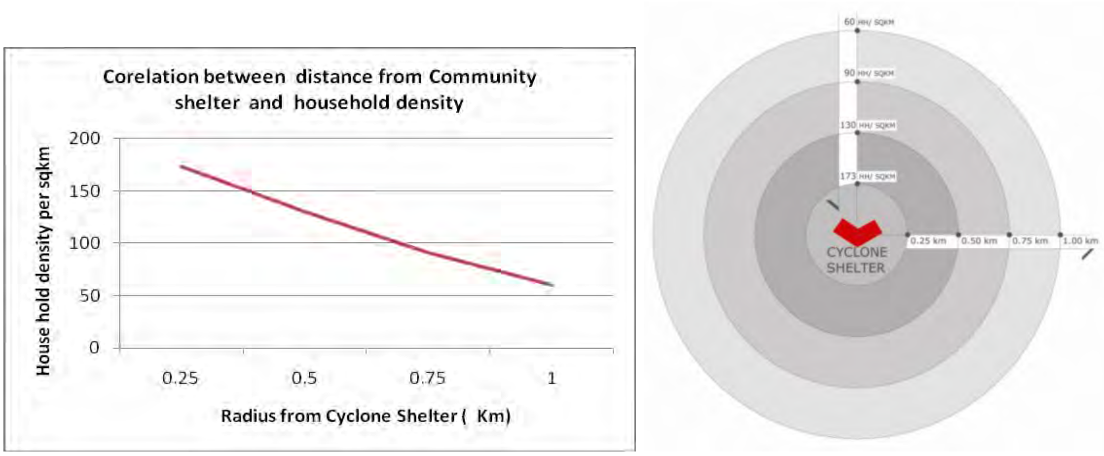
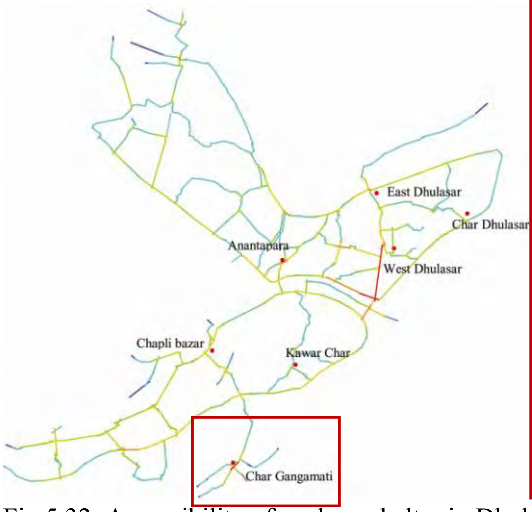


Fig 5.30: Trend of dencification near community shelter in cyclone prone area

5.6.3.2.3. Placement of cyclone shelter in most accessible location

Location of cyclone shelter within the community is an important determinant how effectively it may serve the populace during the disaster event. A syntactic analysis by space syntax[6] of existing communication networks that could be used for rapid access to the cyclone shelters shows that, cyclone shelters in the study union are commonly located along the integrated road or pathway. From table in fig 5.31 it is seen that the local integration value of all usable cyclone shelters are above the average integration that means all these roads have better accessibility in the system. In Char Ganagmti the cyclone shelter is located along the road of highest integration value (1.308) and thus the cyclone shelter in Char Gangamati has better accessibility in spatial term.

[6] Space syntax is a theory of space and a set of analytic, quantitative and descriptive tools for analyzing the layout of space in settlement (Dursun, 2007, p.04). For the analysis the axial map of Dhulashar union is processed in 'Depth map' and eventually superimposed with the location of cyclone shelters. Space syntax explains the structure of a settlement locally through the measure of 'Local integration'. The settlement of Dhulasar has been analyzed here locally through the measure of ―Local integration" (R=4)[6].



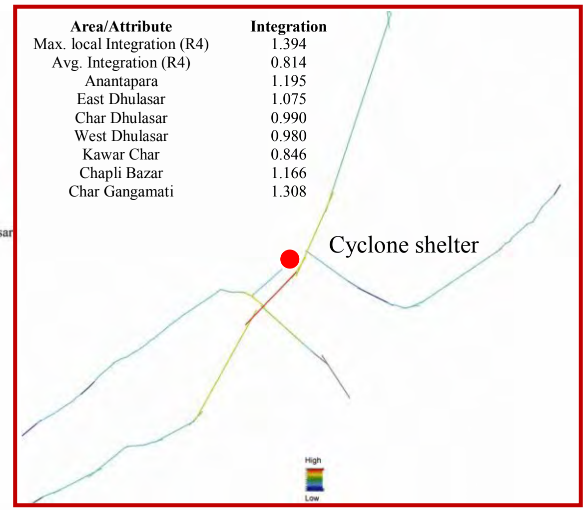


Fig 5.32: Accessibility of cyclone shelter in Dhulashar union
Fig 5.31: Accessibility of cyclone shelter in Char Gangamati

5.6.3.2.4. Community deep tubewell for fresh water supply

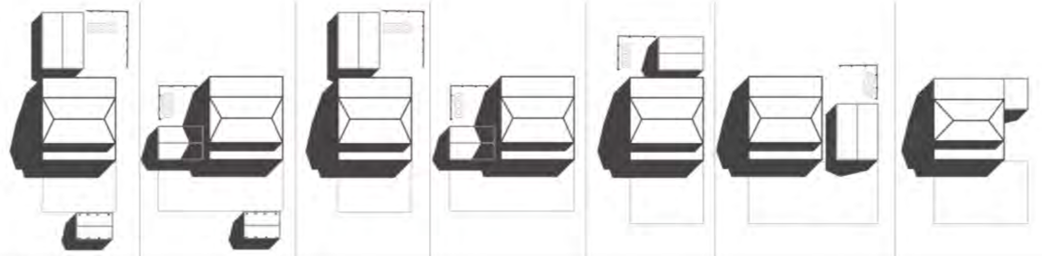
Because of close proximity to the sea, soil and water in the area is highly saline. In addition all the water retention ponds in the area become saline due to flash flood caused by cyclonic surge. This creates scarcity of fresh water in the locality. As a part of Government‘s WatSan program the village is facilitated by deep tubewells. There are six active deep tubewells in Char Gangamati serving total households of 418. That means for every 70 households there is a source of fresh water supply in the community. The tubewells are setup in a common place within walking distance from the homestead area of its catchment population. Besides 54% households in village have shallow tubewells in their homestead. Few households who do not have access to either deep or shallow tubewell are using pond water with a local technique of filtration known as Pond Sand Filters (PSF). In the remote community of patilar char, there is no deep tubewell. Settlers meet their need of water for drinking and other domestic purposes from the only shallow tubewell in the community.


Fig 5.33.a: Community deep tubewell located beside the main access path of Char Gangamti.
Fig 5.33.b: A woman is fetching water from the only shallow tubewell of Patilar char.

5.6.3.2.5. Compact arrangement of Homestead

Based on the location of the annex structures in relation to main house, two generic types of homestead are observed: Type 1: back to back arrangement and Type 2: side by side arrangement. In both types of arrangement outdoor cooking in the private domain and cattle shed if any at public domain adjacent to front yard is common. Table 5.18 shows that a significant ratio (65% -compactness value >0.5) of the household adopted most compact layout of this type. This compact layout of homestead is considerable deviation from traditional pattern of courtyard house. Back to back arrangement is also evident in the remote settlement at Patilar char where the outdoor cooking area is placed at rear side of the house. In addition to its functional and cultural response these homestead arrangement offers protection of annex structure (which is usually constructed with more perishable material) against cyclonic wind by creating wind shadow (fig 5.34).

Table 5.18 Compactness value of homestead structures in Char Gangamti village



Type							
compactness value	0.30-0.41	0.22-0.41	0.56	0.52-0.56	0.64	0.63-0.64	0.55-0.65
% of household	17.39%	8.69%	8.69%	21.73%	8.69%	17.39%	8.69%

Others 8.69%

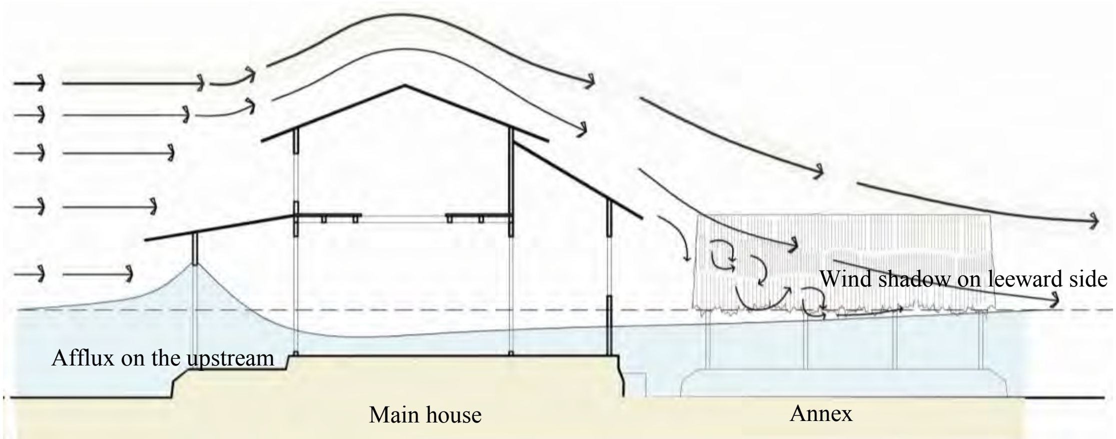


Fig 5.34: Back to back homestead layout diverts the local wind and flowing water away from annex structure

5.6.3.2.6. *Development of House form*

Cyclonic storm and high wind seems the most obvious factor in the development of the local house form. The argument is explained below in reference to scientific findings:

Shape and orientation of house: The shape and orientation of house are the factors how it will perform to cyclonic wind and flood. In principle compact building offers less obstruction to wind and flowing water and are structurally more robust. The best plan shape is a square for wind and flood resistance as it gives maximum robustness to horizontal loading

(Appendix F). The traditional CI sheet house in the study area is almost square with length and width ratio is 1: 1.3. It is to be noted that the length is shorter than the width. In most cases, the house is oriented in a manner so that the shorter face of the house is towards the windward direction of the cyclone. Orientation of the house, however, is also influenced by the plot shape, location of the access road or location of sea. It is observed that in sample area 2, orientation of house is largely determined by the direction of wind / sea irrespective to location of access road or plot configuration. In oppose to that, in sample area 1, houses are mostly parallel to the access roads rather than true direction of wind.

In Patilar char, the traditional thatch houses are rectangular in plan with length and width ratio of 2.2:1. Houses in the community are mostly oriented towards the sea and direction of prevailing wind.

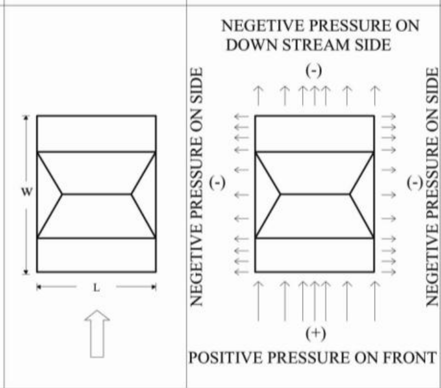
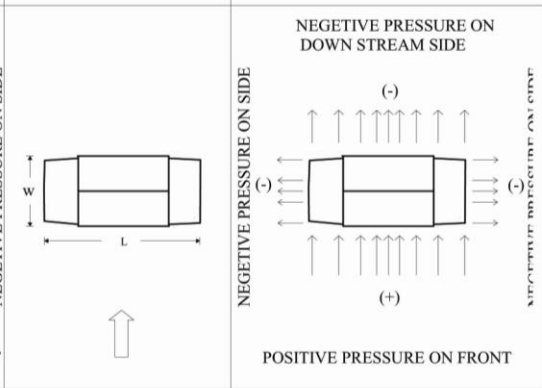
	House shape	Pressure on walls due to moving water	House shape	Pressure on walls due to moving water
				
Type	Type A (Traditional CI sheet House)		Type B(Traditional Thatch house)	
L:W	1:1.3		2.2:1	
% of houses in sample area	77.27%		66.67%	
Remarks	Pressure due to hydrodynamic force on front, side and rare walls is lower than type B		Pressure due to hydrodynamic force on front, side and rare walls is higher than type A	

Fig 5.35: Effect of storm surge flood on typical house of study villages: generally upstream walls have inward loading and side and downstream walls have outward forces.

Roof shape and angle: Experiment have shown that hip roofs with slopes ranging from 25 deg to 40 deg have the best record of resistance during cyclone as no significant difference of suction is formed at leeward side of the roof. (Roy & Seraj , 2000; Haq, 2000).

Majority of the traditional CI sheet houses (71%) in the Char Gangamati village have hip roof over the core unit (ghar). The slope of the roof of this type varies from 30- 35 deg. A small percentage of houses (29%) have gable roof and most of these houses are either relief house or thatch houses of the poor household who couldn‘t construct hip roof due to their poor economic condition. The roof of the traditional thatch houses in Char Gangamati and Patialr char has 4 pitches and is constructed in such a way to maneuver the wind flow. The slope of this type is however steeper than Ci sheet house and typically 45 deg.

Table 5.19 Form of roof in traditional house of Char Gangamati

No of Pitches	Roof form			
	Hipped	%	Gabled	%
2 pitches	0	0.0	3	9.68
3 pitches	0	0.0	4	12.90
4 pitches	3	9.68	2	6.45
5 pitches	5	16.13	0	0.0
6 pitches	14	45.16	0	0.0
Total		70.97		29.03

Enclosed patio / verandah: Open verandah or patio is a common feature of rural houses. The lightweight verandah roof is more susceptible to damage due to uplift force generated by high wind speed. To reduce the damage, the traditional Ci sheet has enclosed verandah with operable windows and the roof of the verandah is constructed with separate structures rather than extensions of the main building so that if it blows off it will not damage the rest of the house. In case of thatch houses the household deliberately avoid any verandah.

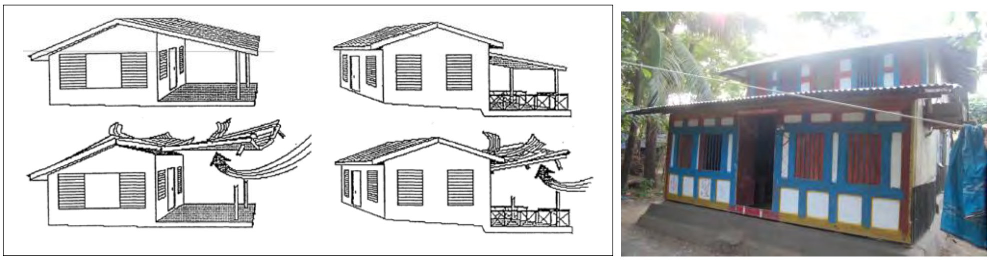


Fig 5.36: Separate verandah structure reduces the probability of damage of main houses to cyclonic wind. (Source: GoI-UNDP, 2007)

Walls and openings: During cyclone associated with storm surge flooding, the walls are subjected to pressure due to both wind and hydrodynamic forces. The front wall has experienced positive pressure (push) while rear and side walls have experienced significant suction effects (pull) caused by the negative pressure. These combined forces often tend to strip the walls away from the house (GoI-UNDP, 2007; H-NFMSC, 2007).

In response to the impact, the front wall of traditional CI sheet house is typically strengthen by wooden framework. The traditional practice of constructing wall around the verandah acts as a protective layer for the core unit by taking the first impact of thrust (fig 5.34). Use of multiple windows in the front (windward side) and a small window in the rear wall (leeward side) is common and the openings are secured by storm shutter. The practice helps them to get proper light and air and to maneuver strong wind during cyclone. Besides from scientific research it is proven that pressure build up in the interior can be relieved by providing a corresponding opening in the leeward side (fig 5.37).

In thatch houses household respond to the impact is different. Houses of this type has very low height wall without any opening except the doorway. Hence the exposure to cyclonic wind is reduced by minimizing the area of the vulnerable surface and maneuvering the wind over the house instead of passing through the inside. The measure infact has limited usefulness against flooding.

Fig 5.37: Corresponding opening on the leeward side may reduce the internal wind pressure

Attic space for emergency storage: Traditionally, family belongings are stored by burial in the mud plinth of the house. In addition to that the local construction of house offers alternative options for domestic storage within the roof structure. In traditional Ci sheet house there is an attic space to store valuable contents during floods. This is not a habitable room but is sufficient to store foods, light furniture and belongings in times of flood. Thatch house has a storage shelf high from the flood level within the triangular volume of ceiling which offers safe storage for household valuables and dry food.

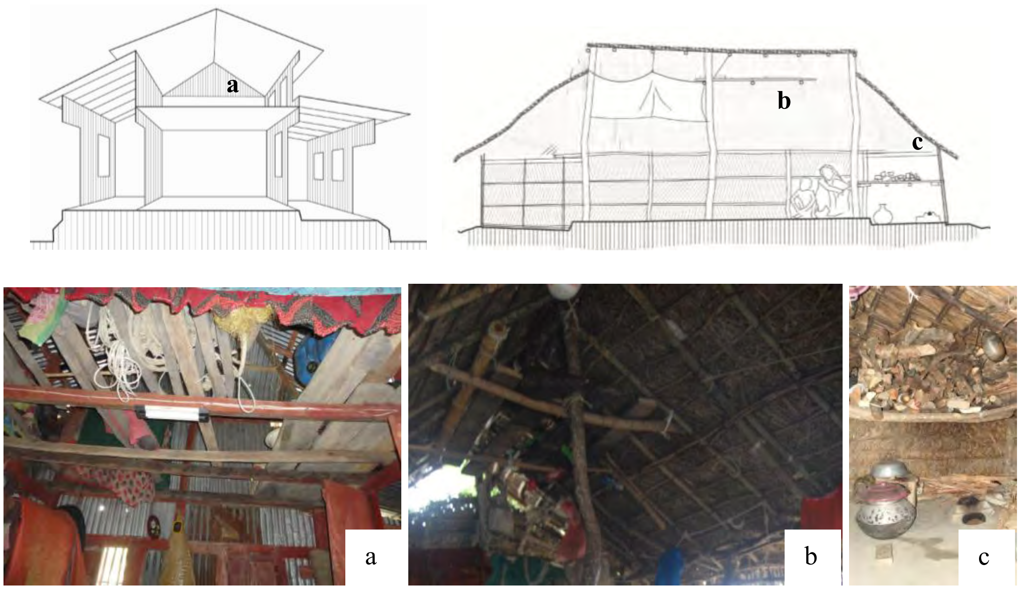


Fig 5.38: Ceiling mounted storage space is a common feature of traditional house in coastal village

5.6.3.2.7. Relief house to compensate post-cyclone crisis

To rehabilitate the severely affected households local NGO provided technical and financial assistance to construct strong houses in the locality. Of the total 31 houses surveyed, 6 of the houses are relief house which represents 19.35% of total households. These houses were constructed by local NGO‘s as a part of post disaster rehabilitation project after the super cyclone Sidr and Aila. These houses are commonly constructed with corrugated steel sheets supported by concrete pillars. Other than houses affected households were facilitated with sanitary latrine.

Fig 5.39: NGO supported relief house and sanitary latrine to cope with post-disaster crisis.

5.6.3.2.8. Plantation practice

Fallen trees and floating debris were a significant cause of housing destruction and injury. House hold generally avoid plantation of trees that has wide spreading branches in windward side to minimize the damage from flying branches or fallen trees during cyclone.

In older part of the settlement a thick layer of homestead vegetation is observed. Newly formed settlements are mostly scattered and it lacks plantation. However in older part of settlement a system of layering in plantation is observed. In first layer palm trees like Tal, Coconut and Betel nut are usually planted followed by shrubs (3-4 m high bushy trees) in front of the homestead. Shrubs of dense foliage act as wind and wave breaker and protect the houses form the direct impact of cyclone. The practice of plantation also provides privacy of household in normal time. To meet the households demand of nutrition fruit trees like Mango, Tamarind, Sofeda , etc is commonly planted in homestead yard. Woody trees like Rendi, Chambol, Koroi, Mehogoni etc are planted at rare side of homestead area.

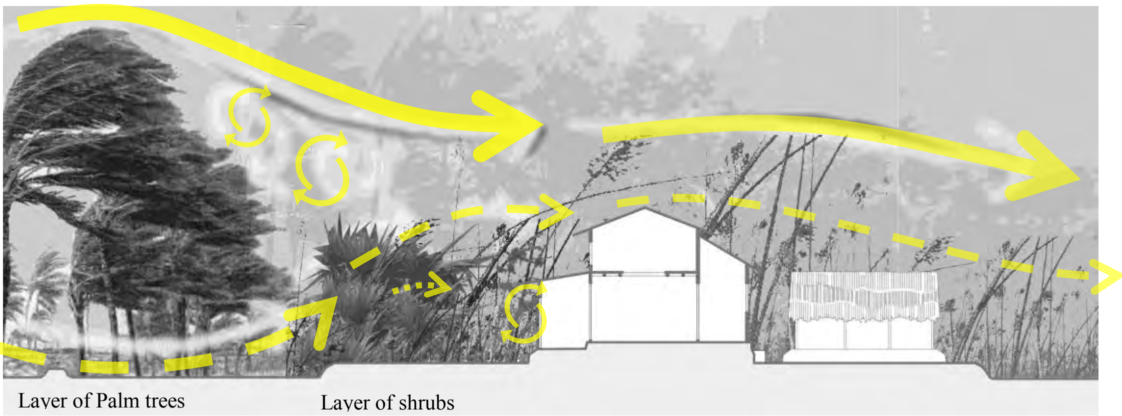


Fig 5.40: Local practice of planting trees in different layer helps to dissipate the strong wind of cyclone

5.6.3.2.9. Solar panel as alternative energy source

Since the study area is deprived of any electrification facility the local household use solar panel provided by the local NGO (Grameen Sakti) as an alternative energy source. The system is available with installment and thus equally adopted by the household whether poor or rich. The panel is easy to dismantle and can be carried with them during evacuation and reassembled it immediately after return.

5.6.3.3 Adaptation by Retreat

5.6.3.3.1 Temporary refuge to Cyclone shelter

Taking temporary refuge in a nearby cyclone shelter is common practice among the inhabitants. People reported that those who could not go to the cyclone shelters, especially due to long distance, took shelter on the tall and strong trees of nearby forest. In the village of Char Gangamati almost 100% households took refuge in the shelter within their community. In case of Patilar char, where the nearest shelter is 3 km away, a considerable percentage of households took shelter on the trees of adjacent forest.

Again, the only cyclone shelter in Char Ganagamati has a capacity for 850 people against a catchment population of 2200. Due to its limited capacity, women and children often get priority to take shelter only. Since there is no Killa in and around the village, the households are forced to free their domestic animals. This often led to experience a serious economic loss of the household as most of these poor animals are flushed away with surge water.

5.6.3.3.2. Seasonal migration to safer place

In the remote village of patialar char, the local households used to send the female and young members of the family to relative‘s house located in safer place earlier to hazard season.

5.6.4 Evaluation of adaptive measures

The measures whether planned or autonomous dicussed above often are not equally responsive to the problem. The following section analyze the responsiveness of the local adaptive measures interms of selective criteria discussed earlier.

Of the protection measures, creation of shelter belt with mangrove forest is highly responsive without any considerable side effect whereas construction of semihard embankment though effective in moderate hazard situation but may not be equally effective to future context of sea level rise. Moreover emankment may damage local ecology and doesn‘t offer protection to all.

Among the measures to accommodate the inhabitants within vulnerable site, construction of multi-purpose cyclone shelter and spontaneous densfication around it seems effective to improve community resilience by minimizing distance between living quarter and safe house. In case of linear settlement back to back compact arragement of homestead with traditional practice of plantation in windward side may reduce the impact of cyclonic wind and storm surge. Tradional Ci sheet house with deep plan , low angel hip roof and enclosed patio is more robust than jupri house of linear plan with steep roof without opening. However CI sheet house is less frindly to environment than Jupri house made of natural material. Engineered relief house, though effective but lacks cultural sensitivity, flexibilty and economic viabilty, often proved unresponsive.

Table 5.20 Responsiveness matrix of local adaptive measures to cyclone and storm surge

	Effectiveness	Suitability to future context/ risk	Implement ability/ feasibility	Flexibility	Environmental friendliness	Ecosystem connectivity	Equity	Economic viability	Local people Participation	Cultural acceptability	Multi-purposefulness
Mangrove Afforestation	H	H	H	M	H	H	H	H	H	H	H
Semi hard Embankment construction	M	L	M	L	L	L	L	L	H	M	H
Multipurpose community shelter on stilts placed at most accessible location	H	H	M	M	H	H	M	M	H	H	H
Densification near Community shelter	H	H	M	M	M	M	H	M	H	M	H
Back to Back compact arrangement of homestead structures	H	H	H	H	H	H	H	H	H	H	M
Traditional CI sheet House with deep plan , low angle hip roof, enclosed patio and rare opening.	M	M	H	H	M	L	M	M	H	H	M
Traditional Jupri house with linear plan and without opening	L	L	H	H	H	H	H	H	H	H	L
Attic space for emergency storage	M	M	H	L	H	L	M	M	H	H	H
Layered plantation around homestead	H	H	H	H	H	H	H	H	H	H	H
Relief House	H	M	M	M	L	L	L	L	L	L	L
Community deep tubewell for fresh water supply	M	M	M	L	M	L	H	M	H	H	L
Solar panel as alternative energy source	M	M	M	H	H	L	H	L	M	M	L
Seasonal migration to safer place	M	H	M	H	L	L	L	M	L	H	M

H=high, **M**=moderate, L = low

5.7 Summary

Settlements in exposed coasts are at risk of sea born hazards like cyclone, storm surge, tidal flooding, salinity etc. The nature of risk and the degree of exposure is not same all over in the study upazila. Settlements along the estuarine channel are exposed to the severe risk of storm surge inundation where as settlements in the central part are at risk of prolonged water logging due to poor drainage. Communities located in charland of foreshore area are vulnerable among all. In addition to its high risk exposure, vulnerability of foreshore settlement is socially induced primarily associated with dispersed pattern of settlement, weak structure of houses and poor access to emergency services and shelter. People living Char area are mostly landless and very recently settled. Settlements in this area are predominantly semi-disperse (combination of linear and disperse pattern) or disperse in pattern where dwellings are located at wide space to each other. Linear settlement is basically resulted from the linear system of plot distribution by the public agencies. Study reveals that, closely-spaced houses in linear regimental pattern is subjected to higher velocity as the obstructions severely restrict flow paths and may increase local velocity and cause damage to houses. In addition lack of community services and shelter and absence of any protective measure from the hazard are the other aspects of vulnerability.

In response to vulnerability, both planned and autonomous measures are taken at household and community/ greater community level to protect and accommodate the inhabitants within the area. However, adaptation by retreat is largely an autonomous measure, as observed, taken by the household in reaction to hazard event. Protection measures are primarily soft and semi-hard intervention confined within the scope of public agencies and planned to safeguard greater interest of permanent residents. Newly settled areas very close to shore line are often devoid of any protective measure. Apart from local government, NGO‘s are also involved in the process and their activities include improvement of housing and infrastructural capacity of the settlement. Autonomous measures taken by the indigenous people are mostly limited within household level and comprise both non structural (social) and structural measures.

Coastal afforestation is proved to be most effective measures of protection as it has manifold benefits with no mentionable drawback. Apart from this, plantation of selective species at different layer in adjoining area of homestead may create effective shelter belt to protect the house from damage. From field investigation it is learned that the local practice of housing is more responsive where cyclonic storm and high wind seems the most obvious factor in the development of traditional house form. There is, however, still scope for improvement where effort should be given to improvement of anchorage detail or foundation. In case of *jupri* houses its responsiveness is rooted within its temporal character. This houses are easy to rebuilt with readily available material from the nature and thus require least recovery cost and time.

SPATIAL LAYERS IN HOMESTEAD IN LINEAR PATTERN

SPATIAL LAYERS IN HOMESTEAD IN LINEAR SETTLEMENT OF CYCLONE PRONE AREA

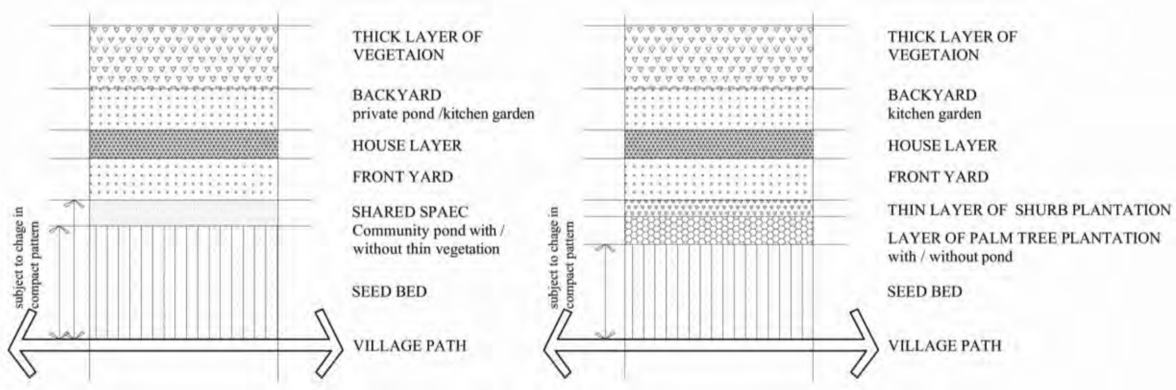


Fig 5.41: Transformation of Spatial layering of homestead pattern in Cyclone prone area

So priority should be given in long term adaption strategies at community level rather than only post disaster relief work or assistance at household level. It is observed that the relief houses, though it claims to be more cyclone resilient, are often lack cultural and environmental responsiveness of local housing practice and thus fail to gain social acceptance. No evidence is found that shows local people are spontaneously adopting this technology while constructing their house. In addition as the households came from different localities are settled in the study area in very recent years (not more than 30 years) lack social bondage. Any measures in community level will enhance community feeling and sense of belongingness and will improve the safety, livability and opportunity within the community despite of its high exposure to geo-climatic risk.

Chapter 6

Discussion and Findings

This study takes an analytic approach to understand the geo-climatic vulnerability and its response in the settlement pattern through micro level assessment of settlement vulnerability and local measures of adaption/coping in selected case study areas representative of two coastal contexts: interior coast and exterior coast. The study based on the conjecture that coping measures to reduce vulnerability to existing climate related hazards can also serve as means of adaptation to climate change. Any measure is taken to reduce the impact of geo-climatic hazard on built environment will enhance the resilience capacity of settlement and thus reduce vulnerability. In this chapter, the collective information from earlier chapter is synthesized to enumerate key aspects of vulnerability of coastal settlement followed by local responses potential for mitigation. Earlier to this a brief discussion about coastal context and settlement pattern is stated bellow:

6.1 Coastal Context and settlement pattern

The coast of Bangladesh is known as a zone of multiple hazards as well as opportunities. Morphologically, coastal zone of Bangladesh is characterized as shallow basin with rugged coastline dotted by hundreds of islands. Three predominant settlement patterns are observed in coastal region. Settlement in offshore islands and foreshore area of exterior coast are newly formed and of scattered type. Besides scattered pattern, linear settlement along the coastal embankment and village path is also observed in this area. Housing condition in this area is predominantly transient in nature and primarily built with perishable material (predominant house type jupri and katcha construction). This area is often devoid of essential infrastructural facilities including protection measures from sea born hazard, inland transportation networks, community services and emergency shelters. Settlement pattern in interior coast is predominantly linear along the bank of rivers or canals. Area that is exposed to water logging and flood, settlement is linear along the road. Clustered pattern is only observed in the eastern zone and older part of the settlement. Avg. settlement density is higher in interior coast than the exterior part but lower than the national average. Avg. settlement size (no of household in a village) is also larger here than the exterior coast. Infrastructural facility and housing condition with predominant katcha and semipacca houses is comparatively better in interior coast than the exterior part.

6.2 Key aspects of vulnerability of coastal settlement

6.2.1. Environmental aspects of vulnerability

Historically coastal settlements are exposed to the risk of different geo-climatic hazard like cyclone, tidal inundation, water logging, salinity and erosion. The impending threats of climate change and sea level rise in near future, as predicted, will further intensify the severity and extent of the hazard including permanent inundation coupled with increased salinity and erosion due to intensification of tidal action and periodic cyclone. But the degree or nature of exposure are not same all through the coastal plain and shows a spatio-temporal variation. The interior part of coastal region is currently subjected to both occasional and long term inundation due to tidal surge and water logging and may experience severe drainage congestion / permanent water logging due to anticipated sea level rise in near future. Whereas exterior coast is presently at risk of seasonal cyclone and storm surge inundation and will experience prolonged inundation due to increased rainfall and rise in sea level along with intensification of existing hazards.

6.2.2 Physical aspects of Vulnerability

Apart from its geo-climatic risk, vulnerability of coastal settlement is a socially induced situation primarily resulted from existing settlement pattern, lack of emergency community services and shelter and absence of any protective measure from the hazard. Physical aspects of socially induced vulnerability of coastal settlement can be generalized as follows:

6.2.2.1 Vulnerability due to location and pattern of settlement

Location and pattern of settlement are the most important factors determining settlement‘s vulnerability to present and future geo-climatic risk. Settlements near to the coast are scattered or linear in pattern and newly formed. Although scattered / dispersed pattern of settlement, where houses are widely apart from each other, allow easy flow of surge water and cyclonic wind without creating any significant obstruction (fig 6.1a and 6.2b), but experiences greater damage than others due to weak structure of the house and lack of plantation around the settlement. In addition, the foundation of this newly formed settlement is not strong enough as the char land is yet in the process of formation. During cyclones, this settlement faced more severe wind speeds and the first onslaught of sea. Besides in water logged condition the isolated settlement on raised mound suffers more as water logging disrupts in land communication and restricts household mobility.

In case of linear settlement along the road and embankment, houses are located side by side very close to each other with narrow gap in between. Simulation result shows that this arrangement of house experience higher local velocity of moving water (fig 6.2.b) and thus subjected to higher load due to hydrodynamic force and is vulnerable to sea surge. Apart from wind speed and sea surge, they are also vulnerable due to damage of the embankment in major cyclone periods.

The clustered settlements are usually located inner part of the coast and are compact in nature, consisting of group of houses called *Baris* with dense tropical forest around. Several closely located *Baris* make up a *Para* (community). This type of settlement is less susceptible to severe cyclonic wind and the later sea surge as no significant increase in local velocity is observed in and around the clustered houses (fig 6.1.c and 6.1.c).

6.2.2.2 Vulnerability due to inappropriate land/plot distribution system

The example of the cyclone-prone areas of Bangladesh demonstrates that land management processes encourage poor people to form scattered settlements in hazardous places without adequate forms of protection. The coastal and island occupants living along the embankment are landless and have lost their homes mostly due to river erosion. For instance, during the early 1980s, approximately 740 households left Sandwip to settle in Urir Char. All of them were landless in Sandwip and formed isolated settlements in Urir Char. Under the enactment of the 1984 Land Reform Ordinance force, the Government of Bangladesh allotted the landless people two acres of *khas* land for each family for agricultural and settlement purposes. These poor people individually made homes in the middle of an allocated plot and therefore produced another aspect of vulnerability to cyclone disasters through the government‘s land management system.

6.2.2.3 Vulnerability due to lack of infrastructure, emergency shelter/ service and their inequity in distribution

The lack of a proper transport infrastructure and emergency shelter and community services is another important factor in settlement‘s vulnerability to water logging and cyclone induced disasters. Cyclone hazard is associated with severe wind and rain. Yet, most of the roads in the near coastal areas are made of earth. A combination of rain and wind may damage or destroy earthen roads. Besides insufficient community shelters in the most hazard-prone areas means that a decision to move to distant and hard-to-reach cyclone shelters becomes a matter of making one‘s life and livelihood vulnerable during the hazard period. Due to lack of *Killa or* shelter for domestic animals within the community, household concerning about loss of their only means of livelihood often do not opt to move to the shelters easily. Moreover unavailability of primary education center and emergency medical facility lessen the household ability to post disaster early recovery. In case of waterlogged situation katcha (unpaved) road is subjected to erosion and often disrupts communication and thus household‘s access to basic services.

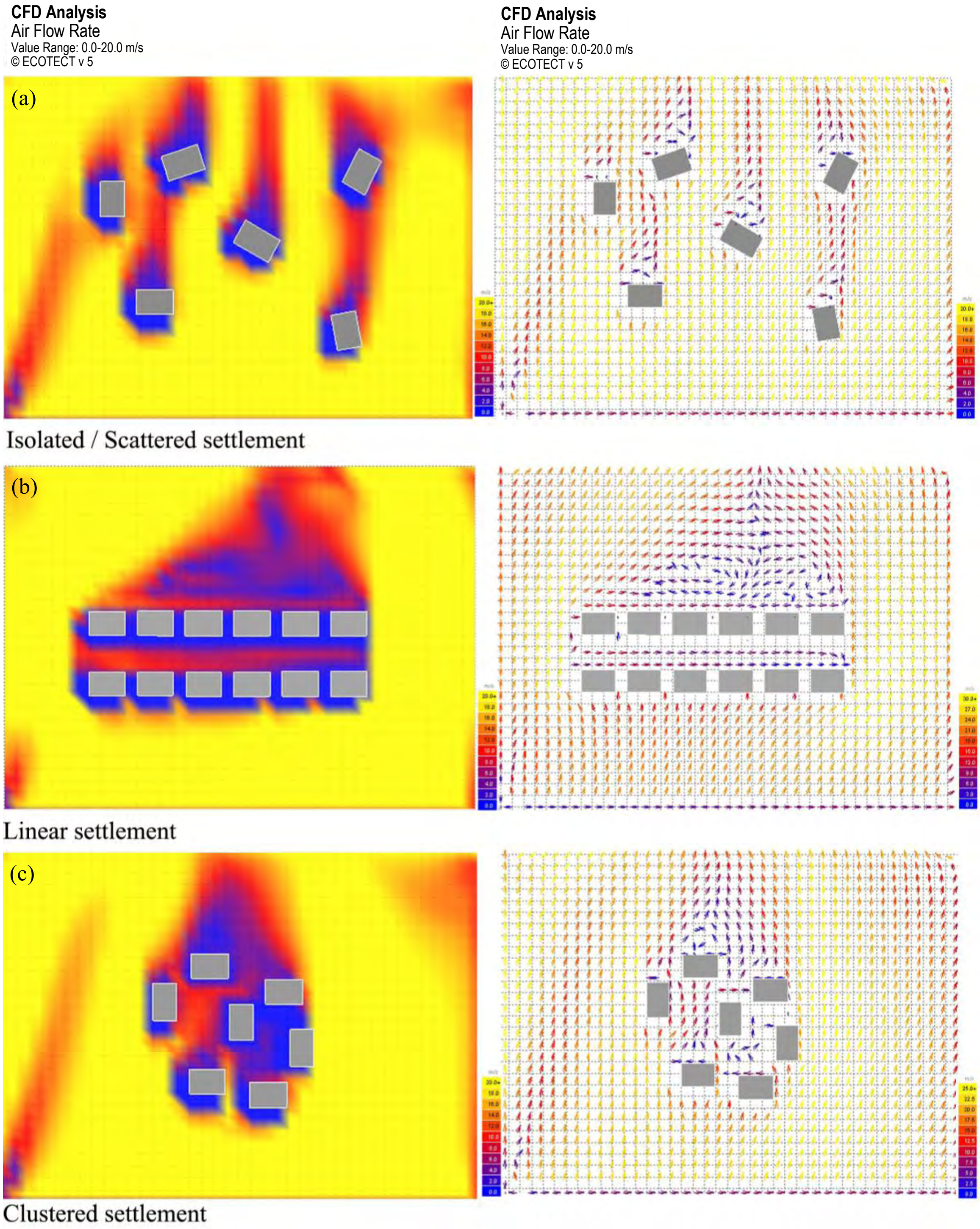


Fig 6.1 Simulation analysis showing pattern of air flow on different types of settlement (Simulation entry: Air velocity- 240 m/s; direction- 15 deg south west (direction of major Cyclones in last 40 years); viscosity- $1.8x10^{-5}$; density - 1.2 kg/m^3)

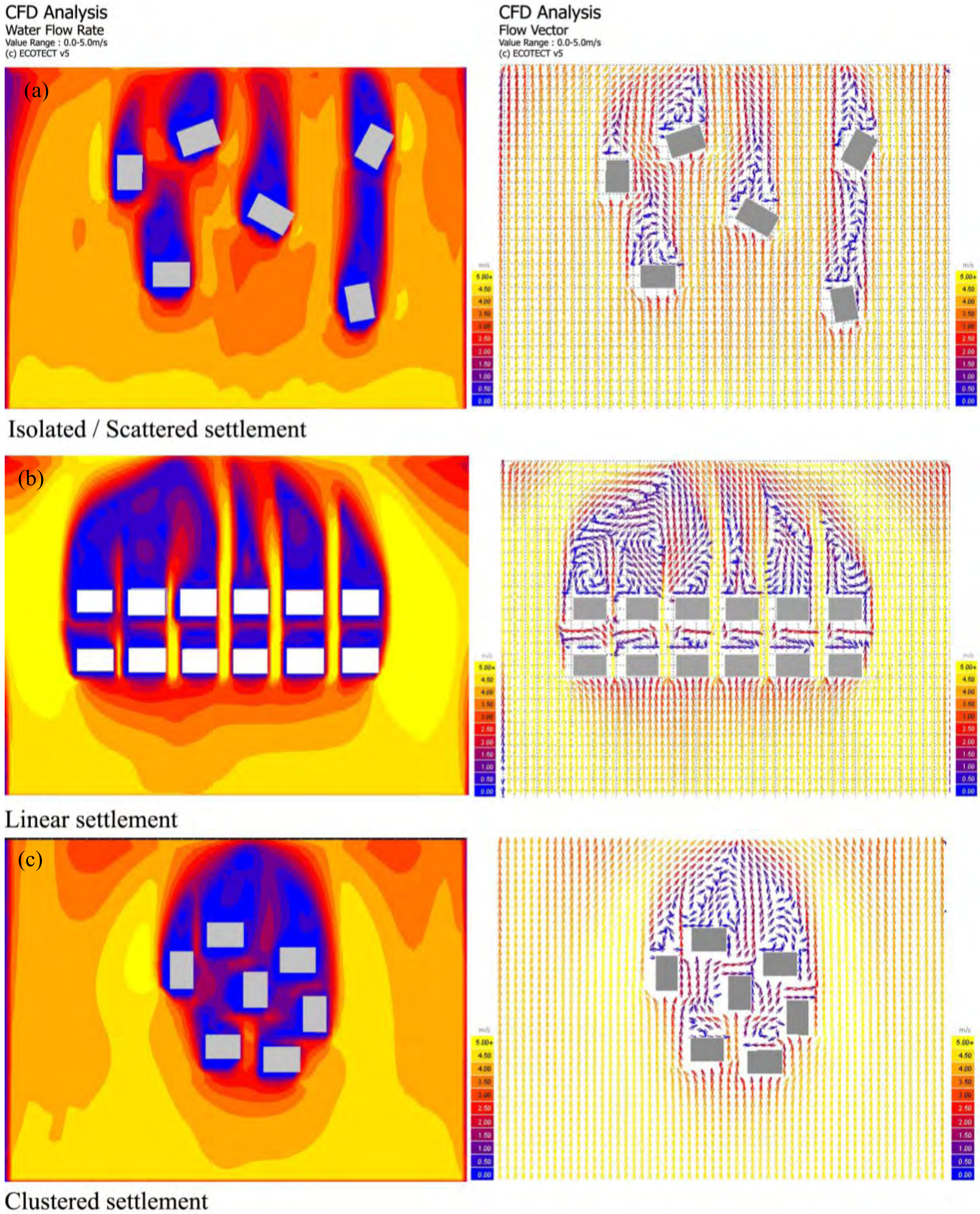


Fig 6.2 Simulation analysis showing pattern of water flow on different types of settlement [Simulation entry: green field velocity- 5.0 m/s ; direction- 0 deg south (sea ward direction) ; viscosity- $1.17x10^{-6}$ m^2/s ; density - 1024 kg/m^3 (density of sea water)]

6.2.2.4 Vulnerability due to weak structure of the house

Weak structure of the houses is another aspect of vulnerability of coastal settlement. In addition to cyclonic wind force houses in coastal area are subjected to hydrodynamic force and hydrostatic force generated from sea surge and stagnant water respectively. Although it has been observed that development of indigenous house form in coastal area is fairly responsive to local hazard but often lack pacca foundation/ plinth , proper jointing and anchorage details to withstand high and sudden loading generated by hydrodynamic and hydrostatic force. Again insufficient weight of these houses when they are subjected to external pressure and suction on the walls during cyclone is the main cause of wind damage on the houses. In addition the fast deterioration of traditional building materials like bamboo, as these are not protected against decay, fungi, termites and high humidity when in contact with the ground is another cause of short life span of houses in coastal area.

6.2.2.5 Vulnerability due to poor resistance of protective measure

Construction of semi hard embankment and creation of shelter belt by mangrove afforestation are key protection measures taken in coastal area. Of them embankments are common in both interior and exterior part of the coast. Although embankment is designed to act as first line of defense to dissipate the energy of cyclonic wave and prevent surge water to get inside but often failed to prove its effectiveness under severe hazard situation in recent past. Due to breaching of environment and overtopping, surge water crosses over the embankment and creates water logging inside the embankment. More over coastal embankment disrupts natural siltation and may cause long term impact on local ecology. Again foreshore and offshore char area often devoid of any protection measure and is more susceptible to sea born hazard.

6.2.3 Socio-cultural aspects of vulnerability

In addition to its geo-climatic and physical aspects vulnerability of coastal settlement is also linked to socio-cultural profile of coastal society. Of them three major socio-economic and cultural aspects that directly influence settlement vulnerability are given bellow:

6.2.3.1 Vulnerability due to poor socio-economic condition of household

Socio-economic condition of the coastal people in general is poor than rest of the part of country. It has been observed that poor people suffers more as they have poor financial capacity to build strong house or rebuild the house after each hazard event.

6.2.3.2 Vulnerability due to farm dependence or lack of employment opportunity

Despite of high risk to hazard, household in coastal area prefer to settle very near to sea and their agricultural land. The close proximity of the sea or farmland from the homestead explains the willingness of the people to remain near to their workplace for easy access and to save time on travel and thus can be pursued at convenience. Household in *charland* are still very much dependent on faming and fishing and they lack marketable skills and education for formal jobs or non-farm economic activities. As a result, any disruption in farming and fishing activity due to prolonged inundation and cyclonic hazard cause serious economic loss to the households.

6.2.3.3 Vulnerability due to lack of social bondage

Communities in charlands of foreshore and offshore areas, households are mostly landless and settled very recently. These people came from different parts of the region and lack blood relation or kinship. During disaster or post disaster recovery phase, they often failed to show any collective resilience at community level. Thus lake of family lineage, short tenure of settlement and lack of social institution all these contributes to weaken social bondage among migrant community. Thus poverty, kinship and lack of education and skills are linked to the settlement vulnerability.

6.3 Local response to vulnerability

As exposure to geo-climatic risk of interior coast and exterior coast is diverse, measures to cope with it also dynamic in response. Both planned and autonomous adaptive measures are taken at regional to local level to mitigate the risk and both public agencies (GO and NGO) and local households are involved in the process. As identified earlier protection, accommodation and retreat are three functional aspects for spatial adaption in settlement in vulnerable area. Protection measures taken in coastal area are mostly soft and semi-hard intervention confined within the scope of public agencies and planned to safeguard primarily the greater community of permanent residents. Accommodative measures are largely autonomous with few contributions from local NGO and Govt. organizations. Autonomous measures taken by the households comprise of both non structural (social) and structural measures. In comparatively older settlement local household has adopted indigenous measures to protect their houses by developing more hazard responsive house form, homestead layout, vegetation pattern etc. But their choice of adaptation strategies for any structural modification is influenced by the relative risk exposure and financial ability of the household. No significant collective effort by the local community is observed for community based adaptation in vulnerable area. In contrast contributions of public agencies to accommodate the inhabitant within the vulnerable site include long term and short term/ immediate measures taken to improve the resilience capacity of the community in general rather than individual. Adaptation by retreat is, however, completely an autonomous measure taken by the household in reaction to hazard event. No significant effort is observed for planned retreat of vulnerable households to safer zone by the public agencies. Due to these measures a significant change in landuse and settlement pattern is observed in coastal area than other inland settlements of the country. The inventory of local adaptive response against specific geo-climatic risk of coastal area is given bellow:

Table 6.1 Inventory of local response to vulnerability of coastal settlement

Response	**Sector**	Region: **Interior coast** Risk: **Water logging**	Region: **Exterior coast** Risk: **Cyclone & storm surge**	**Type/ Stakeholder**	**Remarks**
		Specific measure	**Specific measure**		
Protection	Forestry		Mangrove Afforestation	Planned; Forest Dept. of GoB	Most effective without any significant side effect
	Water resource	Rotational TRM		Planned (adopted from local practice) ; Water Development Board of GoB	Effective against water logging but doesn‘t ensure equity; settlement adjacent to TRM may suffer during its execution years.
	Infrastructure	Semi hard Embankment	Semi hard Embankment	Planned ; Local Govt. and Engineering Dept. (LGED)	Ineffective under severe hazard situation and lacks environmental friendliness, ecosystem connectivity, equity & economic viability.
Accommodation	Infrastructure (Shelter/ services)		Establishment of Cyclone center in most accessible location	Planned; G.O. and N.G.O.	Effective but often lacks equity as distant community may not serve equally due to travel distance and limited capacity.
	Infrastructure (Shelter/ services)		Multipurpose use of cyclone shelter	Planned; at community level	Effective; ensure maintenance and community participation.

Response	Sector	Region: **Interior coast** Risk: **Water logging** **Specific measure**	Region: **Exterior coast** Risk: **Cyclone & storm surge** **Specific measure**	**Type/ Stakeholder**	**Remarks**
Accommodation	Housing	L-shape Compact layout of the homestead structure.	Back to Back compact layout of homestead structures	Autonomous; Local Household	Effective to mitigate potential risk exposure of the context.
			Adoption of Deep plan for house	Autonomous; Local Household	Provide robustness against cyclonic wind & sea surge.
		Adoption of permanent material for housing		Autonomous; Local Household	Effective but lacks flexibility & economic viability
			Adoption of low angle hip roof	Autonomous; Local Household	Effective against wind risk
			Strengthened the wall with timber framework	Autonomous; Local Household	Provide robustness against cyclonic wind & sea surge.
			Construction of enclosed patio	Autonomous; Local Household	Effective against wind and hydrodynamic force; multi-purpose use.
		House built on raised plinth with brick lining		Autonomous; Local Household	Effective against water logging; economically viable
		Building Machan to store raw material	Attic space for emergency storage	Autonomous; Local Household	Effective
			Relief House	Planned; local NGO	Moderately effective but lacks cultural acceptance
		Raising the base of deep tubewell	Establishment of deep tubewell	Planned; Local public agencies & NGO	Moderately effective; subject to damage in severe situation.
		Establishment on sanitary toilet on raised plinth	Establishment of sanitary toilet	Planned; Local public agencies & NGO	Moderately effective; often lacks equity and enough robustness.
	Water and sanitation		Solar Panel	Planned; local NGO	Improve livability by providing alternative source of renewable energy
			Plantation around homestead	Autonomous; Local Household	Effective without any side effect.

Response	Sector	Region: **Interior coast** Risk: **Water logging**	Region: **Exterior coast** Risk: **Cyclone & storm surge**	Type	Remarks
		Specific measure	**Specific measure**		
Accommodation	Energy	Practicing horticulture at courtyard		Autonomous; Local Household	Moderately effective; cultural use of court yard often forfeited.
	Domestic Agriculture	Ring gardening		Planned; local NGO	Moderately effective but lacks cultural acceptance
		Floating garden (Baira)		Planned; agro research institute	Effective but still in experimental phase.
Retreat	Housing	Relocation of homestead near embankment		Autonomous; Local Household	Temporary measure, reduce livability
		Take shelter to nearest school or pacca road	Take shelter on the tree in nearby forest	Autonomous; Local Household	Reactive response of the household
			Seasonal migration to safer place	Autonomous; Local Household	

6.4 Summary

Settlements in coastal region are exposed to various natural hazards (both terrestrial and marine) triggered by climatic and geological variability of the context. Rise in local sea level as anticipated will further intensify the problem including permanent inundation of habitat land. Thus, environmental stress form geo-climate and SLR makes the settlement vulnerable. Apart from geo-climatic risk, vulnerability of coastal settlement is socially constructed primarily resulted from poor socio-economic condition of the household and poor resilience capacity of settlement pattern including disperse settlement, lack of emergency and basic services and absence of any effective protection measure etc. Majorities of the coastal households is poor and build their houses with temporary materials and thus lack both financial and structural capacity to show strong resilience individually to future threats. Coastal society in general lacks marketable skills and education for alternative livelihood which makes them solely dependent on agro and aquatic resources like farming and fishing which will decline with climate change. Again migrant community of foreshore and offshore areas lack social bondage and therefore most vulnerable without showing any collective resilience at community level.

Both public agencies including GO and NGOs and local residents have exerted efforts to ameliorate the impact of geo-climatic change. Attempts taken by public agencies are mostly protection measures including construction of embankment, creation of shelterbelt in cyclone risk area and TRM in rotational basis in water logged area and confined within greater community or regional level.

Efforts should be given to development of more climate resilience settlement pattern and community based collective measures. Simulation results shows that clustered pattern of settlement is more responsive to wind and hydrodynamic force as no significant increase of local velocity is observed in and around the settlement of this type. In area, exposed to risk of cyclone, establishment of multi-purpose community shelter in the most accessible location of the community and a tendency of densification around it is commonly observed. Moreover adaptation of compact homestead layout is a common measure taken by the coastal community on general. This compact layout offers economy in land utilization, is of movement of the occupants and minimize the hazard exposure. In addition coastal people adapt various methods to improve the resistance capacity of housing structure including structural strengthening of plinth, adoption of permanent, material or development of responsive household.

In a nutshell, strategies to settlement adaptation in coastal area should involve planning at two levels: Firstly, in vulnerable area, measures should involve sustainable management of two different but interconnected parts of human settlement i.e. **manmade or built up part** by modifying settlement pattern in responsive to local hazard and **natural part** by management of geo-hydrology to stimulate the natural process and coastal ecosystem. Secondly, in less vulnerable area, measures should involve resettlement of refugee or land less people by managing planned densification. Focus should be given on adoption local knowledge and measures to cope with hazard along with planned intervention responsive to local context and culture.

Chapter 7
Recommendation and Conclusion

Considering present challenge and future threats the following chapter delineates recommended strategy for adaptation in coastal settlement pattern in Bangladesh. In this chapter, micro level strategy to physical planning and design of coastal settlement is formulated. The following section starts with the checklist of adaption for environmental, physical and socio-cultural aspects of vulnerability of coastal area followed by formulation of structural model of adaptation in coastal settlement pattern.

7.1 Vulnerability and adaptation checklist

Vulnerability of any system, as discussed earlier, can be reduced by mitigating the origin of problem or by enhancing adaptive capacity of the system to offset the potential impact of the problem. Since vulnerability of coastal settlement is primarily caused by geo-climate or change in geo-climate which is naturally constructed so strategies to mitigate vulnerability requires limit or control the exposure to risk. Thus development is assumed to be achieved through strengthening the capacities of both the content (society) and the container (physical settlement) of settlement to perform under strenuous situation.

Environmentally, natural hazard like flood, cyclone, salinity, water logging, and erosion are the major threats for coastal settlement. Climate change and anticipated SLR will further deteriorate the situation. Since water plays a vital role in settlement development and livelihood generation in coastal region such environmental stress will significantly affect the hydrology and hence the coastal settlement as a whole (both content and container). So any measure taken to mitigate the impact must ensure reduction of water related hazard risk and availability of water at the same time. As the coastal zone is still in formative stage where accretion and erosion is still active so no measure should be taken that hinder this natural process of land formation. Construction of tidal basin in rotational basis will accelerate the process of natural sedimentation and allow the land to raise with due course. In foreshore area and offshore islands of exterior coast where cyclone and associated storm surges is the prime risk, mangrove afforestation should be given priority as protective measure to create a shelter belt. Consideration should be given to selection of species, layering and width of plantation as these are the factors that determine the effectiveness of a shelter belt. Numerical model shows that even a narrow shelter belt consisting of only two to three rows of trees can create nearly as large a wind protected zone as much wider belts (Wang & Takle, 1996). It has been estimated that a 100 - 200 m wide mangrove belt reduces wave heights by 20 to 25% (MoWR, 2000). It is very important factor for application of shelter belt in settlement area where it is desirable to remove only minimal land area for planting shelter belt.

Physically, disperse and linear settlement along the embankment, weak foundation of the house, poor access to common services and emergency shelter, lack of infrastructure and limited transportation facility are the key weakness of the area. The existing disperse settlements should be altered to more compact or clustered pattern. Plantation of selected species around the homestead in response to cyclonic wind is a local practice adopted by the household mostly in older part of the settlement.) This practice of plantation is proved effective and should be equally adopted by the community as a whole. Local practice of homestead construction (back to back arrangement in cyclone prone area and L –shaped pattern in water logged area) in compact manner should be encouraged as it allows easy flow of wind and surge water without creating any obstruction and thus reduces the vulnerability of housing structure. Traditional makeshift house is also a strength of such community. These houses can be withdrawn and moved in short notice. Besides that indigenous method of house construction in cyclone prone area has proven more responsive to environment and culture than many engineered relief house. However, strengthen the foundation or raising the plinth will enhance its resistance capacity further. Institutional initiative should be taken for the development of the infrastructure and better access to the services and shelter (health facility, bazaar, school etc) at community level and access to amenities (fresh water supply, sanitation) at *para* or neighborhood level. It is observed that existing shelter with limited capacity is often unable to provide shelter to every person in the community. One possible solution would be to modify the existing community facility (mosque and madrasa) into community safe house. Study shows that there are clear advantages in having smaller shelter which are nearer to the community as it will take less time to reach the shelter and people will remain much closer to their homes. All shelters should have provision for livestock. Indigenous mechanism of rain water harvesting should be widely adopted for as an alternative source of fresh water supply in coastal area as climate change will increase the intensity of rainfall in monsoon period (monsoon rainfall may increase by 11% by 2030 and 27% by 2070, Climate Change Cell , GoB, 2006).

Socially, poverty, large family size, illiteracy, farm dependency or lack of marketable skill, Lack of social bondage among the newly settle community etc are the major cause of vulnerability of coastal society. Generation of alternative livelihood opportunities by promoting education and technical skill development and family planning to control population growth will contribute to alleviate the poverty. In addition crop diversification and adaptive for example, in waterlogged area, floating bed cultivation, aquaculture and open water or marine fishing will increase livelihood opportunities of the household. Moreover, community based living should be encouraged where NGO might play a vital role.

Table 7.1 Checklist of vulnerability and adaptation for coastal settlement in Bangladesh context:

	Vulnerability feature	Adaptation or response
Environmental	Inundation due to water logging or storm surge or tidal flooding	Construction of tidal basin to allow natural sedimentation
	Cyclone	Creation of shelter belt with mangrove forest
Physical	Disperse or linear settlement	Compact and clustered settlement
		Plantation around the homestead
	Weak structure of house Biomass foundation	House on stilt or semi-pacca foundation
		Adoption of indigenous method of house construction in cyclone prone area
	Poor access to services and shelter	Construction of safe house at para/neighborhood level
		Multipurpose flood/ cyclone shelter at community level
		Rain water harvesting at house hold to community level
		Adoption of Community Sanitation
		Adoption of alternatives energy source (e.g. Bio gas or solar panel)
	Limited transportation network	Development of water –based transportation network
Socio-cultural	Poor socio- economic condition	Generation of alternative livelihood options
		Family planning / population growth control
	Farm dependency or lack of employment opportunity	Promote education and technical skill development
	Lack of social bondage	Community based living

7.2 Recommended adaptation strategy: Planned Densification

Then again even if proved effective against present hazard context, the local measures may not equally perform in the changing context of climate and resultant sea level rise (SLR) as forecasted. This may lead to mass exodus of population towards the dense urban center otherwise. Accommodating these climate refugees within the existing urban infrastructure is again impossible or very costly and slow. It is likely to be easier if action is taken to adapt in place where development is still sparse as opposed to the dense urban area.

Despite of extreme vulnerability, a close scrutiny of historical trends and inundation risk map for future change clarify the fact that there are zones in the coastal area which can be considered relatively safe from the risk. Since the affected area is predominantly rural and sparse in nature where density is yet lower than the national average and far below than urban area, planned densification should be promoted in the safer zones under the scope of local or regional level adaptive measure. People lives in risk and high risk zone, where problems like permanent inundation, erosion are acute, should be encouraged to resettle in the safer zone within the locality then to regional cities and gradually to bigger cities if necessary. The strategy involves all three measures of structural adaptation including protection (mitigation), accommodation (modification) and retreat (migration) to improve the adaptive capacity and to lessen the exposure to hazard and thus reducing vulnerability. To avoid severe disruptions, measures for each of these need a long lead time.

Physical plan of densification includes integration of four components; 1. Physical / built-up part of settlement in relatively safe area 2. Homogenous part or farm land /aquaculture in risk area 3. Buffer or set back zone in high risk area 4. Circulatory part including both inland and water based transportation network as linking pin (or facilitator) to smoothen the desired process of densification in safer zone.

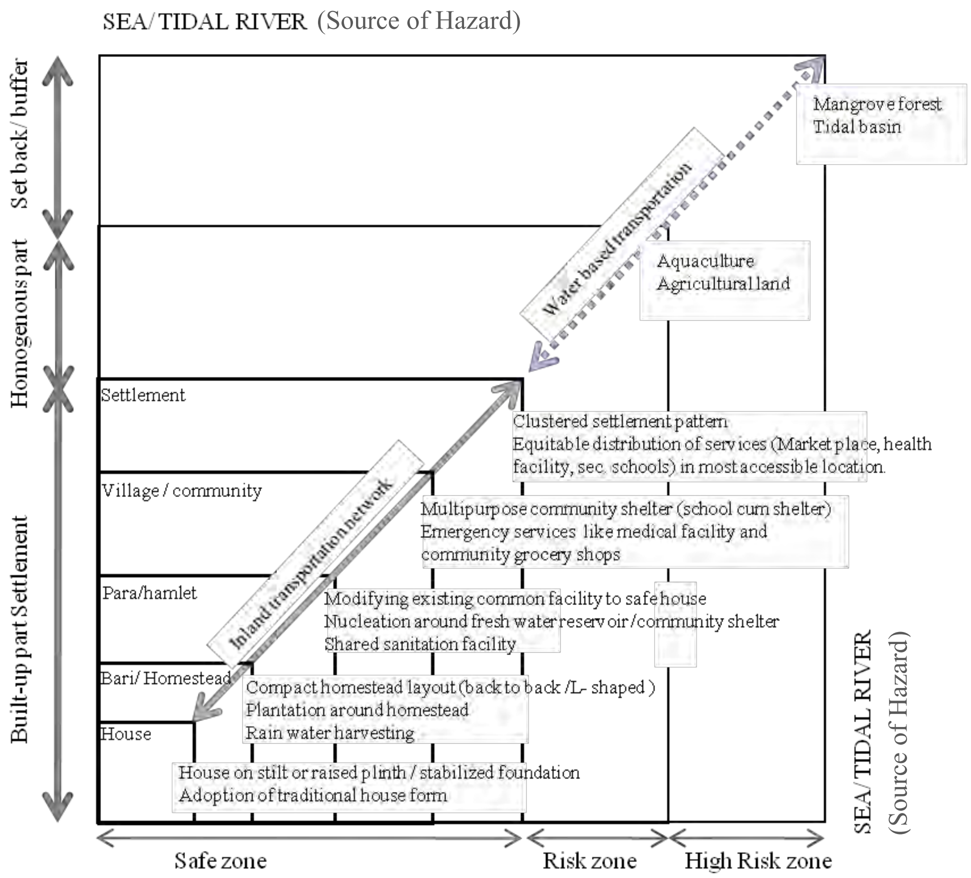


Fig 7.1 Structural model of planned densification in coastal settlement pattern of Bangladesh

7.2.1 Strategies for built-up part of settlement in safer area

The process should be started from preparation of master plan for vulnerability zoning at coastal area to identify of safer zone within the locality/region where planned densification can take place. It is observed that densification process is already happening in the study area. The further settlement growth should be controlled by allowing development within close proximity to common services and shelter. In the process of densification, household living in high risk area should be rehabilitated to safer area where existing semi dispersal settlements should be altered into more compact pattern of cluster settlement to encourage community based living where multipurpose community shelter become the spatial focus. In addition, compact pattern allows easy access of the villagers to shelter and common facilities by reducing the travel distance. Clustering of houses, sharing common spaces / courtyard or even construction of two storied house for joint family living will allow densification without forfeiting the livability of settlement. Besides clustered pattern will help to protect from cyclonic wind or surge in a way that linear or scattered pattern wont. In addition any measures in community level will enhance community feeling and sense of belongingness and will improve the safety, livability and opportunity within the community despite of its high exposure to geo-climatic risk.

In foreshore areas and offshore islands, the concept of *Urir char Model Settlement* can be adopted in response to future risk of inundation where settlements are elevated on stilts and nucleated around a fresh water reservoir.

In the resettlement process introduction of low cost housing through local NGO‘s can be a useful aid. As an alternative option, the newly migrant population can save on construction cost by dismantling their existing structures and carrying them to their new settlement location. The immigrant household is expected to afford more permanent building material in due course by avoiding their recurring losses they used to experience in every hazard.

7.2.2 Strategies for agriculture/ aquaculture area

Despite of low productivity and high damage of crops due to cyclone , flood an salinity majority of coastal people still engage in agriculture. Though densification promotes greater economic diversification and less dependency on agriculture, but safe distance cultivation is a crucial need for success of settlement building in safer area. After the settlement layer, land should be allocated for agriculture or aquaculture purpose. Invention of climate resilient crop and floating bed cultivation has widened the opportunity for agricultural adaption in risk area. Even though the farmland is located a distance away a good water based transportation system will motivate the inhabitants to continue living in safer place.

7.2.3 Strategies for setback or buffer area

The ‗setback' provides a buffer between area of source of hazard (e.g. sea, tidal river) and settlement area. This setback area should includes mangrove forest belt (Exterior coast) flood flow zone and tidal basin (interior coast) and thus provide protection to land and properties against cyclone , coastal flooding and erosion by ensuring that settlements are not located in an area susceptible to these hazards. This measure will to contribute to ecosystem generation and bio diversity coastal area. Depth of setback should be determined on the basis of trends of sea level rise, effective width of shelter belt and rate of erosion etc.

7.2.4 Strategies for transportation network

Transportation modes and network development is a basic requirements for the effective planning of densification. This will increase human mobility and resource flow between safe and vulnerable areas. Good transportation network will also act as safe evacuation route in case of emergency. Considering the riverine nature of the coastal area and future threats of inundation water base transportation can be envisage for the purpose. Table 7.2 points out the opportunities and threats of out of densification against each of the major components of the densification strategies.

Table 7.2 Densification opportunities and threats

Densification components	Opportunities	Threats
Compact settlement in safer zone	- Relative safety to household - Increase accessibility by reducing distance and to common facility	- Social resistance - High density - Environmental degradation
Farm land / aquaculture in relatively risk zone	- vulnerable resource utilization - crop diversification	- increase commuting distance - expose to hazard
Buffer zone : set back area / tidal basin / mangrove forest belt in high risk zone	- allow sedimentation /accretion of new land - ecosystem generation - ensure protection - source of food and fodder	-land grabbing
Transport network (inland and water based as linking element	- Enhance mobility - employment generation - improve drainage	- accident - water pollution

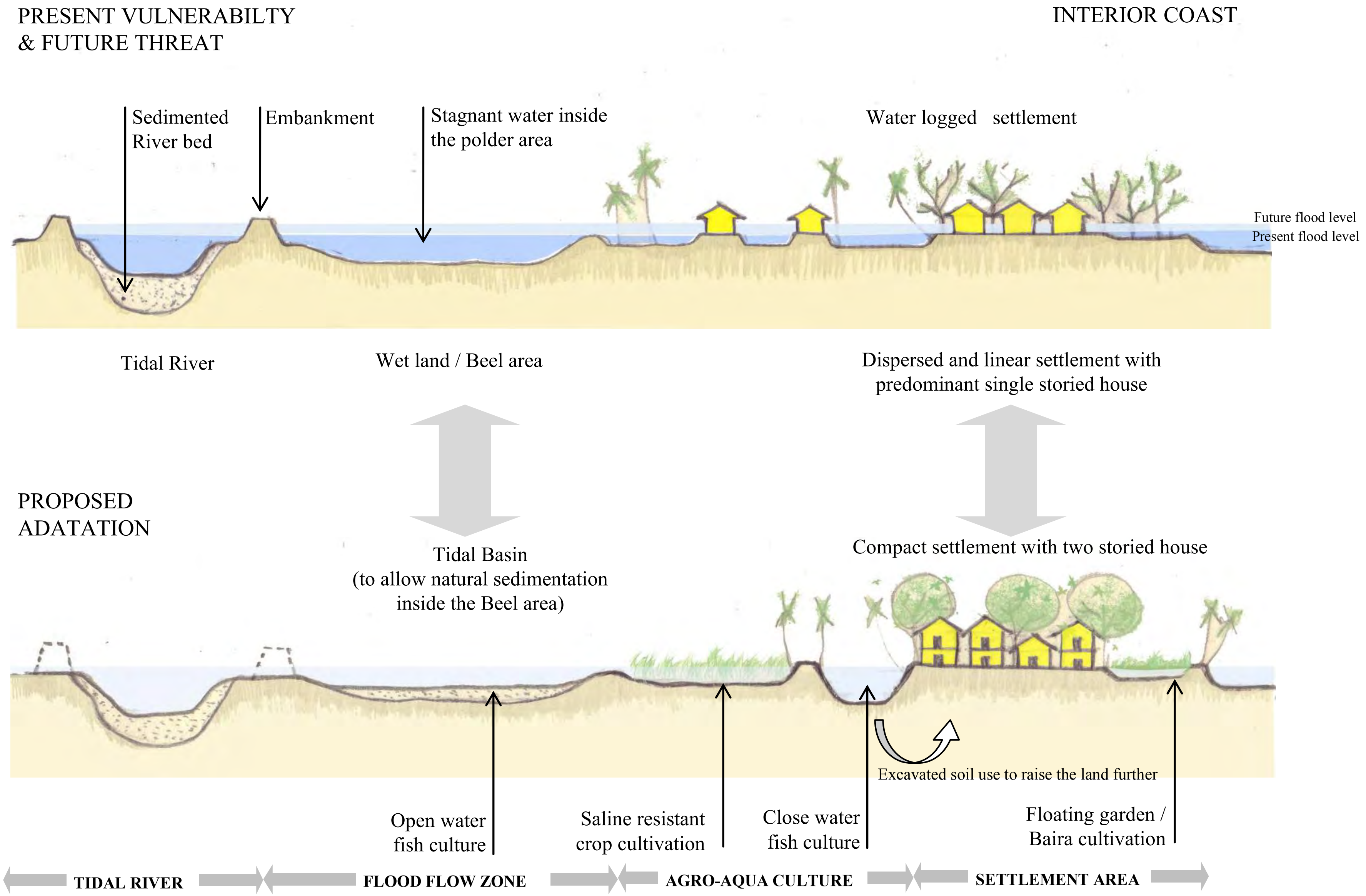


Fig 7.2 Proposed adaptations in settlement pattern in interior coast

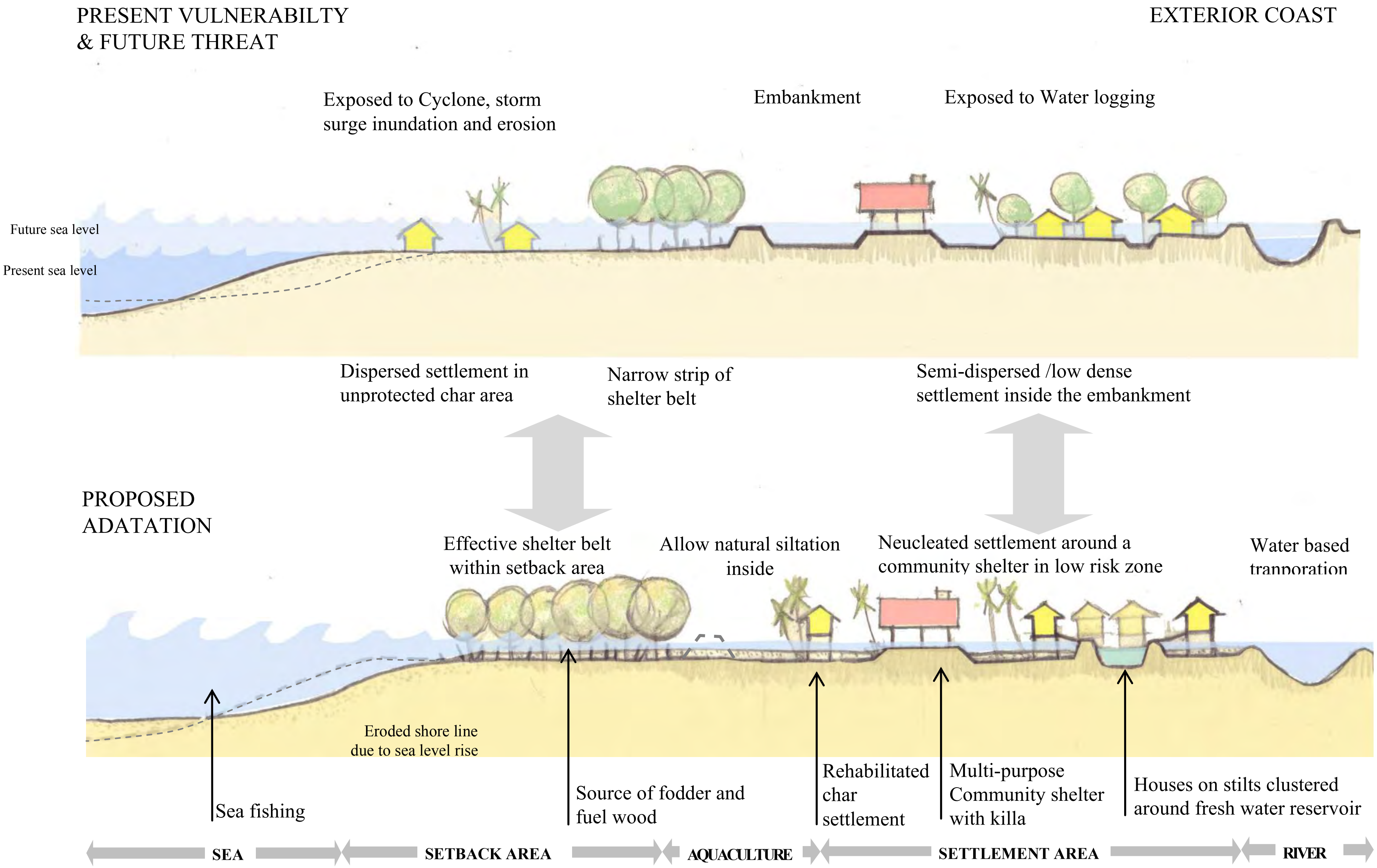


Fig 7.3 Proposed adaptations in settlement pattern in exterior coast

7.3 Conclusion and direction for future research

Considering the fact that, the present study is an exploratory research and confined within selected context, it is hard to draw any conclusion for coastal area in general vulnerable to anticipated climate change. However, the present study is an attempt to address the issue under the scope of settlement planning and design with aim to identify key aspects of settlement vulnerability in geo-climatic risk and possible adaptation strategies in settlement pattern of coastal region of Bangladesh where relevant research work is almost non-existent.

Research identifies that, there are two opposite trends of settlement growth in coastal area depending on the temporal character of the geophysical risk ; in area where the problem is prolonged (waterlogged area of interior coast), the settlement growth is severely restricted and conversely in area where the problem is occasional (cyclone prone area of exterior coast) settlement is growing rapidly. Generally speaking there is an increasing trend in settlement growth in coastal area which has twofold impact on environment. Firstly, uncontrolled settlement development is likely to damage sensitive and important ecosystems and other resources of coastal area. Secondly, coastal settlement, particularly in the foreshore and offshore area, is likely to expose residents to seaward hazards such as sea-level rise and tropical storms, both of which are likely to become more serious with climate change. Unfortunately, such environmental considerations are yet to be initiated in settlement patterns in coastal area as observed. The predominant sparse and isolated pattern of settlement in high risk area has been proved to be most vulnerable both at present and anticipated geo-climatic threats. The weak structure of housing units lacks enough robustness to withstand increased risk of inundation and cyclone. Coastal settlements are also devoid of equitable distribution of community services and shelter which is another aspect of physical vulnerability of settlement pattern. During disaster settlement may damage due to inappropriate or weak protection measure. In addition, inadequate transport infrastructures cause delay to post disaster recovery process and thereby influence the settlement vulnerability of coastal area.

In response to geo-climatic vulnerability, adaptation seems the most viable and manageable way to contend with especially for the least developing country like Bangladesh. Though there is general consensus that coastal community will suffer disastrously in the event of climate change due to their poor adaptive capacity but from the past records study reveals that coastal household with their indigenous coping practices, sometimes being more responsive and proved effective to existing hazard over some planned and reactive measures taken by public agencies in the area, had sustained well in past disaster. Thus the study suggested that prior to planning for any measures in response to climate change; emphasis should be given to context specific development with consideration to existing indigenous coping practice. The collective knowledge on autonomous coping measures practiced by the coastal community in general can be institutionalized and serve as a guideline for sustainable coastal settlement in the context of climate change. Local people experience in hostile climatic effect situation in recent past like Sidr, Aila or Beel Dakatia may be shared in the sea level rise and climate refugee management. However, before adopting any measure in coastal area sustainability of the measure in future context need to be examine in advance. The successful implementation of adaptive measure specially at local level will increase the livability in risk area and will contribute significantly to in-situ adaptation and thus reduce out migration.

Despite all constrains, Government has initiated some sign in positive direction by formulating Climate Change Strategy Action Plan and National Adaptation Program of Action (NAPA). Existing policy should be revised in order to provide more importance and significance to issues related to in-situ settlement adaptation to minimize migrant flow. The proposed adaptive measure can be regarded as ‗guideline solution' for the revised policy. Of these, strategies related to establishment of setback distance along the coastline and management of further growth of settlement in high risk area can be taken as immediate measure. It should be noted that whatever strategies will taken it should be responsive, contextual and not against the cultural norms of the inhabitants. The success of any adaptive measure will depend on the social acceptance of the measure and active participation of the people during its implementation.

Development of adaptation strategies for settlement planning and design in coastal region of Bangladesh in response to current and anticipated geo-climatic vulnerability pose a major challenge. To ensure effective functioning of coastal settlement in strenuous future context it requires a harmonious solution between manmade and natural part of settlement. Conventional set of planning and building regulation may not be sufficient to provide design guideline for this specific situation. Moreover the distinctive character of indigenous settlement developed along the coastal belt suggests that further study should focus on a detail investigation on the morphology of built environment and their sustainability. Their effectiveness in terms of environmental, socio-cultural and economical aspects needs to be studied in detail prior to suggest any modification in built form for adaptation in place. Subsequent research on intervention of process and policies regarding resettlement of climate refugees within existing urban structure need to be studied. In broader perspective, the objective of these efforts should be formulated to guide the transformation process of coastal settlement while maintaining the vitality of natural and societal system coastal area.

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Appendix A: Coastal Zone of Bangladesh

Table A1 Districts, Upazilas and Area of Exterior and Interior Coast

District	Area (km^2)			Upazilas	
	Total	Exposed	Interior	Exposed	Interior
Bagerhat	3,959	2,679	1,280	Mongla, Saran Khola, Morrelganj	Bagerhat Sadar, Chitalmari, Fakirhat, Kachua, MollahatRampal
Barguna	1,831	1,663	168	Amtali, Barguna Sadar Patharghata, Bamna	Betagi
Barisal	2,785		2,785		Agailjhara, Babuganj, Bakerganj, Gaurnadi, Hizla, Mehendiganj, Muladi, Wazirpur, Banari Para, Barisal Sadar
Bhola	3,403	3,403		Bhola Sadar, Burhanuddin, Char Fasson, Daulatkhan, Lalmohan, Manpura, Tazumuddin	
Chandpur	1,704		1,704		Chandpur Sadar, Faridganj, Haimchar, Hajiganj, Kachua, Matlab, Shahrasti
Chittagong	5,283	2,413	2,870	Anowara, Banshkhali, Chittagong port, Double Mooring, Mirsharai, Pahartali, Panchlaish, Sandwip, Sitakunda, Patenga, Halisahar, Kotwali, Boijid Bostami,	Boalkhali, Chandanaish, Lohagara, Rangunia, Chandgaon, Fatikchhari, Hathazari, Patiya, Raozan, Satkania, Bakalia, Karanaphuli, Kulshi
Cox's Bazar	2,492	2,492		Chakaria, Cox's Bazar Sadar, Kutubdia, Ukhia, Maheshkhali, Ramu, Teknaf	
Feni	928	235	693	Sonagazi	Chhagalnaiya, Feni Sadar, Parshuram, Daganbhuiyan
Gopalganj	1,490		1,490		Gopalganj Sadar, Kashiani, Kotali Para, Muksudpur, Tungipara
Jessore	2,567		2,567		Bagher Para, Chaugachha, Jhikargachha, Manirampur, Abhaynagar, Keshabpur, Jessore Sadar, Sharsha
Jhalokati	749		749		Jhalokati Sadar, Kanthalia, Nalchity, Rajapur
Khulna	4,394	2,767	1,627	Dacope, Koyra	Batiaghata, Daulatpur, Dumuria, Dighalia, Khalishpur, Khan Jahan Ali, Khulna Sadar, Paikgachha, Phultala, Rupsha, Sonadanga, Terokhada
Lakshmipur	1,456	571	885	Ramgati	Lakshmipur Sadar, Raipur, Ramganj
Narail	990		990		Lohagara, Narail Sadar, Kalia, Narigati
Noakhali	3,601	2,885	716	Companiganj, Hatiya, Noakhali Sadar	Chatkhil, Senbagh, Begumganj
Patuakhali	3,221	2,103	1,118	Dashmina, Rangabali, Galachipa, Kala Para	Bauphal, Mirzaganj, Patuakhali Sadar
Pirojpur	1,308	353	955	Mathbaria	Bhandaria, Kawkhali, Nazirpur, Pirojpur Sadar, Nesarabad (Swraupkati)
Satkhira	3,858	2,371	1,487	Assasuni, Shyamnagar	Debhata, Kalaroa, Kaliganj, Satkhira Sadar, Tala
Shariatpur	1,182		1,182		Bhederganj, Damudya, Goshairhat, Naria, Palong, Zanjira
Total	**47,201**	**23,935**	**23,266**		

Source: PDO-ICZMP, 2003

Appendix B: Land Use of Coastal Zone, Bangladesh

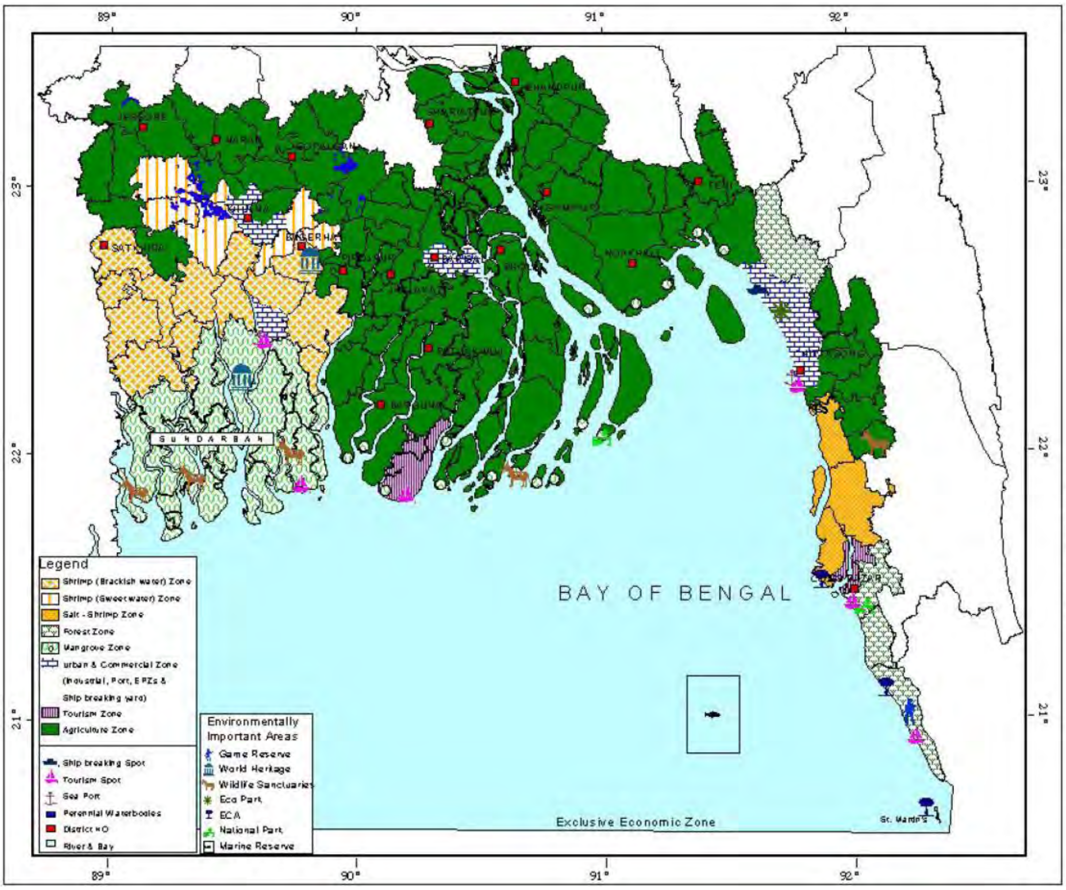


Fig B1**.** Indicative coastal land zones of Bangladesh. Source: Islam et al., 2006.

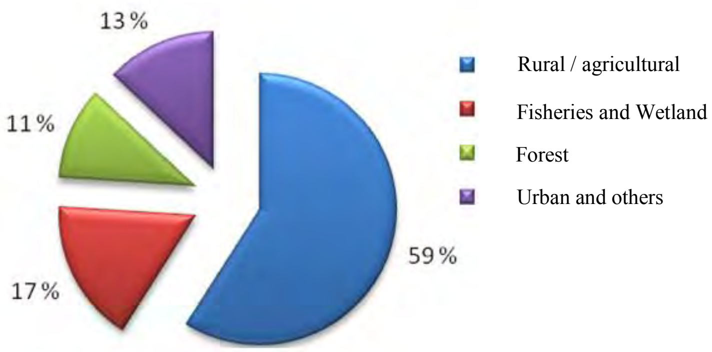
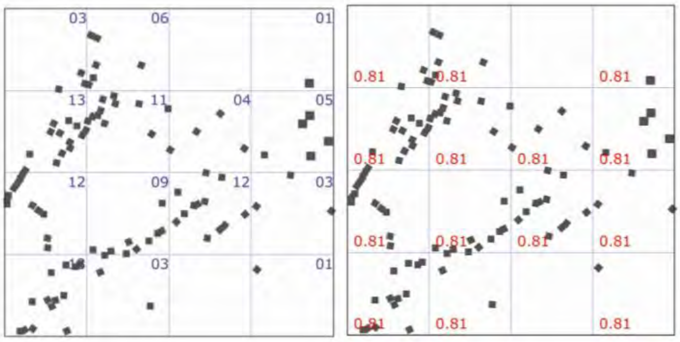


Fig B2**.** Major land uses in Coastal Bangladesh. Source: Field Study, Ahmed, 2010.

Appendix C: Steps to Grid based analysis of Vulnerability
(Calculation of Housing Capacity Index HC_i)

STEP 01: Calculation of No of Katch House in Each cell



03 2.43 0.81	06 4.86 0.81		01 0.81 0.81
13 10.5 0.81	11 8.91 0.81	04 3.24 0.81	05 4.05 0.81
12 9.72 0.81	09 7.29 0.81	12 9.72 0.81	03 2.43 0.81
13 10.5 0.81	03 2.43 0.81		01 0.81 0.81

No of house   Ratio of Katcha house   No of Katcha house

No of Katcha house= No of house in each cell x Katcha house ratio

STEP 02: Calculation of Ratio index Ri :

2.43	4.86		0.81
10.5	8.91	3.24	4.05
9.72	7.29	9.72	2.43
10.5	2.43		0.81

No of Katcha house

0.03	0.06		0.01
0.13	0.11	0.04	0.05
0.12	0.09	0.12	0.03
0.13	0.03		0.01

Ri Katcha house

4.05/ 77.7=**0.05**

Total No of Katcha house

Ri Katcha house= No of Katcha house in each cell / Total no of Katcha house

STEP 03: Calculation of Housing Capacity Index (HCi)

0.12/ 0.13=**0.92**

Ri max

0.23	0.46		0.07
1.00	0.84	0.30	0.38
0.92	0.69	0.92	0.23
1.00	0.23		0.07

Ri Katcha house

0.23	0.46		0.07
1.00	0.84	0.30	0.38
0.92	0.69	0.92	0.23
1.00	0.23		0.07

Housing Capacity Index (HCi)

HCi= **Ri** Katcha house x **Ri max** Katcha house

Fig C1: Stages of generation of spatial **Vulnerability map** using **Analysis Grid** techniques

Appendix D: Spacing of settlements and distribution of services in Keshabpur Upazila, Jessore district

Table D1 Settlement spacing of Keshabpur Upazila

Union	No of villages	Area (sq km)	Spacing (km)	Remarks
Trimohoni	**15**	34.34	1.63	**High spacing**
Sagardari	**17**	29.21	1.41	**High spacing**
Bidyananakati	**24**	32.76	1.26	**High spacing**
Majidpur	**14**	24.73	1.43	**High spacing**
Keshabpur	**17**	33.86	1.52	**High spacing**
Panjia	**19**	28.61	1.54	**High spacing**
Mangalkot	**13**	22.97	1.43	**High spacing**
Gaurighona	**09**	26.14	1.83	**Very high spacing**
Sufalakati	**16**	25.76	1.32	**High spacing**

Source: calculated by author *

- [in the present study, the following equation has been used for the transformation of the settlement density into spacing: $\mathbf{H_d = 1.0746 \sqrt{A/N}}$,

Here, H_d is the Hypothetical distance between two settlements. This formula was first initiated by Barnes and Robinson (1940) and later used by Sultana ,1990 to analyze the spacing of rural settlement pattern of Bangladesh.]

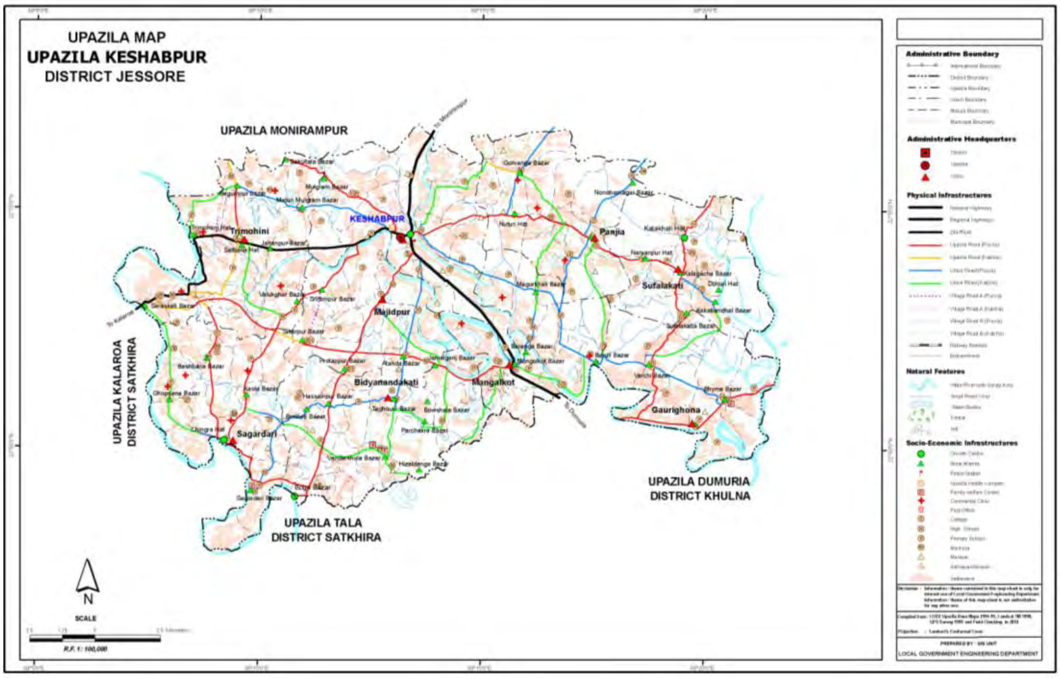


Fig D1: Distribution of services and road network of Keshabpur Upazila

Appendix E: Spacing of settlements and distribution of services in Kalapara Upazila, Patuakhali district

Table E1: Settlement spacing of Kalapara Upazila

Union	No of villages	Area (sq km)	Spacing (km)	Remarks
Chakamaiya	19	33.98	1.44	High Spacing
Tiakhali	7	32.50	2.32	Very High Spacing
Dhankhali	10	58.61	2.60	Very High Spacing
Nilganj	54	62.59	1.16	Mod Spacing
Mithaganj	36	73.98	1.54	High Spacing
Lalua	32	51.59	1.36	Mod Spacing
Khaprabhanga	24	52.12	1.58	High Spacing
Lata chapli	34	56.54	1.39	High Spacing
Dhulasar	18	44.56	1.69	High Spacing

Source: calculated by author *

[< 0.64 = very low spacing, 0.65-1.01=low spacing, 1.02-1.38=moderate spacing, 1.39-1.75=high spacing, >1.76 ; (Sulatana, 1990)]

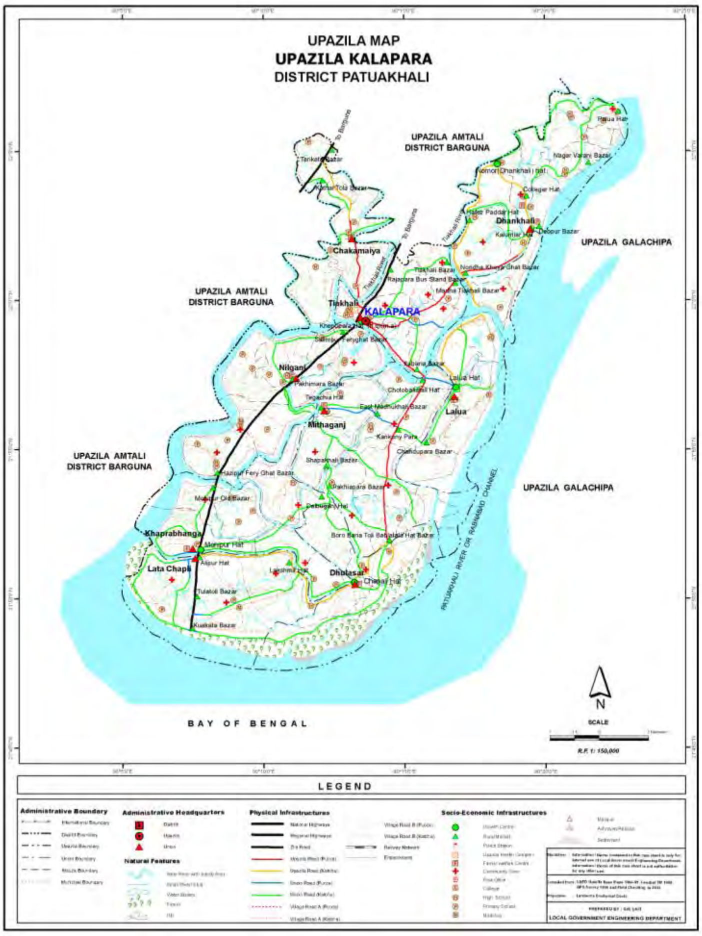


Fig E1: Distribution of services and road network of Kalapara Upazila

Appendix F: Water velocity and flow pattern within development

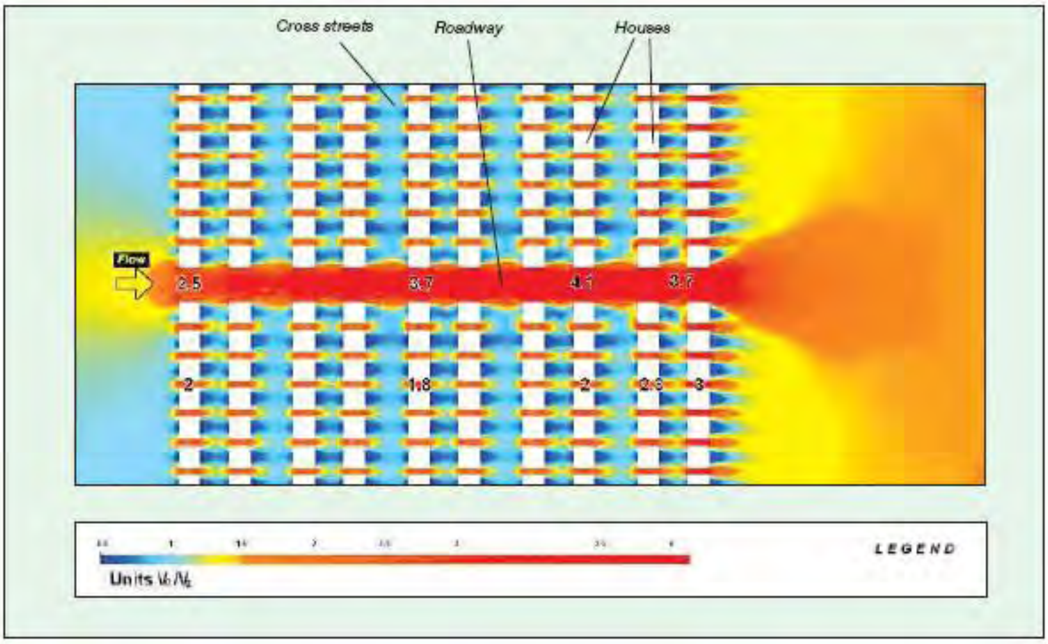
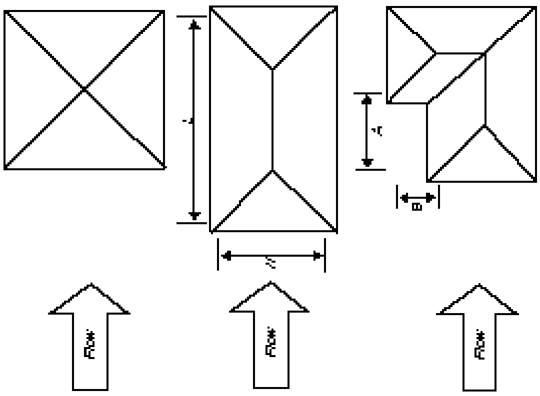


Fig G1. Increased local velocity of flood water within linear / row house development, Source: H-NFMSC (2007), p. 125



(a) Square shape house are preferred as they are generally stronger in flood and wind condition

(b) In case of rectangular house, shorter side should be oriented along the flow direction and L: W should not exceed over 2:1. For wind resistance the recommended L:W is 3:1 max.

(c) The longer side of L shape house should not be oriented along the flood flow direction and side A should be less than 1.5 times than side B

Fig 5.35: Recommended shape and orientation of houses in cyclone and flood prone area. (Source: H-NFMSC, 2007, p.47 and Haq, 2000, p.87)

Appendix G: Settlement pattern of Coastal Bangladesh

Fig G1: Large clustered settlement in Maheskhali off-shore Island , Chittagong, eastern coast

Fig G2: Linear settlement along the coastal embankment, Charfason, Bhola .central coast

Fig G3: Settlement along the forest fringe in Suderban region, western coast

Fig G4: Nucleated settlement around a pond in the waterlogged area of Satkhira , western coast

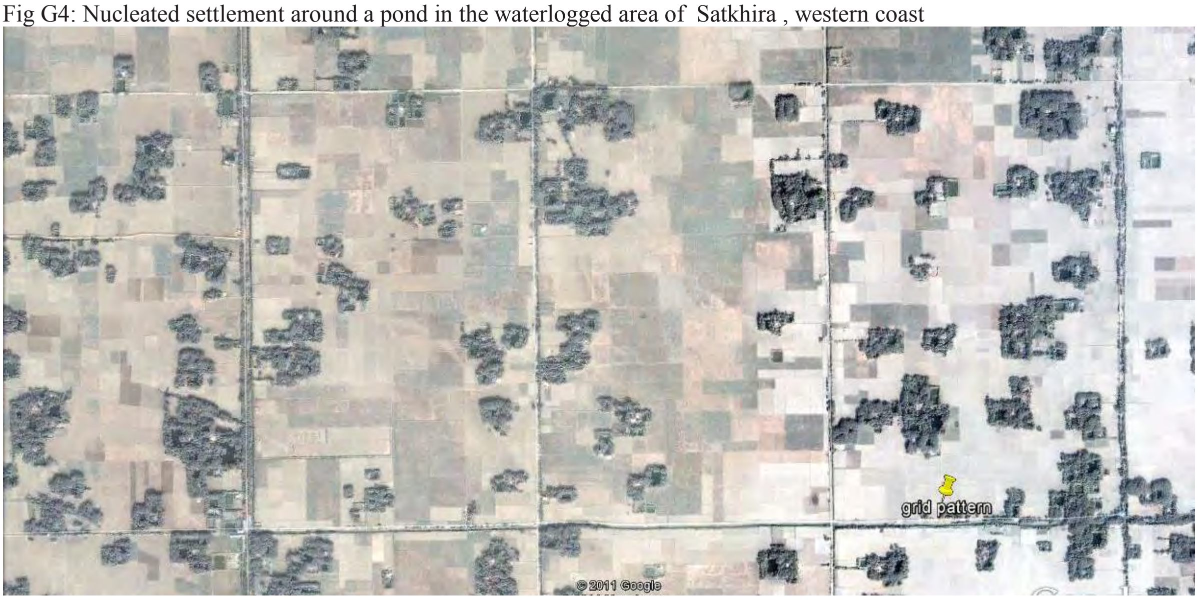


Fig G5: Dispersed settlement with grid street layout in the offshore island, Hatiya , Central coast

Fig G6: Linear pattern in the waterlogged area / Beel area of Satkhira district , western coast

Fig G7: Dispersed settlement in offshore char land, bara baisdia_Golachipa_Patuakhali, Western coast

Fig G8: Scattered settlement in offshore char land , Urirchar, Noakhali , Central coast

Fig G9: Linear pattern along water channel , Patuakhali, western coast

Appendix H: Sample Questionnaire

Sample Key Informant Survey questionnaire for the research project on "A STUDY OF GEO-CLIMATIC VULNERABILITY AND ITS RESPONSE IN THE SETTLEMENT PATTERN IN COASTAL BANGLADESH."

Case study area: Village ……………….. Upazila ……….…..... District ………………

HOUSEHOLD SURVEY:

HOLDING NO: ………………………………………………………………………………………………

Socio-economic profile of the household

1. Head of the household:……………………………………………………………………………..

2. Occupation: Rich Farmer / Farmer / Fisherman / Businessman / Agricultural labour / others ……………

3.Father'sOccupation:…………………………………………………………………………………..

4. Religion and caste:…………………………

5. No of family member:…………………………………………………………………………………….

6. Land holding (amount of farmland owned) ………………………………………. / landless

7. Distance of the farm land / working area……………………………………………..

8. Year of construction of the house (from how long the household has been there)…………………………

9. Domestic animal / poultry (specify the type and number)

Cow / goat / …………… no ……………………. chicken / duck /…….. no ………………

Hazard profile

1. Of the following which problem/ problems seems to you most severe ;

- __ Cyclonic wind
- __ Cyclonic surge / flood
- __ Salinity
- __ Erosion
- __ Water logging
- __ ……………………

2. When did the last severe hazard / cyclone you had experienced in recent years?

3. Was your homestead inundated by the cyclonic surge?

Yes / No /

…………………..

4. What was the depth of inundation?

…………………………………………………………..............................

5. How long did the water stay?

....

6. Was your house destroyed by the storm?

Completely destroyed / partly destroyed / no

7. What did you do when the storm come?

Stay in the house / Take shelter in nearest Cyclone shelter / school / neighbor‘s pacca house / over the embankment/ over rooftop

9. How many times do you need to repair your house per year?

……………………………………………………………….

10. Which part of the house do you need to repair most frequently? Plinth / wall / Roof

11. Provision for Drinking water

	Deep tube well	Shallow tube well	Well	Rainwater harvesting	Pond	other
Dry period						
Inundation period						

- If shared then write ‗S‘ beside the tick

12. How do you prepare / cook food during inundation period?

………

13. Where do you store the dry food during inundation period?

………

14. Where did you keep your cattle during this period?

……..

15. Was there any tree damaged / uprooted during last cyclone?

Yes…………………../ No

16. Are you aware of the risk of sea level rise? Yes / No / Yes but not clear

17. If your homestead will relocated in a safe place, will you agree to shift there? Yes / No

18. If no, then why?

For strong kinship / emotional attachment with paternal land / ……………………………………………

Name and signature of the interviewer:

…………………………………………………………………………………....

Observation sheet:

HOLDING NO: …………………………………………………………………………………………………….
1. Layout of the homestead with north sign (with location with road / entry, adjacent homestead, vegetation, drinking water source / pond etc.)

Notes :

i) Main house ii) guest room / Kachari iii) Kitchen iv) Cattle shed
v) Storage for Firewood vi) Storage for crop viii) toilet vi) others (specify)……………..

4. **Features of Main house**:

Shape: Rectangular / square Orientation: ……………………………….

plinth height :……………………………feet Plinth mat : Kutcha / pucca / semi pucca

Wall: Mud / Thatch / Bamboo / CI sheet / Brick with plaster / Brick without plaster/ sundried brick/……….

Vertical support: bamboo / wood / metal pipe / concrete pillar

Roof type: 8/ 7/ 6/ 5/ 4/ 3/ 2 chala Roof: CI sheet / Clay Tile / Thatch / concrete / ……

5. **Toilet:** Yes / No

Separate / attach Katcha / pucca * plinth height: …………………..

6. Features of other annex building

	Plinth			Wall								Roof			
	Katcha	pucca	Semi pucca	Mud	Thatch	Bamboo	CI sheet	Brick with plaster	Brick without plaster	Wood	others	CI sheet	Clay Tile	Thatch	concrete
Kitchen															
Cowshed															
Storage															

7. Measures the household have taken to protect your house (Observe any innovations like roof joint, foundation type or protective vegetation or technology, water source placement / protection)

i)…………………………………

ii)…………………………………

iii)…………………………………

iv)……………………………….

8. Vegetation pattern:

a. Location of vegetable garden:

In the courtyard / kitchen yard / backyard / no garden

b. Location of Major trees.

North / south / east / west / …………………..

c. Name of the Major trees around the homestead

1._____________________ 2_________________________ 3____________________ 4____________

Focus group discussion

Case study area: Village ………………. Upazila ………………. District ……………

No of participant: …………………………………………………………………………………………….

1. How many families are their in the village? ………………………………………………………………….

2. What is the main problem for the locality: Cyclonic wind / Cyclonic surge / flood /Salinity /Erosion /Water logging

2. In which season cyclone occur? ....

3. Is there any land that remains dry/inundation free in the village? ....

5. Is there any Community shelter in the village? ……………………………………………………………….

4. Did the road inundated during water logging period? ....

4. How long the water stay? ………………………………………………………………………………..

5. What do you do for living during water logging period …………………………………………………………

6. What are the means of communication during water logging period ……………………………………………

8. What are the measures you have taken in the community to adapt with the water logging situation? …… ……

10. Did they face any health/ medical problem during the Hazard period? Yes ………………….. …….. / No

12. Distance of nearest medical assistance / community health facility ……………………………………………

12. What are the measures you have taken for the safety of the children? ....

13. What community facilities do you think should be present in the locality? …… ……..

14. Do you get any support / help from the local NGO / union parishad office? Yes / No

If yes, then specify the type of support: …………………………………………………………………………….

13. What is your suggestion to mitigate the impact of the disaster? Or How the problem can be reduced? …… ……

Additional information:

Nearest bazaar …………………………………………………………………………………………………

Nearest High school ……………………………………………………………………………………………

NOTES: